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Important Value Index (IVI) of Soil Macrofauna in the Traditional Oil Mining Area of Wonocolo

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Abstract. The Wonocolo traditional oil mining area has oil exploitation activities that have the potential to affect the existence and diversity of soil macrofauna. Soil macrofauna play an essential role in maintaining the balance of the soil ecosystem through the processes of organic matter decomposition, nutrient cycling, and soil structure formation. This study aims to evaluate the Importance Value Index (IVI) of soil macrofauna in the Wonocolo traditional oil mining area and analyze the effect of mining activities on the macrofauna community. The research method employed is a quantitative descriptive approach, utilizing a stratified random sampling technique based on the density of oil wells per hectare. Data were collected through field observations, measurements of soil physical and chemical parameters (pH and temperature), and identification and quantification of soil macrofauna. Data analysis was conducted by calculating the IVI based on the density, frequency of presence, and dominance of each species. The results showed that traditional oil mining activities affected the composition and dominance of soil macrofauna. Several species had high IVI values, indicating their essential role in the soil ecosystem, while other species experienced population declines due to environmental changes. This study concludes that oil mining activities impact the existence and diversity of soil macrofauna; therefore, environmental management efforts are necessary to maintain the balance of the soil ecosystem in the area.

Keywords: Soil Ecosystem, Important Value Index, Soil Macrofauna, Traditional Oil Mining

I. INTRODUCTION

Traditional oil mining has been a long-standing part of Indonesia's history of natural resource exploitation. One area that still maintains this practice is Wonocolo Village in Bojonegoro Regency, East Java. This area is known as the 'Texas of Java' due to the local oil mining activities that have been ongoing since the colonial era and passed down through generations. Although these traditional mining activities contribute economically to the surrounding community, they are often carried out without regard for environmental and sustainability aspects [1]. Mining activities carried out continuously without adequate environmental impact assessments can cause damage to the soil structure.

Soil is a component of the Earth's crust composed of minerals and organic substances that support plant life by providing essential nutrients, retaining water, and anchoring plant roots. Soil formation is influenced by various factors, including parent material, climate, organisms (both microorganisms and macroorganisms), topography, time, and others [2]. Mining activities cause significant soil pollution, which occurs when chemicals enter and alter the natural composition of the soil. This is typically caused by the leakage of liquid waste or chemicals from industrial or commercial facilities and the direct disposal of industrial waste into the soil without proper procedures (illegal dumping). Hazardous materials that contaminate the soil can evaporate, be carried away by rainwater, or seep into the ground, eventually accumulating and forming toxic substances within the soil [3]. The poisonous substance adversely affects the species diversity of the soil community.

Species diversity within a community reflects the stability of an ecosystem. A high level of diversity indicates that the species in the ecosystem occupy a wide range of ecological niches. However, highly complex ecosystems are particularly vulnerable to disturbances.

Such conditions must be adequately managed and carefully avoided to avoid damage and disruption to the cycles operating within the ecosystem [4].

The presence of soil fauna is strongly influenced by soil conditions, particularly the content of organic matter. These organisms can serve as indicators of soil quality, particularly because soil fauna that function as bioindicators of fertility often exist in relatively large populations. One example of such organisms is soil macrofauna. Each type of soil fauna plays a specific role and fulfills a particular ecological function. The diversity of soil fauna can therefore be used as a biological indicator of soil health. All categories of soil fauna have the potential to serve as bioindicators, as their survival is highly dependent on both biotic and abiotic factors in the soil. Biotic factors that influence the ecosystem include microflora and plants. Meanwhile, abiotic factors involve physical aspects, such as soil texture and structure, as well as chemical properties, including pH, salinity, organic matter content, and soil mineral composition [5].

Rahmawati, L.A., et al. (2024) found that the biodiversity level in the Wonocolo traditional oil mining area is low, reflected in the limited diversity of soil macrofauna, which indicates reduced ecosystem productivity [6]. This reflects significant pressure from mining activities, including pollution and habitat destruction, which have contributed to environmental instability. Although biodiversity across all categories of oil well density falls within the low range, a notable decline is observed as oil well density increases. This study aims to identify the types of soil macrofauna present in the Wonocolo traditional oil mining area and to calculate the Important Value Index (IVI) to determine the level of macrofauna diversity. Through this approach, it is expected that a more comprehensive understanding of the impact of mining activities on soil conditions and quality will be gained, serving as a foundation for the development of sustainable environmental management strategies in mining areas.

II. METHODS

Place and Time

This study was conducted in November 2024 in the Wonocolo traditional oil mining area, Bojonegoro Regency, East Java. It employed a descriptive quantitative design with an exploratory approach. This approach was used to explore the structure of soil macrofauna communities in environments affected by traditional mining activities, which have not been extensively studied scientifically. The primary focus of this study was to calculate the Important Value Index (IVI) to determine the level of macrofauna diversity in the Wonocolo traditional oil mining area.

Determination of Sampling Location

The determination of soil sampling locations in this study was conducted using the *Stratified Random Sampling* method. This method involves dividing the population into several groups (strata) based on specific characteristics, and then taking random samples from each stratum. The determination of soil sampling points in this study used the Stratified Random Sampling method. This method is a sampling technique that divides the population into several groups (strata) based on specific characteristics, and then a random sample is taken from each stratum. In this study, the method for determining sampling points was based on healthy density per hectare. There are three categories based on healthy density: Rare (R) (1–3 wells/ha), Medium (M) (4–5 wells/ha), and Dense (D) (6–8 wells/ha). Three samples were taken from each category, resulting in a total of nine sampling points.

Sampling Method

Before taking soil samples, the first step is to measure the soil temperature using a soil thermometer and the soil pH with a pH meter. After measuring the temperature and pH, the sampling locations are marked with raffia rope and nails. Soil is then collected from an area measuring 30 × 30 cm to a depth of 15 cm. The collected soil is placed into a plastic container.

Next, the soil is sorted using the hand sorting method. This method is used to obtain active soil macrofauna. The macrofauna collected is placed into sample bottles according to the plot and preserved using 70% alcohol. Afterward, the macrofauna samples are taken to the laboratory for further identification and analysis.

Tools and materials

The tools used in this study include trowels, small shovels, raffia ropes, nails, rulers, soil thermometers, pH meters, microscopes, tweezers, and petri dishes. The primary material used is 70% alcohol for preserving macrofauna samples. The data recording process is carried out using an observation sheet to record the number of individuals, types of species, and the results of soil temperature and pH measurements.

Data analysis

The data were analyzed quantitatively by calculating the relative abundance, relative frequency, and Importance Value Index (IVI) values for each species.

a. Elative abundance is calculated using the formula:

$$KR = \frac{ni}{n} \times 100\%$$

KR = relative abundance
ni = Number of individuals in species-i
n = total number of individuals

b. Relative frequency is calculated using the formula:

$$FR = \frac{fi}{\Sigma f} \times 100\%$$

FR = Relative frequency
Fi = frequency for the i-th species
Σf = total sum of frequencies for all species

c. The importance value index is calculated using the formula:

$$INP = KR + FR$$

INP = Importance value index
KR = Relative abundance
FR = Relative frequency

III. RESULTS AND DISCUSSION

The research results showed that the order, species, and number of individuals found at each location and within each category varied. This suggests that the structure of the macrofauna community and the ecosystem conditions in the three area categories are also distinct [6]. These differences indicate variations in the suitability of environmental conditions at each location, such as soil pH and temperature. In addition to soil pH and temperature, the presence of litter can also affect the presence of ants. The thickness of the litter influences the amount of biomass that can be decomposed; thicker litter will produce more organic matter [7].

Soil pH is a standard measure of the acidity or alkalinity of the land. It has a complex impact on biogeochemical processes, influencing the biological, chemical, and physical characteristics of the soil as a whole. pH is strongly correlated with the distribution and density of macrofauna [6], [8]. The results of the pH and temperature measurements are presented in Table 1.

TABLE 1
RESULTS OF SOIL PH AND TEMPERATURE MEASUREMENTS

No.	Location	pH	Temperature (°c)
1.	R1	8	35
2.	R2	6	30
3.	R3	8	28
4.	M1	7	27
5.	M2	8	34
6.	M3	7	27
7.	D1	8	38
8.	D2	8	28
9.	D3	7	30

The soil pH ranged from 6 to 8, indicating relatively neutral to slightly alkaline soil conditions. This pH range is favorable for the existence and activity of macrofauna. A pH of 7 is considered neutral, pH values less than 7 are acidic, and pH values greater than 7 are alkaline [9].

Temperature is a crucial factor that influences the dynamics of soil ecosystems and affects the diversity of fauna species within the soil. Additionally, the rate of organic matter decomposition in the soil is significantly impacted by variations in environmental temperature [6], [10]. The measured soil temperature ranged from 27 °C to 38 °C. The lower temperatures observed at locations M1 and M3 may be attributed to better vegetation cover, which helps lower soil temperatures by increasing humidity. In contrast, higher temperatures, such as those at location D1, are a result of exposure to direct sunlight. The effective temperature range for the development of soil fauna is 15°C (minimum), 25°C (optimum), and 45°C (maximum), conditions that support the growth of soil macrofauna [11].

Soil Macrofauna Identification Results

The identification results revealed 23 species of soil macrofauna belonging to 13 orders in the Wonocolo Traditional Oil Mining Area. A total of 93 individuals were identified, with varying distributions across nine sampling locations. The most frequently found order was Hymenoptera, which consisted of 6 species and a total of 44 individuals. In addition to being the most abundant order, Hymenoptera was also the most commonly observed order across all sampling locations.

Identification results based on the sampling categories—classified according to oil well density—showed the following: In the rare category, 15 individuals from 5 orders and eight species were found, with Hymenoptera being the dominant order. In the moderate category, 43 individuals from 9 orders and 11 species were found, with Haplotaxida being the most abundant (22 individuals), while Hymenoptera and Araneae exhibited the highest species diversity (2 species each). In the dense category, 35 individuals from 6 orders and 11 species were identified, with Hymenoptera being the most dominant (24 individuals, five species).

Overall, Hymenoptera consistently exhibited the highest abundance and diversity across all oil well density categories. This finding is consistent with previous studies, which identified Hymenoptera as one of the most abundant orders in areas contaminated by petroleum refining waste, compared to uncontaminated regions [6], [12], [13]. The results of the soil macrofauna identification are summarized in Table 2.

TABLE 2
IDENTIFICATION RESULTS SOIL MACRORAUNA

Species	R1	R2	R3	M1	M2	M3	D1	D2	D3	Amount
Scolopendromorpha										
Scolopendra cingulata	2	1			1					4
Scolopendra subspinipes	1									1
Σ	3	1			1					5
Hemiptera										
Pangaeus bilineatus	1									1
Σ	1									1
Blattodea										
Blackthorn	1						3			4
Eurycotis floridana								1		1
Σ	1						3	1		5
Orthoptera										
Tarbinskiellus portentosus	1									1
Pygomorpha conica				2				1		3
Σ	1			2				1		4
Hymenoptera										
Odontomachus brunneus	1	4		3	2	1	1			12
Camponotus protestant	1		1				1		2	5
Anoplolepis gracilipes			1							1
Camponotus pennsylvanicus							1	7		8
Leptothorax acervorum							1			1
Dolichoderus sp					6			7	4	17
Σ	2	4	2	3	8	1	4	14	6	44
Isopods										
Armadillidium sp							4			4
Σ							4			4
Coleoptera										
Harpalini sp							1			1
Ocypus olens					1					1
Σ					1		1			2
Uropygi										
Mastigoproctus giganteus							1			1
Σ							1			1

Species	R1	R2	R3	M1	M2	M3	D1	D2	D3	Amount
Haplotaxida										
Lumbricus rubellus				16	5	1				22
Σ				16	5	1				22
Araneae										
Oxyopes javanus				1						1
Euphorbia frontalis				1						1
Σ				2						2
Lepidoptera										
Lemyra sp. larvae				1						1
Σ				1						1
Arachnoidea										
Ixodes sp					1					1
Σ					1					1
Dictyoptera										
Blatella germanica						1				1
Σ						1				1
Number of individuals	8	5	2	24	16	3	13	16	6	93

Soil Macrofauna Domination Location

Three locations dominate the presence of soil macrofauna: M1, M2, and D2. In contrast, location R3 is where the fewest soil macrofauna were found. Location M1 has the highest number of individuals, with 24 individuals from 6 species and five orders. The most abundant species at this location is *Lumbricus rubellus* (earthworms). The temperature at location M1 is 26.9°C, and the pH is 7. The soil pH at this location is 7, and earthworms are found in large numbers. This can be attributed to the favorable temperature and the excellent vegetation cover in the area. The vegetation in the M1 area is quite diverse and relatively dense. This area features a diverse range of plants, including wild grasses, small shrubs, and seasonal crops such as corn. The diversity of vegetation provides a source of organic matter and helps maintain soil moisture, which is essential for earthworms [14], [15]. Temperature conditions greatly influence the fertility of earthworms in a habitat. Extreme temperatures, either too high or too low, can lead to the mortality of earthworms. Generally, soil temperature affects the growth, reproduction, and metabolism of earthworms [16], [17].

In addition to pH and temperature, the presence of earthworms in the soil is highly dependent on land cover conditions. The availability of food, such as plant litter and organic remains from other organisms, plays a significant role in determining their population [18].

Location M2 had 16 individuals, comprising six species and five orders. The temperature at this location was relatively high compared to other places, reaching 38°C, with a pH of 8. Despite the higher temperature and pH, a significant number of soil macrofauna, particularly *Dolichoderus sp.*, were found. This condition can be attributed to the abundant vegetation surrounding the sampling area. The vegetation in the M2 area appears to be relatively sparse, dominated by wild grasses and a few small shrubs. The sparse vegetation leaves extensive open spaces, and the openness of a habitat can be related to the surface conditions of the soil, which is where ants are often highly active [19]. Previous research has demonstrated that the presence of vegetation in secondary forests affects the diversity and abundance of ants, as vegetation provides essential food sources, nesting sites, habitats, and shelter for these insects [20].

At location D2, 16 individuals from 4 species and three orders were recorded. The most common species were *Camponotus pennsylvanicus* and *Dolichoderus sp.*, each with seven individuals. The presence of ants is closely linked to habitat conditions and several key limiting factors, including low temperatures, inadequate nesting sites, limited food sources, and less supportive roaming areas [21], [22]. The optimal air temperature for ant activity ranges from 15°C to 28°C. The study results showed a temperature of 27.6°C at location D2. In addition to pH and temperature, the amount of litter at location D2 influenced the presence of ants. This finding aligns with previous research, which states that the thickness of litter affects the amount of decomposable biomass, with thicker litter producing more organic material [22].

Ants are essential arthropods in the decomposition process of organic matter, and litter serves as a food source for ants. Thicker litter can also create a microclimate that supports the existence of ants.

Location J3, however, had the fewest individuals, with only two individuals from 2 different species. The temperature and pH at this location were considered normal, with readings of 27.6°C and pH 8. The low number of soil macrofauna at this location may be due to dry soil conditions. Dry soil inhibits the presence of macrofauna, as soil moisture is critical for providing organic materials that serve as food sources for macrofauna [5].

TABLE 3
SOIL MACROFAUNA INP RESULTS

Order - species	abundance	Abundance relative (%)	frequency	Frequency presence (%)	Frequency relative (%)	INP (%)
Scolopendromorpha						
Scolopendra cingulata	4	4.30	3	3.33	7.49	11.79
Scolopendra subspinipes	1	1.08	1	1.11	2.50	3.57
Hemiptera						
Pangaeus bilineatus	1	1.08	1	1.11	2.50	3.57
Blattodea						
Blackthorn	4	4.30	2	2.22	4.99	9.29
Eurycotis floridana	1	1.08	1	1.11	2.50	3.57
Orthoptera						
Tarbinskiellus portentosus	1	1.08	1	1.11	2.68	3.76
Pygomorpha conica	3	3.23	2	2.22	4.99	8.22
Hymenoptera						
Odontomachus brunneus	12	12.90	6	6.67	14.97	27.88
Camponotus protestant	5	5.38	4	4.44	9.98	15.36
Anoplolepis gracilipes	1	1.08	1	1.11	2.50	3.57
Camponotus pennsylvanicus	8	8.60	2	2.22	4.99	13.59
Leptothorax acervorum	1	1.08	1	1.11	2.50	3.57
Dolichoderus sp.	17	18.28	3	3.33	7.49	25.77
Isopods						
Armadillo sp	4	4.30	1	1.11	2.50	6.80
Coleoptera						
Harpalini sp	1	1.08	1	1.11	2,50	3.57
Ocypus olens	1	1.08	1	1.11	2.50	3.57
Uropygi						
Mastigoproctus giganteus	1	1.08	1	1.11	2.50	3.57
Haplotaxida						
Lumbricus rubellus	22	23.66	3	3.33	749	3114
Araneae						
Oxyopes javanus	1	1.08	1	1.11	2.50	3.57

Euphorbia frontalis	1	1.08	1	1.11	2.50	3.57
Lepidoptera						
Lemyra sp. Larva	1	1.08	1	1.11	2.50	3.57
Arachnoidea						
Ixodes sp.	1	1.08	1	1.11	2.50	3.57
Dictyoptera						
Blatella germanica	1	1.08	1	1.11	2.50	3.57
Amount	**93**	**100.00**	**40**	**445.3**	**100.00**	**200.00**

The results of observations on the abundance and frequency of soil macrofauna at 9 locations in the Wonocolo Traditional Oil Mining Area showed that the species *Lumbricus rubellus* from the order Haplotaxida had the highest abundance, with 22 individuals. This was followed by *Dolichoderus sp.* from the order Hymenoptera, with 17 individuals, and *Odontomachus brunneus* from the Hymenoptera order, with 12 individuals. This abundance reflects the number of individuals found across the nine sampling locations.

The species with the highest frequency was *Odontomachus brunneus* from the Hymenoptera order, which was found at six sampling locations. It was followed by *Camponotus protestans* from the Hymenoptera order, which was found at four sampling locations. Frequency refers to the number of places where a species was observed.

Table 3 presents the results of soil macrofauna, showing that *Lumbricus rubellus* from the order Haplotaxida had the highest Important Value Index (INP), at 31.14%. The high INP for this species is supported by its abundance, particularly at location M1, where 16 individuals were found. *Lumbricus rubellus*, an earthworm belonging to the Epigeic group, lives on the surface and feeds on litter, making it suitable for use as a lead metal-degrading agent for surface soil waste [17], [18].

Earthworms are considered ecosystem engineers because their activities, such as burrowing, producing waste, and mixing soil, significantly contribute to improving soil structure and quality [23]. Interestingly, earthworms can survive and reproduce even in soils heavily contaminated with heavy metals [24], [25]. Previous studies have demonstrated a significant correlation between earthworm density and lead (Pb) concentrations in soil, with higher Pb levels associated with higher earthworm densities in that area [26]. This finding aligns with previous studies that identified the presence of heavy metals in the region [27].

The species with the second-highest INP is *Odontomachus brunneus* from the Hymenoptera order, with an INP of 27.88%. Its frequency of occurrence supports the high INP for this species across six sampling locations, as well as its abundance of 12 individuals. The abundance of ant species is influenced by the presence of undergrowth, which provides both food sources and shelter [28]. Ants are also relatively resistant to environments polluted by heavy metals due to their ability to accumulate metal content in their body tissues.

The species with the third-highest INP is *Dolichoderus sp.* from the Hymenoptera order, with an INP of 25.77%. The abundance of 17 individuals supports this INP value; however, its frequency of presence is lower, as Dolichoderus sp. was only found at three sampling locations, all within the medium and dense categories. The species' limited presence at only 3 locations suggests that it prefers certain conditions not found in areas with lower well densities, indicating that *Dolichoderus sp.* is more dominant in places with higher well densities and pollution levels. This is consistent with previous research, which explains that ants of the genus *Dolichoderus* can compete fiercely between colonies and often act as foragers. As a result, these ants can thrive in various types of habitats and are known to dominate in disturbed environments [29], [30].

IV. CONCLUSION

A total of 93 individuals of soil macrofauna were found in the Wonocolo Traditional Oil Mining Area, representing 13 orders and 23 species. The distribution of individuals across the sampling locations was as follows: 8 individuals from 7 species at location R1, five individuals from 2 species at location R2, two individuals from 2 species at location R3, 24 individuals from 6 species at location M1, 16 individuals from 6 species at location M2, three individuals from 3 species at location M3, 13 individuals from 8 species at location D1, 16 individuals from 4 species at location D2, and six individuals from 2 species at location D3.

The species with the highest INP were *Lumbricus rubellus* (31.14%), followed by *Odontomachus brunneus* (27.88%) and *Dolichoderus sp.* (25.77%). Based on the results, it can be concluded that *Lumbricus rubellus* plays a crucial role in improving soil quality through bioturbation activities and the reduction of heavy metals. *Odontomachus brunneus* functions as a predator and a bioindicator of pollution, while *Dolichoderus sp.* contributes to vegetation regeneration.

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