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Diversity of soil macrofauna in the coastal karst area of Gunung Sewu, Paranggupito Sub-district, Wonogiri District, Indonesia

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Abstract. *Pramono CL, Ramadhani G, Zahra JA, Wahyuningtyas J, Nugroho GD, Indrawan M, Setyawan AD. 2025. Diversity of soil macrofauna in the coastal karst area of Gunung Sewu, Paranggupito Sub-district, Wonogiri District, Indonesia. Indo Pac J Ocean Life 9: 1-11.* As a region with unique characteristics of limestone formations and a complex drainage system, the karst region faces environmental challenges that affect its macrofauna diversity. This study aims to identify soil macrofauna and analyze the relationship between abiotic factors that influence their presence in agroforestry land in a coastal karst area of Gunung Sewu, a United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Geopark, including Paranggupito Village, Gudangharjo Village, and Gunturharjo Village of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia, that was conducted in October 2024. To achieve the study's objectives, we measured abiotic factors, including physical and chemical elements of the environment, such as temperature, air humidity, soil humidity, light intensity, altitude, soil pH, and soil temperature. This study involved two types of plantation patterns in each village, namely woody and intercropping vegetation, with 18 research points divided into 2 stations in each area, each consisting of 3 sub-stations with 90 pitfall traps. Soil macrofauna samples were collected using the pitfall trap method, and data were analyzed using a diversity index and Pearson correlation between the diversity of soil macrofauna and its abiotic factors. The results showed that 16 different species were found in all three villages, and the sugar ant (*Camponotus consobrinus*) species dominated the intercropping vegetation, with a total of 347 individuals and 104 individuals in woody vegetation. The diversity of macrofauna at each station was relatively low. In contrast, the relationship between abiotic factors and diversity showed varying correlations, such as soil moisture, light intensity, and air humidity were negatively correlated by -0.59, -0.41, and -0.39, respectively, which means when the values increase, then the diversity tends to decrease and vice versa; In contrast, pH soil, soil temperature and air temperature were positively correlated by 0.79, 0.62, 0.78, respectively showing a moderately strong relationship whereas the soil values increase, the diversity also tends to increase. The discovery of soil macrofauna species in this study shows that macrofauna are able to survive in karst areas, which have an important role in maintaining soil health and fertility, so their existence must be maintained and preserved, highlighting their resilience and the importance of preserving their habitats to maintain soil health and fertility.

Keywords: Coastal, intercropping, karst, pitfall trap, vegetation, woody

INTRODUCTION

Karst is known as an area with a landform composed of limestone with a distinctive morphological and hydrological arrangement (Aprilia et al. 2021). In geology, the term karst represents the physiognomic phenomenon of dissolved carbonate rocks, for example, the development of carbonic acid salts (Anjum et al. 2014). The typical hydrological characteristics found in karst areas are rock formations that are easily dissolved and have good secondary porosity, for instance, limestone, marble, and gypsum (Prihatanto et al. 2022). Aside from its uniqueness, the karst area faces many challenges, including water availability, high physical, chemical, and biological heterogeneity or variation, and sensitivity to environmental changes that influence the suitability of agricultural systems (Wang et al. 2019). The choice of plants in karst regions depends on their ability to adapt to limiting factors in the environment, such as scarce water resources and nutrient-poor soil that lacks essential elements like nitrogen and phosphorus (Liu et al. 2021).

An agricultural system is an ecosystem with unique characteristics and often faced with limited resources in water, soil, and land (Pretty and Bharucha 2014). For sustainable reasons, an agricultural system requires a population or social resources (Anjum et al. 2014). The existence of irrigation as a substitute for natural rainfall is an example of maintaining the stability of the water supply and overcoming drought in karst areas. It has already happened in a coastal karst area of Paranggupito Sub-district, located at the southern tip of Wonogiri District, Central Java, Indonesia, which has been designated as an area that is highly vulnerable to drought by the Wonogiri Regional Disaster Management Agency (Widjajadi 2019). Research by Wang et al. (2019) showed that there is a positive correlation between the density of soil macrofauna and soil water content which decreases due to drought. For this reason, the agricultural system in Paranggupito must implement a strategy to help with the adaptation of macrofaunas. In the study of Wardani et al. (2021), forms of short-term and medium-term adaptation strategies that can be applied to the agricultural system are presented, such as planning planting times, selecting superior drought-tolerant plant varieties, implementing intercropping systems, economic adaptation, empowering farmers, and utilizing sloping land.

Soil macrofauna plays a key role in maintaining soil quality and agricultural productivity. Abiotic factors like temperature, humidity, and soil pH influence the metabolism and activities of these organisms (Masebo et al. 2024). Optimal soil temperature can boost macrofauna activity in digging, digestion, and reproduction (Dacal et al. 2022). Adequate soil moisture supports their mobility and enhances aeration, while a neutral pH promotes higher diversity (Chamorro-Martínez et al. 2022). Favorable abiotic conditions improve soil quality through aeration, decomposition, and nutrient cycling, whereas poor conditions can cause stress or death in macrofauna, harming soil ecosystem health (Rajwar et al. 2021). Soil macrofauna are soil-dwelling organisms larger than 2 mm (Gongalsky 2021) and often serve as soil health indicators in agricultural systems. Their diversity and abundance can reflect soil quality and the health of nutrient-cycling micro-ecosystems. Soils rich in macrofauna are typically more fertile, with improved texture and greater support for plant growth (Bufebo et al. 2021; Coelho et al. 2021).

Soil macrofauna influences biological processes that support soil fertility and agricultural productivity. Soil macrofauna often found include earthworms, ants, termites, beetles, centipedes, and several types of insects and other arthropods (Coleman et al. 2024). Soil macrofauna is able to decompose organic matter, such as dead plant and animal remains (Gongalsky 2021). This decomposition process accelerates the formation of humus, an important part of fertile soil. In addition, these organisms have a role in supporting nutrient cycles, improving soil structure, and improving the soil's ability to absorb and store water (Anitha et al. 2020). Prabowo et al. (2024) researched the vegetation characteristics of the Wonogiri karst region. However, little research has been carried out on soil macrofauna in the Wonogiri karst area. Therefore, this research is essential to identify soil macrofauna and understand their relationship with abiotic factors, especially in the agroforestry land of coastal karst area in Wonogiri District, Central Java, Indonesia, as those macrofaunas play a critical role in terms of soil health and nutrient cycling of agroforestry practices in an ecologically fragile region.

MATERIALS AND METHODS

Study area

The study was conducted in October 2024 in the agroforestry land in the coastal karst area of Gunung Sewu, a United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Geopark, of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia, including three villages/stations, i.e., Paranggupito Village, Gudangharjo Village, and Gunturharjo Village (Figure 1). Wonogiri has a fairly wide variety of habitats, ranging from reservoir waters, rivers, and forests to agricultural land. This diversity provides a variety of environments that support a diversity of microfauna, allowing more profound observation and analysis of diverse microfauna species.

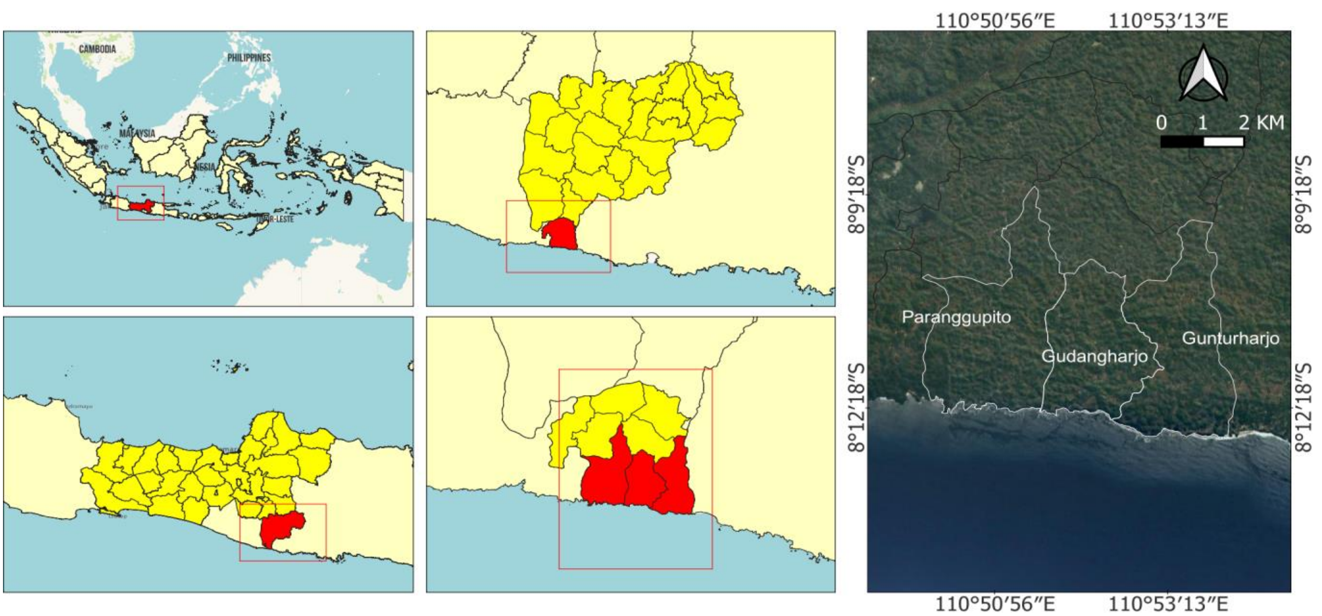

Figure 1. Research location in the coastal karst area of Gunung Sewu, i.e., Paranggupito, Gudangharjo, and Gunturharjo villages of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

Figure 2. Research locations in the coastal karst area of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia. A. Woody vegetation; B. Intercropping vegetation

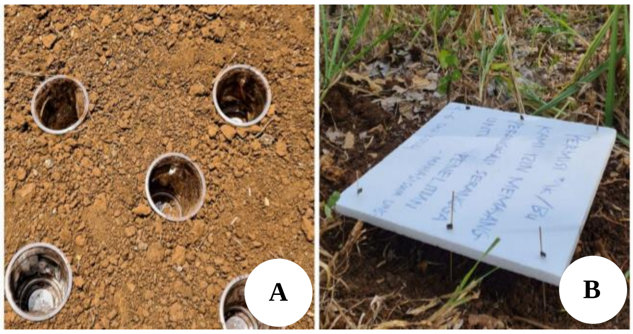

Figure 3. A. Installation of plastic cups; B. Pitfall trap shade

The location is part of the Gunung Sewu Karst area, which is spread across five districts: Eromoko, Pracimantoro, Giritontro, Paranggupito, and Giriwoyo Districts. This area is dominated by limestone hills with hilly contours, and there are natural limestone caves scattered in various locations resulting from the process of dissolving limestone by rainwater. Each station in one village represents 2 sampling points based on different vegetation, namely woody and intercropping vegetation (Figure 2). Station 1 is located in Paranggupito Village, mainly in woody vegetation with coordinates 8.09'55" S-110.051'9" E and in intercropping vegetation with coordinates 8.09'53" S-110.051'8" E. Then, station 2 is located in Gudangharjo Village, in woody vegetation with coordinates 8.010'16" S-110.052'16" E and intercropping vegetation with coordinates 8.010'15" S-110.052'14" E. The last station is located in Gunturharjo Village in woody vegetation with coordinates 8.012'20" S-110.054'02" E and intercropping vegetation with coordinates 8.010'55" S-110.052'38" E.

The research area has 2 stations in each village that are distinguished based on the type of plantation pattern (woody vegetation and intercropping vegetation) as in Figure 2, with each having 3 sub-stations (5 pitfall traps every sub-station), so the total number of stations is 18 points with 90 cups of pitfall traps. This is because vegetation management in different agroforestry systems can affect the diversity of soil macrofauna (Masebo et al. 2024). The tools used in this study included 500 mL plastic cups, stirrers, hoes, foam tape, styrofoam, scissors, rulers, smartphones, tweezers, plastic clips, jerry cans, and satay skewers. Enviro-meter tools, such as ITuin Soil Testers, Alla France Soil Thermometers, Krisbow AS803 Lux Meter, and NTL-HM370 Hygro Thermometer were used to determine the abiotic conditions in the research area. The materials used were liquid detergent, distilled water, shrimp paste, and 70% alcohol.

Procedures

Environmental factor measurement

Environmental parameter measurements were carried out at each trap installation point at three different times, namely morning (07.00-08.00), afternoon (12.00-13.00), and evening (16.00-17.00), to represent the environmental conditions of observation (Ahmad et al. 2024). The environmental conditions of the study were based on the abiotic factors measured: air temperature, air humidity, soil humidity, light intensity, soil pH, and soil temperature.

Preparation of attractant solution

The attractant solution attracts soil macrofauna to the installed trap. It is made by mixing detergent liquid (25 mL), 70% alcohol (50 mL), and distilled water (75 mL) in a ratio of 1: 2: 3 for 1 cup of pitfall trap. The mixture is stirred until it becomes a homogeneous solution and stored in a clean jerrycan before being poured into the pitfall trap.

Pitfall trap making

The sampling method used was a pitfall trap (Figure 3). The pitfall trap method is a simple trap made by digging the ground and then submerging a plastic cup so that the lip of the plastic cup is parallel to the ground surface to obtain samples of macrofauna that are active on the ground surface (Heddle et al. 2023). The plastic cup contains an attractant solution in the form of a mixture of detergent, alcohol, and distilled water to kill and preserve the sample so that the specimen is not easily damaged (Rahmawati et al. 2024). Liquid detergent is added to eliminate the tension on the water surface so that the sample does not float on the solution (Graux et al. 2024). This study placed 5 plastic cups by random simple sampling with an attractant solution of 150 mL at each sub-station so that the total pitfall traps installed were 90. The trap's inside was baited with shrimp paste attached to the plastic cup's wall to increase the attraction of incoming macrofauna. The top of the trap is shaded with styrofoam with skewers as supports (Figure 3) to prevent water, pollutants, or other vertebrates from entering the trap (Gardarin and Valantin 2021). Pitfall traps are installed in the morning (07.00-08.00) and evening (18.00-19.00) and then observed after 24 hours in the hope of being able to represent the ecological conditions of each category of soil macrofauna (nocturnal and diurnal).

Table 1. Macrofauna community structure value criteria

Index	Range	Category
Biodiversity (H')	H' ≤ 2	Low diversity
	2 < H'≤ 3	Moderate diversity
	H ≥ 3	High diversity

Source: Ulfah et al. (2019)

Identification of soil macrofauna

The soil macrofauna samples obtained will be observed and measured using a ruler, tweezers, and a smartphone telephoto camera at the family, genus, and species level with key guidelines from the book, namely Insect Determination Key (Lilies 1991) and An Introduction to the Study of Insects (Borror et al. 1989), then a scientific study by Peritika et al. (2012), Sembiring et al. (2021) and Rahmawati et al. (2024). The number of samples for each species was counted manually to determine the dominant species of certain trapped macrofauna.

Data analysis

Diversity index

Soil macrofauna sample data is used to calculate the Shannon-Wiener diversity index (Putro et al. 2023) by comparing the high and low diversity of macrofauna species in each area with the formula:

$$H' = -\sum_{i=1}^{s}(Pi)(\text{In}Pi)$$

Where: Pi: ∑ni/N; H': Shannon-Wiener diversity index; Pi: Number of individuals of a species/total number of all species; ni: Number of individuals of the i-th species; N: Total number of individuals. Macrofauna community structure value criteria can be seen in Table 1.

Pearson correlation

Furthermore, a Pearson correlation analysis was carried out to determine the relationship between the soil macrofauna diversity index and various environmental factors variables such as soil moisture, pH, soil temperature, light intensity, air temperature, and air humidity. Many abiotic factors indirectly affect the reproduction of soil macrofauna, including changes in rainfall, temperature, humidity, and air direction (Peritika et al. 2012; Safitri 2016). One method is used to determine the relationship status between a variable and another variable. One of the popular correlation techniques is the Pearson correlation. This correlation technique involves one dependent variable and one independent variable. The Pearson correlation coefficient measures the extent of the linear relationship between two variables. However, suppose the relationship between the two variables is non-linear. In that case, the Pearson correlation coefficient results will not accurately represent the strength of the relationship between the two variables, even though they have a strong relationship (Safitri 2016). The Pearson correlation coefficient value is between -1.0 and 1. A value of 1 indicates a positive correlation, while -1 represents a negative correlation, and a value of 0 signifies no correlation (Windarto 2020). The formula for determining Pearson correlation is shown as follows:

$$r = \frac{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{[(\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2)(\frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y})^2)]^{\frac{1}{2}}}$$

Where: r: Pearson coefficient; n: Number of pairs of the stock; $\sum xy$: Sum of products of the paired stocks; $\sum x$ = Sum of the x scores; $\sum y$ = Sum of the y scores; $\sum x^2$ = Sum of the squared x scores; $\sum y^2$ = Sum of the squared y scores.

RESULTS AND DISCUSSION

Soil macrofauna are a group of animal organisms that live in and/or on the surface of the soil with large sizes, usually more than 2 mm (Zhou et al. 2022). Soil macrofauna plays an important role in the soil ecosystem by helping the decomposition process, loosening the soil, and increasing air and water circulation (Handayani and Winara 2020). Installing pitfall traps is carried out to determine the density or abundance of soil macrofauna, especially active insects above the soil surface.

Table 2 shows that the sugar ant (*Camponotus consobrinus* (Erichson, 1842)) species dominate the soil macrofauna in Gunturharjo Village, with a total of 54 individuals in intercropping vegetation land and 229 individuals in woody vegetation land. In woody vegetation land in Gudangharjo Village, the dominant soil macrofauna species are *C. consobrinus*, with a total of 49 individuals, and *Odontoponera* sp., with a total of 32 individuals. *Camponotus consobrinus* also dominates intercropping vegetation land in Gudangharjo with 42 individuals. In addition, the *Odontoponera* sp. species has a total of 15 individuals, which is quite significant compared to other species. *Camponotus consobrinus* species still dominates in Paranggupito Village in intercropping vegetation land with a total of 76 individuals. Meanwhile, in soil macrofauna in woody vegetation land, there are no species that dominate significantly because the difference number of individuals between species is very small; the most individuals found are the *Odontoponera* sp. species, with a total of 3 individuals.

Based on Table 3, the number of soil macrofauna individuals in Gunturharjo Village and Paranggupito Village was more inland with intercropping vegetation. Meanwhile, soil macrofauna in Gudangharjo Village was mostly found on land with woody vegetation. Gunturharjo Village has the largest total number of individuals among the other 2 villages, namely 299 individuals. Based on species diversity, macrofauna in intercropping vegetation land are more diverse in Gudangharjo and Paranggupito Villages. In Gunturharjo Village, the number of species between woody vegetation land and intercropping vegetation land showed balanced results. Overall, the number of species in Gunturharjo Village was the largest among the three villages, namely 9 different species.

Table 2. Identification of soil macrofauna diversity in the coastal karst area of Gunung Sewu, Paranggupito Sub-district, Wonogiri District, Indonesia

Village	Vegetation	Ordo	Species	Number of individuals
Gunturharjo	Woody	Hymenoptera	*Odontoponera* sp.	3
		Hymenoptera	*Dolichoderus* sp.	4
		Hymenoptera	*Camponotus consobrinus* (Erichson, 1842)	54
		Coleoptera	*Harpalini* sp.	4
		Orthoptera	*Teleogryllus emma* (Ohmachi & Matsuura, 1951)	1
	Intercropping	Hymenoptera	*Camponotus consobrinus* (Erichson, 1842)	229
		Arthropoda	Arthropods species	1
		Arthropoda	*Tegenaria* sp.	1
		Hemiptera	*Leptocorisa oratoria* (Fabricius, 1794)	1
		Lepidoptera	*Eressa confinis* (Walker, 1854)	1
Gudangharjo	Woody	Hymenoptera	*Odontoponera* sp.	32
		Hymenoptera	*Camponotus consobrinus* (Erichson, 1842)	49
		Diptera	*Musca domestica* (Linnaeus, 1758)	5
	Intercropping	Hymenoptera	*Odontoponera* sp.	15
		Hymenoptera	*Camponotus consobrinus* (Erichson, 1842)	42
		Arthropoda	*Tegenaria* sp.	3
		Araneae	*Badumna insignis* (L.Koch, 1872)	1
		Isopoda	*Philoscia* sp.	6
		Diptera	*Musca domestica* (Linnaeus, 1758)	9
		Coleoptera	*Harpalini* sp.	1
		Blattodea	*Blatella* sp.	4
Paranggupito	Woody	Hymenoptera	*Odontoponera* sp.	3
		Hymenoptera	*Camponotus consobrinus* (Erichson, 1842)	1
		Hemiptera	Hemiptera species	2
		-	Unidentified	2
	Intercropping	Diptera	*Musca domestica* (Linnaeus, 1758)	2
		Hymenoptera	*Camponotus consobrinus* (Erichson, 1842)	76
		Hymenoptera	*Odontoponera* sp.	1
		Coleoptera	*Paederus fuscipes* (Curtis, 1826)	2
		-	Unidentified	1

Table 3. Number of individuals and dominant species in the coastal karst area of Gunung Sewu, Paranggupito Sub-district, Wonogiri District, Indonesia

Village	Vegetation	Number of individuals	Total individuals	Number of species	Total different species
Gunturharjo	Woody	66	299	5	9
	Intercropping	233		5	
Gudangharjo	Woody	86	167	3	8
	Intercropping	81		8	
Paranggupito	Woody	8	90	4	6
	Intercropping	82		5	

The results of the species analysis found in Gunturharjo Village, Gudangharjo Village, and Paranggupito Village showed that there were 16 different species. *Camponotus consobrinus* species can be found in all villages of the research location, both in woody and intercropped vegetation. Then, it can be seen in Figure 4 that the soil macrofauna in woody vegetation land contains 8 different species dominated by *C. consobrinus* species. Figure 5 shows that the soil macrofauna in intercropped vegetation land is more diverse, with 13 species dominated by *C. consobrinus* species.

Table 4 shows that in Gunturharjo Village, the diversity index in woody vegetation was recorded at 0.71, while in intercropping vegetation, it was lower at 0.11. Soil moisture in this village is at 2%, with soil pH remaining neutral with pH 7 and 6.5, respectively. Soil temperature is slightly different, where woody vegetation was recorded at 29.5°C, and in intercropping, it was 29°C. This village also shows a significant difference in light intensity, where woody vegetation only receives 4,810 Lux, while intercropping vegetation receives a much higher intensity of 345,406 Lux. Air humidity is slightly higher in woody vegetation (34.1°C) than intercropping (32.6°C), with air humidity recorded at 29 and 30%, respectively. In the second research location, namely Gudangharjo Village, the diversity index is higher in intercropping vegetation (1.32) than in woody (0.85). The soil moisture in this village is only 1%, with the soil pH remaining neutral (pH 7) for both types of vegetation. The soil temperature in woody vegetation reaches 30.4°C, while in intercropping it is 30°C. Woody vegetation receives 5,550 Lux of light, much lower than intercropping, which reaches 336,905 Lux. The air temperature in woody vegetation is higher (35.1°C) than intercropping (34.5°C), with air humidity ranging from 28 to 30%. At the third research location, namely in Paranggupito Village, the diversity index in woody vegetation was recorded at 1.32, while in intercropping vegetation, it was lower, namely 0.38. The soil moisture in both vegetation types is at 1%, with a neutral soil pH (pH 7). The soil temperature ranges from 29.5°C in woody vegetation and 29.2°C in intercropping. The light intensity also differs significantly, where woody vegetation only receives 6,040 Lux, while intercropping reaches 340,533 Lux. The air temperature in woody vegetation is higher (36.5°C) than intercropping (34.5°C), with air humidity recorded at 29 and 31%, respectively.

Table 5 shows the Pearson correlation value between the species diversity index and various abiotic factors. Soil moisture has a moderate negative correlation of -0.59, which means that the higher the soil moisture, the species diversity tends to decrease. On the other hand, the soil moisture p-value of 0.22 indicates an insignificant correlation between soil moisture and diversity. Many ways can affect this finding, such as the size and the variability of the sample. The pH showed a strong positive correlation to the Shannon-Wiener diversity index with a correlation value of 0.79. This indicates that species diversity tends to increase as the pH approaches neutrality (closer to 7). The p-value of the pH variable is 0.06, which also indicates a low significance of the correlation between pH and diversity.

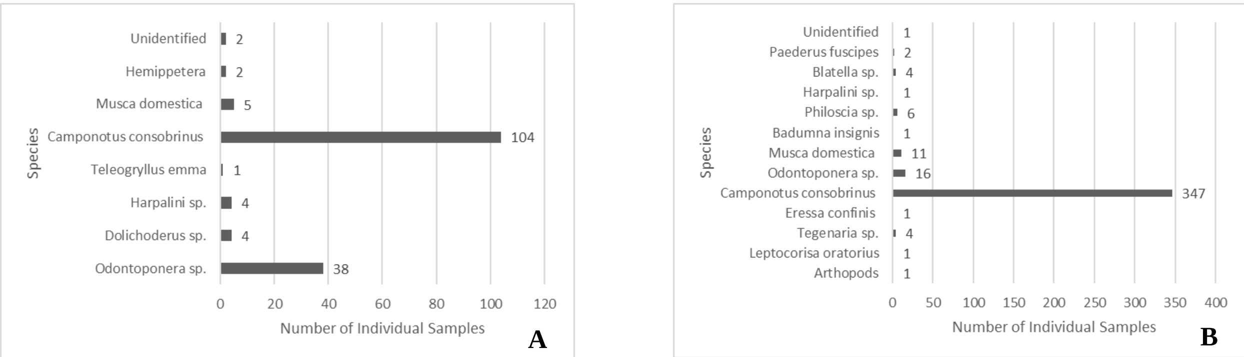

Figure 4. Soil macrofauna dominance in the coastal karst area of Gunung Sewu, Paranggupito Sub-district, Wonogiri District, Indonesia: A. Woody vegetation; B. Intercropping vegetation

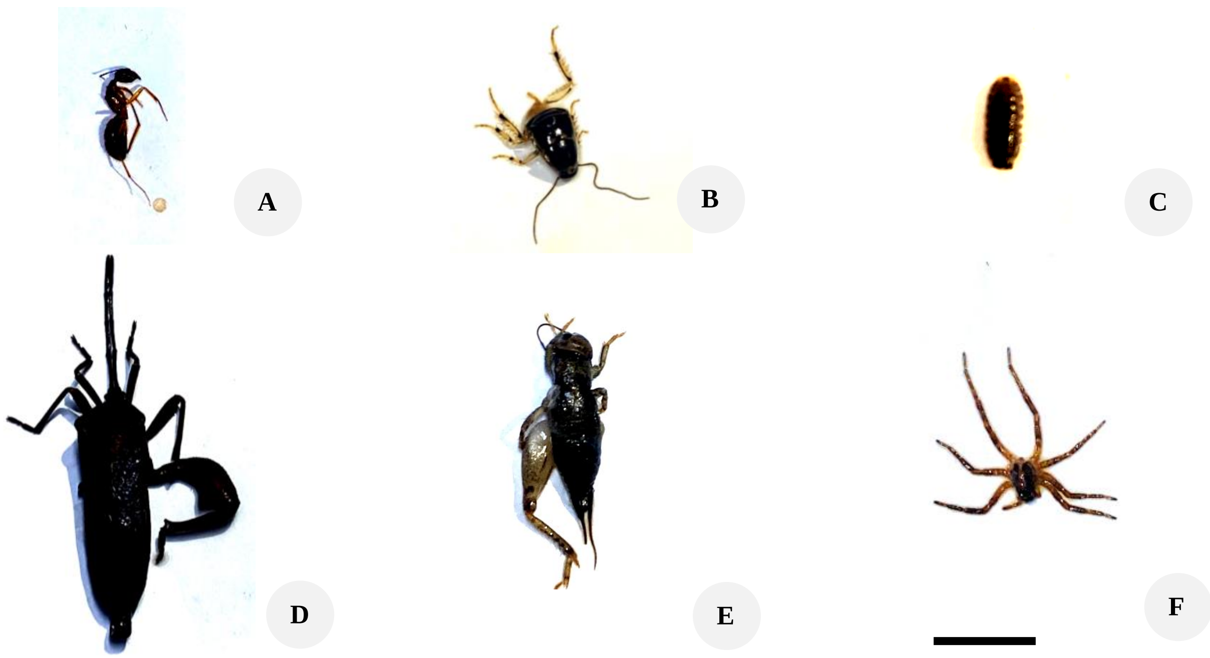

Figure 5. Some soil macrofauna specimens found in the coastal karst area of Gunung Sewu, Paranggupito Sub-district, Wonogiri District, Indonesia: A. *Camponotus consobrinus*; B. *Blatella* sp.; C. Unidentified; D. *Leptocorisa oratoria*; E. *Teleogryllus emma*; F. Arthropod. Bar = 1 cm

Table 4. Shannon-Wiener diversity index and abiotic factors of research locations in the coastal karst area of Gunung Sewu, Paranggupito Sub-district, Wonogiri District, Indonesia

Village	Vegetation	Diversity index	Abiotic factors					
			Soil moisture (%)	pH	Soil temp. (°C)	Lux meter	Air temp. (°C)	Air humidity (%)
Gunturharjo	Woody	0.71	2	7	29.5	4810	34.1	29
	Intercropping	0.11	2	6.5	29	345406	32.6	30
Gudangharjo	Woody	0.85	1	7	30.4	5550	35.1	28
	Intercropping	1.32	1	6,9	30	336905	34.5	30
Paranggupito	Woody	1.32	1	7	29.5	6040	36.5	29
	Intercropping	0.38	1	6,7	29.2	340533	34.5	31

Table 5. Pearson correlation of Shannon-Wiener diversity index and abiotic factors

Correlation factor	P Value	Pearson correlation
Soil moisture (%)	0.22	-0.59
pH	0.06	0.79
Soil temperature (°C)	0.19	0.62
Lux meter (light intensity)	0.42	-0.41
Air temperature (°C)	0.07	0.78
Air humidity (%)	0.44	-0.39

The soil temperature has a moderate positive correlation of 0.62, which indicates that an increase in soil temperature is related to an increase in species diversity. Meanwhile, the p-value shows a high value of 0.19. Conversely, the light intensity or Lux Meter has a weak negative correlation of -0.41, which indicates that an increase in light intensity slightly decreases diversity. The p-value of light intensity is 0.42, which is a fairly strong category between the value of light intensity and diversity. The air temperature factor has a strong positive correlation with a value of 0.78, meaning that the higher the air temperature, the greater the species diversity. While the p-value shows 0.07, that means a high value. Finally, air humidity shows a weak negative correlation of -0.39, which is a weak category between the value of air humidity and diversity, where an increase in air humidity is associated with a slight decrease in species diversity. The p-value of air humidity is 0.44. The calculation of the p-value on all variables shows a high value >0.05, which means that between each variable and the diversity has a low correlation significance.

Discussion

Relationship between macrofauna diversity and abiotic factors in karst areas

This study found that macrofauna diversity in the karst region of Gunung Suwu karst area including Paranggupito Village, Gudangharjo Village, and Gunturharjo Village of Paranggupito Sub-district, Wonogiri District, Central Java, is dominated by 16 species, with *C. consobrinus* being the most prevalent. The study also identified several abiotic factors, including soil moisture, light intensity, air humidity, soil pH, soil temperature, and air temperature, that significantly influence macrofauna diversity. According to Rohyani and Sulistiani (2022), the abundance of soil macrofauna in each area is determined by extrinsic factors, which include biotic and abiotic components, as well as intrinsic factors, namely the tendency of macrofauna to prefer environments with certain conditions. The study also found that the dry season exerts environmental pressure on soil macrofauna, leading them to become more active in their search for food or suitable habitats to survive on the soil surface. This heightened activity increases the likelihood of capture using the pitfall trap method. This finding aligns with the study by Oktapiani et al. (2024), which reported that the dominance of the dry season tends to exhibit higher soil macrofauna diversity, with observed family abundance being nearly four times greater than in the rainy season. Furthermore, deploying pitfall traps during the dry season can minimize environmental disturbances, such as water pooling, rain, and wet litter, which could otherwise reduce the trap's effectiveness (Kelly et al. 2020).

When analyzed based on soil moisture parameters, Gunturharjo Village is the only village with soil moisture of 2% among other villages. However, the results of the diversity index at the location showed small numbers for woody vegetation and intercropping, namely 0.71 and 0.11, respectively. Generally, a humid soil environment has a positive impact on the activity of soil organisms (Sofo et al. 2020). However, based on the Pearson correlation calculation, the results show that soil moisture and species diversity in the study area are negatively correlated. In dry and semi-arid environments, including karst areas, soil moisture parameters are a crucial environmental factor for forming biological communities, including macrofauna communities (Ge et al. 2021). Soil moisture is highly dependent on the unique characteristics of the soil in the karst area. The porosity and drainage properties of the karst area affect the ability of the soil to absorb water so that soil moisture is fluctuating and unstable (Wang et al. 2023).

Like other organisms, macrofauna lives by interacting with abiotic and biotic environmental factors in their habitat. For example, soil pH can be a determinant factor for macrofauna density due to its correlation with nutrient availability in the soil, as shown in Zhou et al. (2022) research that shows a positive correlation between soil macrofauna and soil pH. A similar outcome was observed across all locations within the karst area in this research, showing a strong positive correlation with a value of 0.79. As shown in Table 4, all locations in the woody vegetation category have the same pH level of 7, which is neutral and considered optimal for soil macrofauna life. If the soil contains extreme pH levels, it can affect the growth of soil macrofauna through the disruption of enzyme activity and ionization balance (Zhang et al. 2024). Although the value of pH in the intercropping vegetation category varies and indicates increased acidity, it remains suitable for macrofauna because, according to Nurrohman et al. (2015), most soil macrofauna prefer to live in soil with a pH ranging from 6-7 because of the high availability of nutrients. The unsuitability of soil pH levels can affect the food sources of macrofauna because it can inhibit the growth of plants and microorganisms (Zhang et al. 2024)

The results of the Pearson correlation show a negative correlation, which means that the higher the light intensity at Gunturharjo and Paranggupito Villages, the lower the macrofauna diversity value. The presence of vegetation is one factor affecting light intensity, due to the lack of vegetation, so that no canopy can block sunlight from directly hitting the ground surface. Direct exposure to sunlight can result in death for soil macrofauna (Wibowo and Slamet 2017). The species most commonly found out of all locations with the highest light intensity is *C. consobrinus*, which belongs to the Formicidae (ants) family. Ants are a species resistant to sunlight, so they are often found in parts of the litter that are directly exposed to sunlight. Many factors can affect the results of light intensity measurements, such as measurement time, stand composition, vegetation density, and the angle of incidence of the sun (Ahmad et al. 2024).

Another physical factor that affects the life of soil fauna is soil temperature. Fluctuations in soil temperature affect the availability of nutrient sources for soil insects because they are closely related to the level of decomposition of soil organic material (Rachmasari et al. 2016). Soil macrofauna species generally prefer lower soil temperatures. However, based on the results of the Pearson correlation shows that the higher the soil temperature, the greater the increase in species diversity. The results of the Pearson correlation for air temperature parameters also show the same thing. Temperature plays an important role in the growth and development of soil macrofauna. A positive correlation between soil temperature and air temperature on macrofauna diversity can occur because, in general, the metabolism of macrofauna will increase as the temperature increases, so its growth and development will also increase (Wang et al. 2024).

The humidity parameters at each research location showed inverse results. If the air temperature is high, the percentage of air humidity will decrease. Air humidity will majorly impact soil macrofauna if extreme temperatures occur because when humidity levels increase, the evaporation rate will be reduced, consequently allowing greater retention of soil moisture (Köhli et al. 2021). Generally, soil macrofauna is more suitable for living in highly humid habitats (Wasis et al. 2024). It can be seen in the results of the diversity index in Gudangharjo Village, with a higher type of intercropping vegetation compared to other locations and a fairly high air humidity, which is 30%.

Macrofauna diversity in different vegetation types in karst areas

The intercropping vegetation type is an agricultural system where more than one type of vegetation is planted on land to maximize land use and optimize resource use. As an area that is ecologically known to be vulnerable, karst areas can apply efficient agroforestry technology for water and soil resources. Therefore, intercropping vegetation types can be found in karst areas because of their conservation function. Several previous studies have found an increase in soil macrofauna such as earthworms and ants in intercropping vegetation types because the increasing species of plants will encourage ongoing nutrient recycling and provide a more suitable habitat for soil organisms to grow and develop (Punyalue et al. 2018). It is in accordance with the results of macrofauna identification in the three villages in the intercropping vegetation type, where Formicidae or ants were found in all locations. Ants are one of the macrofauna that can improve the physical structure of the soil and the composition of minerals and organic matter in the soil, and the intercropping vegetation type is beneficial for ants because it will reduce competition in obtaining additional resources from intercropped plants (Usamah et al. 2023).

The type of woody vegetation affects the microhabitat at the location, as the tree canopy can reduce the intensity of direct sunlight exposure to the soil. This affects the life of soil macrofauna. In addition, some soil macrofauna species also prefer forest environments with sufficient foliage and food sources. However, in this study, the species of soil macrofauna that dominates both vegetation types is the same, namely *C. consobrinus* species. That factors can influence include high levels of adaptation.

Identification of dominant macrofauna families in karst areas

Camponotus consobrinus is a species of the Formicidae family that lives in colonies. *Camponotus consobrinus* species, known as sugar ants, is the most dominant species found at the research location. This is because *C. consobrinus* is a pest insect that likes to colonize woody vegetation by building its nest under wood with a large underground area (Kulsum 2018). In addition, its nest can also be found in various places, including plant roots, tree branches, and shrubs, between rocks, in the soil, and under paving stones. These ants have a high tolerance to climate variations, with an ideal arena between 18 to 28°C and a nest part between 21 to 24°C (Fraser et al. 2000). According to Middleton (2014), *C. consobrinus* shows that individuals can handle various light intensities and temperature variations ranging from 7.7-32.3°C in foraging activities. *Camponotus consobrinus* is a nocturnal ant that forages more often at night but can also forage during the day. The dominance of *C. consobrinus* species at the research location may be due to *C. consobrinus* species attacking the nests of other ant species randomly while ignoring other ants nearby (Taylor et al. 2018). These ants are 0.7-1.3 cm in size. The sugar ants have sub-trigonal to elongated-triangular jaws (Khairunnisa 2023). Another species that is abundant is *Odontoponera* sp. *Odontoponera* is a genus of small ants in Southeast Asia in the Formicidae family. There are 2 species of this genus whose distribution is limited to the Southeast Asian region, namely *Odontoponera denticulata* (F.Smith, 1858) and *Odontoponera transversa* (Smith, 1857) (Schmidt et al. 2014). *Odontoponera* sp. are locally abundant, with *O. denticulata* having the widest distribution of this species, from mainland Asia to the Philippines and Sundaland; *O. transversa* is found from the Malay Peninsula south to the islands of Sundaland (Yamane 2009). *Odontoponera* sp. are adaptable and can nest in various environments but prefer to nest in forest areas.

Formicidae family is the dominant family in woody and intercropping vegetation in the research location. This family is a eusocial insect that belongs to the order Hymenoptera, along with bees and wasps. The Formicidae family is an insect that lives in almost every type of ecosystem, except in the polar regions, with various ecosystem roles. Ants are abundant in islands and large land areas and are estimated to reach 15,000 species (Ilhamdi et al. 2024). The results of the research show that the Formicidae family mainly consists of the species *C. consobrinus* and *Odontoponera* sp. The research location is a karst area covered with woody vegetation and an intercropping system with a porous soil structure that supports aeration and water infiltration. Biodiversity can maintain the availability of resources that maintain interactions between plants, microorganisms, and insect species and also contribute to the productivity and health of the karst ecosystem. The existence of soil macrofauna insects in an ecosystem has a very important role in the ecosystem, including as the main predator of several small invertebrates, seed eaters, nectar, plant secretions, aphid secretions, and shredders of dead organic matter (Agus and Septianjaya 2021). Ants help maintain soil aeration and mixing, which increases water infiltration and keeps the soil healthy. They form a symbiosis with other insects and plants and actively spread plant seeds. The role of the Formicidae family is considered quite vital because it will affect other animal species.

Formicidae can be used as a bioindicator of soil fertility. The distribution of the Formicidae family in a habitat is influenced by vegetation structure, human activities, the spread of invasive species, and habitat conditions (Abdillah et al. 2019). Formicidae family is known as a predator in the ecosystem because it searches for food in colonies and has been assigned to go out to find food in a large roaming area (Sijabat et al. 2020). In intercropping vegetation, the Formicidae family has an important role in spreading plant seeds with elaiosomes as an energy source, moving them to the nest, and accelerating the spread and growth of seedlings. However, over time, the karst ecosystem also faces various challenges, both caused by natural factors and anthropogenic activities that have an impact on the distribution of the Formicidae family.

In conclusion, the study found that 16 different species were found in all three villages, and *C. consobrinus* dominated the intercropping vegetation across most locations, outnumbering other species. This study found 16 species, but one of them stated as unidentified due to the limitations of the author and the equipment used, so it needs to be studied further. The diversity index of macrofauna in intercropping was generally lower than in woody vegetation, which offered a more stable microhabitat and protection from direct sunlight. Woody vegetation supported higher macrofauna diversity due to its ability to reduce sunlight and provide organic matter, with *Odontoponera* sp. also abundant in these areas. The diversity of macrofauna at each station was relatively low. In contrast, the relationship between abiotic factors and diversity showed varying correlations, such as soil moisture, lux meter, and air humidity were negatively correlated by -0.59, -0.41, and -0.39, respectively, which means when the values increase, then the diversity tends to decrease and vice versa; In contrast, pH soil, soil temperature, and air temperature were positively correlated by 0.79, 0.62, and 0.78, respectively, showing a moderately strong relationship. Whereas the values increase, the diversity also tends to increase. The discovery of soil macrofauna species in this study shows that macrofauna are able to survive in karst areas, which have an important role in maintaining soil health and fertility, so that their existence must be maintained and preserved.

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