

COMMUNITY PATTERNS OF GROUND-DWELLING INSECTS ACROSS A CANOPY COVER GRADIENT IN A TROPICAL CAMPUS LANDSCAPE

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ABSTRACT

Canopy cover influences soil surface microhabitats and may affect the structure of ground-dwelling insect communities, yet evidence from plantation-dominated landscapes remains limited. This study examined ground-dwelling insect community patterns in relation to canopy cover and selected environmental variables across three sites within the IPB Dramaga Campus: Arboretum (83.91%), Oil Palm (71.91%), and Cikabayan (0.00%). Canopy cover was quantified using hemispherical photography, and insects were sampled using pitfall traps over five consecutive days in July 2024. Community composition was analyzed using PERMANOVA, which indicated no significant differences among sites ($R = 0.861$, $p = 0.067$). Non-metric Multidimensional Scaling (NMDS) was therefore applied as an exploratory ordination to visualize community patterns and interpreted descriptively given the limited sample size. A total of 1,711 individuals were recorded, with overall abundance highest in the Oil Palm site, followed by Cikabayan and the Arboretum. The Arboretum exhibited lower total abundance but higher evenness and Shannon diversity, whereas the Oil Palm site showed high abundance with lower diversity and evenness, reflecting dominance by a few families. Cikabayan displayed intermediate diversity patterns. Differences among sites were primarily reflected in relative abundance and dominance rather than clear taxonomic turnover. Overall, canopy structure was associated with variation in ground-dwelling insect assemblages, although statistically significant compositional differences were not detected, highlighting the need for broader spatial and temporal sampling before firm management recommendations can be made.

Key words: Gryllidae, habitat heterogeneity, light intensity, multivariate analysis, soil arthropods

INTRODUCTION

Insect diversity and occurrence are often used as indicators of ecosystem health due to their sensitivity to environmental changes (Segev et al., 2023a; Huerta et al., 2024). One of the insect communities with significant ecological roles is the ground-dwelling insect assemblage. This community comprises various species that inhabit and complete most of their life cycles within the upper soil and litter layers, contributing to organic matter decomposition, nutrient cycling, and serving as natural predators of other organisms (Segev et al., 2023b; Narwade et al., 2024). The presence and diversity of ground-dwelling insects are influenced by multiple environmental factors, particularly canopy cover density (Schowalter, 1989; Vaca-Sanchez et al., 2023). Moreover, a closed canopy reduces the amount of light reaching the soil surface, enhances humidity, and lowers soil temperature, thereby creating favorable conditions for

diverse ground-dwelling insect species (Damayanti et al., 2023). Conversely, open canopy conditions can result in greater fluctuations in temperature and moisture, potentially limiting insect abundance and diversity (Damayanti et al., 2023).

Previous studies have shown that differences in vegetation structure, including canopy density, influence the diversity and composition of ground-dwelling insect communities. For example, research in Gunung Geulis Forest, Sumedang, revealed that zones with denser vegetation supported higher diversity than more open areas (Kinasih et al., 2017). Similarly, a study in agroforestry landscapes in Wonosalam, Jombang, reported that ground arthropod diversity was influenced by organic matter availability and habitat characteristics associated with vegetation density (Wijayanto et al., 2022). Another study found that areas with higher canopy cover supported greater arthropod diversity compared to more open sites (Normasari, 2012). In addition, changes in land cover and distance from forest edges also affected insect community composition, further emphasizing the importance of canopy cover in shaping ground-dwelling insect assemblages (Haneda et al., 2024).

Although numerous studies have examined the relationship between vegetation structure and ground-dwelling insect communities, research that specifically investigates the role of varying canopy cover densities remains limited. Therefore, this study aims to assess the community patterns of ground-dwelling insects in relation to canopy cover and to identify key environmental factors contributing to community assembly. This research is expected to provide valuable insights for biodiversity management and conservation in tropical forest ecosystems.

MATERIALS AND METHODS

The study was conducted at the IPB University Dramaga Campus, Bogor, which covers an area of approximately 250 hectares and includes various landscapes such as gardens, plantations, and educational forests. Three sites were selected using purposive sampling based on differences in canopy cover characteristics (Fig. 1). The first site, the IPB Faculty of Forestry Arboretum (Arboretum, 0.56 ha; 6° 33 '27.25"S, 106° 43 '46.50"E). The second site, the Cikabayan Oil Palm Experimental Plantation (Oil Palm, 7.40 ha; 6°32'58.56"S, 106° 42' 59.48"E). The third site, the Cikabayan Experimental Farm is open grassland (Cikabayan, 3.34 ha; 6° 33 '3.65"S, 106° 42' 55.58"E).

These three locations were chosen to represent distinct vegetation structures with contrasting canopy cover. The Arboretum represented a forested area with dense canopy cover,

the Oil Palm plantation represented an area with medium canopy cover, and Cikabayan represented an open habitat with no canopy cover.

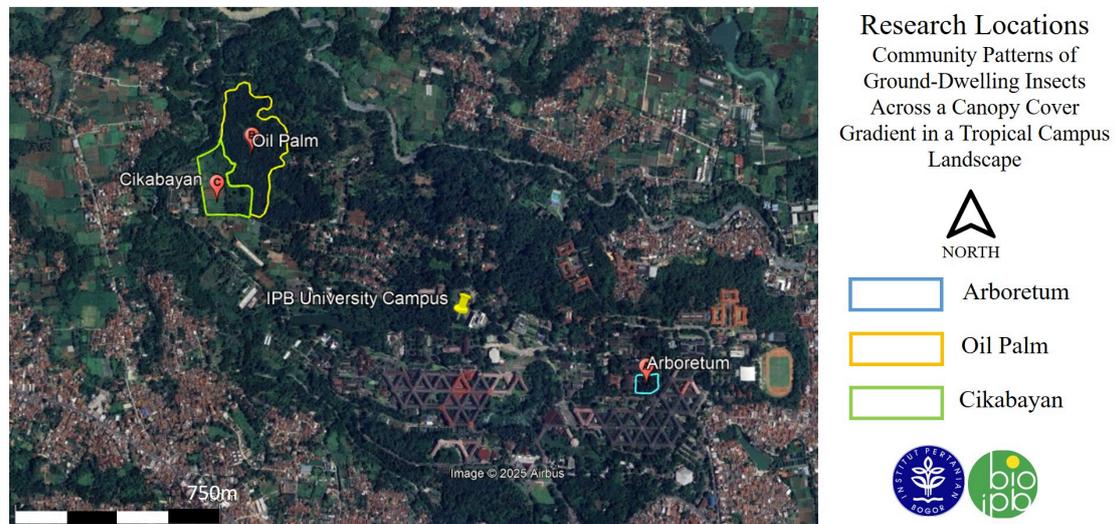


Figure 1. Research locations: Arboretum of the Faculty of Forestry, IPB University (light blue outline); Cikabayan Oil Palm Experimental Plantation (yellow outline); and Cikabayan Experimental Farm (green outline). The study was conducted within the IPB Dramaga campus, West Java.

Environmental data were collected using a thermometer, soil tester, lux meter, and hygrometer. Measured parameters included air temperature, air humidity, soil moisture, soil pH, canopy cover, and light intensity. Measurements were taken twice daily for five consecutive sampling days. Canopy cover was quantified using the hemispherical photography method (Rich, 1990), which converts captured light transmission into pixel values to provide quantitative estimates of canopy closure using the ImageJ software (Beckschäfer, 2015). Canopy photographs were taken with the front camera of an ROG 6 smartphone (13 MP) in a square frame (1:1). The camera was positioned perpendicular to the canopy, facing directly upward. A total of 10 photographs were taken along each transect and processed in ImageJ to obtain canopy cover values. For comprehensive canopy cover measurements, the hemispherical photography method typically employs fisheye lenses, which allow image capture with an angle of up to 180°. In this study, however, canopy photographs were taken using a smartphone camera with a lens angle of 63°. The use of a smartphone camera represents a simplified approach to hemispherical photography (Wayan & Dharmawan, 2020).

Insect sampling was conducted in July 2024 using pitfall traps, brushes, and plastic containers. A detergent solution with a water-to-detergent ratio of 10:1 was used as the trapping medium. Collected specimens were preserved in 70% ethanol in labeled vials. Identification

was conducted to the family level following standard taxonomic keys. Although finer taxonomic resolution can improve ecological inference, family-level identification has been widely applied to detect broad-scale community patterns in hyperdiverse insect assemblages, particularly under logistical and time constraints (Andersen, 1995; Borror et al. 1996; Basset et al., 2012). Identification limited to the family level represents an important methodological constraint of this study. While family-level resolution can capture broad ecological patterns, it may obscure species- or genus-specific responses to environmental gradients, particularly in diverse tropical insect assemblages. As noted by previous studies, finer taxonomic resolution could improve sensitivity in detecting community differentiation and bioindicator potential. Future research should incorporate genus- or morphospecies-level identification for dominant taxa to refine ecological interpretation. A total of 30 pitfall traps were deployed across the three study sites, with 10 traps per site and 5 traps placed along each 50 m transect (Buchori et al., 2018; Tasen & Duangjai, 2024). Traps were monitored over five consecutive days, and insects were collected every 24 hours, to allow for standardized comparisons among canopy cover density categories within the same temporal window.

Data analyses were conducted using a range of complementary analytical methods. Species diversity was evaluated using the Shannon–Wiener diversity index, dominance index (D), and evenness index (E) (Magurran, 1988). Variations in insect community composition among sampling sites were assessed using permutational multivariate analysis of variance (PERMANOVA) (Tudor et al., 2023; Fromenthal et al., 2024). Patterns of community similarity were investigated through Non-metric Multidimensional Scaling (NMDS) coupled with environmental fitting (*envfit*) (Leal et al., 2016; Rahayu et al., 2017). Canonical Correspondence Analysis (CCA) was employed to determine the effects of environmental variables on the structure of ground-dwelling insect communities (Fulan et al., 2008; Buchori et al., 2018). All statistical analyses were conducted using the R statistical computing environment (R Core Team, 2022). Diversity indices, PERMANOVA, NMDS, *envfit*, and CCA were implemented using the *vegan* package (Oksanen et al., 2024). Basic statistical analyses were carried out using the *stats* package included in base R (R Core Team, 2022). Figures were generated using the *ggplot2* package (Wickham, 2011).

RESULTS

Environmental parameters and canopy cover

Sampling locations were determined using specific criteria aligned with the research objectives (Nyimbili & Nyimbili, 2024). The primary criterion was canopy density, which

initially assessed visually and subsequently quantified using the hemispherical photography method.

Canopy cover in this study was quantified using a simplified hemispherical photography approach based on a smartphone camera with a limited lens angle ($\sim 63^\circ$), rather than a standard fisheye lens capturing a full 180° field of view. Consequently, the canopy cover values obtained should be interpreted as relative measures for comparison among study sites rather than as absolute estimates of canopy closure. While this approach limits the precision of canopy quantification, consistent application of the same method across all sites allows meaningful relative comparisons of canopy-related patterns.

The results (Fig. 2 and Table 1) indicated that the highest canopy cover was found in the Arboretum (83.91%), followed by the Oil Palm site (71.91%). No canopy measurements were conducted at the Cikabayan site because it lacked tree cover.

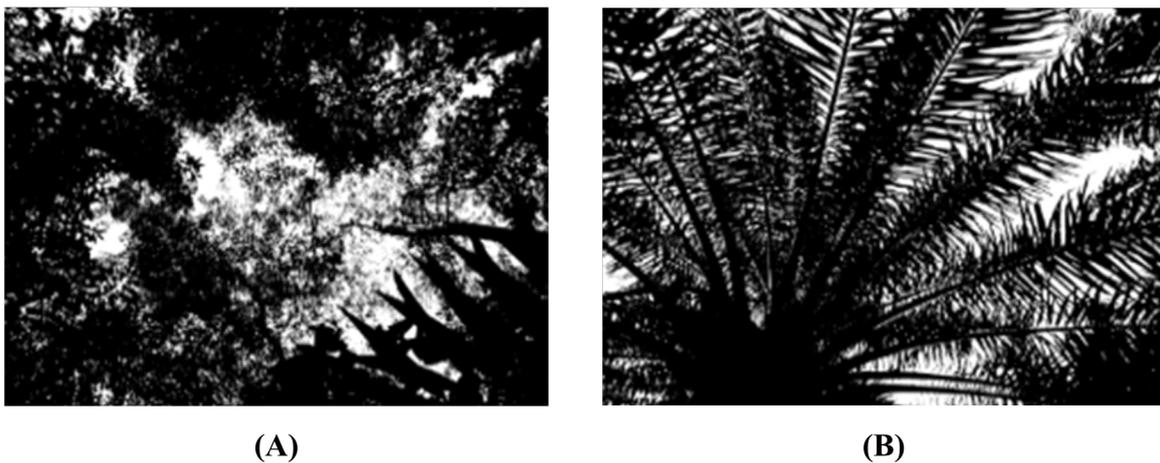


Figure 2. Canopy cover in the Arboretum (A) and Oil Palm site (B). Photographs were converted to 8-bit format and threshold adjustments were applied using ImageJ software.

Table 1. Mean values of environmental parameters measured across sampling sites within the IPB University campus, Dramaga, Bogor, West Java

Location	Air Temperature (°C)	Air Humidity (%)	Light Intensity (lux)	Soil pH	Soil Moisture (%)	Canopy Cover (%)
Arboretum	31.27±0.56	60.6±3.28	657.33±323.37	5.97±0.09	54.67±3.77	83.91±2.32
Oil Palm	31.53±0.66	65.33±5.13	1501.67±866.89	5.67±0.48	57.67±3.30	71.91±6.90
Cikabayan	31.37±0.61	64.33±6.26	13096.67±3787.97	5.5±0.33	53.33±3.40	0.00

Ground-dwelling insect communities

Across all pitfall traps deployed at the three study sites, a total of 7 insect orders comprising 12 families were recorded (Table 2), with some dominating families (Fig. 3). The highest number of individuals was found in the Oil Palm site (836 individuals), followed by Cikabayan (651 individuals) and the Arboretum (220 individuals).

According to Magurran (1988), Shannon–Wiener diversity index values between 1 and 3 indicate moderate diversity. Based on this criterion, none of the study sites reached the category of high diversity, and all locations were characterized by moderate diversity levels. A total of 1,711 ground-dwelling insect individuals representing several orders and families were recorded across the three study sites. The Oil Palm site showed the highest abundance (836 individuals), followed by Cikabayan (651) and the Arboretum (220). Across all sites, the community was dominated by Orthoptera and Hymenoptera, particularly Gryllidae (585 individuals) and Formicidae (504 individuals). In the Arboretum, overall abundance was lower, but community structure was more evenly distributed among families, reflected by the highest Shannon diversity ($H' = 1.559$) and evenness ($E = 0.870$). In contrast, the Oil Palm site exhibited the lowest diversity ($H' = 1.431$) and evenness ($E = 0.651$), driven by strong dominance of Formicidae and Gryllidae. Cikabayan showed intermediate diversity ($H' = 1.498$) and evenness ($E = 0.682$), with high abundances of Gryllidae, Formicidae, and Scarabaeidae.

Table 2. Ground-dwelling insect communities are classified by order and family within the IPB Dramaga campus, Bogor

Order	Family	Number of Individuals			Total
		Arboretum	Oil Palm	Cikabayan	
Diptera	Drosophilidae	35	10		45
	Tachinidae			25	25
Coleoptera	Nitidulidae	7	8	4	19
	Elateridae	12			12
	Scarabaeidae	17	25	79	115
Hymenoptera	Formicidae	62	333	109	504
Dermaptera	Anisolabididae	87			87
	Spongiphoridae		7		7
Orthoptera	Acrididae		28	45	73
	Gryllidae		253	332	585
Blattodea	Blattidae		172	49	221
Hemiptera	Nabidae			8	8
Total individuals		220	836	651	1711
Diversity (H')		1.559	1.431	1.498	
Dominance (D)		0.760	0.707	0.686	
Evenness (E)		0.870	0.651	0.682	

Overall, variation among sites was primarily associated with differences in relative abundance and dominance patterns rather than the presence or absence of major taxa. These moderate diversity values are comparable to those reported from similar tropical habitats with varying vegetation structure and canopy cover, including secondary forests, agroforestry systems, and plantation landscapes (Magurran, 1988; Wijayanto et al., 2022; Damayanti et al., 2023). Studies in managed and post-disturbance tropical ecosystems further indicate that such diversity patterns commonly arise from habitat heterogeneity and microclimatic gradients rather than exceptionally high species richness (Rahayu et al., 2017; Buchori et al., 2018). From an ecological perspective, moderate diversity combined with low dominance and relatively high evenness suggests that key ecosystem functions such as organic matter decomposition, nutrient cycling, and regulation of soil-surface food webs are likely maintained across sites despite differences in canopy cover (Magurran, 1988; Segev et al., 2023; Narwade et al., 2024).

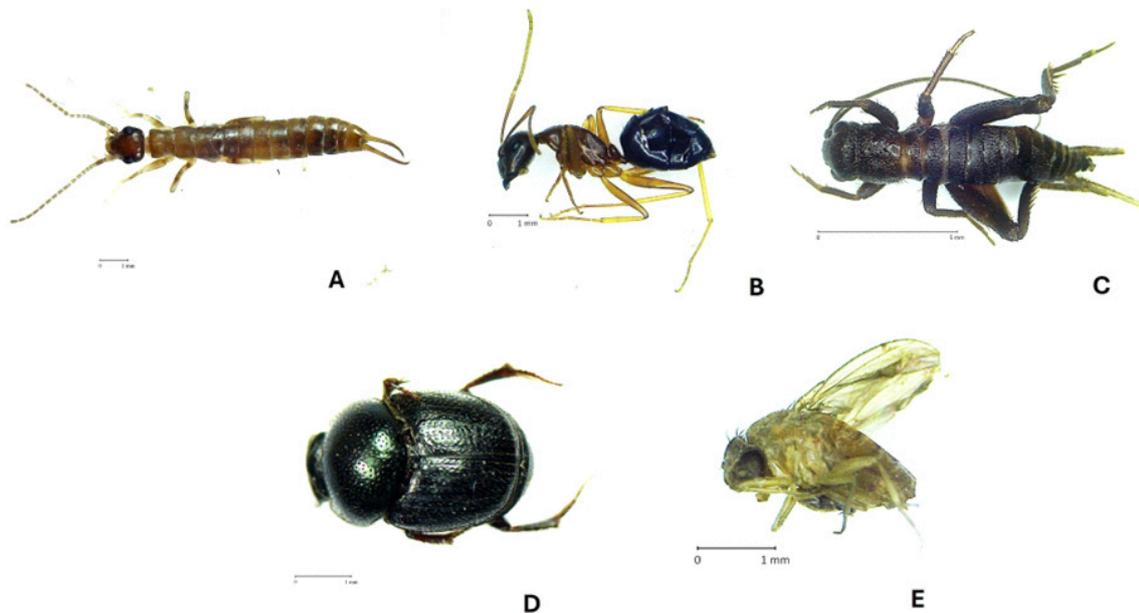


Figure 3. Ground-dwelling insects representing dominant families found in research site A) Anisolabididae, B) Formicidae, C) Gryllidae, D) Scarabaeidae, and E) Drosophilidae

Community dissimilarity

PERMANOVA results indicated that community composition did not differ significantly among the three study sites ($R = 0.861$, $p = 0.067$). Accordingly, no statistically supported differences in the number or composition of ground-dwelling insect communities were detected between the Arboretum, Oil Palm, and Cikabayan sites. Non-metric Multidimensional Scaling (NMDS) was used as an exploratory ordination technique to visualize patterns of community

composition across sites (Rahayu et al., 2017). Given that PERMANOVA did not detect statistically significant differences among sites ($p = 0.067$), NMDS results were interpreted descriptively and used solely to illustrate potential compositional gradients rather than to infer statistically supported differences. NMDS analysis based on Bray-Curtis distances successfully separated the three study sites (Fig. 4).

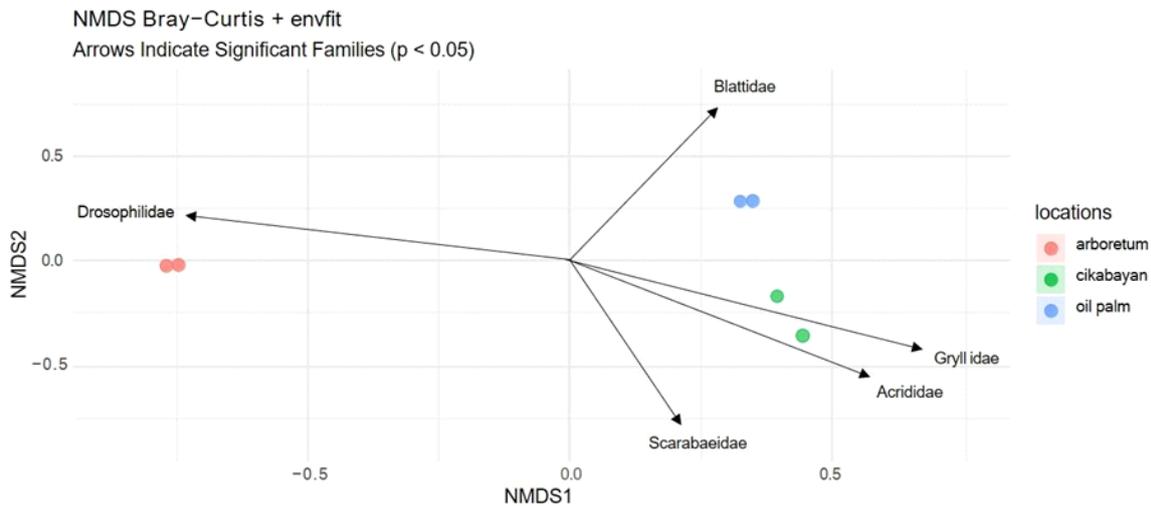


Figure 4. Non-metric Multidimensional Scaling (NMDS) ordination of ground-dwelling insect community composition across study sites (stress = 0.00). Environmental and taxonomic variables were passively fitted onto the ordination using the *envfit* function to visualize correlations with ordination structure. The extremely low stress value is interpreted cautiously due to the limited sample size and potential overfitting, and the ordination is presented for exploratory visualization only.

The extremely low NMDS stress value (0.00) observed in this study should be interpreted cautiously, as it likely reflects the limited sample size and reduced dimensionality of the dataset. Such conditions can lead to overfitting in ordination analyses, and therefore the NMDS results are presented solely as exploratory visualizations rather than evidence of statistically supported community differentiation. Pairwise Bray-Curtis dissimilarity values ranged from 0.119 to 0.886, indicating varying degrees of dissimilarity across sites. The ground-dwelling insect community in the Oil Palm site was more similar to that in Cikabayan than to the Arboretum. Conversely, the Arboretum exhibited a distinct community structure compared to both Cikabayan and Oil Palm. Long vector lines in the *envfit* analysis represented families that contributed substantially to site separation in the ordination space (Pérez-Luque et al., 2021). *Drosophilidae* significantly contributed to the Arboretum community, *Blattidae* contributed to the Oil Palm community, whereas *Gryllidae* and *Acrididae* were key contributors to community formation in Cikabayan ($p < 0.05$).

Environmental variables shaping ground-dwelling insect communities.

Canonical Correspondence Analysis (CCA) was performed to examine the relationship between ground-dwelling insect community composition and the measured environmental variables (Ghani & Maalik, 2020). The overall CCA model was statistically significant ($F = 1.8028$, $p = 0.001$), indicating that the observed relationships were not due to random variation.

Axis CCA1 had an eigenvalue of 0.3984, explaining 54,96% of the variation attributable to environmental variables, while CCA2 had an eigenvalue of 0.1847 (25,48%). Together, these two axes accounted for 80,44% of the explained variation, making them sufficiently representative for visualization in a two-dimensional biplot.

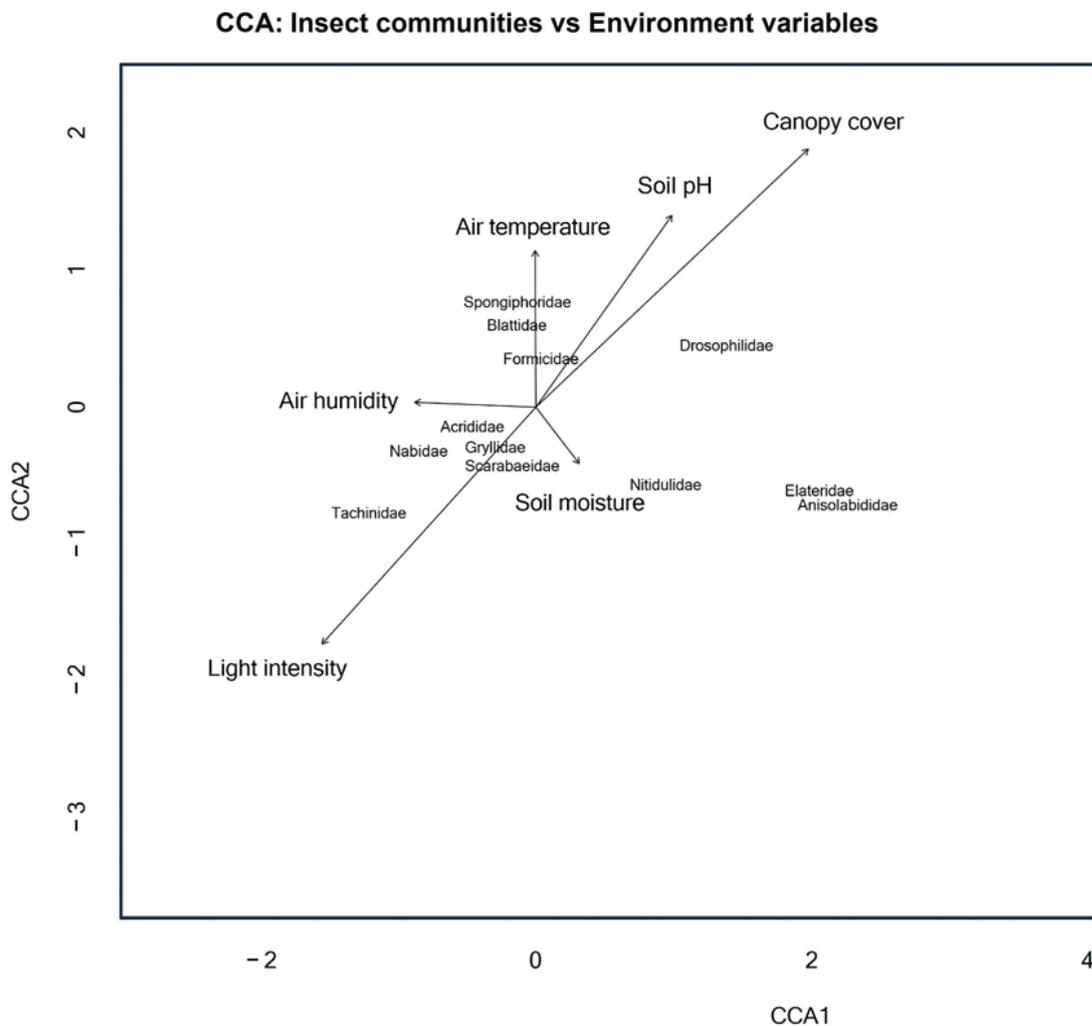


Figure 5. Results of Canonical Correspondence Analysis of environmental variables. Vector length indicates the contribution of each environmental variable to the structuring of ground-dwelling insect communities, while vector orientation reflects correlations among variables.

Partial significance testing (by term) revealed that out of six tested variables, only light intensity ($F = 2.7917$, $p = 0.008$) and canopy cover ($F = 3.9573$, $p = 0.003$) had highly significant effects on the composition of ground-dwelling insect communities (Table 4, Fig. 5). The other variables were not significant, likely due to their relatively low contributions or collinearity with the significant variables.

The CCA biplot indicated that Drosophilidae, Formicidae, and Blattidae tended to be associated with canopy cover, whereas Gryllidae, Acrididae, and Scarabaeidae were more strongly related to the gradient of light intensity. The length of the vectors in the biplot reflected the strength of each environmental variable's influence, while the direction of the vectors represented environmental gradients shaping species distributions.

DISCUSSION

Canopy cover analysis

This study aimed to compare the composition of ground-dwelling insect communities under three levels of canopy cover—dense, medium, and sparse. The canopy cover classification in this research adopted the hemispherical photography method commonly applied for mangrove canopy studies (Purnama et al., 2020; Kassagi et al., 2024). According to the Decree of the Indonesian Ministry of Environment No. 201/2004 on Mangrove Forest Damage Standards, canopy cover is categorized as dense ($>75\%$), medium ($50\text{--}75\%$), and sparse ($<50\%$). Although originally designed for mangrove monitoring, this classification has been applied in other forest ecosystems, such as the study by Oktarina et al. (2024) in the Bukit Barisan Protected Forest, West Sumatra. Based on these criteria, the Arboretum represented a dense canopy condition ($83.91 \pm 2.32\%$), the Oil Palm plantation represented medium canopy cover ($71.91 \pm 6.90\%$), and Cikabayan represented an open site with no canopy cover (0%). These canopy cover values were directly influenced by the vegetation composition at each site.

Vegetation composition shaping canopy cover

The Arboretum had dense canopy cover due to its relatively high tree density and greater species richness. Tree density reached 233 individuals/ha, comprising approximately 14 tree species dominated by *Shorea leprosula* (Zaskia et al., 2020). The forest floor was dominated by leaf litter, contributing to dense canopy closure through structurally diverse and abundant stands compared to the other sites. The Cikabayan Oil Palm Experimental Plantation (Oil Palm) was dominated by *Elaeis guineensis* with an understory comprising up to 80 species, including

ferns, broad-leaved plants, narrow-leaved plants, and grasses (Wulandari et al., 2025). As a monoculture plantation with relatively homogeneous canopy cover, Oil Palm represented medium canopy density but supported diverse understory vegetation. In contrast, the Cikabayan Experimental Farm (Cikabayan) was designed as an open agricultural field and integrated farming laboratory for student training and crop development (Nabilah et al., 2017). Vegetation in this site was periodically replaced depending on teaching purposes, and the landscape was dominated by shrubs and grasses, resulting in no canopy cover (0%). The presence or absence of trees and understory vegetation across these three locations shaped canopy cover and consequently influenced soil-surface microhabitats.

Contribution of canopy cover to soil-surface microhabitats

CCA analysis (Fig. 5) provided insights into correlations among the analyzed environmental factors. Canopy cover and light intensity vectors were positioned orthogonally, indicating a strong negative correlation between these two variables. Increases in canopy cover corresponded with decreases in light intensity. Canopy cover moderated maximum and minimum daily temperature fluctuations within shaded microclimates (Vasconcelos & Sacht, 2020), which was evident in the Arboretum, where air temperature variation showed the smallest standard deviation among the three sites (Table 1). Moreover, canopy cover helped buffer against elevated air temperatures above the understory (Keppel et al., 2017). Although this study presented air temperature data, soil-surface temperature was not measured, representing a limitation of the research.

Canopy cover also exhibited a strong positive correlation with soil pH, as shown by the narrow angle of their vectors along the same axis in the CCA biplot (Fig. 5). This finding is consistent with previous studies demonstrating that soils under canopy cover contain higher levels of organic matter, calcium, magnesium, potassium, and higher pH compared to open grasslands (Tyler, 1989; Isichei & Moughalu, 1992). Nevertheless, despite its correlation with canopy cover, soil pH did not significantly contribute to shaping insect community composition.

Although canopy cover influenced soil moisture microclimates, with generally higher moisture levels under closed canopy conditions due to reduced evaporation and increased litter accumulation (Kokila et al., 2024), soil moisture did not emerge as a primary factor structuring ground-dwelling insect communities in this study. This apparent decoupling may be explained by several non-mutually exclusive mechanisms. First, although moisture is physiologically

important for insects, empirical studies have shown that insect distribution responses to soil moisture gradients can be variable and taxon-specific, often depending on other habitat factors such as substrate structure or food resources (Kirichenko-Babko et al., 2020). Second, instantaneous or short-term soil moisture measurements may not adequately reflect biologically relevant temporal dynamics, especially in tropical environments where moisture conditions can fluctuate rapidly after rainfall events, such temporal variability can decrease the strength of static soil moisture - community relationships (Benefer et al., 2016). Third, ground-dwelling insects may respond more strongly to indirect habitat attributes mediated by canopy cover, such as litter depth, structural complexity, and resource availability, which can provide physical refugia and trophic resources independently of soil moisture per se (Thanuja et al., 2025). Consequently, while moisture remains biologically relevant at the individual level, its influence on community level patterns in this study may be overridden by habitat structural factors associated with canopy cover density. Overall, canopy cover and light intensity significantly structured environmental parameters at the soil surface and were the most influential factors shaping the variation in ground-dwelling insect community composition.

Dominant family analysis

Formicidae was the most abundant taxon overall (504 individuals) and occurred at all sites (Table 3), reflecting the generalist characteristics of ants and their high tolerance to a wide range of environmental conditions (Zina et al., 2022). Gryllidae (585 individuals) and Acrididae (73 individuals) were more abundant in the Oil Palm and Cikabayan sites, indicating their preference for habitats with lower canopy cover that provide favorable conditions for foraging and reproduction. Similar patterns have been reported for Orthoptera, which commonly reach higher abundance in open habitats with dense understory vegetation such as grasses and shrubs (Damayanti et al., 2023).

Conversely, Anisolabididae (87 individuals), Drosophilidae (45 individuals), and Elateridae (12 individuals) were recorded more frequently in the Arboretum, suggesting their association with shaded environments characterized by relatively stable humidity and lower light intensity, as well as forest floors enriched with organic litter. For example, *Drosophila melanogaster* (Drosophilidae) shows a preference for dimly lit microhabitats for daily activities (Rieger et al., 2007), and its reproductive success has been reported to increase under low light conditions (Izutsu et al., 2012). Elaterid beetles (Elateridae) typically inhabit moist, organic-rich substrates, with larvae developing in soil, leaf litter, and decomposing organic material (Traugott et al., 2015), conditions that are well represented in the Arboretum.

Anisolabididae (earwigs) complete their life cycle in dark and humid soil-surface environments, rely on organic litter as a food source and act as predators of other ground-dwelling insects (Gasch et al., 2013). However, despite their relatively high abundance, Anisolabididae did not significantly influence overall community structure in the Arboretum ($p > 0.05$). Scarabaeidae showed a contrasting pattern, with their highest number of individuals recorded in the open Cikabayan site (79 individuals), which may be related to their ecological role as decomposers in grassland soils, particularly under drier conditions when earthworm activity is reduced (Dortel et al., 2013).

Although several families exhibited high relative abundance at specific sites (Table 3), dominance index values indicate that no single family exerted ecological dominance within the community. The low dominance ($D = 0.271\text{--}0.313$) and relatively high evenness observed across sites suggest a balanced distribution of individuals among families. Therefore, the families listed in Table 3 should be interpreted as the most abundant families at each site, rather than dominant taxa in terms of overall community structure. Differences in the occurrence of other families are better explained by NMDS and *envfit* analyses, which describe their contribution to community differentiation rather than numerical dominance.

Table 3. Three dominant families of ground-dwelling insect communities across the three study sites

Location	Total individuals	Three Dominant Families	Number of Dominant Individuals	%
Arboretum	220	Anisolabididae	87	39.55
		Formicidae	62	28.18
		Drosophilidae	35	15.91
Oil Palm	836	Formicidae	333	39.83
		Gryllidae	253	30.26
		Blattidae	172	20.57
Cikabayan	651	Gryllidae	332	51.00
		Formicidae	109	16.74
		Scarabaeidae	73	11.21

Interaction between ground-dwelling insect communities and environmental factors

CCA results indicated that light intensity ($p = 0.008$) and canopy cover ($p = 0.003$) were the two environmental variables that significantly influenced community structure. High light intensity in Cikabayan (0% canopy cover) and partially in the Oil Palm site (71.91%) was positively associated with the presence of Gryllidae and Acrididae. Conversely, high canopy

cover in the Arboretum supported taxa requiring shaded and relatively humid conditions, such as Drosophilidae and Elateridae (Rieger et al., 2007; Izutsu et al., 2012; Traugott et al., 2015). Other factors, including air temperature, soil moisture, and soil pH, did not show significant effects on the structuring of ground-dwelling insect communities.

Table 4. Results of Canonical Correspondence Analysis of environmental variables measured in this study

Variable	df	Chi-square	F	N.Perm	P
Air temperature	1	0.06157	0.9189	999	0.423
Air humidity	1	0.07596	1.1337	999	0.294
Light intensity	1	0.18706	2.7917	999	0.008**
Soil pH	1	0.05617	0.8382	999	0.549
Soil moisture	1	0.07887	1.1771	999	0.267
Canopy cover	1	0.26517	3.9573	999	0.003**

*Significant difference ($\alpha = 0.05$)

**Significant difference ($\alpha = 0.01$)

Ecological implications and recommendations

This study demonstrates that canopy cover plays an important role in shaping ground-dwelling insect community structure, but its effect differs across community attributes. Medium canopy cover (70%) was associated with higher overall insect abundance, often characterized by dominance of particular taxa, whereas higher canopy cover (80%) supported communities with greater evenness and compositional differentiation. These patterns indicate that abundance and diversity respond differently to canopy cover gradients and should not be treated interchangeably. The 70% canopy cover value discussed here should therefore be interpreted as a pragmatic reference based on observed abundance patterns, rather than a statistically derived ecological threshold. From a management perspective for conservation and agroecosystems areas, maintaining heterogeneous canopy conditions may be more effective than applying a single canopy cover target, particularly in agroecosystems such as oil palm plantations, where balancing productivity and biodiversity conservation is a key challenge.

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