Interaction of soil characteristics with subterranean termite diversity in pine and rosewood stands in Alas Bromo, Central Java, Indonesia

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Abstract. The diversity of subterranean termites in forest ecosystems plays an important role as eco-engineers, contributing to the decomposition of organic matter and providing benefits to the forest ecosystem. Termite diversity is influenced by stand type and soil physical conditions, such as soil moisture content, soil bulk density, and availability of soil organic matter. This study aims to determine the relationship between subterranean termite diversity and the physical properties of pine and rosewood stands of the same age in Alas Bromo. This study uses a quantitative descriptive approach with survey and exploratory methods. Termite sampling was carried out using Modified Standard Transect, while soil samples were taken for analysis of soil physical properties. The results showed that in pine stands, 4 genera of termites were found (*Microtermes*, *Macrotermes*, *Odontotermes*, and *Schedorhinotermes*), while in rosewood stands, 3 genera were found (*Microtermes*, *Macrotermes*, and *Odontotermes*). The Shannon-Wiener index showed moderate diversity in pine (H'=1.00) and low in rosewood (H'=0.70). Correlation analysis showed that soil moisture content, bulk density, aggregate stability, water holding capacity, and organic matter were significantly correlated with the presence of termites in both stands.

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1 Introduction

Soil, as part of an ecosystem, provides nutrients and water, serves as a growing medium for plants and a habitat for various soil organisms. Soil organisms are essential for the decomposition of organic matter, nutrient cycling, and nutrient absorption, as well as maintaining a healthy soil structure for plant growth. Termites play a crucial role in soil fauna. Termite activity in the soil can regulate soil aggregates, thus creating a more stable soil structure and water-holding capacity, thus being known as eco-engineers in the ecosystem [1]. Termites also serve as bioindicators, responding to changes in environmental and soil conditions (especially for subterranean termites). However, termite activity is often considered detrimental due to their ability to digest lignocellulose through cellulase enzymes, which can damage the wood structure of trees [2]. Therefore, the presence of termites requires further study, particularly in relation to soil and forest ecosystems. Similarly, research analysis revealed that there was an average increase in Acari (mite) abundance of 12.5% for every 1°C increase in temperature, but the Collembola (springtail) population actually decreased by 9.6% [3].

Environmental factors such as humidity, temperature, rainfall, and the availability of organic matter significantly influence termite activity and distribution. Furthermore, global climate change, through rising temperatures, shifting rainfall patterns, and increased seasonal variability, can alter microclimate conditions and soil moisture. These climate-induced changes affect soil conditions, including the rate of organic matter decomposition, which in turn impacts the quality of soil habitats for organisms such as termites. These impacts can influence changes in termite species diversity, foraging behavior, and the suitability of termite habitats to their environment. For example, grassland ecosystems have experienced disruptions in the ecological balance of soil fauna due to climate change.

Differences in forest stand types also create variations in microhabitats that influence termite diversity. The Alas Bromo Educational Forest in Karanganyar Regency, Central Java, is a forest area dominated by pine (*Pinus merkusii*) and rosewood (*Dalbergia latifolia*) [4]. These two stand types have distinct characteristics that potentially impact soil conditions and the communities of organisms within them.

Based on this study, although the role of termites in forest ecosystems is widely recognized, studies on termite diversity and its relationship to soil physical properties beneath pine and rosewood stands across different seasons are still limited. Therefore, this study aims to determine termite diversity in pine and rosewood stands in the Alas Bromo Educational Forest and the relationship between soil physical properties and termite diversity in the soil conditions within these two stands.

2 Materials and Methods

2.1 Research Location

The research was conducted from April to July 2025 under the 2018 pine stand and the 2018 rosewood stand. The research location was the Alas Bromo Educational Forest in Karanganyar Regency, Central Java, Indonesia. Alas Bromo Educational Forest features diverse vegetation structures and slope variations ranging from less than 8% to over 40%, conditions that significantly impact soil physical properties and biological activity. The topography and characteristics of Alas Bromo's land are dominated by Alfisol soils with low to moderate organic matter content [5].

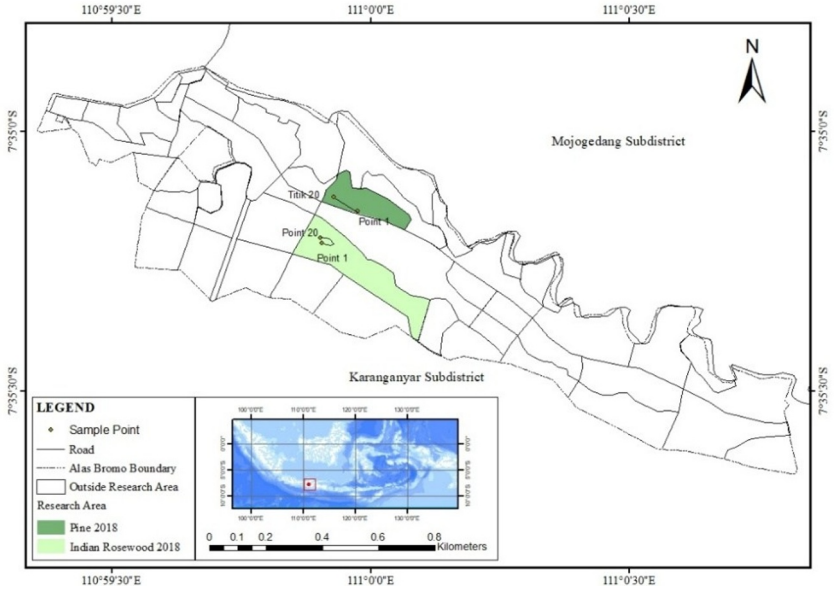

Fig 1. Map of Research Locations in Alas Bromo.

The research location map shows sampling points in the Alas Bromo Educational Forest (Figure 1). The research location was selected by purposive sampling within pine and rosewood stands planted in 2018. These stands are considered representative of young plantation conditions, making them suitable for examining how stand type and soil conditions relate to termite presence. Soil and termite morphology analyses were conducted at the relevant laboratories in the Department of Soil Science, Faculty of Agriculture, Sebelas Maret University.

2.2 Research Method

This study used the Modified Standard Transect method when collecting termite samples (Figure 2a), which is a modification of the Standard Transect [6] measuring 100 m × 2 m. In this study, the transect size was expanded to 100 m × 4 m to enrich the termite diversity data. The surveyed area (100 m × 2 m) has been proven to be quite efficient for investigating termite community structure [7].

Each transect was divided into 20 observation plots on the right and left sides (Figure 2b), each measuring 5 m × 2 m. The starting and ending points of the transect were determined based on the coordinates of the research location. In the 2018 pine plantation, the first point was located at coordinates 7˚35'9.14‘ S, 110˚59'58.45’ E, while the 20th point was located at coordinates 7˚35'7.57‘ S, 110˚59'55.71’ E. Meanwhile, in the 2018 rosewood plantation, the first point was located at coordinates 7˚35'12.89‘ S, 110˚59'54.28’ E and the 20th point at coordinates 7˚35'12.23‘ S, 110˚59'54.17’ E.

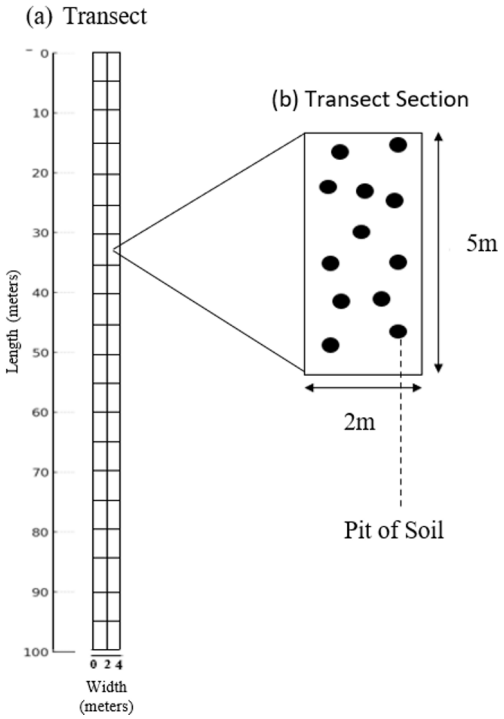

Fig. 2. Modified Standard Transect

Observations in each transect section were conducted by digging approximately 12 holes measuring 12 × 12 × 10 cm. Termite specimens obtained were collected in bottles containing 70% alcohol and coded according to the location of the discovery. The coding system uses a combination of letters and numbers: T for transect, A or B for sub-transect, and R for termite sequence (e.g., T10A3R2). Soil samples were taken both at points where termites were found and not found, then adjustments were made in sub-sections where termites were found based on genus. Data analysis Termite diversity was analysed using the Shannon-Wiener index (H'), *while* the relationship between soil physical properties and termite presence was analysed using SPSS software.

3 Results and Discussion

3.1 Termite Diversity in Pine and Rosewood Stands in 2018

Termite identification results in the 2018 pine and rosewood stands revealed the same genera of *Microtermes*, *Odontotermes*, and *Macrotermes*. The two stands also showed differences

in the number of genera and the number of termite colonies within each genus. The 2018 pine stand found *Schedorhinotermes*, while the 2018 rosewood stand did not (Figure 3).

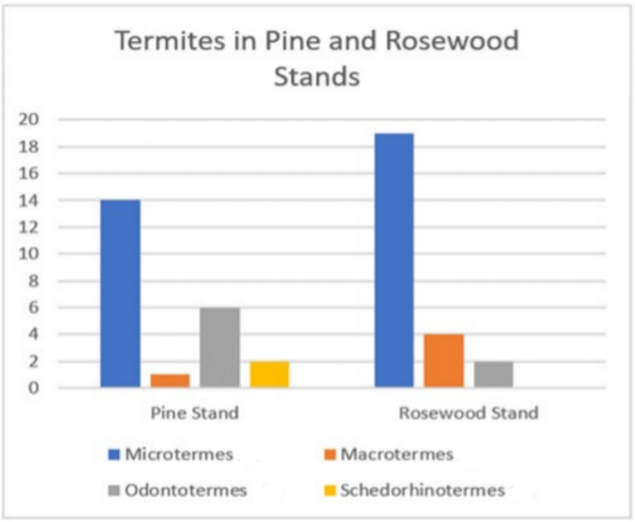

Fig. 3. Comparison of the Number of Termites Found

In the pine stand, four termite genera were found with a total of more colonies compared to the 2018 rosewood stand. The dominant termite genus in the pine stand was *Microtermes* with 14 colonies, followed by *Odontotermes* with around 6 colonies. Other genera were *Schedorhinotermes* with only 2 colonies and *Macrotermes* with only 1 colony. Meanwhile, the termite genera found in the rosewood stand were three genera, namely *Odontotermes*, *Microtermes*, and *Macrotermes*. *Microtermes* remained the dominant genus with around 19 colonies, *Macrotermes* with around 4 colonies, and *Odontotermes* with only 2 colonies. In both stands, the most dominant genus was *Microtermes*, where the *Microtermes* genus generally dominates the subterranean termite community in various types of tropical habitats due to its high adaptability to variations in organic matter and soil conditions. Furthermore, the presence of *Odontotermes* and *Microtermes* in both stands also indicates that these two genera are common in tropical forests such as those in Indonesia, where both have large nests in soil with relatively high clay content. Both genera also play a role as wood decomposers [8]. The different wood structures in the two stands resulted in one genus being found only in pine stands, while *Schedorhinotermes* is typically found in stands with more fragile wood structures and dead tree material.

Diversity using the Shannon-Wiener index (H') showed differences in the level of termite diversity between the two stands (Table 1).

Table 1. Shannon-Wiener Diversity Index (H')

Stands	**H'**
Pine 2018	1.00
Rosewood 2018	0.70

Pine stands have an H' value of 1.00, while rosewood stands have an H' value of 0.70. Based on the Shannon-Wiener index criteria, the value of pine stands is included in the medium diversity category where H' is in the range of 1-3, while the H' value of rosewood stands in 2018 is included in the low category where H' is less than 1. The higher H' value in pine stands indicates that the abundance of individuals is more evenly distributed among termite genera compared to rosewood stands. Although rosewood stands have lower H' and

total colonies, rosewood stands show a stronger dominance by *Microtermes* compared to the distribution in pine stands. This is also supported by tropical forest habitats that tend to be homogeneous in terms of vegetation structure and soil characteristics.

3.2 Soil Physical Properties Conditions in Pine and Rosewood Stands

Microclimate measurements in the two stands also revealed differences that may influence soil conditions and termite activity. The average daily air temperature in the pine stand was 28.28°C, with a soil temperature of 27.78°C, while the rosewood stand had a slightly lower air temperature of 28.01°C and a soil temperature of 27.47°C. These air temperatures surrounding the stand and the soil temperature beneath the stand can influence soil moisture, the rate of organic matter decomposition, and the overall microhabitat suitability for subterranean termites. The slightly cooler soil temperatures in the rosewood stand may support higher moisture conservation, which is consistent with the physical soil conditions described in Table 2.

The results of measuring the physical properties of the soil in the two stands showed differences in characteristics (Table 2) which could influence the presence and activity of termites as explained previously.

Table 2. Soil Physical Properties Conditions in Pine and Rosewood Stands

Stands	MC	BD	PD	AS	WHC	OM
Pine 2018	10.46	1.26	2.65	52.58	55.30	2.06
Rosewood 2018	10.80	1.24	2.62	60.56	55.38	2.55

*) MC = Moisture Content (%); BD = Bulk Density (gr/cm³); PD = Particle Density (gr/cm³);
AS = Aggregate Stability (%); WHC = Water Holding Capacity (%); OM = Organic Matter (%)

Table 2 shows several important differences in soil conditions between the two stands that influence termite presence. These land cover types have distinct characteristics and different management practices that directly influence soil properties [9]. Soil moisture content in the rosewood stand was slightly higher (10.80%) compared to the pine stand (10.46%). This difference is relatively small, indicating similar soil conditions at both locations. Subterranean termites are highly dependent on water content for survival. The soil moisture content of alfisols, ranging from 10-11%, indicates sufficiently moist soil conditions and the soil has received decomposed organic matter, making it ideal for supporting subterranean termite activity. The 2018 pine and rosewood stand had similar bulk density and particle density values: 1.26 gr/cm³ and 1.27 gr/cm³ for bulk density, and 2.65 gr/cm³ and 2.62 gr/cm³ for particle density, respectively. The soil's water holding capacity values were nearly identical at approximately 55% for both stands, meaning both soils were equally good at storing water. The table shows the most clear and important difference is the organic matter content in the soil. The rosewood stand had higher organic matter (2.55%) compared to the pine stand (2.06%). Organic matter is the primary source of energy and nutrients and additionally affects soil bulk density because organic matter acts as a binding agent for soil particles, improving soil aggregation, increasing soil pore space, and decreasing soil bulk density. Soil aggregate stability in rosewood was higher than in pine with a difference of approximately 8%. This value indicates that soil beneath rosewood has slightly more stable aggregation, likely influenced by the higher organic matter content. Therefore, the higher organic matter content in the rosewood stand can create microhabitat conditions more favorable for termites. The influence of stand type on soil properties is consistent [10], who showed that land use significantly determines the distribution of humic compounds formed from the decomposition of organic matter and stored in macro- and micro-aggregates. This

is related to aggregate stability and results in different soil physical characteristics among different vegetation types.

3.3 The Relationship between Termite Diversity and Soil Physical Properties

The results of the correlation analysis between Soil Physical Properties and Termite Diversity (Table 2) show a significant relationship between termite diversity and various parameters of soil physical properties in pine and rosewood stands.

Table 3. Results of Correlations Analysis

Variable	Termite Count in Pine	Termite Count in Rosewood
MC	.364*	.341*
BD	-.375*	-.479**
PD	.222	.362*
AS	.378*	.381*
WHC	.355*	.401*
OM	.481*	.433**

*) MC = Moisture Content (%); BD = Bulk Density (gr/cm³); PD = Particle Density (gr/cm³); AS = Aggregate Stability (%); WHC = Water Holding Capacity (%); OM = Organic Matter;
* significant at α=0.05; ** = significant at α=0.01

Table 3 shows the relationship between various soil physical properties and termite presence in both stands. Soil moisture content showed a significant positive correlation with termite diversity in both stands. The relatively similar correlation values between the two stands indicate that soil moisture is a major factor important for termite activity. In addition, the significant Water Holding Capacity (WHC) values in both stands indicate the soil's equally good ability to store water. Good soil conditions in storing water are very supportive for metabolic activities, movement, and the construction of subterranean tunnels [11].

Soil bulk density showed a significant negative correlation with termite diversity in both stands. The correlation was stronger in rosewood than in Pine. This indicates that loose soil structure is preferred by termites for digging and tunneling activities [12]. Soil bulk density showed a different correlation pattern between the two stands. The pine stand had an insignificant correlation ($r=0.222$, $p>0.05$), while in rosewood it had a significant positive correlation ($r=0.362^*$, $p<0.05$). This difference indicates that there is a different influence of soil mineral composition on the termite community in the two stands. Although there is a shift in soil fractions carried out by termites, this change is not large enough to significantly affect soil bulk density in the pine stand. Thus, the insignificant correlation in Pine indicates that soil density is not a major limiting factor for termite communities in Pine in 2018.

Soil aggregate stability was significantly positively correlated with termite diversity in both stands, with very similar values (Pine: $r=0.378^*$, $p<0.05$; Rosewood: $r=0.381^*$, $p<0.05$). Stable aggregates allow for easier soil penetration, maintain pore moisture, and create ideal microhabitat conditions for termite activity [13].

Soil organic matter showed a significant positive correlation with termite diversity in both stands (Pine: $r=0.481^*$, $p<0.05$; Rosewood: $r=0.433^{**}$, $p<0.01$). Organic matter is a factor that plays an important role in termite ecology because it is the main source of nutrition. In addition, it can also improve habitat quality by improving soil structure and nutrient availability . The high correlation value in Pine ($r=0.481$) indicates that the availability of organic matter is a lower limiting factor compared to rosewood stands. This is because Pine needle leaf litter decomposes slowly [14] resulting in lower organic matter compared to rosewood broadleaf litter, which is more easily decomposed. Rosewood stands have a slightly lower correlation value ($r=0.433^{**}$) but a higher significance level ($p<0.01$).

Although some soil properties show almost the same values between the two stands, namely bulk density, particle density, and WHC. However, the correlation with the presence of termites shows a very distinct difference between the two. This indicates that the response of the termite community to soil conditions is not only determined by one physical property of the soil, but by the interaction of various physical properties of the soil, including vegetation and the availability of organic matter [8]. The dominance of *Microtermes* and *Macrotermes* is closely related to lose soil conditions rich in organic matter that support soil digging processes [1]. In rosewood stands, the relatively better aggregate stability has the potential to interact with loose soil structure and high organic matter, thus creating increasingly ideal physical conditions for the genus *Microtermes* and *Macrotermes* which require soil with a combination of looseness and stability for nest building activities. These analysis results confirm that understanding termite ecology should focus not only on one soil physical property but needs to understand interactions between soil parameters with appropriate ecological conditions for each genus.

4 Conclusion

The results of this study indicate that termite diversity differs between pine and rosewood stands and is closely related to important soil physical properties, particularly organic matter, soil structure, and moisture conditions. The research objective was also met, as different stand conditions can influence termite communities, and soil characteristics play a significant role in their activity and habitat. These findings highlight the need to maintain soil quality to support termite-driven ecological processes. In the context of climate change, where temperature differences can affect soil conditions, soil management and forest floor protection will become increasingly important to maintain ecosystem resilience.

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