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Impacts of tourism and fire on ground-dwelling insect diversity in tropical pine forests of South Sulawesi, Indonesia

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Abstract. *Sadapotto A, Christine SAP, Prastiyo A. 2025. Impacts of tourism and fire on ground-dwelling insect diversity in tropical pine forests of South Sulawesi, Indonesia. Biodiversitas 26: 5109-5117.* Ground-dwelling insects serve as sensitive bioindicators of environmental change in tropical pine forests. This study aimed to compare the structure of ground-dwelling insect communities across three management areas of the Tala-Tala pine forest, South Sulawesi, Indonesia, namely the tourism area, non-tourism area, and post-fire area. This is the first study of ground-dwelling insect communities in Sulawesi's tropical pine forests. Sampling was conducted using multiple insect collection techniques, and ecological indices were applied to evaluate diversity, richness, evenness, and dominance. Statistical analyses were employed to compare land-use types and to assess their relationships with environmental factors. Diversity and evenness were lower in protected areas, whereas the tourism zone exhibited higher richness and dominance. Statistical analysis indicated significant ($p<0.05$) differences among land-use types in Shannon diversity, species richness, evenness, and dominance indices. Person correlation analysis showed a very strong negative correlation between diversity and dominance (r: -0.99), and a strong positive correlation between richness and soil pH (r: 0.99). Cluster analysis grouped the post-fire and tourism habitats, indicating similar disturbance levels, while PCA revealed that distinct environmental variables and ecological indices influenced each land-use type. The findings suggested that integrating biodiversity-friendly tourism practices with targeted post-fire habitat restoration supported insect diversity. These approaches also sustained the ecological and recreational value of tropical pine forests.

Keywords: Ecological indicators, fire ecology, habitat disturbance, pine forest, Sulawesi

INTRODUCTION

Indonesia's forests harbor high biodiversity, supported by a stable tropical climate and geographical conditions as an archipelagic nation. Among faunal groups, insects exhibit particularly high diversity (Budiadi et al. 2020; Rohyani 2020). Ground-dwelling insects play a crucial role in maintaining ecosystem balance and supporting biological control functions (Jankielsohn 2018; Verma et al. 2023). Particularly in response to environmental pressures such as tourism activities and forest fires, the measures remain limited. This lack of empirical data on insect assemblages in post-fire pine forests and under tourism disturbance limits the ability to predict how disturbance regimes influence insect-mediated ecosystem processes in tropical pine ecosystems.

Although pine forests are ecologically important, few studies have examined insect responses to tourism activities and forest fire in tropical pine forests. Ground-dwelling insects are integral components of the soil ecosystem, acting as detritivores, predators, and herbivores in the soil food web (Menta and Remelli 2020). Their presence is strongly influenced by habitat conditions such as soil moisture, litter structure, and vegetation cover. Although not as well-recognized as pollinators or canopy insects, ground-dwelling insects are susceptible to environmental changes, making them potential bioindicators in ecological studies (Parikh et al. 2021; Chowdhury et al. 2023). Habitat disturbances resulting from human activities can lead to changes in the composition and dominance of ground insects (Barton and Evans 2017).

Pine forests, particularly *Pinus merkusii*, are widely developed in Indonesia and have adapted well to tropical regions with rocky, dry soils (Imanuddin et al. 2020; Supartono et al. 2023). The pine needle litter creates a distinct substrate on the forest floor that shapes microhabitats for soil-dwelling insects (Marquez et al. 2017). Pine forests in Indonesia are primarily managed for production purposes and eco-tourism, leading to varying levels of disturbance depending on management intensity (Setyaningrum et al. 2019; Utami et al. 2022). Thus, it is essential to investigate how differences in forest function and environmental pressures in tourist, non-tourist, and post-fire areas influence ground-dwelling insect communities. However, no previous study has directly compared these three management contexts within a single tropical pine forest landscape in Sulawesi. This research represents the first study in Sulawesi's tropical pine forests to examine the response of ground-dwelling insects to the combined ecological pressures of tourism and fire disturbance.

Tropical pine forests in Indonesia provide distinctive ecological conditions, such as dry soils and open canopies, that influence ground-dwelling insect communities (Budiaman et al. 2025a, b). The Tala-Tala pine forest in

Maros District, South Sulawesi, comprises a tourism, non-tourism, and a fire-affected site. In the burned area, fire had spread since September 11, 2023, and was successfully extinguished by a joint team on September 13, 2023 (Pranata 2023). Tourism activities can degrade soil and vegetation due to visitor traffic, facility construction, and unsustainable management practices (Wolf et al. 2019). Conversely, conservation tends to be more ecologically stable, whereas post-fire areas often experience decreased moisture and litter loss, which directly affects soil fauna diversity (Zaitsev et al. 2016; Malik et al. 2025).

Previous studies have shown that fires can cause homogenization of insect communities and the increased dominance of opportunistic species (Arnan et al. 2020). Similarly, eco-tourism without sustainable management has also been shown to simplify and reduce diversity in the long term (Noriega et al. 2020; Pablo-Cea et al. 2021). Conversely, semi-natural habitats protected from disturbance pressures tend to maintain a more diverse and stable faunal composition (Holland et al. 2016; Guo et al. 2022). The scarcity of comparative studies directly comparing ground-dwelling insect communities in tourism, non-tourism, and post-fire areas within a single landscape limits our understanding of the ecological responses of ground-dwelling insects to anthropogenic and natural pressures.

The objective of this study is to investigate differences in community composition and community structure of ground-dwelling insects across tourist, non-tourist, and post-fire areas. It hypothesizes that non-tourism areas have the highest diversity and evenness, while tourism and post-fire areas show greater dominance by disturbance-tolerant taxa. This study is expected to provide a scientific basis for the sustainable management of pine forest areas and support ecosystem restoration through locally relevant conservation policies in tropical regions, particularly in South Sulawesi, Indonesia.

MATERIALS AND METHODS

Study area

This study was conducted in the Tala-Tala pine forest, in Tompobulu Sub-district, Maros District, South Sulawesi, Indonesia (Figure 1). The area is a highland region dominated by *P. merkusii* vegetation and is within easy access from Maros and Makassar. The research focused on three distinct management areas: tourism, non-tourism, and post-fire areas, each exhibiting distinct ecological conditions. The tourism area, situated at coordinates 5.097619°S and 119.742280°E with an elevation of 332 meters above sea level, is managed by the local community through the Tourism Awareness Group (POKDARWIS). Designed to facilitate recreation, with wider tree spacing to increase light penetration and allow sunlight to reach the forest floor.

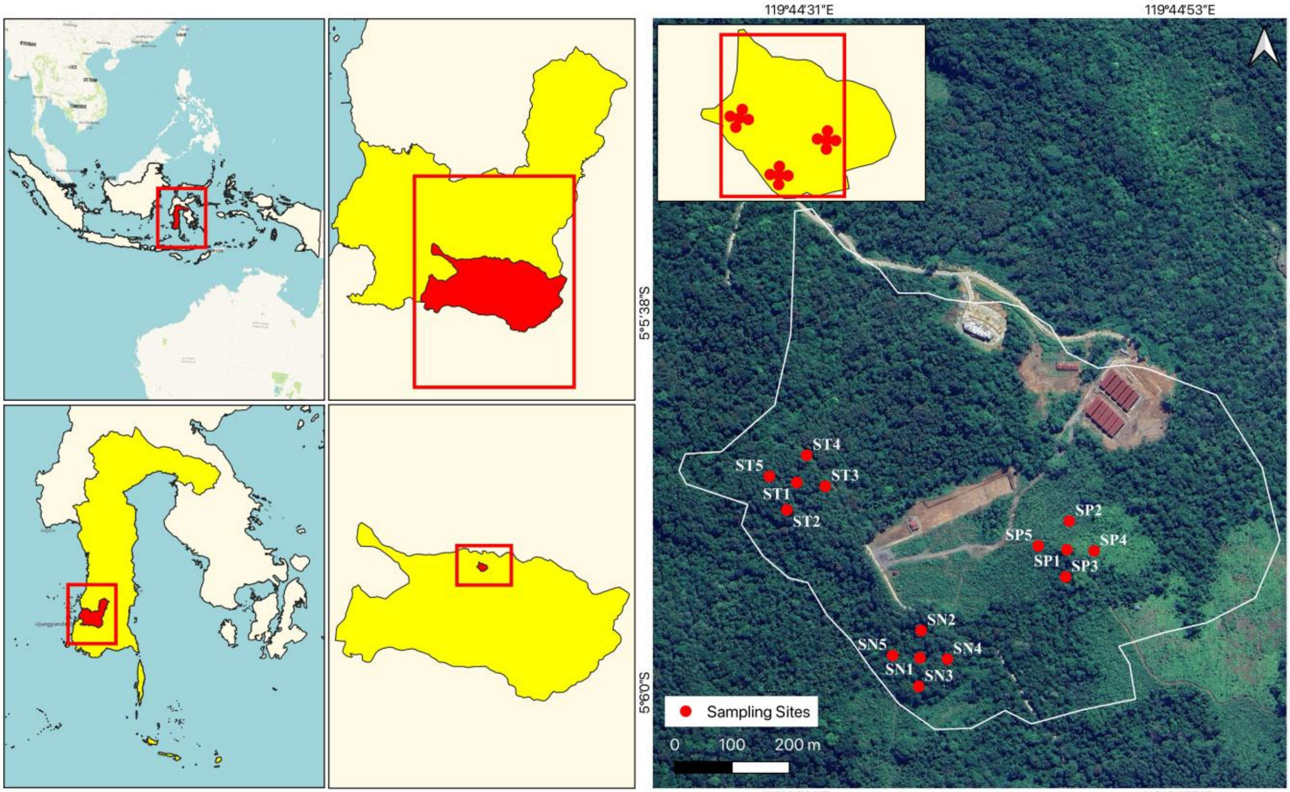


Figure 1. Map of the study site in Tala-Tala pine forest, Maros, South Sulawesi, Indonesia, showing the locations of the tourism, non-tourism, and post-fire areas used for sampling ground-dwelling insects. ST: Tourism area, SN: Non-tourism area, SP: Post-fire area

Table 1. Geographic coordinates of the three site types in the Tala-Tala pine forest, Maros District, South Sulawesi, Indonesia

Site	Plot	Coordinate
Tourism area	ST1	5°5'47.994" S, 119°44'31.170" E
	ST2	5°5'49.553" S, 119°44'30.612" E
	ST3	5°5'48.200" S, 119°44'32.794" E
	ST4	5°5'46.435" S, 119°44'31.728" E
	ST5	5°5'47.647" S, 119°44'29.616" E
Non-tourism area	SN1	5°5'57.943" S, 119°44'38.199" E
	SN2	5°5'56.385" S, 119°44'38.263" E
	SN3	5°5'59.571" S, 119°44'38.136" E
	SN4	5°5'58.007" S, 119°44'39.752" E
	SN5	5°5'57.808" S, 119°44'36.646" E
Post-fire area	SP1	5°5'51.750" S, 119°44'46.501" E
	SP2	5°5'50.122" S, 119°44'46.635" E
	SP3	5°5'53.307" S, 119°44'46.437" E
	SP4	5°5'51.814" S, 119°44'48.054" E
	SP5	5°5'51.545" S, 119°44'44.877" E

Note: ST: Tourism area, SN: Non-tourism area, SP: Post-fire area

Table 2. Environmental data from the three study areas

Site	Temperature (°C)	Humidity (%)	Soil pH
Tourism area	30.25±2.04	65.67±4.81	7.54±0.05
Non-tourism area	28.03±3.43	62.22±8.17	7.10±0.10
Post-fire area	36.07±6.96	51.22±13.84	7.22±0.25

In contrast, the non-tourism area, at an elevation of 343 meters, features dense pines, low light, and high humidity, supporting understory growth and wildlife. The third area is a post-fire land that was burned in September 2023, at an elevation of 340 m. This site is characterized by severely disturbed conditions, with remnants of charred trees, higher temperatures, and full sun exposure compared to adjacent areas. However, pioneer plant species such as *Melastoma malabathricum* and *Homalanthus populifolius* have begun to recolonize the area, contributing to ecological restoration. The proximity of these three areas within the same landscape enables a comparative approach to examine how ground-dwelling insect diversity responds to different habitat conditions shaped by anthropogenic and natural disturbances. The study site locations are presented in Figure 1 and Table 1, showing the geographic positions of each area.

Data collection

Ground-dwelling insects were sampled from March to May 2025 in three land-use types in Tala-Tala pine forest, Maros District, South Sulawesi. A combination of pitfall traps, yellow sticky traps, and direct hand collection was used to maximize the capture of ground-dwelling insect taxa. Sampling was conducted monthly for three consecutive months in 24-hour sessions. In each land-use type, insects were hand-collected and sampled with 15 pitfall traps and five yellow sticky traps. The distance between plots was 50 m, and the distance between locations ranged from 200 to 400 m. Trap positions and numbers were standardized across plots and land-use types to ensure comparability. This design allowed for comparison of insect community composition across land-use types, while ensuring adequate sampling effort and statistical rigor. All fieldwork was conducted with permission from the relevant local authorities (Permit No. 01045/UN4.16/PT.01.04/2025), in accordance with ethical guidelines for invertebrate sampling.

Environmental variables were measured (Table 2), focusing on three key variables: temperature, humidity, and soil pH, to assess their influence on ground-dwelling insect communities in the Tala-Tala pine forest. Temperature and humidity were measured using a digital thermo-hygrometer three times a day at each plot during the sampling period, and the mean values were calculated for analysis. Soil pH was measured using a digital pH meter at a depth of 8-10 cm from the ground surface. The average values of each environmental parameter were employed to assess correlations with insect diversity indices and to classify locations based on ecological similarity.

Identification

Insect specimens were identified in stages to maximize the accuracy of taxonomic classification. Field-captured insects were initially sorted by order based on distinct morphological characteristics such as wing structure, antennae, and body shape. Specimens that could be readily identified to the genus or species level were classified in situ using standard field guides for tropical insects. At the same time, unidentified specimens were transported to the laboratory for further examination. In the lab, identification was performed using a stereo microscope (Stem 2000 model) equipped with an Erc 5S phototube camera to document morphological features. The examination included careful examination of morphological characteristics such as wing venation, tarsal structure, antenna segmentation, and body coloration patterns. Species-level identification was based on key resources, including tropical ground-dwelling insect identification keys, arthropod handbooks, and recent scientific publications. To enhance identification accuracy, specimen images were matched against online databases such as iNaturalist, allowing for comparison with thousands of verified specimen images from Indonesia and beyond. Correctly identified specimens were labeled, cataloged, and preserved in 70% ethanol for long-term preservation. This procedure ensured that final classifications were based not only on morphology but also supported by digital validation and secondary literature. This integrative approach, which combines field identification, microscopic analysis, scientific references, and digital platform validation, was employed to minimize identification errors and enhance the taxonomic reliability of ground-dwelling insect data in the study area. Two entomology experts cross-checked taxonomic determinations to ensure accuracy.

Data analysis

Data from ground-dwelling insects were analyzed to evaluate community structure across three management areas in the Tala-Tala pine forest: tourism, non-tourism, and post-fire areas. The first step involved computing the Shannon-Wiener diversity index to assess species variation based on relative abundance. The Shannon-Wiener diversity index value was used to provide an overview of community complexity and ecosystem stability in each area. Next, the species richness index was calculated to determine the number of species found in each site, reflecting the diversity potential of the habitat. The evenness index was also calculated to measure the distribution of individuals among species. To quantify species dominance, the Simpson dominance index was used to indicate the extent to which one or a few species dominate the ground-dwelling insect community.

After calculating the ecological indices described above, a One-Way Analysis of Variance (ANOVA) was performed to test for significant differences in diversity, richness, evenness, and dominance among the three management areas. If statistically significant differences were found ($p<0.05$), a post-hoc Tukey HSD test was conducted to identify which areas. We directly measured environmental variables, temperature, humidity, and soil pH, were directly measured in the field. These parameters were then correlated with each ecological index using Pearson correlation analysis to assess relationships between microclimatic conditions and insect community structure. All statistical analyses were performed using SPSS software version 31.1.1. To further explore patterns of similarity and dissimilarity in species composition across management areas, a cluster analysis was conducted using the Bray-Curtis dissimilarity index with Ward's linkage method in XLSTAT. Complementary to this, a Principal Component Analysis (PCA) was performed using XLSTAT to reduce the dimensionality of the ecological and environmental dataset. PCA was used to visualize the multivariate relationships among sampling sites, species assemblages, and environmental variables (temperature, humidity, soil pH). The first two principal components (PC1 and PC2) explained most of the variance, indicating key environmental gradients shaping community patterns across land-use types.

RESULTS AND DISCUSSION

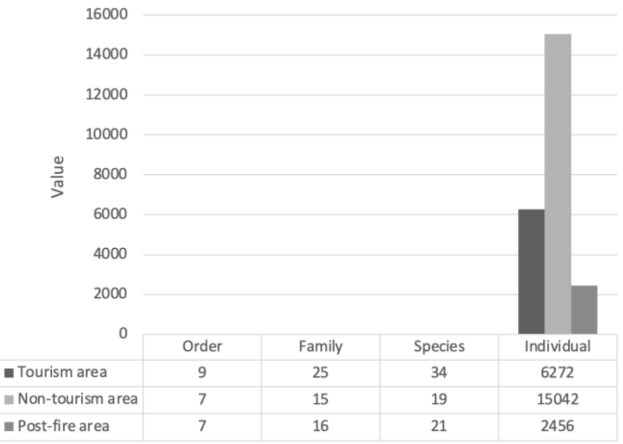
Composition of ground-dwelling insects

A total of 9 orders, 33 families, and 48 species of ground-dwelling insects were collected during research in the Tala-Tala pine forest (Table 3). The tourist area had the highest taxonomic richness, while the non-tourist area had the highest abundance. In contrast, the post-fire area exhibited intermediate richness but the lowest abundance, due to the impact of the fire disturbance. The ant *Anoplolepis gracilipes* was consistently dominant, particularly in disturbed areas (tourist and post-fire zones). In more stable habitats like the non-tourist area, a greater diversity of dominant ants, such as *Dolichoderus thoracicus* and *Carebara diversa*, was observed. Multiple dominant ant species were present. The presence of species like *Euborellia* sp. and *Acheta domesticus* in the post-fire zone indicated early successional stages.

Figure 2 presents the taxonomic composition and abundance of ground-dwelling insects in three areas of the Tala-Tala tropical pine forest. The tourist area had the highest taxonomic richness, with 9 orders, 25 families, and 34 species, totaling 6,272 individuals. In contrast, the non-tourist area had 7 orders, 15 families, and 19 species. However, it showed the highest abundance with 15,042 individuals, reflecting the dominance of certain species. The post-fire area had 7 orders, 16 families, and 21 species, but the lowest abundance (2,456 individuals), reflecting fire impacts on ground-dwelling insects. These differences indicate that the intensity of environmental disturbance influences both taxonomic diversity and insect abundance. The tourist area maintained higher diversity, the non-tourist area had a high abundance of certain species, and the post-fire area was in an early stage of ecological recovery.

Presence of specific indicator taxa

The Venn diagram (Figure 3) shows the species overlap of ground-dwelling insect species across the three areas of the Tala-Tala pine forest. The tourist area had the highest number of unique species (17 species), indicating a distinct community composition despite the dominance of certain species. The post-fire area also had 8 distinctive species, reflecting the presence of disturbance-tolerant species. The non-tourist area had 5 unique species, indicating a stable and balanced community. A total of 8 species were found together across all three areas, indicating the presence of generalist species tolerant to varying environmental conditions. Meanwhile, one species was present only in the non-tourist and post-fire areas. This pattern indicates that despite widespread species, each area retains a distinctive community shaped by ecological conditions and disturbance levels.



	Order	Family	Species	Individual
■ Tourism area	9	25	34	6272
■ Non-tourism area	7	15	19	15042
■ Post-fire area	7	16	21	2456

Figure 2. Comparison of the number of orders, families, species, and individuals of ground-dwelling insects in tourist, non-tourist, and post-fire areas in the Tala-Tala pine forest, South Sulawesi, Indonesia

Table 3. Records of ground-dwelling insects in three areas in the Tala-Tala pine forest, South Sulawesi, Indonesia

Order	Family	Species	Ground-dwelling insect		
			Tourism	Non-tourism	Post-fire
Blattodea	Blattidae	*Drymaplaneta semivitta* Walker (1868)	+	+	+
Blattodea	Ectobiidae	*Blattella asahinai* Mizukubo (1981)	+	+	+
Blattodea	Ectobiidae	*Blattella germanica* Linnaeus (1767)	+	-	+
Blattodea	Termitidae	*Macrotermes gilvus* Hagen (1858)	-	+	-
Coleoptera	Carabidae	*Discoderus parallelus* Haldeman (1843)	+	+	-
Coleoptera	Chrysomelidae	*Chrysolina staphylaea* Linnaeus (1758)	+	-	-
Coleoptera	Chrysomelidae	*Nisotra breweri* Baly (1877)	+	-	-
Coleoptera	Chrysomelidae	*Nisotra gemella* Erichson (1843)	+	-	-
Coleoptera	Coccinellidae	*Oenopia lyncea* Olivier (1808)	+	-	-
Coleoptera	Coccinellidae	*Procula ferruginea* Olivier (1808)	+	-	-
Coleoptera	Curculionidae	*Otiorhynchus sulcatus* Fabricius (1775)	+	-	-
Coleoptera	Histeridae	*Margarinotus obscurus* Kugelann (1792)	+	-	-
Coleoptera	Hydrophilidae	*Hydrobius fuscipes* Linnaeus (1758)	+	-	-
Coleoptera	Mordellidae	*Mordella holomelaena* Apfelbeck (1914)	+	-	-
Coleoptera	Scarabaeidae	*Eophileurus chinensis* Faldermann (1835)	-	-	+
Coleoptera	Scarabaeidae	*Popillia japonica* Newman (1841)	+	-	-
Dermaptera	Anisolabididae	*Euborellia annulipes* Lucas (1847)	+	+	-
Dermaptera	Anisolabididae	*Euborellia* sp.	+	-	+
Diptera	Hybotidae	*Bicellaria* sp.	-	+	+
Diptera	Tephritidae	*Philophylla caesio* Harris (1780)	+	+	+
Hemiptera	Alydidae	*Leptocorisa acuta* Thunberg (1783)	+	-	+
Hemiptera	Cicadidae	*Dilobopyga opercularis* Walker (1858)	+	-	-
Hemiptera	Coreidae	*Notobitus meleagris* Fabricus (1787)	+	-	-
Hemiptera	Delphacidae	*Nilaparvata lugens* Stål (1854)	-	+	-
Hemiptera	Membracidae	*Leptocentrus taurus* Fabricus (1775)	+	-	+
Hemiptera	Rhyparochromidae	*Metochus uniguttatus* Thunberg (1822)	+	+	-
Hymenoptera	Formicidae	*Anoplolepis gracilipes* Smith (1857)	+	+	+
Hymenoptera	Formicidae	*Camponotus irritans* Smith (1857)	+	+	+
Hymenoptera	Formicidae	*Carebara diversa* Jerdon (1851)	-	+	-
Hymenoptera	Formicidae	*Dolichoderus thoracicus* Smith (1860)	+	+	-
Hymenoptera	Formicidae	*Echinopla striata* Smith (1857)	-	-	+
Hymenoptera	Formicidae	*Myopia amblyops* Roger (1861)	-	-	+
Hymenoptera	Formicidae	*Odontomachus simillimus* Smith (1858)	+	+	-
Hymenoptera	Gasteruptiidae	*Gasteruption assectator* Linnaeus (1758)	-	-	+
Hymenoptera	Halictidae	*Lasioglossum pauxillum* Schenck (1853)	-	-	+
Hymenoptera	Mutillidae	*Ronisia brutia* Petagna (1787)	-	+	-
Hymenoptera	Ormyridae	*Ormyrus pomaceus* Geoffroy (1785)	+	+	+
Lepidoptera	Geometridae	*Eupithecia* sp.	+	-	-
Mantodea	Deroplatyidae	*Euchomenella heteroptera* Haan (1842)	+	-	-
Orthoptera	Acrididae	*Schistocerca nitens* Thunberg (1815)	-	-	+
Orthoptera	Acrididae	*Xenocatantops brachycerus* Willemse (1932)	-	+	-
Orthoptera	Gryllidae	*Acheta domesticus* Linnaeus (1758)	+	+	+
Orthoptera	Gryllidae	*Sonotrella bipunctata* Chopard (1969)	-	-	+
Orthoptera	Gryllotalpidae	*Gryllotalpa gryllotalpa* Linnaeus (1758)	-	-	+
Orthoptera	Rhaphidophoridae	*Ceuthophilus* sp.	+	+	+
Orthoptera	Tettigoniidae	*Isophya camptoxypha* Fieber (1853)	+	-	-
Orthoptera	Tettigoniidae	*Tettigonia viridissima* Linnaeus (1758)	+	-	-
Orthoptera	Trigonidiidae	*Metioche vittaticollis* Stål (1861)	+	-	-

Note: +: Indicates species recorded (present), -: Indicates species not recorded (absent)

Diversity, richness, evenness, and dominance indices of ground-dwelling insects

Diversity (Figure 4.A), richness (Figure 4.B), and evenness (Figure 4.C) indices were highest in the non-tourism area, reflecting a more balanced and resilient ecosystem. In contrast, the tourist area showed the highest dominance (Figure 4.D) and lowest evenness, indicating reduced ecological balance due to human activity. The post-fire area fell between the two, consistent with a recovering system. These differences were statistically significant ($p<0.05$).

Correlation of ground-dwelling insects with microclimate

Statistical analysis (Figure 5) revealed that species diversity was negatively correlated with dominance (r: -0.99) and soil pH, and positively correlated with evenness. Temperature and humidity had a limited influence, while soil pH significantly shaped species richness (r: 0.99) and dominance. These findings suggest that biotic interactions and soil chemistry more strongly influence community structure than climatic factors.

The results of cluster analysis based on the Bray-Curtis dissimilarity index using the Ward method indicate the presence of two main groups of soil insect communities across the three land use types. Figure 6 illustrates that the tourist and non-tourist areas are combined into one cluster (C1), reflecting high similarities in soil insect community structure. Meanwhile, the post-fire area forms a separate cluster (C2), indicating a high level of dissimilarity compared to the other two areas.

Table 4 shows the eigenvalues and percentage of variability explained by the two principal components (PC1 and PC2) resulting from the PCA analysis of soil insect communities and environmental variables. PC1 has an eigenvalue of 4.736 and explains 67.66% of the variation, while PC2 has an eigenvalue of 2.264, contributing 32.34% of the total variation. Cumulatively, both components explain 100% of the variation in the data, adequately representing the two-dimensional structure of the data.

Figure 7 depicts a PCA biplot visualizing the distribution of environmental variables and ecological indices across three land use types: tourism, non-tourism, and post-fire. The vectors indicate the contribution of each variable, where humidity and temperature have opposite directions. Non-tourism locations are strongly associated with diversity and evenness, while tourism locations are associated with soil pH and species richness, and post-fire locations are more closely associated with low temperature and diversity.

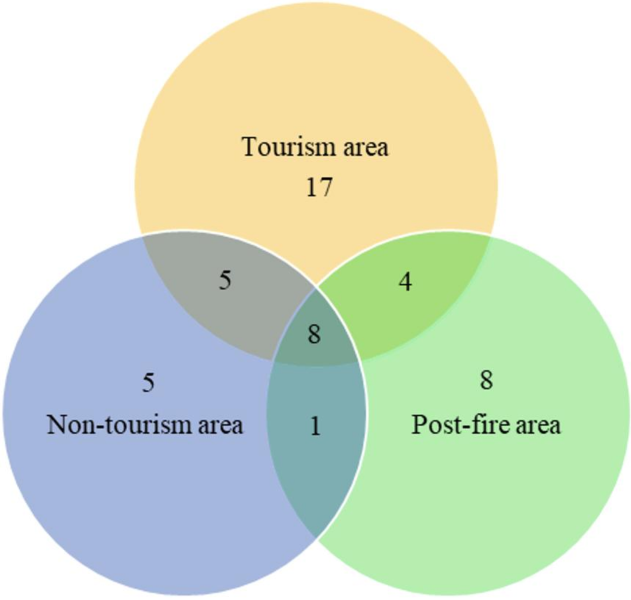


Figure 3. Venn diagram of ground-dwelling insect species composition in three areas of Tala-Tala pine forest, South Sulawesi, Indonesia

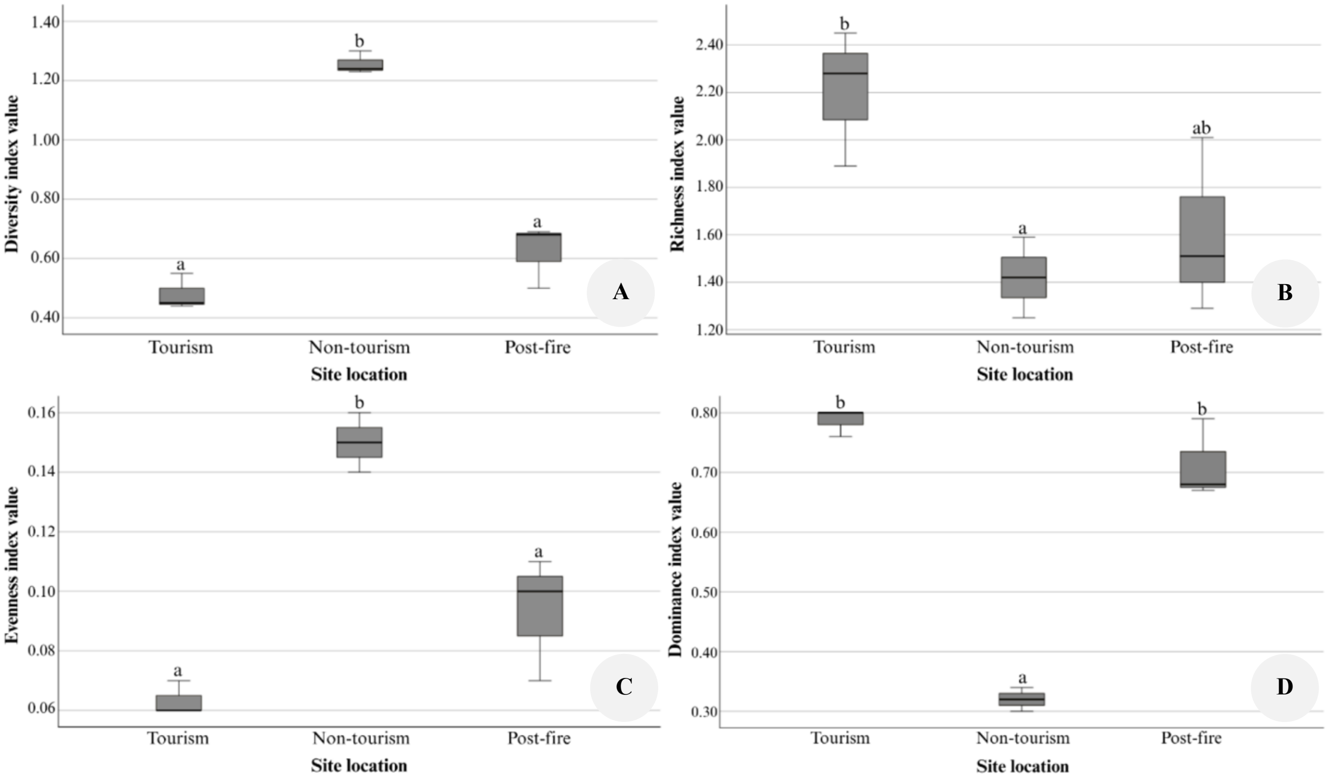


Figure 4. A. Diversity index, B. Richness index, C. Evenness index, D. Dominance index values of ground-dwelling insects in Tala-Tala pine forest, South Sulawesi, Indonesia

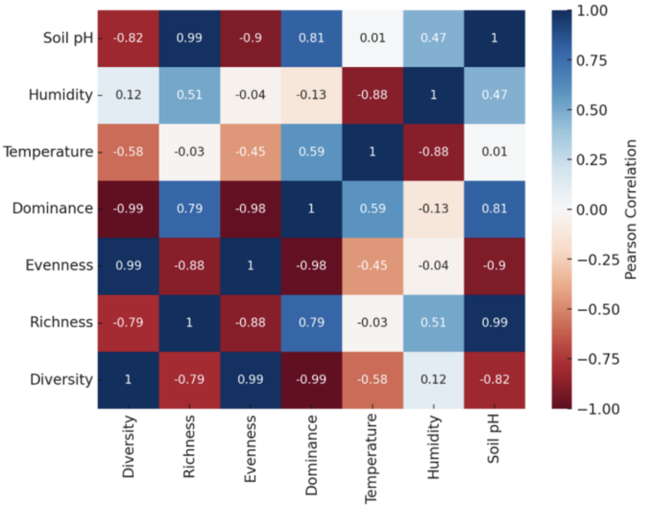


Figure 5. Correlation plot of the ecological index with environmental conditions

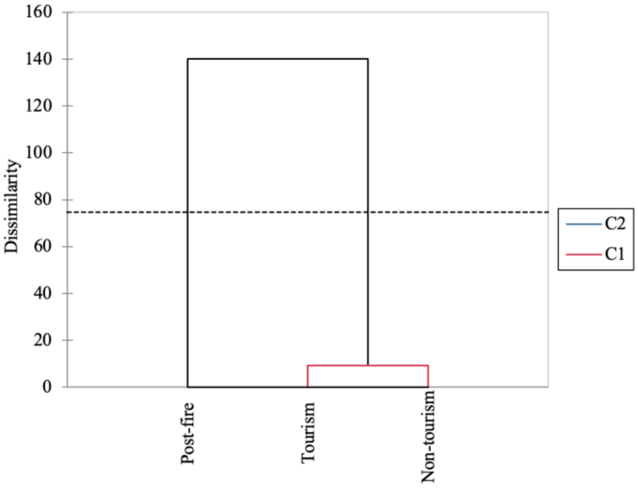


Figure 6. Cluster analysis based on Bray-Curtis dissimilarity index using Ward's method of ground-dwelling insect communities across three land-use types: Post-fire, Tourism, and Non-tourism. The dendrogram reveals two main clusters: Cluster 1 (C1), which includes tourism and non-tourism areas with high similarity, and Cluster 2 (C2), which comprises the post-fire area, indicating a high level of dissimilarity in insect community structure compared to the other land uses. The horizontal dashed line represents the dissimilarity threshold used to define clusters

Table 4. Eigenvalues and explained variance of the first two principal components (PC1 and PC2) derived from PCA on the ground-dwelling insect community and environmental variables

	PC1	**PC2**
Eigenvalue	4.736	2.264
Variability (%)	67.662	32.338
Cumulative %	67.662	100.000

Discussion

Ground-dwelling insect assemblages varied significantly across disturbance gradients. The tourist area had the highest number of unique species (17), reflecting habitat heterogeneity influenced by light, litter input, and human activity. In contrast, the post-fire area had eight unique species, suggesting adaptation to early-successional open habitats, as also reported by Lazarina et al. (2017). This unique species composition is typically favored by light intensity, detritus availability, and human activities that contribute to habitat heterogeneity (Staudacher et al. 2018; Katunzi et al. 2021). The non-tourist area, with only five unique species, maintained a more stable but less habitat structural complexity environment. Eight species were shared across all three areas, indicating a core tolerant assemblage capable of surviving a range of environmental conditions.

Higher Shannon and evenness values in the tourist area indicate a more equitable community structure with low dominance. This aligns with the concept that moderate disturbance fosters coexistence. In contrast, the post-fire area, despite being species-rich, was dominated by a few resilient taxa, notably predatory beetles (Carabidae, Staphylinidae). Previous studies indicate that certain ground-dwelling insect taxa, particularly fast-colonizing predators, tend to thrive in disturbed or post-fire habitats due to reduced competition and simplified vegetation structure (Christine 2025). Predatory insect species such as those from the Carabidae and Staphylinidae families are known to have high colonization and reproduction capabilities in disturbed habitats, including post-fire areas (Zenkova et al. 2024; Zumr et al. 2024). The non-tourist area, although ecologically stable, showed lower diversity because dominance of a few species limited diversity, supporting the intermediate disturbance hypothesis (Bulleri et al. 2016), which states that the highest diversity occurs at intermediate levels of disturbance. Insects such as ants (Formicidae) and ground beetles (Carabidae) were common across all sites, signifying their role as resilient taxa and functional indicators. In post-fire habitats, pioneer decomposers and predators are essential for restarting nutrient cycling and facilitating succession. In tourism areas, decomposer diversity indicates that ecological processes remain functional despite disturbance. Non-tourism areas, while less diverse, provide a reference baseline for assessing anthropogenic and natural impacts.

Diversity was negatively correlated with dominance (r: -0.99), reinforcing that species evenness played a critical role in maintaining community balance. Soil pH showed strong positive correlations with species richness (r: 0.99), suggesting that minor variations in soil pH influence insect survival, particularly among detritivores and predators sensitive to soil chemistry. That is consistent with findings from boreal forests on the relationship between soil pH and species richness, while the present study provides new insights from tropical pine ecosystems. This positive relationship between soil pH and dominance and richness was also found in a boreal forest study by Robinson et al. (2018), which showed that more neutral soil pH supported a greater number of ground-dwelling insect species.

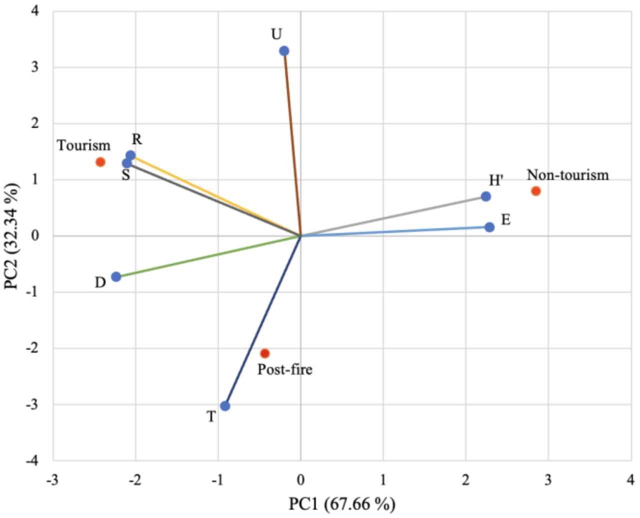


Figure 7. PCA biplot showing the distribution of environmental variables and ecological indices across three land-use types: tourism, non-tourism, and post-fire. Vectors represent environmental factors: T: Temperature, U: Humidity, S: Soil pH; and ecological indices: D: Dominance, R: Richness, H′: Diversity, E: Evenness

The ecological roles of ground-dwelling insects in these three areas are highly diverse. Groups such as Formicidae and Carabidae, which are common in all areas, serve as indicators of soil health and the balance of microhabitat food chains. In post-fire areas, the presence of pioneer insects is crucial for restarting nutrient cycling and accelerating ecological succession (Ogwayo 2023; Thomas 2023). Meanwhile, in tourist areas, diverse decomposers suggest that despite disturbance, the ecosystem still supports key ecological processes. Non-tourist areas, while less disturbed, provide a baseline for assessing the natural dynamics of insect communities without external pressures.

These findings resonate with previous research while highlighting regional specificity. For instance, ant dominance as an ecological indicator in tropical pine forests was also reported by Budiaman et al. (2025a, b). Studies from Central Europe and Indo-Pacific atolls (Steibl et al. 2021; Galle et al. 2022) reported biodiversity loss due to fire and tourism. In contrast, insect communities in tropical pine ecosystems exhibit greater resilience, supported by vegetation dynamics and microclimatic buffering. Such insights underscore the importance of contextual ecological assessments in disturbed tropical forests. Steibl et al. (2021) reported that tourism and urban development on Indo-Pacific atolls reduced invertebrate diversity through habitat fragmentation and vegetation loss, similar to the Tala-Tala tourism area. In contrast, this study in a tropical pine forest with distinct vegetation and soil moisture provides a new perspective on insect community resilience to disturbance.

In conclusion, the composition of ground-dwelling insect communities in the Tala-Tala pine forest showed distinct responses to anthropogenic (tourism) and natural (post-fire) disturbances. The tourism area exhibited the highest diversity with an even distribution of species, while the post-fire area harbored unique species adapted to early successional or disturbed habitats. Statistical correlations confirmed that dominance, soil pH, and evenness were the key factors influencing community structure. These results emphasize the importance of soil insects as bioindicators of ecosystem health in monitoring the health and dynamics of disturbed tropical ecosystems. These findings enhance understanding of how anthropogenic and natural disturbances affect soil biodiversity and support local data-driven conservation strategies. Forest managers and tourism operators should maintain vegetation cover, minimize soil compaction, and regulate visitor access in sensitive areas to preserve insect diversity. Future research should address seasonal variation, long-term post-disturbance recovery, and the effectiveness of restoration interventions in enhancing soil insect biodiversity.

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