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Altitudinal Variation in Termite Species Diversity and Distribution in Agroforestry Systems of Lore Lindu National Park, Indonesia

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ABSTRACT

Agroforestry, widely practised by the community, is considered a significant contributor to the economy of people living around forest areas. Changes in land use to agroforestry also lead to changes in the biophysical condition of the environment and the diversity of soil organisms. Termites are one of the soil organisms that can be used as indicators of environmental change and are easily found in the tropics because their distribution and activities are strongly influenced by environmental factors. Differences in altitude have an impact on the number and types of termites found. Understanding termite diversity is critical for sustainable agroforestry management because termites play key roles in soil health, nutrient cycling, plant growth, and ecosystem functioning. By understanding the different species present, their behaviors, and their ecological roles, agroforestry managers can make informed decisions that enhance the productivity and biodiversity of the system. The purpose of the study was to determine the characteristics and biophysical environment in agroforestry and determine species richness, abundance, distribution patterns of termites on agroforestry land based on altitude strata in Lore Lindu National Park Indonesia. The research method consists of collecting biophysical environmental data (vegetation, soil, organic matter, and microclimate), termite community data (species richness, diversity index, and evenness index), and site characteristics. The results showed that elevation factors strongly influence the microclimate on agroforestry land in Lore Lindu National Park; the higher the elevation, the lower the temperature and light intensity, but the higher the humidity. The diversity of constituent plants on complex agroforestry land is higher than that of simple agroforestry at all levels of growth. The results of soil pH analysis were in the range of 5.88 to 6.72 (close to neutral). Organic C and Nitrogen levels increased with increasing altitude. For litter biomass, the highest values were found in complex agroforestry land at 600 masl, and the lowest in simple agroforestry at 1000 masl. The results of termite identification on agroforestry land at various altitudes found 13 termite species grouped into 7 genera and 3 families. Four genera belong to the Termitidae family, two genera belong to the *Rhinotermitidae* family, and one genus belongs to the *Kalotermitidae* family. *Microcerotermes dubius* is the species with the lowest proportion, while the highest is *Schedorhinotermes javanicus*. *Odontotermes* sp. 1 was the species with the highest relative abundance, while *Microcerotermes dubius* was the species with the lowest relative abundance.

1. INTRODUCTION

Tropical deforestation and conversion of forests to other land use systems are important reasons for the loss of biodiversity and are a threat to ecosystem function and sustainable land use. One form of land use that is widely practiced by the community is Agroforestry land [1]. Various types of agroforestry systems are managed by the community, both complex agroforestry types (agroforestry that still retains some native forest plant species) and simple types (consisting of only 2 to 3 types of plants) [2, 3]. This condition continues to be maintained considering that agroforestry management contributes greatly to the economy of the people living around the forest area [4].

Changes in the biophysical condition of the environment due to changes in land use into agroforestry are followed by changes in soil biota diversity [5]. Termites are one of the soil biota that is very sensitive to environmental variations, and can change their behaviour in response to environmental changes [6]. Changes in termite behaviour can cause termite status to change into a very harmful insect [7]. The destructive ability of termites is closely related to their very high population, wide range and good adaptability to the environment, so the possibility of damage is very large [8].

The level of damage caused by termites is also strongly influenced by the termite distribution area itself [9, 10]. The distribution of termites is related to temperature and rainfall so that most types of termites are found in the tropical lowlands and some are found in the highlands [1]. However, it is possible that termites spread not only in lowlands but also in highlands. Altitude is an important factor for termite life [9]. Altitude affects changes in air temperature and humidity, where the higher the place, the lower the air temperature or the colder the air temperature [9, 11]. Differences in altitude have an impact on the number and types of termites found [12].

Lore Lindu National Park (LLNP) is a UNESCO-recognised conservation area, located in the Wallacea region which is globally recognised as a biodiversity hotspot due to its high endemism of species and unique ecosystems [13]. Lore Lindu National Park is one of Indonesia's most important conservation areas, located in the central part of Sulawesi, the fourth-largest island in Indonesia [14]. The park is renowned for its biodiversity, cultural significance, and unique ecosystems, and it plays a crucial role in conservation efforts, particularly for endemic species and ecosystems that are rare and globally significant. It is located between 1° 8' to 1° 30' N and 119° 58' to 120° 16' East. While in government administration, the Lore Lindu National Park area is located in two districts namely Poso and Sigi. Based on Minister of Forestry Decree No. 464/Kpts-II/1999, dated 23 June 1999, the area of Lore Lindu National Park is 217,99.18 ha. Lore Lindu is located in the Wallacea region [13]. The area around Lore Lindu is increasingly being used for agroforestry systems, which can serve as buffer zones that extend forest functions and support biodiversity [1]. The Lore Lindu National Park area has varying altitudes, ranging from 200 to 2,610 metres above sea level. The park consists mostly of mountain and sub-mountain forests (±90%) and a small portion of lowland forests (±10%). Zulkaidhah et al. [5] reported that forest conversion to agroforestry reduces termite diversity in the Lore Lindu National Park area. Although there have been many studies on termite diversity, they only focus on examining their species diversity [8]. Research on termite species diversity at different altitudes is still very limited. Termite research at several altitudes with different types of constituent vegetation and the level of damage caused is very important to see the level of adaptation of termites to environmental conditions, as a consideration in making decisions to determine termites as bioindicators [5].

Agroforestry formed due to forest conversion consists of several types with different constituent plants [15]. In addition, the location of agroforestry, which is spread across several altitudes, greatly affects the vegetation cover, physical structure and microclimate of the agroforestry [11, 15]. Furthermore, it will affect the diversity and abundance of termite species present [1, 5]. Previous research conducted by Zulkaidhah et al. [5] was only limited to termite communities due to forest conversion to agroforestry. The results showed that the conversion of forest to agroforestry affected the diversity of termite species. Research on termite species diversity in cocoa monoculture has also been conducted by Zulkaidhah et al. [16]. The same research has also been conducted by Arif et al. [17] on termite species diversity in the Hasanuddin University Education Forest. Further research on termite species diversity at different altitudes has been conducted by Aditya and Syaukani [18], the research shows that altitude can be a limiting factor for termite species diversity in the Seulawah Ecosystem Area. Environmental conditions that do not support the development of termites are the main factor in changing the status of termites into harmful pests. Research on termite attacks on teak plants in agroforestry land has been carried out, the results show that one of the main types of pests on teak plants is termites. In addition, research on termite infestation has focused on damage to buildings and commercial timber.

This research aims to examine termite species diversity across various agroforestry types at different altitudes. The problem-solving approach of this research is to identify termite species in each type of agroforestry (simple and complex) at each altitude while measuring biophysical environmental factors (vegetation, soil, organic matter and microclimate) to determine the extent of correlation between biophysical environment and termite species diversity. Determining the level of attack caused by termites (frequency and intensity of attack), observations were made on the constituent vegetation to further determine the attack score of each individual as a reference in determining the overall attack condition. The development of research that will examine more deeply the termite community is not only on agroforestry land in general but based on the types of agroforestry (constituent plants) and based on the altitude of the agroforestry location. This study will illustrate how termites respond to biophysical environmental conditions, including changes in behavior that may lead to pest outbreaks. This will be seen from the level of attack (intensity and frequency of attack) caused. Termite response is the basis for determining termites as environmental bioindicators.

Understanding termite diversity in agroforestry management is crucial for several reasons, as termites play significant roles in soil health, nutrient cycling, plant growth, and ecosystem services within agroforestry systems. Termites, often regarded as ecosystem engineers, can have both positive and negative impacts on agroecosystems, depending on their species composition and behavior. Understanding termite diversity is critical for sustainable agroforestry management, as termites significantly contribute to soil health, nutrient cycling, plant growth, and ecosystem functioning. By understanding the different species present, their behaviors, and their ecological roles, agroforestry managers can make informed decisions that enhance the productivity and biodiversity of the system. Additionally, recognizing the positive and negative impacts of termites allows for more targeted, effective management strategies that support both agricultural production and biodiversity conservation.

2. RESEARCH METHOD

2.1 Research sites

The research was conducted in 2 types of Agroforestry (complex agroforestry and simple agroforestry) at different altitudes. Sites were selected at an altitude of 600 masl, 800 masl and 1000 masl. Two types of agroforestry were selected for each altitude (1 complex type and 1 simple type). So in total there are 6 observation locations. Simple agroforestry is the combination of agricultural/plantation crops with forestry crops consisting of a small number of elements, i.e. one or two elements of economically important or ecologically important trees with an element of seasonal or other crops such as Cocoa (Theobroma cocoa L.).

Complex agroforestry are systems consisting of many tree elements (consisting of 3 or more tree species) and seasonal or other crops such as Cocoa (Theobroma cocoa L.) whose physical appearance and dynamics are similar to those of forest ecosystems [19, 20].

2.2 Site characteristics

Data on site characteristics consisted of coordinates, topography, plant age and agroforestry land management concepts.

2.3 Biophysical environment

2.3.1 Vegetation

Vegetation data were collected from 20 m × 100 m observation plots in each Agroforestry type. The sample plots were divided into 20 subplots measuring 10 m × 10 m. Sample plots were divided into 3 sizes, namely 10 m × 10 m for tree/stem level (dbh ≥ 10 cm), 5 m × 5 m for sapling level (2 cm ≤ dbh < 10 cm), 2 m × 2 m for seedling and understorey level by systematic sampling. Vegetation types were identified at Herbarium Celebense Palu, Tadulako University. In addition, basal area calculations were also carried out [1].

2.3.2 Soil

Soil samples for testing soil physical and chemical properties were taken along the observation plot. Soil samples for testing soil chemical properties are composite soil samples, while for testing soil physical properties are whole soil samples using ring samples taken at a soil depth of 15 cm from the soil surface [1, 5].

2.3.3 Organic matter

To determine the accumulation of organic matter in each type of agroforestry, observations were made of necromass biomass and litter biomass [1, 5].

2.3.4 Microclimate

Microclimate measurements consisted of collecting data on rainfall, daily temperature, humidity and light intensity at each location [1, 5].

2.4 Termite community

Observations of termite ecological characters were carried out using the transect method. Transect placement was carried out by considering the shape of the topography, access distance and land slope. Transects measuring 2 m × 100 m were divided into 20 sections (each measuring 2 m × 5 m) [1, 5].

Termite samples were collected manually and preserved with 70% alcohol for identification purposes. The results of termite identification are classified based on their characters and morphology (mandible shape, presence or absence of fontanelles on the head, pronotum shape, marginal teeth, shape and number of antenna segments) using a termite identification guidebook [1, 5].

2.5 Data analysis

Measures of plant community quantity consisting of: dominance (D), frequency (F), individual density (KI), basic area (LBD) and important value index (INP). Biodiversity was interpreted with the Shannon-Wiener species diversity index (H). Density, Frequency, Dominance and Importance Index of each agroforestry species were analysed based on studies [21-24], namely:

$$D = \frac{Number\ of\ individuals}{Sample\ area} \quad (1)$$

$$D = \frac{Density\ of\ a\ species}{Density\ of\ all\ species} \quad (2)$$

$$F = \frac{Number\ of\ plots\ where\ a\ species\ was\ found}{Total\ number\ of\ plots} \quad (3)$$

$$RF = \frac{Frequency\ of\ a\ species}{Frequency\ of\ all\ species} \quad (4)$$

$$Do = \frac{Basal\ area\ of\ a\ species}{Sample\ plot\ area} \quad (5)$$

$$RDo = \frac{Dominance\ of\ a\ species}{Dominance\ of\ all\ species} \quad (6)$$

Index of importance (IOI) for trees and saplings

$$IOI = RD + RF + RDo \quad (7)$$

Index of importance (IOI) for seedlings and understorey

$$(IOI) = RD + RF \quad (8)$$

where,

D = Density

RD = Relative density

F = Frequency

RF = Relative Frequency

Do = Dominance

Rdo = Relative Dominance

In ecological research, the base area often refers to the area covered by the cross-sectional area of the tree trunks (at breast height, typically 1.3 meters above the ground) within a given plot. This is commonly measured in square meters per hectare (m^2/ha). To calculate the base area, the formula used is:

$$BA = \frac{\Pi d^2}{4} \quad (9)$$

Necromass biomass is calculated based on the following formula:

$$necromass\ biomass = \frac{\Pi\ \rho\ H\ D^2}{40} \quad (10)$$

where,

Π = 3,14

ρ = wood density

H = length/height of necromass

D = diameter of necromass

Litter biomass was calculated based on the following formula:

$$Total\ DW\ (g) = \frac{WD\ Sub\ example\ (g)}{WW\ Sub\ example\ (g)} \times Total\ WW\ (g) \quad (11)$$

where,

DW = dry weight litter biomass

WW= wet weight litter biomass

The biomass of each tree found in the observation plot was estimated using allometric equations.

The allometric for trees (natural forest) is

$$Y = 0{,}0439\ D^{2{,}7587} \quad (12)$$

The allometric for cacao is

$$Y = 10.582e^{0.0882D} \quad (13)$$

And the allometric for palm is

$$Y = 4{,}5 + 7{,}7*H \quad (14)$$

In addition, the biomass of the understory was also calculated [25].

Termite species richness (S) was calculated based on the number of species found. Shannon diversity index (H') and Pielou evenness index (E), Similarity index were calculated with the help of Ecological Methodology 2nd edition software programme [26].

3. RESULTS AND DISCUSSION

3.1 Site characteristics

Site characteristics are primary data taken in the field according to existing conditions. Data include temperature, humidity and light intensity (Table 1).

Table 1. Site characteristics: Plant types, microclimate, and land management

Location	Vegetation Type	Temperature (°C)	Humidity (%)	Light Intensity (Lux)	Land Management
SA 600 masl	- Theobroma cocoa L. - Aleurites moluccana Wild - Durio zibethinus Merr	31	62	50	- Land Condition Well maintained. - Active maintenance activities. - Occasionally use pesticides for pest control.
CA 600 masl	- Theobroma cocoa L. - Durio zibethinus Merr - Arenga pinnata Merr - Aleurites moluccana Wild - Nephelium lappaceum L - Gliricidia maculata - Psidium guajava L	32	62	47	- Land condition is well maintained. - Active maintenance is done by land clearing, pruning and pest control. - There is often a slow harvest, especially for cocoa.
SA 800 masl	- Gliricidia maculata - Theobroma cocoa L. - Aleurites moluccana Wild	30	65	45	The condition of the land is quite well maintained, but plant maintenance activities are very lacking so that existing plants are less productive.
CA 800 masl	- Theobroma cocoa L. - Aleurites moluccana Wild - Persea americana P.Mill - Gliricidia maculata - Arenga pinnata Merr	30	68	45	- Land condition is well maintained. - Active maintenance is done by land clearing, pruning and pest control.
SA 1000 masl	- Theobroma cocoa L. - Aleurites moluccana Wild - Durio zibethinus Merr	25	76	40	Land condition is not well maintained and maintenance activities are very low, it can be seen from the condition of plants, especially cocoa, that are not pruned so that they are less productive.
CA 1000 masl	- Theobroma cocoa L. - Anthocephalus macrophyllus - Aleurites moluccana Wild - Duabanga moluccana Blume - Gliricidia maculate - Persea americana P.Mill	25	76	40	- The land is in an unkempt condition and there are no more plant management and maintenance activities so that almost all existing plants are no longer productive. - Dense with undergrowth due to lack of human activity.

Description: SA: Simple Agroforestry; CA: Complex Agroforestry; masl: meters above sea level.

Higher altitudes often have different vegetation compared to lowland areas, which can affect the availability of food sources for termites. For instance, termite species that feed on decaying wood or plant matter might be less diverse at higher altitudes due to a scarcity of suitable resources [27]. Plant diversity of agroforestry land constituents seen in Table 1 above, that complex agroforestry has a high diversity of species compared to simple agroforestry [1]. For agroforestry land at an altitude of 600 and 800 masl, the types of constituent plants that are native to natural forests consist of 2 species, while in agroforestry land at an altitude of 1000 masl, there are 5 types of constituent plants native to natural forests. Plant diversity in agroforestry systems indicates that there are ecological benefits to minimise the risk of losing diverse plants so as to maintain plant sustainability [28, 29]. However, this condition is also inseparable from biological factors (human intervention). It can be seen that along with the altitude of agroforestry land, human intervention decreases, and management activities are getting lower. The influence of humans on the distribution and preservation of plants is very large. The difference in plants will affect the diversity of arthropods that live in that habitat [30]. This is due to differences in vegetation that will affect the existing organic matter, the intensity of light reaching the soil, and soil moisture [15, 31].

Termites are ectothermic, meaning they are sensitive to temperature changes. As altitude increases, temperature typically decreases, and the relative humidity may vary, influencing termite survival and activity. At higher altitudes, the colder climate can limit termite species diversity due to fewer species being adapted to survive in those conditions [32]. Elevation factor is also one of the factors causing the diversity of plant species composing different agroforestry [33, 34]. The higher an area the colder the temperature, and vice versa when lower means the air temperature in the area is hotter. Every 100 metres the average air temperature drops by about 0.5 degrees celsius [35, 36]. Therefore, the height of the earth's surface has a great influence on the type and distribution of plants. Areas where the air temperature is humid, wet in the tropics, the plants are more fertile with high diversity compared to areas where the temperature is hot and dry [37]. Elevation factors are very influential in the place and growth of trees with temperature being a factor that plays a major role in the existence and development of tree species in the ecosystem because each tree species has its own tolerance to the temperature in an ecosystem. The presence of a plant species in a particular place is influenced by environmental factors that are interrelated with one another, including climate, edaphic (soil), topography and biotic [38]. The distribution of species is indirectly influenced by the interaction between the vegetation itself, temperature, air humidity, physico-chemical soil that produces certain environmental conditions that cause the presence or absence of a species and spread with varying degrees of adaptation [39]. Changes in altitude can create microclimates, such as more sheltered areas or those with higher moisture retention, that may support certain termite species. Some species might thrive in montane forests while others are restricted to lowland ecosystems. Microclimate refers to the small-scale climate conditions within a specific habitat or area, and it is a critical factor influencing termite activity and survival. Key aspects of microclimate that affect termites include: Temperature: Termites are ectothermic, meaning their activity levels are highly dependent on temperature. Most termite species prefer warm temperatures (20-30°C) and become less active in extreme heat or cold [32]. Thus, microclimates with moderate, stable temperatures provide favorable conditions for termite colonies to thrive. At high altitudes, where temperatures tend to be cooler, termite populations may be less abundant or restricted to certain species adapted to colder conditions. Humidity: High humidity is essential for termite survival as it prevents desiccation. Microclimates that maintain high moisture levels, such as those found in dense forests, wetland areas, or areas with significant leaf litter, provide ideal conditions for termites. On the other hand, dry areas or regions prone to droughts may have reduced termite populations due to insufficient moisture. Light Levels: Termites are sensitive to light and tend to stay hidden in dark environments [40]. Thus, areas with dense canopy cover or sheltered environments will likely have higher termite populations due to reduced light exposure. On the other hand, open or exposed areas with high light levels may deter termites [32].

3.2 Biophysical environment

3.2.1 Vegetation

The number of tree species at the research site is highest in Agroforestry complex at an altitude of 600 which is 7 species. Then in complex agroforestry at 1000 masl with 6 species, then in simple agroforestry at 800 masl with 5 species and the lowest in simple agroforestry at 600, 800 and 1000 masl which only have 3 species each. Plant species that dominate all lands. Agroforestry is Theobroma cocoa L. which is the main crop cultivated on the land. The types of trees found in these locations are presented in Table 2.

Table 2. Tree species found in agroforestry land at various altitudes

	Location					
	CA 600 masl	**SA 600 masl**	**CA 800 masl**	**SA 800 masl**	**CA 1000 masl**	**SA 1000 masl**
	Trees					
∑ (Number of species)	7	3	5	3	6	4
H' (Shannon diversity index)	1.59	0.67	1.35	0.72	1.45	1.05
S (species richness)	1.12	0.39	0.75	0.39	0.94	0.58
E (Evenness index)	0.82	0.61	0.84	0.66	0.81	0.76
ID (individual density) (∑/Ha)	1055	815	1015	825	1010	845
BA (base area) (m^2/Ha)	6.30	2.96	6.07	3.85	5.28	3.66
	Saplings					
∑ (Number of species)	-	-	3		3	-
H' (Shannon diversity index)	-	-	1.07	-	1.08	-
S (species richness)	-	-	0.60	-	0.60	-
E (Evenness index)	-	-	0.98	-	0.98	-
ID (individual density) (∑/Ha)	-	-	140	-	140	-
BA (base area) (m^2/Ha)	-	-	0.16	-	0.16	-
	Seedlings					
∑ (Number of species)	3	3	2	3	4	3
H' (Shannon diversity index)	0.85	0.92	0.68	0.24	1.08	0.80
S (species richness)	0.51	0.48	0.43	0.50	0.36	0.46
E (Evenness index)	0.77	0.84	0.98	0.84	0.99	0.73
ID (individual density) (∑/Ha)	6500	8125	1250	875	30250	9750
BA (base area) (m^2/Ha)	0.85	0.92	0.68	0.24	1.08	0.80

Description: SA: Simple Agroforestry; CA: Complex Agroforestry; masl: meters above sea level.

The number of tree species in the study site is highest in complex agroforestry at an altitude of 600 which is 7 species. Then in complex agroforestry at 1000 masl with 6 species, then in simple agroforestry at 800 masl with 5 species and the lowest in simple agroforestry at 600, 800 and 1000 masl which only have 3 species each. Plant species that dominate on all lands agroforestry is *Theobroma cocoa* L. which is the main crop. On agroforestry land at all altitudes is an old agroforestry land so that generally only tree and seedling growth levels are found. For the sapling level only found in complex agroforestry at altitude of 800 masl and 1000 masl. While in other locations no saplings were found. Seedling level is found in complex agroforestry and simple agroforestry at altitude of 600, 800 and 1000 masl. At the seedling level, Theobroma cocoa L. is also the species with the highest INP. This is because in almost all agroforestry lands the level of land management is decreasing. Maintenance activities are also very minimal so that very many fruits that are slow to harvest fall by themselves and cause the seeds to grow back into new seedlings. This condition does not only occur in the type of Theobroma cocoa L., but also occurs in almost all types of constituent plants. The diversity of tree species is highest in complex agroforestry land at 1000 heights so that the types of seedlings at that height also have high species diversity. The high diversity at the seedling level is in line with the high number of individuals and the number of species.

The height of the agroforestry land has an impact on plant diversity [28]. Plants will adapt and grow well at certain altitudes, thus affecting the distribution, structure, composition and diversity of species [34]. In addition to the influence of the biophysical environment (altitude), vegetation density is also influenced by human intervention in its management [41]. Plant species diversity index in simple agroforestry land has a lower value than in complex agroforestry land [19]. Low diversity can be due to the presence of plant species that dominate. The dominance of a species with a disproportionate number of individuals can reduce the value of the species diversity index [42].

For tree level, complex agroforestry at altitude 600 had the highest plant diversity (1.59) followed by complex agroforestry at altitude 1000 (1.45), complex agroforestry at altitude 800 (1.35), simple agroforestry at altitude 1000 (1.05), simple agroforestry at altitude 800 (0.72) and simple agroforestry at altitude 600 (0.67). While for the sapling level, complex agroforestry at an altitude of 1000 had a high plant diversity (1.08) compared to complex agroforestry at an altitude of 800 (1.07), while in other agroforestry no sapling level was found (Table 2). At the seedling level, complex agroforestry at elevation 1000 had the highest plant diversity (1.08) followed by simple agroforestry at elevation 600 (0.92), then complex agroforestry at elevation 600 (0.85), simple agroforestry at elevation 1000 (0.80), complex agroforestry at elevation 800 (0.68) and the lowest was simple agroforestry at elevation 800 (0.24) (Table 2).

Plant species richness for tree level was highest in complex agroforestry at altitude 600 (1.12), then successively in complex agroforestry at altitude 1000 (0.94), complex agroforestry at altitude 800 (0.75), simple agroforestry at altitude 1000 (0.58) and lowest in simple agroforestry at altitude 600 and 800 which were 0.39 each. For sapling level, species richness between complex agroforestry height 800 is the same as complex agroforestry height 1000 which is 0.60 each and in other locations no saplings were found. While for the seedling level, the highest was in the agroforestry complex at altitude 600 (0.51) and the lowest was in the complex agroforestry at altitude 1000 (0.36).

Evenness value for tree level, the highest in complex agroforestry at altitude 800 (0.84), then successively in complex agroforestry altitude 600 (0.82), complex agroforestry altitude 1000 (0.81), simple agroforestry altitude 1000 (0.76), simple agroforestry altitude 800 (0.66) and the lowest in simple agroforestry altitude 600 (0.61). For the sapling level, the evenness value between the complex agroforestry altitude 800 is the same as the complex agroforestry altitude 1000 which is 0.98 each and in other locations no saplings were found. While for the seedling level, the highest in complex agroforestry at 1000 heights (0.99) and the lowest in simple agroforestry at 1000 heights (0.73).

The highest tree-level individual density in complex agroforestry at an altitude of 600 is 1055 individuals / ha with a base area value of 6.30 m^2/ha. The lowest in simple agroforestry at an altitude of 600 is 815 individuals / ha with a basal area value of 2.96 m^2/ha. For the sapling level, the density of individuals between the complex agroforestry height 800 is the same as the complex agroforestry height 1000, namely 140 individuals / ha each with a basal area of 0.16 m^2/ha each. While at the seedling level, the highest individual density in the complex agroforestry altitude 1000 is 30250 individuals / ha and the lowest in simple agroforestry altitude 800 is 875 individuals/ha. Land management by the community and differences in altitude are factors that cause changes in the structure and composition of plant species [43]. Biogeographical differences cause differences in growth and productivity, in general plants require better growing locations according to altitude, sunlight, temperature, availability of water and nutrients [37]. Agroforestry systems often create complex habitats with a mix of trees, shrubs, and crops, which provide a variety of microhabitats and food sources for termites. The more complex the agroforestry system, the more likely it is to support a higher diversity of termite species, as different species may specialize in different niches within the system [19, 20]. The variety of plant species in agroforestry systems can provide diverse food resources for termites, from decaying wood to plant matter. This can enhance termite abundance and diversity. Agroforestry systems with a high canopy cover or more leaf litter can create favorable microclimates that maintain higher humidity levels, which are beneficial for termite activity and survival. Intensive agroforestry practices, such as monoculture planting or pesticide use, may reduce termite diversity by disrupting habitat complexity or poisoning termites. In contrast, more diversified agroforestry systems can maintain or even increase termite diversity by preserving a variety of habitats [19].

3.2.2 Soil

pH is one of the important parameters of a plant can grow or not. The lower the soil pH, the more difficult it is for plants to grow because the soil is acidic and contains toxicants [44]. Conversely, if the soil pH is high, the soil is alkaline and contains lime [45]. The results of the analysis of soil chemical properties on agroforestry land with different heights can be seen in Table 3. The results of the pH analysis show that the soil pH at the research site is in the range of 5.88 to 6.72. Based on the classification of acidity according to the USDA, the pH range is classified as slightly acidic class approaching neutral pH. The ratio of carbon and nitrogen is important for the soil because it affects various processes that take place in the soil. Simple agroforestry at 1000 altitude has the highest C/N ratio compared to other types which is 15 and the lowest in complex agroforestry at 600 altitude and simple agroforestry at 800 altitude which is 10. The C-org content decreases with decreasing altitude followed by total N which also decreases with decreasing altitude.

C-Organic describes the state of organic matter in the soil. From Table 3, it can be seen that C-Organic in agroforestry land has higher levels at each increase in altitude. For N-Total levels increased along with increasing altitude. The increase in N-Total levels at greater altitudes is thought to be due to organic matter which is a source of Nitrogen also increased. Organic matter is one of the sources of N for the soil [46].

Table 3. Soil chemical properties of agroforestry land at various altitudes

Location	pH (H_2O)	C-org (%)	CEC (cmol/kg)	N-tot (%)	C/N	P (ppm)	K (cmol/kg)
CA 600 masl	6.59	1.85	20.35	0.16	12	10.25	0.25
SA 600 masl	6.20	2.16	15.36	0.22	10	12.14	0.24
CA 800 masl	6.31	2.10	19.65	0.22	10	12.25	0.16
SA 800 masl	6.29	2.21	17.52	0.19	12	10.75	0.19
CA 1000 masl	5.88	2.24	15.28	0.15	15	9.65	0.21
SA 1000 masl	6.72	2.52	20.14	0.24	11	13.22	0.23

Description: SA: Simple Agroforestry; CA: Complex Agroforestry; masl: meters above sea level.

Soil is an essential component for termite survival, influencing both their food sources and habitat preferences. Key aspects of soil that affect termite populations include Soil Texture: Sandy soils: These are often less favorable for termites, as they offer less moisture retention and limited food sources. Termites in sandy soils may have to move frequently to find food or moisture. Clay soils: These soils tend to retain moisture better and are more conducive to termite burrowing and colony formation [40, 47]. They also provide more stable environmental conditions, which are beneficial for termite survival. Soil Moisture: Termites require high humidity levels to survive, as they are susceptible to desiccation. Soils with high moisture content support termite activity by maintaining a stable microhabitat. Soil moisture is influenced by rainfall, irrigation practices, and vegetation cover. Areas with poor drainage may create ideal conditions for termites, as they maintain the necessary moisture levels. Soil Organic Matter: Termites feed on decaying organic material such as wood, leaf litter, and plant roots. Soils rich in organic matter support larger termite populations because they provide an abundant food source. This factor is particularly important in forested and agroforestry systems where plant material is abundant. Soil pH: Termites generally prefer slightly acidic to neutral soils. Extremes in pH (highly acidic or alkaline) can affect termite activity and colony survival. Soil pH can be influenced by parent material, organic decomposition, and human activities (e.g., fertilization), all of which can shape termite diversity [47].

3.2.3 Organic matter

Litter is the main source of nutrients in an ecosystem. The thickness of litter on the soil surface can be indicated by the dry weight of litter taken on the soil surface. The results of the measurement of surface litter biomass showed that complex agroforestry altitude 600 produced the highest surface litter biomass of 5.12 Mg/ha (Figure 1), then successively in simple agroforestry altitude 800 (4.16 Mg/ha), simple agroforestry altitude 600 (2.94 Mg/ha), complex agroforestry altitude 800 (2.73 Mg/ha), complex agroforestry altitude 1000 (2.72 Mg/ha), and the lowest in simple agroforestry altitude 1000 (2.49 Mg/ha).

The role of litter in reducing or increasing soil organic matter content is inseparable from the quality of litter. In agroforestry land, the addition of organic matter into the soil, one of which is through the return of crop pruning, can improve the total reserve of soil organic matter which is useful for maintaining soil fertility conditions both chemically and physically soil. It can be seen that agroforestry at an altitude of 600 has the highest litter biomass. This condition is supported by land management activities (maintenance) that are still good in the form of pruning activities on Theobroma cocoa L. plants.

3.3 Termite community

3.3.1 Termite species

The results of termite identification on agroforestry land at various altitudes found 13 termite species grouped into 7 genera and 3 families (Table 4). Four genera belong to the Termitidae family, two genera belong to the *Rhinotermitidae* family, and one genus belongs to the *Kalotermitidae* family.

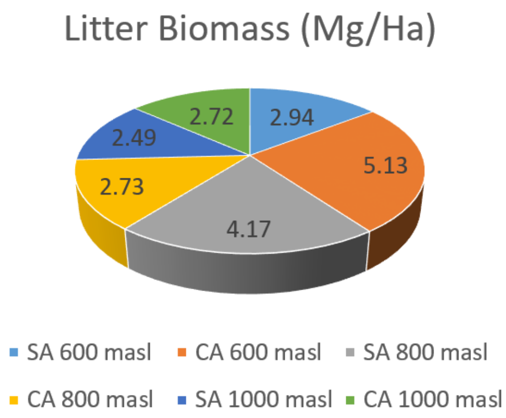

Figure 1. Graph of litter biomass

The genus *Hospitalitermes* (Termitidae) is the only termite of the epiphytic termite group found at 800 and 1000 masl. This termite group feeds on crustose lichens and algae, lives freely grazing and moving freely on the surface of the stem [1]. The termite family Termitidae, which belongs to the wood termite group, is very identical with various eating habits. The difference in the number of termite species at different altitudes is thought to be closely related to differences in environmental conditions at each altitude [5]. Differences in the altitude of a place will be followed by differences in environmental conditions which include light intensity, temperature and humidity [34]. Different environmental conditions can be a supporting factor for the existence of a type of organism and can also be a limiting factor for other types of organisms [1]. So that the number of types of organisms that inhabit habitats at one altitude can vary [48, 49].

Table 4. Termite species in agroforestry lands at various altitudes

Termite Species	Location					
	CA 600 masl	SA 600 masl	CA 800 masl	SA 800 masl	CA 1000 masl	SA 1000 masl
Glyptotermes sp.	-	-	√	-	-	-
Hospitalitermes sp.	-	-	√	√	-	√
Odontotermes sp. 1	√	√	√	√	-	√
Odontotermes sp. 2	-	√	-	√	√	-
Odontotermes sp. 3	√	-	√	-	√	√
Coptotermes kalshoveni	√	√	-	√	-	-
Coptotermes sepangensis	√	-	-	√	-	√
Coptotermes javanicus	√	-	-	-	√	-
Nasutitermes havilandi	-	√	√	√	√	-
Nasutitermes matangensis	√	√	√	√	√	-
Nasutitermes neoparvus	√	-	-	√	-	√
Microcerotermes dubius	-	-	-	-	-	√
Schedorhinotermes javanicus	-	√	√	-	-	-
Total species	7	6	7	8	5	6

Description: SA: Simple Agroforestry; CA: Complex Agroforestry; masl: meters above sea level.

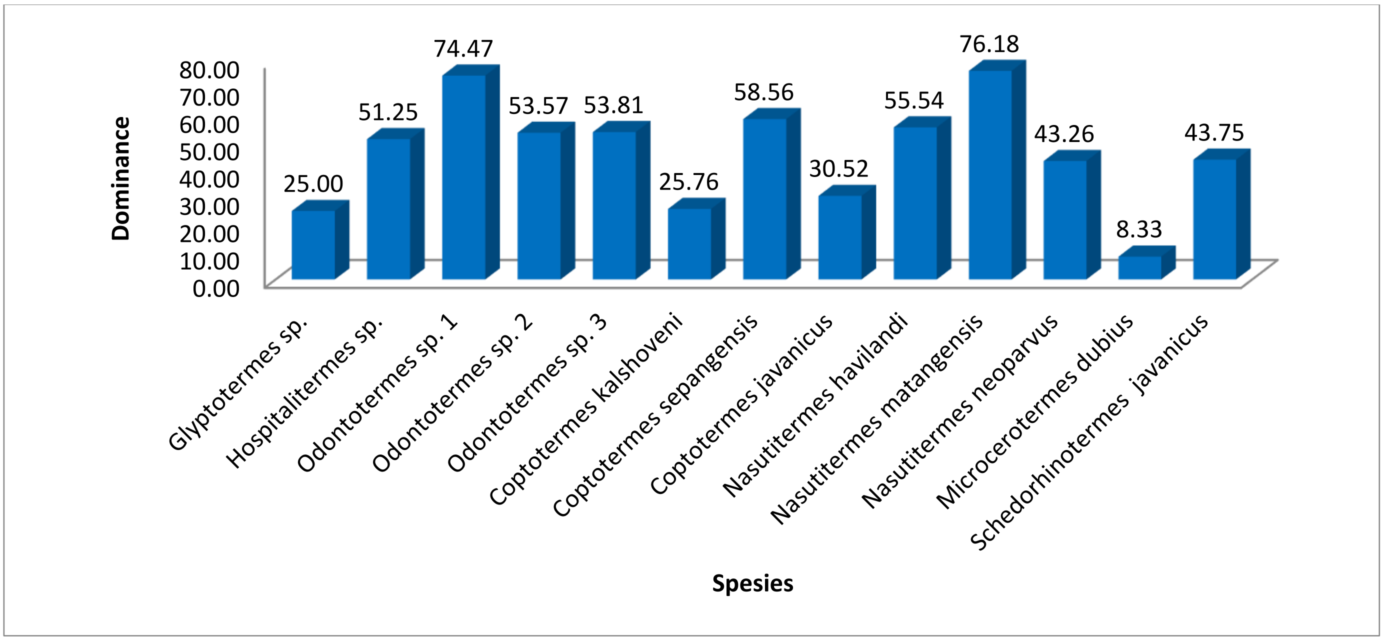

Figure 2. Proportion (%) of termite species in agroforestry fields at various altitudes

3.3.2 Termite species dominance

The results of the analysis of the proportion of termite species in all agroforestry land at various altitudes can be seen in Figure 2. *Microcerotermes dubius* is the species with the lowest proportion, which is 8.33% each, while the highest is *Nasutitermes matangensis* (76.18%).

Differences in agroforestry types and differences in altitude lead to changes in the composition of termite species found. A total of 3 termite species were found at 600m above sea level but not at 800 and 1000m above sea level. There is one termite species (*Glyptotermes* sp.) that is only found in agroforestry at an altitude of 800 but not found at an altitude of 600 and 1000 masl. Likewise, in agroforestry at an altitude of 1000 only one species (*Microcerotermes dubius*) was found but not found at an altitude of 600 and 800 masl. One of the causes of differences in termite species composition at each altitude is the biophysical conditions of the agroforestry land, both in the form of the level of human activity and the way of land management in the form of tillage, weeding, fertilisation and other activities. Termites *Nasutitermes matangensis* and *Odontotermes* sp. are the species that have the highest tolerance levels. This means that these species are able to adapt to various microclimatic conditions, soil conditions and varying levels of food availability.

3.3.3 Level of species diversity

Each form of agroforestry at the various altitudes observed had varying species richness. In complex agroforestry at altitude 800 (8 species), while in collective agroforestry at altitude 600 and simple agroforestry at altitude 800 had the same species richness of 7 species. In simple agroforestry at altitude 600 also has the same species richness as simple agroforestry at altitude 1000, namely 6 species each and the lowest in complex agroforestry at altitude 1000, namely only 5 species (Table 5).

The highest level of termite species diversity is found in the agroforestry complex at 800 heights, namely 2.01; while the lowest level of termite species diversity is found in the agroforestry complex at 1000 heights (1.57). The smallest evenness value is seen in simple agroforestry at an altitude of 1000, which indicates that on this land there are dominant, sub-dominant and non-dominant termite species because the abundance between species in the community is uneven. Differences in the type and amount of vegetation in complex and simple agroforestry also affect microclimate conditions. This condition is caused by the level of tree canopy cover, necromass, litter and understorey. The increase in temperature as a result of reduced canopy cover leads to a decrease in termite diversity. High temperatures that cause a decrease in humidity levels are conditions that do not favour the development of termites, which tend to prefer high humidity. Temperature is a factor that affects termite activity, development and behaviour. The distribution of termites is also related to humidity, so most termite species are found in tropical lowlands, and only a small number are found in highlands [50].

Table 5. Level of termite species diversity in agroforestry lands at various altitudes

Site	S	H'	DMG	E	Dominant Species
SA 600 masl	6	1.72	4.67	0.64	*Nasutitermes havilandi*
CA 600 masl	7	1.87	4.53	0.69	*Coptotermes sepangensis*
SA 800 masl	7	1.84	2.52	0.89	*Glyptotermes* sp.
CA 800 masl	8	2.01	2.06	0.97	*Hospitalitermes* sp.
SA 1000 masl	6	1.71	4.41	0.63	*Coptotermes sepangensis*
CA 1000 masl	5	1.57	2.65	0.76	*Odontotermes* sp. 2

Description: SA: Simple Agroforestry, CA: Complex Agroforestry; masl: meters above sea level; S: Species Richness, H': Species Diversity, DMG: Margalef Index, E: Evenness Index.

The high availability of organic matter in the forest type is not only a food source for termites, but also followed by a decrease in soil temperature. This organic matter also has a high ability to bind water. Soil with high organic matter is able to bind more water when compared to lower organic matter content. The dominance of one termite species in a field indicates that there is a range of environmental conditions that can be tolerated by certain termite species up to a certain height. However, there are also certain termite species that can survive in high altitude environmental conditions. *Hospitalitermes* is one of the termite species whose existence is highly dependent on the presence of crustose moss as a food source and can only be found at certain altitude conditions. The distribution of termite species found at each altitude with different environmental conditions shows this indication. Differences in the altitude of a place will be followed by differences in environmental conditions [51]. Different environmental conditions can be a supporting factor for the existence of one type of organism and can also be a limiting factor for other types of organisms. So that the number and types of organisms that inhabit habitats at one altitude can vary as well.

Nasutitermes havilandi: This species is found in simple agroforestry systems 600 and forest edges. Role in Agroforestry: It breaks down deadwood and organic matter, contributing to nutrient cycling. Additionally, it indirectly enhances soil health by adding decomposed organic materials. Furthermore, it creates microhabitats for other organisms in the wood it decomposes.

Coptotermes sepangensis: This species is found in complex agroforestry systems 600 masl and natural forests. Role in Agroforestry: It decomposes deadwood, releasing nutrients such as nitrogen and phosphorus into the soil. Its tunneling activities improve soil structure and water infiltration. It alters the physical environment, creating habitats for other soil organisms. *Glyptotermes* sp.: This species is found in simple agroforestry systems 800 masl. Role in Agroforestry: It breaks down smaller deadwood fragments, contributing to nutrient recycling. It converts lignocellulosic material into nutrient-rich residues. Its wood-decomposition activities provide niches for microbes and small invertebrates.

Hospitalitermes sp.: This species is found in complex agroforestry systems 800 masl. Role in Agroforestry: It breaks down leaf litter, reducing surface clutter and returning nutrients to the soil. It converts plant residues into bioavailable nutrients. Its presence attracts predators such as ants and birds, which may also target agroforestry pests. *Coptotermes sepangensis*: This species is found in simple agroforestry systems 1000 masl with abundant deadwood and tree cover. Role in Agroforestry: Decomposer. It facilitates nutrient cycling through woody material breakdown. Additionally, it improves soil porosity and water retention via tunneling. *Odontotermes* sp. 2: This species is found in complex agroforestry systems 1000 masl with a mix of litter and woody debris. Role in Agroforestry: It decomposes a wide range of plant materials, including crop residues. Additionally, it releases nutrients through fungal degradation and organic matter decomposition. Its foraging and nest-building activities enhance soil fertility, aeration, and biodiversity.

3.3.4 Termite finding frequency

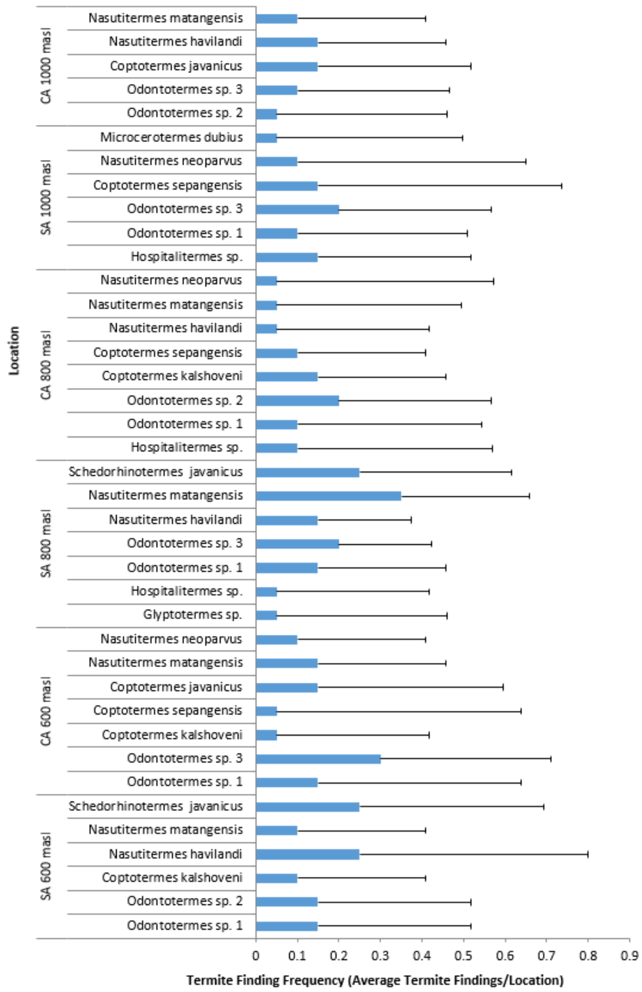

Figure 3. Frequency of termite species found in agroforestry fields at various altitudes

Termite finding frequency can indicate the presence of termites per unit time in a habitat. The frequency of presence can illustrate the distribution of a termite species in a habitat. The frequency of termite presence in agroforestry land at various altitudes can be seen in Figure 3. The highest frequency of termite findings is *Coptotermes sepangensis* at 600 and 1000 masl. While *Odontotermes* sp. 3 is the genus with the lowest frequency of findings. This indicates that there has been an increase in the dominance of a termite species. This may be related to the availability of increasingly homogeneous foodstuffs in simple agroforestry.

4. CONCLUSION

The high diversity in complex agroforestry systems has significant implications for biodiversity conservation and can influence agroforestry management practices in various ways. Agroforestry systems that are more complex characterized by a variety of plant species, both woody and herbaceous, as well as diverse structural layers offer numerous ecological, environmental, and economic benefits. Below is a discussion of the implications of high diversity in complex agroforestry systems for biodiversity conservation and how these findings could inform agroforestry management strategies. The variety of plants in complex agroforestry systems also creates multiple microhabitats (e.g., shaded areas, decaying wood, leaf litter) that support diverse groups of organisms. For instance, termites may thrive in decaying wood, while different pollinators may find shelter in flowers or shrubs. These microhabitats increase resource availability, which supports a wide range of species, from decomposers to apex predators. Complex agroforestry systems often serve as biodiversity hotspots, hosting species that might otherwise be at risk in more simplified agricultural landscapes. By offering diverse habitats and resources, these systems can function as refugia for species that are rare or threatened in other areas. In regions of high agricultural expansion, complex agroforestry can act as an important tool for conserving biodiversity and maintaining gene flow between fragmented habitats. The high diversity found in complex agroforestry systems suggests that biodiversity-friendly management practices can play a key role in promoting both ecological sustainability and economic productivity. The following management practices could be informed by the findings about biodiversity in these systems. Diversified Planting Agroforestry management should prioritize plant diversity by including a mix of tree species, shrubs, ground cover plants, and crops. This can involve selecting species that fulfill different ecological roles (e.g., nitrogen fixers, shade providers, or food sources for wildlife) to mimic natural ecosystems. Planting a variety of native species that support local wildlife and ecosystem functions can enhance biodiversity conservation while maintaining agricultural productivity. The high diversity found in complex agroforestry systems has profound implications for biodiversity conservation. These systems provide a wide range of habitats, resources, and ecological functions that support species richness, resilience, and ecosystem services. In turn, these findings can influence agroforestry management practices by emphasizing the importance of designing systems that prioritize species diversity, integrate conservation goals, and promote sustainable farming practices. By adopting these practices, agroforestry can become a tool not only for food and timber production but also for conserving biodiversity and enhancing the ecological health of landscapes. Based on the findings, several areas for further research can deepen the understanding of agroforestry practices and their ecological implications, particularly concerning biodiversity and the role of termites. Here are some suggested directions: Specific contributions of termite species to ecosystem functioning explore the functional roles of termite species (e.g., *Nasutitermes havilandi*, *Odontotermes* sp., *Hospitalitermes* sp.) in ecosystem processes like nutrient cycling, soil health, and carbon dynamics. Role of Termite-Mediated Carbon Sequestration in Agroforestry System. Assess the contribution of termite activity to carbon cycling and storage in agroforestry landscapes.

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