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Soil Macrofauna as Bioindicators of Soil Fertility in Cocoa Plantations *Theobroma cacao* L.) at Different Elevations in Kota Komba Subdistrict, East Manggarai Regency

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ABSTRACT: Cocoa (*Theobroma cacao* L.) thrives in tropical regions, including the Kota Komba subdistrict. However, knowledge and utilization of soil macrofauna as bioindicators of soil fertility remain limited, resulting in suboptimal land management practices that impact cocoa productivity and sustainability. This study aims to analyze the diversity of soil macrofauna and its role as a bioindicator of soil fertility in cocoa plantations in the Kota Komba subdistrict. Samples were collected from three locations at different elevations: 125 m above sea level, 435 m above sea level, and 856 m above sea level. The sampling method used was direct observation in the cocoa plantation. Soil macrofauna samples were collected using pitfall traps and hand sorting, while soil samples were analyzed to determine organic carbon content, pH, cation exchange capacity (CEC), and base exchange capacity (BEC). Diversity index (H'), abundance index (R1), and dominance index (C) were calculated to analyze macrofauna diversity. Data were analyzed using SPSS ANOVA BNT software to test macrofauna as bioindicators of soil fertility. The results showed that 11 soil macrofauna species from 3 phyla were found, with the highest diversity at an altitude of 435 m above sea level (11 species), followed by 125 m above sea level (10 species), and 856 m above sea level (7 species). The diversity index (H') ranged from 1.761 to 2.203 (moderate category), with the highest value at 435 m above sea level, and the evenness index (E) ranged from 0.905 to 0.937 (high category). pH and organic carbon significantly influenced ($p<0.05$) macrofauna diversity, while CEC and base saturation were not significant ($p>0.05$). Soil macrofauna has proven to be an effective bioindicator of soil fertility due to its sensitivity to edaphic conditions and its role in bioturbation, organic matter decomposition, and soil structure formation. A stable macrofauna community ($E > 0.9$) indicates a balanced soil ecosystem and can be used as a practical bioindicator for assessing the fertility of cocoa plantation soils.

KEYWORDS: Cocoa plantations, Macrofauna, Bioindicators, Soil fertility

I. INTRODUCTION

The cocoa plant (*Theobroma cacao* L.) is a strategic plantation commodity with high economic value that is the main source of income for millions of small farmers in Indonesia (Geke *et al*., 2022). Indonesia ranks third among the world's largest cocoa producers, contributing 13% of exports, after Côte d'Ivoire (38%) and Ghana (20%). National cocoa production reaches 593,331 tons per year, with 94.78% coming from smallholder plantations (Geke *et al*., 2022). Kota Komba Subdistrict, East Manggarai Regency, is the largest cocoa production center with a production of 2,370 tons in 2023 (BPS, 2024). The geographical conditions at an altitude of 500-1,400 meters above sea level provide unique environmental characteristics for cocoa cultivation. Cocoa plants generally thrive at elevations of 200–1,000 meters above sea level, but tolerance varies depending on the variety, climate, and environmental conditions (Sitohang *et al*., 2023). Elevations of 815–1,350 meters above sea level have been shown to improve the physical characteristics of cocoa fruits and beans (Sitohang *et al*., 2023).

Elevation significantly impacts soil ecosystems, particularly soil macrofauna communities. Soil macrofauna are organisms larger than 2 mm that play a vital role in ecosystem balance through organic matter decomposition, soil structure improvement, increased aeration, and nutrient distribution (Rai *et al*., 2020; Manurung, 2020). The presence of macrofauna is influenced by environmental factors such as temperature, humidity, and soil pH, which vary with elevation (Saputra, 2019). Soil macrofauna serve as bioindicators of soil fertility in various agricultural systems. Macrofauna such as ants, termites, and earthworms play a crucial role in improving the physical, chemical, and biological properties of soil (Wibowo *et al*., 2017).

Macrofauna diversity reflects soil fertility levels, where higher diversity indicates increased soil fertility (Diana, 2021). Soil macrofauna in cocoa plantations include the class Insecta (ants), Gastropoda (snails), phylum Annelida (earthworms), and class

Diplopoda (millipedes). Ants act as decomposers (Nuratika, 2021), snails as bioindicators of heavy metal pollution (Wulandari *et al*., 2018), earthworms in the decomposition of organic matter (Wibowo *et al*., 2017), and millipedes in the decomposition of plant residues (Suwandi, 2019). Intensive cocoa cultivation is often accompanied by the use of pesticides to control pests and diseases. Intensive pesticide use can threaten the existence of soil macrofauna (Endrik *et al*., 2018). Soil macrofauna diversity is vulnerable to harmful chemicals that can cause ecosystem imbalance and the extinction of certain species (Asep, 2019).

Research on the relationship between elevation and soil macrofauna diversity in cocoa plantations is still limited. Stefania (2022) found a significant relationship between soil organic matter content and macrofauna diversity at an elevation of 1,318 m above sea level. Naimnule (2023), stated that macrofauna diversity can be used as a bioindicator of soil fertility, while Lias (2023) emphasized that macrofauna diversity depends on environmental conditions. Based on the above studies, further research was conducted on soil macrofauna as a bioindicator of soil fertility in cocoa plantations (*Theobroma cacao* L.) at several elevations in Kota Komba District.

II. RESEARCH METHODS

1. Research Time and Location

This study was conducted from September to October 2024 on cocoa plantation land in Kota Komba Subdistrict, East Manggarai Regency. Soil analysis and identification of soil macrofauna were conducted at the Laboratory of Soil and Environment of Agroecotechnology Study Program, Faculty of Agriculture, Udayana University.

This study was conducted at three cocoa plantation sites with different altitudes for soil macrofauna observation. Trapping and sampling of soil macrofauna were carried out at coordination points at three different elevations: location I (125 masl), location II (435 masl), and location III (856 masl).

2. Materials and Tools

This study was conducted at three cocoa plantation sites with different altitudes for soil macrofauna observation. Trapping and sampling of soil macrofauna were carried out at coordination points at three different elevations: location I (125 masl), location II (435 masl), and location III (856 masl).

3. Research Procedures

3.1 Determination of Research Location

The research method involved purposive selection of cocoa plantation land based on elevation measured using Accurate Altimeter application. The research sites were selected by considering the proximity of land to compare differences in land use at each altitude. Determination of sample points using random diagonal sampling method with 5 sample points measuring 1m x 1m randomly placed for trap installation at each location. A total of 5 traps were set in each of the 3 different altitude locations, so that soil macrofauna data were obtained from each research location.

3.2 Soil Macrofauna Sampling

3.2.1 Pitfall Trap Method

Sampling of soil macrofauna that are active on the surface of the soil is done with the Pitfall Trap method. The pit fall trap method is done by setting a trap in the form of a plastic cup that has been filled with 95% alcohol solution as much as ± 50 ml as a killer and preservative and mixed with a little surface tension detergent solution in the alcohol solution.

3.2.2 Quadratic and Hand Sorting Methods

The quadrat method is used for sampling soil macrofauna that are less active on the soil surface but more active in the soil. Soil macrofauna found in the soil are taken by hand sorting method (sorted by hand) carefully.

3.2.3 Identification of Soil Macrofauna Samples

The identification process was carried out using soil macrofauna samples brought from the field, grouped according to the similarity of morphological characteristics and then preserved in 95% alcohol. Soil macrofauna taken are macrofauna that have a body length > 1 cm or that have a body width of 2 - 20 mm. This size is most often used in the process of grouping soil macrofauna based on body size by researchers in Asia, especially in Indonesia. The determination and identification process is carried out by paying attention to morphology (external body shape) through loupes and stereo microscopes and using several books.

4. Parameters

4.1 Shannon-Wienner Diversity Index (H')

The diversity of soil macrofauna was analyzed by the Shannon Wienner method with the following formula:

$$H' = \sum_{i=1}^{S} Pi\ In\ Pi$$

The magnitude of the Shannon-Winner species diversity index is defined as follows:

a. H'1 value> 3: high species diversity

b. H'1 value 1 ≤H 1 ≤ 3 : moderate diversity

c. H'1<1: low diversity

4.2 Species abundance index (R1)

The abundance index was measured using the Magalef index method (Magurran, 2005).

$$R1 = \frac{S - 1}{\ln N}$$

The abundance index value is defined using the Magalef index (Magurran, 2005) as follows:

a. R1 value < 3.5 = Low Abundance Index

b. 3.5 < R1 < 5.0 = Moderate Abundance Index

c. R1 < 5.0 = High Abundance Index

4.3 Species Dominance Index (C)

The species dominance index was calculated using the Menheinick index (Maguran, 2005).

$$C = \sum (pi)^2$$

4.4 Organic Materials

In determining soil organic matter by the Walkley and Black method, the correctness value is 77%.

$$C = (A-B) \times 3{,}596 \times N\ FeSO_4 \times \frac{100 + KU}{100}$$

Organic matter content = C content (%) x 1.7241

Description:

N = normality of $FeSO_4$

B = ml of blank

A = ml sample

$\frac{100}{58}$ derived from the average C content in 58% organic matter = 1.7241

KU = air dry soil moisture content

4.5 KB

$$\% KB = \frac{\text{ml Blanko - ml sample) x N NaOH x 100/25x100/b. sample x100}}{\text{KTK}}$$

4.6 KTK

$$\text{KTK (me/100 g)} = \frac{\text{ml Blanko - ml sample) x N NaOH x 100}}{\text{Sample weight}}$$

5. Data Analysis

Data analysis used ANOVA test with decision-making criteria based on significance values. A significance value of <0.05 indicates a significant difference between macrofauna groups as bioindicators of soil fertility in Kota Komba Sub-district, while a significance value of >0.05 indicates no statistically significant difference.

III. RESULTS AND DISCUSSION

1. Components of Soil Macrofauna

Soil macrofauna components observed in cocoa plantations at elevations of 125 m above sea level, 435 m above sea level, and 856 m above sea level. The results of the study conducted on cocoa plantation land at elevations of 125 m above sea level showed various types of soil macrofauna grouped by phylum/class, order, family, and species, which differed based on plant type. The data are presented in Table 5.1 as follows:

Table 1. Results of Soil Macrofauna Component of Cocoa Farmland with 125 meters above sea level.

Filum/Class	Order	Family	Species	Indonesian Name
I. Annelida				
1. Clitellata	1. Haplotaxida	1. Megascolecidae	1.Megascolex sp. 2. Pheretima sp.	Earthworms
II. Arthopoda				
2. Arachnida	2. Araneae	2. Therididae	3. Parasteatoda tepidariorum	Spiders

3. Chilopoda	3. Scolopendromorpha	3. Scolopendridae	4. Scolopendra sub spinipes	Yellowspotted Centipede
4. Hexapoda	4. Diptera	4. Muscidae	5. Musca domestica	House flies
5. Insecta	5. Hymenoptera	5. Formicidae	6. Odontomachus sp.	Black Ants
			7. Camponotus pennsylvanicus	
			8. Oecophylla smaragdina	Rangrang ants
III. Molusca				
6. Gastropoda	6. Stylommatophora	6. Achatinidae	9.Anguispira alternata	Snails
			10.Achatina fulica	Snails
Total number of species found 10				

Table 2. Results of Soil Macrofauna Component of Cocoa Farmland with 435 meters above sea level.

Filum/ Kelas	Order	Family	Species	Indonesian Name
I. Annelida				
1.Clitellata	1. Haplotaxida	1.Megascolecidae	1. Megascolex sp.	Earthworms
			2. Pheretima sp.	
II. Arthopoda				
2.Arachnida	2. Araneae	2. Therididae	3. Parasteatoda tepi dariorum	Spiders
3.Chilopoda	3.Scolopendromorpha	3.Scolopendridae	4. Scolopendra subs Pinipes	Yellowspotted Centipede
	4. Lithobiomorpha	4.Lithobiidae	5. Lithobius sp.	Centipede
4. Hexapoda	5. Diptera	5. Muscidae	6.Musca domestica	House flies
5. Insecta	6.Hymenoptera	6.Formicidae	7.Odontomachus sp.	Black Ants
			8. Camponotus pennsylvanicus	
			9. Oecophylla smaragdina	Rangrang ants
III. Molusca				
6.Gastropoda	7.Stylommatophora	7.Achatinidae	10.Anguispira alternata	Snails
			11. Achatina fulica	Snails
Total number of species found 11				

Table 3. Results of Soil Macrofauna Component of Cocoa Farmland with 856 meters above sea level.

Filum/ Kelas	Order	Family	Species	Indonesian Name
I. Annelida				
1.Clitellata	1. Haplotaxida	1.Megascolecidae	1. Megascolex sp.	Earthworms
			2. Pheretima sp.	
II. Arthopoda				
2.Chilopoda	2.Scolopendromorpha	2.Scolopendridae	3.Scolopendra subspinipes	Yellowspotted Centipede
3. Insecta	3.Hymenoptera	3.Formicidae	4.Odontomachus sp.	Black Ants
			5. Camponotus pennsylvanicus	
			6. Oecophylla smaragdina	Rangrang Ants
III. Molusca				
4.Gastropoda	4.Stylommatophora	4. Achatinidae	7. Anguispira alternata	Snails
Total number of species found 7				

Soil macrofauna in three cocoa plantation sites comprised three phyla, dominated by Arthropoda (four classes, seven species), followed by Mollusca and Annelida (one class and two species each). The highest diversity was found at moderate elevations (435 m above sea level), indicating optimal habitat conditions compared to low elevations (125 m above sea level) and high elevations (856 m above sea level). The classes Arachnida and Hexapoda were absent at 856 m above sea level, suggesting physiological tolerance limits to environmental factor changes (temperature, humidity, soil characteristics). Some species, such as earthworms (*Megascolex* sp., *Pheretima* sp.), centipedes (*Scolopendra subspinipes*), and ants, were consistently found at all elevations, indicating high adaptation to environmental variations. The decrease in diversity at high elevations is due to ecological factors such as low temperatures and oxygen limitations.

Insecta dominate the phylum Arthropoda in cocoa plantations due to species diversity, widespread distribution, and morphophysiological adaptation to various environmental conditions. The orders Hymenoptera and Diptera play a crucial role in cocoa pollination, increasing production and yield. Three ant species (*Odontomachus* sp., *Camponotus pennsylvanicus*, *Oecophylla smaragdina*) were consistently found at all three study sites. This finding aligns with John's (2022) study on oil palm plantations, which identified 20 Insecta species. The research by Ferdiansyah *et al*., (2024), found 252 insect individuals that contribute to improving soil structure and nutrient availability. Mooduto *et al*., (2024) identified 11 soil insect taxa in Gorontalo, with the Formicidae family dominating, acting as predators and organic decomposers with high adaptability to environmental changes.

Elevation significantly influences soil macrofauna diversity in cocoa plantations in Kota Komba District, with the following distribution patterns: medium elevation (435 m above sea level) has the highest diversity (11 species), followed by low elevation (125 m above sea level) with 10 species, and high elevation (856 m above sea level) with only 7 species. Taxonomic composition variation is clearly evident with a reduction in classes, orders, and families at the highest elevation, including the absence of Arachnida and Hexapoda, indicating physiological tolerance limits to environmental conditions. The mid-elevation zone provides an optimal combination of ecological factors supporting the presence of unique species such as Lithobius sp. Arthropods remain dominant at all elevations despite a reduction in classes at the highest elevation, demonstrating high adaptive capacity to varying environmental conditions.

2. Diversity Index and Species Diversity

Table 4. Results of Species Diversity and Uniformity Indices

Elevation (above sea level)	Diversity Index (H')	Type Uniformity (E)
125 meters above sea level	2.157 (Medium)	0.937 (High/Stable)
435 meters above sea level	2.203 (Medium)	0.919 (High/Stable)
856 meters above sea level	1761 (Medium)	0.905 (High/Stable)

2.1 Diversity Index (H')

Soil macrofauna plays a vital role in improving the fertility of cocoa plantation soil through the decomposition of organic matter into essential nutrients and the improvement of soil structure through nutrient recycling. Based on the results of research by Lias et al. (2023), it is evident that soil macrofauna plays an important role in the decomposition of organic matter, which leads to improved soil fertility. The highest soil biota diversity is found in the ridge area, which contributes to soil health and cocoa plant productivity. According to Siregar (2019), species diversity in an area is measured based on the number of organism species that form the community within it. The more species present, the higher the diversity level, and vice versa.

Based on the results of the analysis of the soil macrofauna diversity index in cocoa plantations in Kota Komba District, differences in diversity values were found at three different elevations. At an elevation of 125 m above sea level, the diversity index reached 2.157, classified as moderate, indicating significant variation in macrofauna species despite not yet reaching optimal conditions. At 435 m above sea level, the diversity index increased to 2.203, indicating that environmental factors at this elevation, such as temperature, humidity, and food availability, are more supportive of macrofauna diversity compared to lower elevations. Meanwhile, at an elevation of 856 m above sea level, there was a decrease in the diversity index to 1.761, the lowest value among the three locations, indicating the presence of limiting environmental factors such as low temperature and insufficient vegetation variation that do not support soil macrofauna diversity at that elevation.

Differences in pest control practices were identified at the three cocoa plantation sites studied at various elevations. At the 856 m a.s.l. site, no pest control efforts were observed, likely due to farmers' limited understanding of effective control methods, leading them to rely on natural plant recovery. This passive strategy has resulted in a decline in cocoa production over time. Ardiani (2023) emphasizes that the inaccuracy of Helopeltis spp. control has caused significant losses, including a 30-50% reduction in production, a 30-40% economic loss of total production, and damage to the plantation ecosystem. Conversely, at elevations of 125 m and 435 m above sea level, pest control is carried out by utilizing ants as biological control agents. Bao *et al*., (2024), demonstrated that black ants (*Dolichoderus bituberculatus*) and weaver ants (*Oecophylla smaragdina*) effectively control Helopeltis spp. by disrupting pest activity and preventing egg laying. This finding is in line with the research by Romarta *et al*., (2020), which identified the role of predators from the ant species *Anoplolepis gracilipes*, *Crematogaster borneensis*, and *Monomorium floricola* in controlling pests in oil palm plantations with a significance value of 0.57 for each species.

2.2 Species Diversity Index (E)

The Species Evenness Index (E) plays an important role in measuring the evenness of distribution of individuals among soil macrofauna species in cocoa plantations. This evenness of distribution is a critical factor in maintaining soil health and cocoa plant productivity, as it creates a stable environment that supports overall biodiversity. Based on the research by Al Karim *et al*., (2025), this understanding is reinforced through an analysis of the phytoplankton evenness index (E=0.47–0.93) in Litopenaeus vannamei shrimp ponds at MSTP UNDIP, which shows species distribution dynamics ranging from moderate to high. The research findings reveal that an E value >0.6 (such as 0.93) indicates even distribution and stable environmental conditions, while an E value approaching 0.47 reflects a tendency toward dominance by a single species, in this case *Chlorella* sp., with a density reaching 440,000 cells/mL.

Based on the results of the species evenness index (E) analysis presented in Table 4, the cocoa plantations in Kota Komba Subdistrict show high stability in the distribution of soil macrofauna at the three studied elevations. The evenness index values ranged from 0.905 to 0.937, indicating a relatively even and stable distribution of individuals among macrofauna species. At an elevation of 125 m above sea level, the E value reached 0.937, the highest among the three locations, indicating a very even distribution of macrofauna without significant dominance by any particular species. The 435 m above sea level elevation showed a slight decrease with an E value of 0.919, but still reflected high evenness. At the 856 m above sea level elevation, the E value reached 0.905, the lowest among the three locations but still indicating an even distribution. Based on the analysis results of *Syakirah et al*., (2024), the E value in the area ranges from low to moderate, indicating the dominance of certain species, particularly Acacia mangium. A low E value (<0.3) indicates strong dominance, while a moderate value (0.3–0.6) indicates a more even distribution despite the presence of dominance.

The decrease or moderate value in the species evenness index (E) may be caused by several environmental and biological factors that influence the distribution of soil macrofauna in cocoa plantations. Habitat heterogeneity is the main cause, where variations in environmental conditions such as resource availability, humidity, and temperature differences create conditions that are favorable only for certain types of macrofauna. According to Wasis *et al*., (2024), low or moderate species evenness index (E) values indicate uneven distribution of individuals among species in an ecosystem. This condition reflects an imbalance, where some species show significant dominance, while others have low abundance or are even rarely found. This unevenness may indicate ecological pressure, habitat disturbance, or other factors affecting community structure, resulting in some species having competitive advantages or better adaptations compared to others. Rizqiyah *et al*., (2017), the soil macrofauna diversity index in the Dieng area ranges from 0.62 to 1.04, which is classified as moderate to low. This level of diversity is influenced by differences in the number of macrofauna between shaded and open areas, as well as soil depth. Other contributing factors include soil physical-chemical characteristics, land and plant types, and fertilizer use.

3. Results of ANOVA Tests of Soil Macrofauna on Soil Parameters

The results of the ANOVA test of soil macrofauna BNT with soil parameters such as pH and organic C in cocoa plantations in Kota Komba District are presented in Tables 5 and 6 below.

Table 5. Results of ANOVA pH on Macrofauna Index

Altitude	Treatment	Average (mm)	Description
856 m above sea level	Ph- Macrofauna Index	62.700	b
125 m above sea level	Ph- Macrofauna Index	70.260	a
435 m above sea level	Ph- Macrofauna Index	71.660	a

Note: Figures followed by the same letter indicate no significant difference based on the BNT test at the 5% level.

Table 6. Results of ANOVA C organic matter on the Macrofauna Index

Altitude	Treatment	Average (mm)	Description
856 m above sea level	C Organic-Macrofauna Index	21.794	b
125 m above sea level	C Organic-Macrofauna Index	35.504	a
435 m above sea level	C Organic-Macrofauna Index	37.036	a

Note: Figures followed by the same letter indicate no significant difference based on the BNT test at the 5% level.

The ANOVA test showed a very significant difference ($p < 0.001$) in macrofauna diversity at three elevations: 125 m above sea level (pH 7.03), 435 m above sea level (pH 7.17), and 856 m above sea level (pH 6.27). The 5% BNT test showed that elevations of 125 and 435 m above sea level were not significantly different, while 856 m above sea level was significantly different. The lower pH at 856 m above sea level created less optimal conditions for macrofauna. Neutral pH (125–435 m above sea level) supported optimal biological activity, while acidic pH (856 m above sea level) inhibited macrofauna diversity. Macrofauna were found to be responsive to pH changes and have the potential to serve as bioindicators of soil quality. ANOVA tests showed that organic carbon content significantly influenced ($p < 0.001$) the macrofauna diversity index at three elevations: 435 m above sea level (3.70), 125 m above sea level (3.55), and 856 m above sea level (2.18). The 5% BNT test showed that elevations of 125 and 435 m above sea level were not significantly different, while 856 m above sea level was significantly different. The intermediate elevation (435 m above sea level) has optimal conditions for macrofauna with a balance of temperature, humidity, and the best availability of organic matter. Organic carbon content positively correlates with macrofauna diversity, as abundant organic matter provides food sources and optimal habitats. Macrofauna are sensitive to variations in organic carbon and have the potential to serve as bioindicators of soil fertility.

Soil pH significantly influences macrofauna diversity despite being neutral at all three elevations. The sensitivity of macrofauna to changes in soil chemical conditions causes even small pH variations to have a noticeable effect. Neutral pH conditions support the activity of decomposing microorganisms and optimal nutrient availability, which enhances macrofauna diversity. Wasis (2024) emphasizes that soil pH is an important ecological factor for soil fauna, with the presence and density of macrofauna highly dependent on pH levels. The optimal pH range for soil macrofauna is 5.5–8.0 (Hambali et al., 2019).

Organic carbon content shows a significant influence on macrofauna diversity with consistent patterns across elevations. High organic carbon content at 125 m above sea level (3.0–4.3%) and 435 m above sea level positively correlates with high diversity indices, while low content at 856 m above sea level (1.64–2.85%) results in lower diversity. Abundant organic matter provides an optimal food source and habitat for macrofauna. Maulana et al. (2024) explain that as elevation increases, organic carbon content also increases due to slower decomposition processes caused by lower temperatures.

4. Soil Macrofauna as Bioindicators of Soil Fertility

Soil macrofauna is a group of relatively large organisms (diameter >2 mm or length >10 mm) that can be observed with the naked eye and live in soil ecosystems. This group includes earthworms, ants, termites, and various other types of insects that serve as effective biological indicators for detecting changes and assessing soil fertility (Naimnule, 2023). The presence of soil macrofauna reflects the overall condition of the soil environment, making it a useful tool for sustainable land management and maintenance. Research in various plantation locations shows the consistent role of macrofauna as bioindicators. Nurrohman et al. (2018) identified macrofauna species including soil insects, millipedes, spiders, earthworms, centipedes, and snails that play a role in organic matter decomposition, soil structure improvement, and nutrient distribution. Naimnule *et al*., (2023), identified Lumbricus rubellus, Dolichoderus thoracicus, Isoptera, and Diplopoda as fertility indicators based on their functions in decomposition and nutrient distribution processes. Munthe *et al*., (2023), identified macrofauna from the phyla Arthropoda, Mollusca, and Annelida with high diversity levels, reflecting fertile and healthy soil.

Research in cocoa plantations in Kota Komba District at elevations of 125, 435, and 856 meters above sea level identified 11 species of soil macrofauna that function as bioindicators of fertility. *Megascolex* sp. and *Pheretima* sp. are the primary bioindicators due to their sensitivity to changes in soil conditions and their role in bioturbation and nutrient enrichment through the production of nutrient-rich casts (Andriana, 2022; Nurrohmah *et al*., 2022). These two earthworm species are positively correlated with soil fertility parameters such as organic matter, moisture, and C/N ratio. Soil arthropods such as Parasteatoda tepidariorum, Scolopendra *subspinipes*, and *Lithobius* sp. function as indirect bioindicators through their role in maintaining ecosystem balance. Utami *et al*., (2022), state that the presence of spiders indicates adequate prey populations and complex food webs. Rahmawati *et al*., (2024), reported high abundance of S. subspinipes in areas with sufficient organic matter content and low pollution levels. Yusuf *et al*., (2021), found *Lithobius* sp. with high abundance in locations with dense vegetation cover and high organic matter content.

Insects such as *Musca domestica* and ant groups (Odontomachus sp., Camponotus pennsylvanicus, Oecophylla smaragdina) play a significant role in soil nutrient cycles. Khoiriah *et al*., (2020), noted a positive correlation between the abundance of M. domestica and the availability of organic matter and habitat stability. Haneda *et al*., (2020) and Dwi *et al*., (2025), show that ant groups play a role in organic matter decomposition, the spread of beneficial microorganisms, and the improvement of soil physical structure through nest-building activities. Gastropods such as Anguispira alternata and Achatina fulica function as bioindicators of soil pH and moisture conditions. Whalen *et al*., (2021) state the role of A. alternata in organic matter decomposition and nutrient recycling with high abundance in fertile soils. El-Gendy *et al*., (2020), state that A. fulica is sensitive to changes in soil quality, with stable populations indicating healthy and fertile soil.

Soil macrofauna in cocoa plantations in Kota Komba District have proven to be effective, practical, and economical bioindicators for assessing soil fertility. The diversity of the 11 identified species provides important information for farmers to accurately monitor soil conditions and enhance productivity and sustainability in cocoa farming. The macrofauna bioindicator system supports environmental conservation through biodiversity preservation, natural erosion control, and increased organic carbon sequestration in the soil. The implementation of this system promotes long-term sustainability by creating added value through income diversification, sustainable cocoa premium prices, and the strengthening of farmer groups trained in macrofauna-based soil health monitoring.

V. CONCLUSIONS

1) Elevation significantly affects the type and diversity of soil macrofauna in cocoa plantations in Kota Komba District. The highest diversity was found at medium elevation (435 m above sea level), followed by low elevation (125 m above sea level), and the lowest at high elevation (856 m above sea level). Differences in taxonomic composition between elevations indicate physiological limitations at high elevations, although some species such as earthworms and ants are able to adapt to all elevations.
2) Soil macrofauna are effective as bioindicators of soil fertility in cocoa plantations in Kota Komba District. The diversity and presence of macrofauna reflect the physical, chemical, and biological conditions of the soil, particularly in relation to pH and organic carbon content. The highest diversity occurs at neutral to slightly acidic pH and optimal organic carbon content, with statistical evidence showing a significant influence of soil chemical factors on the macrofauna community.

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