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Composition and role of ants (Formicidae) as indicators of habitat conditions in different stands in urban forest, Makassar, South Sulawesi, Indonesia

BUDIAMAN♥, SITTI NURAENI, NURHAINI, ANDI PRASTIYO
Department of Forestry, Faculty of Forestry, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, South Sulawesi, Indonesia.
Tel./fax.: +62-811-1128299, ♥email: budiaman@unhas.ac.id

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Abstract. *Budiaman, Nuraeni S, Nurhaini, Prastiyo A. 2025. Composition and role of ants (Formicidae) as indicators of habitat conditions in different stands in urban forest, Makassar, South Sulawesi, Indonesia. Biodiversitas 26: 145-152.* Urban forests provide ecological services such as air, microclimate, and environmental biodiversity, ecosystems in urban areas, assessing their quality and health through ecological indicators such as ants (Formicidae), which are very sensitive to habitat changes and serve as effective bioindicators for urban forest management sustainable. This research aims to identify the diversity and distribution of ant species and assess the potential of ants as ecological indicators of environmental conditions in urban forests. Sampling was done in three different stands: teak (*Gmelina arborea*), suren (*Toona sureni*), and mahogany (*Swietenia mahagoni*). The trap method uses a pitfall trap to collect ant specimens, which were then identified. Data analysis was carried out by calculating diversity, dominance, abundance, and evenness indices, as well as further analysis using correlation and principal component analysis (PCA). The results showed that there was significant variation in ant species composition among various stand types with 9 species, 6 genera, and 3 subfamilies. Species from the *Camponotus* genus dominate in urban forests, with *Camponotus virulens* dominating in teak stands, *Camponotus* sp. in suren stands, and *Pheidole plagiaria* in mahogany stands. The findings of the correlation analysis demonstrated a highly significant and positive relationship between humidity and ant dominance (0.989). This suggests that humidity is the environmental factor that exerts the greatest influence on the increased dominance of specific species. Furthermore, the very strong and positive relationship between diversity (H') and evenness (E) (0.943) indicates that ecosystems with high diversity tend to have a more even distribution of species. PCA analysis revealed a relationship between ant species composition and environmental factors such as temperature and humidity. The differences in ant species (Formicidae) composition across various stand types in the Makassar city forest are influenced by environmental conditions, such as temperature and humidity, making them suitable ecological indicators for assessing habitat quality and urban forest ecosystem health. This information supports sustainable urban forest management and biodiversity conservation efforts in urban environments, highlighting the importance and significance of ants in ecological studies.

Keywords: Biodiversity, ecology, ecosystem services, environment, foraging behavior

INTRODUCTION

Environmental changes that occur in urban forests are one of the factors in reducing biodiversity. One of those affected by this change is the diversity of insects, especially ants. Ants are indicators of habitat health that are often found in urban, rural, and forest ecosystems (Zina et al. 2021). Rapid urbanization in various cities, including Makassar, Indonesia, has resulted in major changes to the structure and function of natural ecosystems. Increasing human activity in urban areas has led to the decline of various insect species (Prastiyo et al. 2024). This impact is caused by pollution and changes in land use, directly or indirectly, which affect biodiversity. The main challenge faced is maintaining ecological balance and biodiversity, especially in urban forests (Chivulescu et al. 2023).

The existence of urban forests has a role as a conservation area and green area that supports ecological quality, including providing habitat for flora and fauna. Ants play an important role in the ecosystem as bioindicators (Lutinski et al. 2024). Ants have high sensitivity to environmental changes and serve as effective bioindicators for assessing ecosystem health (Bharti et al. 2016). Ants can provide important information about habitat conditions, environmental changes, and potential threats to biodiversity (Tiede et al. 2017). Ants, as eusocial insects that live in colonies, show a fast response to disturbances, making them an ideal species to be used as indicators for monitoring habitat changes in urban forest areas. Urban forests offer ample opportunities to explore how different types of presence influence ant communities. The Makassar city forest area has various types of dominant stands, such as teak stands (*Gmelina arborea*), suren stands (*Toona sureni*), and mahogany stands (*Swietenia mahagoni*). Each type of vegetation creates different microhabitat conditions, which can influence the diversity and composition of insect species (Meloni et al. 2020). Ant diversity in various habitat types can provide information for understanding how habitat changes impact insect communities in urban forests (Melliger et al. 2018).

The species composition of ants in various tree stands in urban forests plays an important role in reflecting the

health condition of the habitat. Each type of vegetation/ stand provides different structures and resources, which will influence the types of ant species that can survive and thrive in that environment (Farji-Brener and Werenkraut 2017). In teak stands, different temperature conditions, shade, and humidity are ideal for ant species that require dry soil conditions. Suren stands that have a denser leaf layer can provide a more humid environment, supporting ant species that are more adaptive to high humidity. Mahogany, which has different canopy characteristics, has the potential to support more specific ant species in certain soil and litter layers. This variation creates a different composition of ant species in each stand, which can be used as an indicator of habitat health because high ant diversity often indicates stable and balanced ecosystem conditions (Triyogo et al. 2020). Meanwhile, low diversity can cause disruption or decrease in habitat quality.

Apart from their role as environmental indicators, ants also play a very important ecosystem role in urban forests, especially in the process of decomposition and seed distribution. Ants, as organisms that live in colonies and have high environmental exploration capabilities, play a role in breaking down organic material helping the natural decomposition process (Verma et al. 2023). This will ultimately enrich the nutrient content of the soil and will indirectly affect the ecosystem in the environment. Use of ants as biological indicators of soil quality (Venuste et al. 2018). Several species of ants have a mutualistic relationship with plants in the myrmecochory process (Rico-Gray and Oliveira 2008). Seeds transported and dropped by ants in new locations provide the opportunity for plant regeneration in a wider area (Devenish et al. 2019). Ant assemblages exhibit variation across different environmental types due to their sensitivity to habitat characteristics, which influence their composition and distribution, making them effective indicators of habitat conditions and contributors to the maintenance of ecological functions in urban forest ecosystems.

Research into the diversity and abundance of ants contributes to the development of the science of urban ecology. Understanding the interaction between humans and the environment in cities can create management in sustainable urban forest development (Steenberg et al. 2019). Ants, as indicators of habitat conditions, could be a step in providing the baseline data needed to understand how certain species may adapt or be threatened by changes in urban environments. The results of this research are not only useful for urban forest management in Makassar but can also be a reference for other cities that have similar conditions. Therefore, this research focuses on the composition and diversity as well as the role of ant species in various types of stands in urban forests as indicators of ecosystem health. This study is expected to reveal that each species possesses distinct ecological functions and potentials as bioindicators of environmental conditions, thereby contributing to the sustainable management of urban forests. The differences in ant species composition across various stand types in Makassar's urban forest are influenced by environmental factors such as temperature and humidity while also supporting biodiversity conservation and ecological functions.

MATERIALS AND METHODS

Site location

The research was conducted on three stands in the urban forest, Makassar, South Sulawesi, Indonesia (Figure 1). The three stands are teak (119.492, -5.134), mahogany stands (119.488, -5.135), and suren stands (119.489, -5.139). The research location was chosen based on the dominance of the three stands in the urban forest.

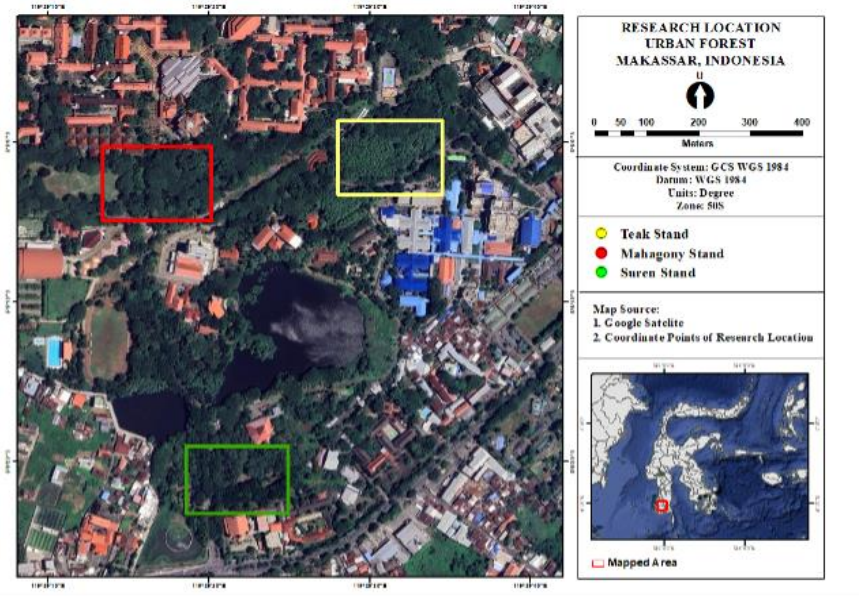

Figure 1. Research location in three stands in urban forest, Makassar, South Sulawesi, Indonesia

Based on observations, temperature and humidity were measured using a thermohygrometer HTC1 in the morning (06.00-08.00), afternoon (11.00-13.00), and afternoon (16.00-18.00). Temperature measurements were carried out 3 times during the research, and it was found that the temperature in the Makassar city forest ranged between 28-31ºC with humidity around 70-80% and a height of between 20-25 meters above sea level. Where, the distance between each stand is around 500-1000 m.

Ant sampling

Sampling was carried out in three urban forest stands in Makassar. Data were collected using purposive sampling by considering the number of types of ant colonies. Sampling was carried out using the pitfall trap method, and 9 pitfall traps were installed in each stand. Traps were made from plastic cups with a height of 15 cm and a diameter of 9 cm. The trap is buried in the ground with a quarter of air soap added to kill the sample and a plastic/styrofoam cover is placed over the trap so that the trap does not get rained on. Sampling was carried out 24 hours per session to collect ant samples. This process was repeated for three consecutive days to ensure the accumulation of representative data regarding the diversity and distribution of ants at the study site. The von Bertalanffy species accumulation curve is used in sampling to describe the relationship between the number of species accumulated and sampling effort, following a growth model to estimate the level of species diversity to near asymptote (Romanov and Masterov 2023).

Identification

Each ant sample was counted to see the number of distributions at each location. Samples from each location were identified for the type of ant using a stereo microscope (Stem 2000 with an Erc 5S phototube camera) at the Integrated Forestry and Environment Laboratory. Identification was assisted by literature such as Bolton (1994), (Hashimoto 2003), and Nazarreta et al. (2021).

Data analysis

Data analysis in this study was conducted using a quantitative approach to evaluate ant species diversity and the influence of environmental factors, namely temperature and humidity, in the urban forests of Makassar, South Sulawesi, Indonesia. The calculation of diversity indices was carried out using the Shannon-Wiener formula (H') to measure species diversity, the abundance index (R) to indicate species distribution, the evenness index (E) to assess population uniformity, and the dominance index (D) to identify dominant species (Magurran 2004). Correlation analysis is a method of evaluating the relationship between variables. In this analysis, the variables under consideration are the diversity index, abundance index, dominance index, evenness index, temperature and humidity. The purpose of correlation analysis is to ascertain the extent to which one variable influences or is related to other variables. This process provides more insight into the interactions between environmental factors and community structure being analyzed. Furthermore, it provides a stronger basis for interpreting the results of principal component analysis (PCA). The variables included in PCA are the diversity index, abundance index, dominance index, evenness index, temperature and humidity. Principal component analysis (PCA) was employed to identify the principal components that exhibited the greatest variability in the data. The objective of this analysis was to explore the relationship between temperature, humidity, and ant species diversity across diverse geographical locations.

RESULTS AND DISCUSSION

Composition and role of ants

The research results indicate that the number of ant species found in various types of stands (teak, mahogany, and suren) in the Makassar city forest exhibits different species accumulation patterns in each habitat. In the third stand, the number of trapped ant species increased with increasing traps, but the rate of this increase appeared to slow after a certain point, reflecting the effect of the sampling effort. It is imperative to recognize that inadequate sampling can impede the capacity to discern the full spectrum of species within a given habitat. Consequently, it is essential to ascertain the true species diversity present in each habitat type. The von Bertalanffy curve is a relevant metric for estimating the number of additional species discovered through continued sampling (Renner-Martin et al. 2018). Mahogany stands showed higher accumulation levels of trapped species with 6 species compared to teak stands with 5 species, and the lowest in suren stands with 3 species (Figure 2). The three curves tend to converge towards higher trap counts, suggesting an asymptote of detectable species with the current sampling level.

Based on the research results, it was found that 150 ants were captured in the teak stand, 123 in the mahogany stand, and 384 in the suren stand, with a total of 657 individuals trapped across the three stands. The composition and role of ants are very diverse and important for environmental balance (Table 1). As part of the Formicidae family, ants have a wide variety of species, each with specific roles that support ecosystem function. The composition of ants can be grouped based on morphological characteristics, with several species acting as predators, decomposers, or seed harvesters (Wills and Landis 2018). The ecological role of ants can increase soil fertility, as well as help in recycling nutrients through the decomposition of organic matter (Khisore et al. 2024). In addition, ants contribute to biological control by preying on insect pests, thereby maintaining the balance of populations of other organisms in the ecosystem (Exelis et al. 2022).

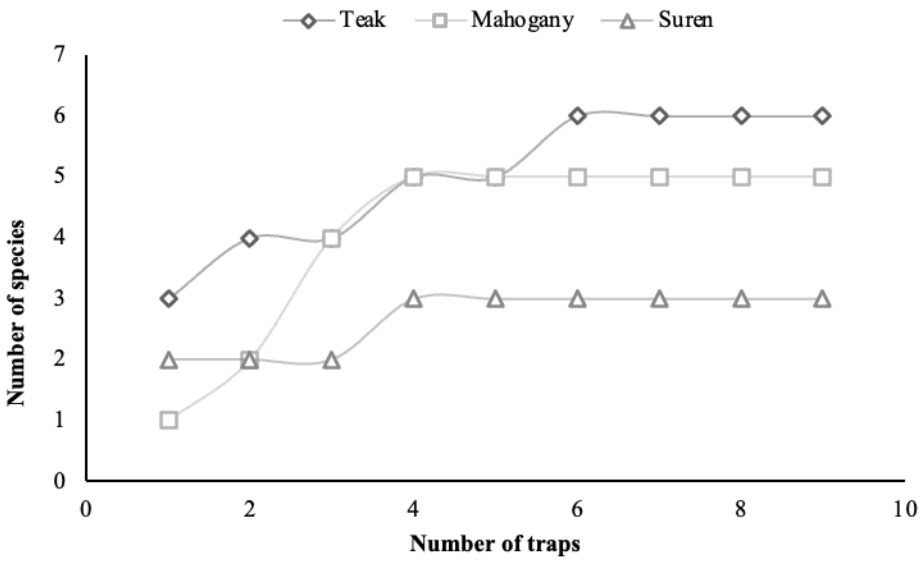

Figure 2. Accumulation curves of ant species found in different stands in urban forest, Makassar, South Sulawesi, Indonesia

The distribution of ant species in each stand provides more specific information regarding the dominance of certain species and their ecosystem interactions (Figure 3). For example, a high distribution of the *Camponotus virulens* species in a stand indicates that there is a species that is dominant in competition for resources or adaptation to the environmental conditions in that stand. On the other hand, the distribution is balanced between various species such as *Pheidole megacephala*, *Oechopylla smaragdina*, *Leptogenys laeviceps*, and *Aphaenogaster* sp., indicating high biodiversity and habitat conditions that support the various needs of ant species. Ant species can be bioindicators of environmental quality (Jimenez-Carmona et al. 2020).

The role of ants as bioindicators in this type of stand is very important to identify the quality and stability of the urban forest ecosystem. Stands that have high ant diversity, especially species with broad ecological tolerances, tend to exhibit healthier ecosystems. In contrast, stands inhabited by only a small number of species indicate habitat degradation or high environmental pressure. Urban forest vegetation supports a high diversity of ants (Perfecto and Philpott 2023). Several species of ants found in urban forests have ecological functions, such as acting as predators, pollinators, seed harvesters, decomposers, scavengers, omnivores, predators, and biocontrol, which ultimately contribute to soil health and vegetation regeneration. A relatively balanced habitat will provide various resources, such as food and ideal nesting conditions for insects (Elizalde et al. 2020).

The distribution of ant species across three stand types provides an important insight into the health and condition of the ecosystem in the area. The temperature in teak stands is 30.7°C with 73.7% humidity, mahogany stands are 31°C with 71% humidity, and suren stands are 30.7°C with 80% humidity. Each vegetation has different microhabitat conditions, such as variations in the availability of food sources, humidity, and temperature, which play a role in influencing the distribution of ant species (Landsman and Thiel 2020). The distribution of ant species in each stand can describe the ecosystem in providing the living needs of various ant species, such as food and shelter (Lanan 2014). These factors make some species more adaptable or even dominant, while other species are fewer or less common.

The composition of ant species in forest ecosystems can reflect diverse habitat conditions, especially in the three different stand types under study, and serves as a powerful reflection of diverse habitat conditions. Ants are known as effective bio-ecological indicators and are highly responsive to environmental changes, such as variations in humidity, temperature, availability of food sources, and vegetation structure (Diame et al. 2017). The significant variations in ant species composition between different stands, including teak, mahogany, and suren stands, underscore the importance of this research. Each vegetation type has specific microhabitat characteristics that support the existence of insect species (Basile et al. 2020). Ants from the Myrmicinae subfamily tend to be found in teak stands, which have a more open canopy and higher humidity of around 74%. For instance, ants from the Myrmicinae subfamily are more commonly found in mahogany and suren stands, while the Ponerinae is found in teak stands. These findings highlight the crucial role of ants as bio-ecological indicators in understanding species preferences in habitats that are more stable in terms of humidity and temperature (Warren and Chick 2013).

Ant diversity in the urban forest

The diversity of ants in three types of stands in the urban forest was measured using the Shannon-Wiener diversity index, dominance index, Margalef abundance index, and evenness index (Figure 4). Based on the highest value of the Shannon-Wiener index, the suren stand is capable of providing a more diverse and stable habitat, thereby supporting a greater number of ant species. This finding underscores the crucial role of the urban forest in fostering diverse ant communities, offering a rich array of food and shelter resources.

The highest ant abundance was found in the teak stand with a value of 6.725, indicating a high number of individuals with few species compared to the other two locations. This novel finding challenges existing perceptions of species abundance in different habitats. High species abundance in certain habitats is related to environmental factors such as abundant food availability and stable microclimatic conditions (Konig et al. 2024). At the same time, the evenness index also shows the highest value in the mahogany stand (0.170), which illustrates that the species in this stand have a more even distribution. These findings support diversity and balanced distribution in an ant community. The evenness of insect species may reflect lower levels of competition between species (Liu et al. 2024) and allow more species to coexist in relatively stable numbers, further enhancing the novelty of our research.

Correlation of temperature and humidity on ant diversity

The ant diversity and environmental parameters in three types of stands in the urban forest of Makassar (Table 2). The highest Shannon diversity index was observed in the suren stand (0.580), followed by mahogany (0.542), and the lowest in teak (0.203). The highest dominance values were recorded in the suren (0.090) and teak stands (0.015), while mahogany had the lowest dominance value (0.001). The highest relative abundance occurred in the teak stand (6.725), followed by mahogany (4.685) and suren (2.758). The highest evenness index was found in the mahogany stand (0.170), while suren (0.141) and teak (0.056) showed lower evenness. Temperature across all stands was relatively uniform, with values of 30.7°C in the teak and suren stands and 31.0°C in the mahogany stand. Meanwhile, the highest canopy humidity was recorded in the suren stand (80.0%), followed by teak at 73.7%, with mahogany showing the lowest humidity value at 71.0%. These results indicate that the suren stand supports higher diversity with a more evenly distributed dominance compared to the other stands.

Table 1. Distribution and role of ants in three stands in the urban forest, Makassar, South Sulawesi, Indonesia

Subfamily	Species	Stands			Roles
		Teak	Mahogany	Suren	
Myrmicinae	*Aphaenogaster* sp.	✓			Foragers, seed dispersers, and predators (Aupanun et al. 2018)
Formicinae	*Camponotus virulens*	✓	✓	✓	Foragers
Formicinae	*Camponotus* sp.		✓	✓	Foragers
Formicinae	*Camponatus bedoti*		✓		Foragers
Ponerinae	*Leptogenys laeviceps*	✓			Foragers
Formicinae	*Oecophylla smaragdina*	✓			Foragers, biocontrol agents, carnivorous (Rezki et al. 2023)
Myrmicinae	*Pheidole megacephala*	✓			Foragers, biocontrol agents (Ogogol et al. 2017)
Myrmicinae	*Pheidole plagiaria*	✓	✓		Foragers, scavengers, and omnivores (Ohkawara and Akino 2005)
Myrmicinae	*Tetramorium bicarinatum*		✓	✓	Foragers, biocontrol agents, and predators (Lutinski et al. 2024)

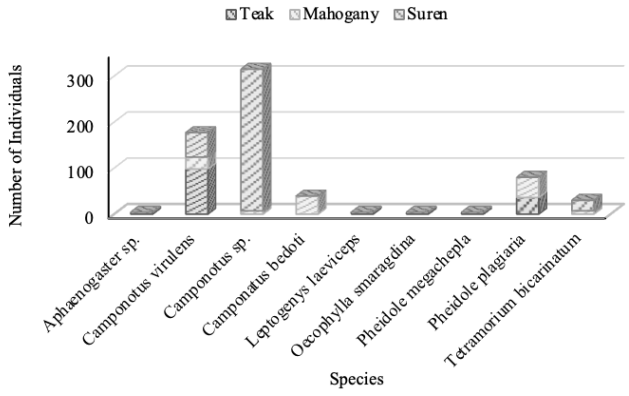

Figure 3. Distribution of ant species in three stands

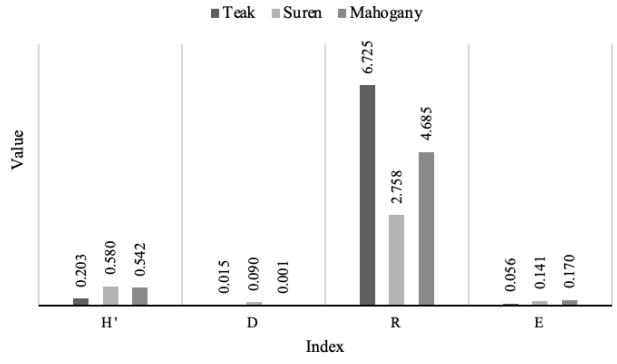

Figure 4. Diversity (H'), dominance (D), abundance (R), and evenness (E) index values of ants in urban forests, Makassar, South Sulawesi, Indonesia

Temperature and humidity are the main environmental factors that influence the diversity of ant species in various habitats. Ants are eusocial organisms, so their activity and distribution are strongly influenced by temperature conditions. Temperatures are optimal for ants to move efficiently, while extreme temperatures can limit their dispersal (Parr and Bishop 2022). Humidity also plays an important role in supporting the sustainability of ant colonies, especially in tropical and subtropical areas, where water availability is closely related to reproductive success and colony survival. The combination of suitable temperature and adequate humidity encourages a high diversity of ant species, while unstable environmental conditions can inhibit the development of ant communities (Fernandez-Bou et al. 2020).

The correlation between temperature and humidity with the index of diversity, dominance, abundance, and uniformity of ants demonstrates a range of relationships (Table 3). The diversity index exhibited a modest positive correlation with temperature (0.419) and humidity (0.313). Conversely, the dominance index exhibits a negative correlation with temperature (-0.621) but a strong and positive correlation with humidity (0.989). This finding suggests humidity exerts a more substantial influence on ant dominance than temperature. High humidity can increase the activity of dominant ant species (Azhar et al. 2024). Furthermore, the abundance index demonstrates a negative correlation with temperature (-0.016) and humidity (-0.770), while the uniformity index exhibits a significant positive correlation with temperature (0.697) but a weak negative correlation with humidity (-0.020). The relationship between diversity and uniformity has a very strong and positive correlation (0.943), while diversity has a strong negative correlation with abundance (-0.915). These results illustrate that temperature exerts a stronger influence on uniformity than humidity, while humidity significantly impacts ant dominance within a specific ecosystem. Higher temperatures have been shown to promote an even distribution between species, while humidity has been observed to increase the dominance of certain species (Arnan et al. 2014). Temperature and humidity are thus identified as pivotal factors that regulate the distribution and dynamics of ant communities in diverse habitats (Reymond et al. 2013).

The PCA results (Figure 5) illustrating the correlation between temperature and humidity with diversity, dominance, evenness, and species abundance of ants. Humidity has a strong positive relationship with the variables diversity, dominance, and evenness, indicating that higher humidity can increase the diversity, dominance, or evenness of certain species in the ant community. On the other hand, temperature was closely related to species abundance, indicating that higher temperature levels favor species abundance. Temperature and humidity are important factors in determining patterns of ant diversity and dominance (Nowrouzi et al. 2016). Optimal conditions for ant activity and reproduction vary depending on the species. Habitat characteristics and uniform microclimatic conditions influence ant community composition (Perz-Sanchez et al. 2023).

The relationship between temperature and humidity on ant diversity in three stand types and can provide insight into environmental factors that influence the distribution of ant species (Figure 6). Principal component analysis is a multivariate statistical method that emphasizes the main variability contributing to data distribution patterns (Gewers et al. 2021). This research describes the contribution of temperature and humidity as vectors that influence the variability of ant diversity in three different stand types. The elongated vectors in the biplot vividly portray the environmental variables that are dominant in influencing species distribution, while the angles between vectors reveal the correlation between these environmental factors. These findings, which are at the forefront of research, indicate that temperature and humidity play an important role in ant diversity patterns, with each stand type having different ecological tolerances and adaptations. The influence of temperature and humidity factors on the composition and distribution of ant species in the ecosystem is significant and opens up new avenues for further exploration (Kuate et al. 2022).

Table 2. Ant diversity and the environment in three stands in urban forest, Makassar, South Sulawesi, Indonesia

Stand	Diversity	Dominance	Abundance	Evenness	Temperature (°C)	Humidity (%)
Teak	0.203	0.015	6.725	0.056	30.7	73.7
Suren	0.580	0.090	2.758	0.141	30.7	80.0
Mahogany	0.542	0.001	4.685	0.170	31.0	71.0

Table 3. Correlation of temperature and humidity with indices of diversity, abundance, dominance, and evenness of ants

Variables	Diversity (H')	Dominance (D)	Abundance (R)	Evenness (E)	Temperature (C)	Humidity (P)
Diversity (H')	1					
Dominance (D)	0.452	1				
Abundance (R)	-0.915	-0.773	1			
Evenness (E)	0.943**	0.129	-0.729	1		
Temperature (C)	0.419	-0.621	-0.016	0.697*	1	
Humidity (P)	0.313	0.989**	-0770	-0.020	-0.731	1

Notes: The symbol (*) indicates a strong correlation, while (**) indicates a very strong correlation between variables

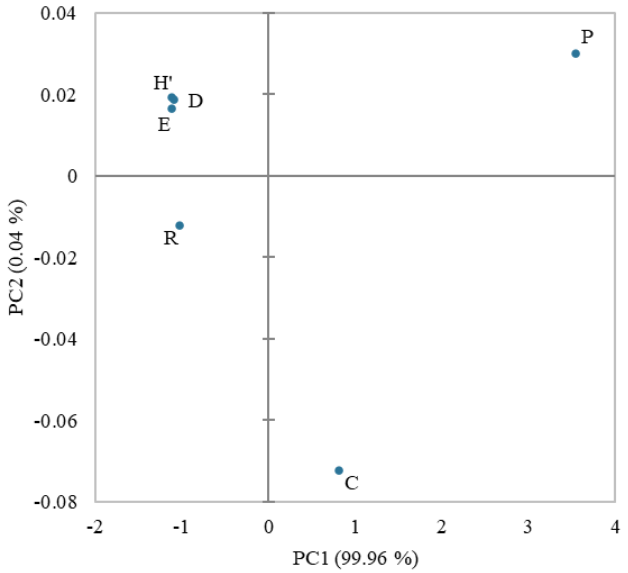

Figure 5. PCA results of correlation of temperature (C) and humidity (P) with diversity (H'), abundance (R), evenness (E) and dominance (D) of ants

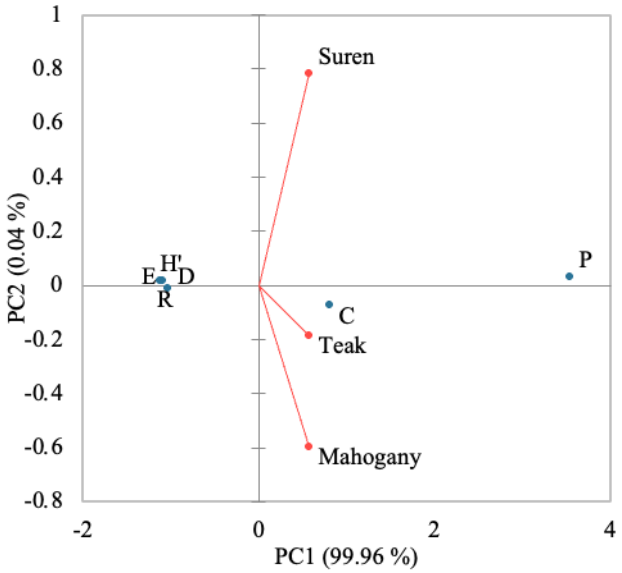

Figure 6. PCA biplot of the relationship between temperature and humidity on ant diversity in three stands

The presence and abundance of ants as a bioindicator can be used to monitor changes in environmental conditions over time. Ant species that are sensitive to disturbance, such as the genus *Camponotus*, tend to decline in numbers in stands that are more frequently disturbed by human activities (Hoenle et al. 2024). Generalist ant species, such as those from the genera *Pheidole* and *Tetramorium*, dominate in stands exposed to higher levels of disturbance because these species can adapt to environmental changes and limited resources (Tuma et al. 2020). These observations demonstrate that variation in ant composition can serve as an indicator for identifying anthropogenic pressures in urban habitats. Urban forests, such as in Makassar, are vulnerable to the impacts of development and spatial changes, so responsive ecological indicators are needed for regular monitoring.

Apart from being indicators, the ecosystem role of ants in the three types of stands is different. This suggests that ants contribute directly to ecosystem stability through trophic interactions. Ants, as predators and scavengers, help control other insect populations and recycle nutrients in the soil (Verma et al. 2023). In mature tree stands, more intense ant activity in foraging and nest building helps increase soil aeration and nutrient availability for plants. The composition and role of ants in urban forests is not only an indicator of habitat conditions but also supports ecosystem function (Zina et al. 2021). Overall, these findings emphasize that conserving ant diversity in these stands can strengthen the resilience of urban ecosystems to climate change and human disturbance. Ant composition provides important information for sustainable urban forest management. Based on these findings, this research explains that the variation and distribution of ant species in various stand types in the Makassar city forest is influenced by main environmental factors such as temperature and humidity. This research concludes the important role of ants as ecological indicators, providing valuable insights for assessing habitat quality and improving biodiversity conservation efforts in urban ecosystems.

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