HAYATI
Journal of Biosciences

Vol. 33 No. 4, July 2026 864-877
DOI:10.4308/hjb.33.4.864-877
ISSN: 1978-3019
EISSN: 2086-4094

Research Article

Population Dynamics of Pests and Natural Enemies of Rice (*Oryza sativa* L.) Across a Karst Distance Gradient in the Bantimurung-Bulusaraung Exokarst Region, Bantimurung District, Maros Regency, South Sulawesi

Amiruddin Amin, Sylvia Sjam*, Itji Diana Daud

Department of Plant Pest and Disease, Faculty of Agriculture, Hasanuddin University, Makassar 90245, Indonesia

ARTICLE INFO

Article history:
Received August 28, 2025
Received in revised form January 22, 2026
Accepted January 30, 2026
Available Online March 5, 2026

KEYWORDS:
Microclimate,
Nephotettix virescens,
Lycosa pseudoannulata,
Biodiversity,
Integrated pest

ABSTRACT

Exokarst landscapes possess distinctive geomorphological and microclimatic characteristics that influence arthropod abundance and community structure in rice (*Oryza sativa* L.) ecosystems. Cooler and more humid microhabitats near karst formations can function as refuges that support resource stability, habitat connectivity, and trophic interactions. This study examined how distance from a karst cliff affects the abundance and composition of pest and natural enemy arthropods. Observations were conducted at three distances (0, 200, and 400 m), representing near-karst, transitional, and outer-karst microclimate zones in Kalabbirang, Bantimurung District, Maros Regency, South Sulawesi, Indonesia. A total of 1,483 individuals from 21 species were recorded. Arthropod abundance was highest at 400 m (549 individuals), followed by 0 m (477 individuals) and 200 m (457 individuals). Although total abundance was lower at 200 m, this site showed the highest species richness (S = 2.78), Shannon diversity (H′ = 2.15), and evenness (E = 0.76), indicating a more balanced community structure. Dominance was greatest at 400 m (D = 0.20), largely due to the high abundance of *Coccinella* sp. (205 individuals). *Bactrocera dorsalis* was most abundant at 0 m (125 individuals), *Nephotettix virescens* peaked at 200 m (106 individuals) but declined at 400 m (10 individuals), while *Leptocorisa oratorius* increased toward 400 m (70 individuals). Predator communities were dominated by *Lycosa pseudoannulata* (317 individuals). Correlation and PCA results indicate that karst-related microclimatic gradients structure arthropod communities and contribute to stronger natural pest suppression in outer-karst zones.

1. Introduction

Indonesia, as an agricultural country, plays a crucial role in the national economy. Rice (*Oryza sativa* L.) is the primary food crop and a main source of carbohydrates for the majority of the population. Population growth continues to drive the increasing demand for rice, making rice cultivation productivity a priority to ensure national food security. According to the Central Statistics Agency (BPS), national rice production in 2025 is projected to reach 57.60 million tons of dry milled grain (GKG) with a harvested area of approximately 10.86 million hectares. One rice-producing area with unique characteristics is the Bantimurung-Bulusaraung Exo-Karst region in Maros Regency, South Sulawesi, where rice production in 2024 reached 193,850 tons, with a harvested area of 26,617 hectares (BPS Kab. Maros 2024).

The Bantimurung District, covering an area of 173.7 km^2, relies heavily on agriculture, particularly wetland rice cultivation, as the main livelihood for the local population. The total agricultural land covers approximately 4,175 ha, although portions have been allocated for residential, industrial, mining, and livestock purposes. Land-use trends show a reduction in rice fields

---

*Corresponding Author
E-mail Address: sylviasjam@yahoo.com

and an expansion of nonagricultural land; however, rice cultivation remains a vital component of local agriculture, especially in Kalabbirang Sub-district (Sari 2025). Karst landscapes, covering approximately 12–15% of the global land area, play an important role in water supply and provide habitats for diverse flora and fauna, including arthropods (Aprilia *et al.* 2021; Wulandari *et al.* 2023). Exokarst features, such as limestone towers, dolines, and sinkholes, along with endokarst features, such as caves and underground rivers, create unique microclimatic conditions that influence arthropod abundance and community composition around rice fields (Wu and Wang 2024).

Arthropods play a key role in agricultural ecosystems through pollination, decomposition, and pest control (Maqsood *et al.* 2020). Arthropod diversity in agroecosystems is essential for maintaining ecological balance and reducing the need for external inputs, such as pesticides. The presence and abundance of arthropods in an agricultural ecosystem can serve as indicators of its overall health and ecological stability. In rice cultivation systems, arthropods may function as harmful pests and beneficial natural enemies that support sustainable crop production (Altieri and Nicholls 2018). Major rice pests, including the rice seed bug (*Leptocorisa oratorius*) and green leafhopper (*Nephotettix virescens*), can significantly reduce the yield. However, integrated pest management using natural enemies, resistant varieties, and sustainable practices effectively mitigates this damage (Octaviani & Ikawati 2022; Pasaribu 2024). Arthropod abundance and diversity are influenced by abiotic factors such as temperature, humidity, and light intensity, as well as biotic factors, including vegetation structure and diversity. Gradients of distance from the karst create microclimatic variations that generate diverse ecological niches for insects, affecting pest and natural enemy dynamics in rice agroecosystems (Kurniawan *et al.* 2020; Aprilia *et al.* 2021).

This study aimed to identify arthropod species (pests and natural enemies) in rice fields at varying distances from the karst, assess species abundance and population dynamics, compare pest and natural enemy populations along the karst distance gradient, evaluate the influence of abiotic factors on community indices, and characterize ecological similarities and differences among sites using Principal Component Analysis (PCA).

2. Materials and Methods

2.1. Study Area

This study was conducted at three sites in the Kalabbirang Sub-district, Bantimurung District, Maros Regency, South Sulawesi, Indonesia (Figure 1). Sampling will be conducted at three different sites based on the distance of the rice fields from the karst area between December 2024 and March 2025. Arthropod identification and abundance calculations were performed at the Pest Laboratory, Department of Plant Pests and Diseases, Faculty of Agriculture, Hasanuddin University, Makassar, South Sulawesi, Indonesia. Arthropod identification was performed using the reference book “Borror and DeLong’s Introduction to the Study of Insects” (Triplehorn and Johnson 2005), supported by additional visual verification using the iNaturalist biodiversity platform and species occurrence data accessed through GBIF.org.

2.2. Tools and Materials

The tools used in this study included an insect net, pitfall traps, yellow traps, insect boxes, labels, film bottles, insect pins, pinning blocks, raffia string, buckets, sieves, tweezers, plastic cups, dibble sticks, measuring tapes, gauze, fine wire, writing instruments, a Global Positioning System (GPS), an altimeter, a thermometer, a hygrometer, and a camera. The materials used were 70% alcohol, wood, detergent, and water.

2.3. Sampling Method

Arthropod sampling was performed using pitfall and yellow sticky traps, selected because each method targets different arthropod groups: pitfall traps effectively capture ground-dwelling predators, such as spiders and ants, whereas yellow sticky traps attract flying arthropods, particularly leafhoppers and planthoppers. No single method can collect arthropods that occupy different strata of the rice ecosystem. The fields were planted using a tabela (direct seeding) system, allowing rice to germinate and establish directly in the field without transplant shock, ensuring uniform early growth conditions suitable for observing initial arthropod colonization. The Inpari 50 rice variety was sown at a 25 × 25 cm spacing to maintain consistent plant density across sites, since crop structure and canopy microclimate

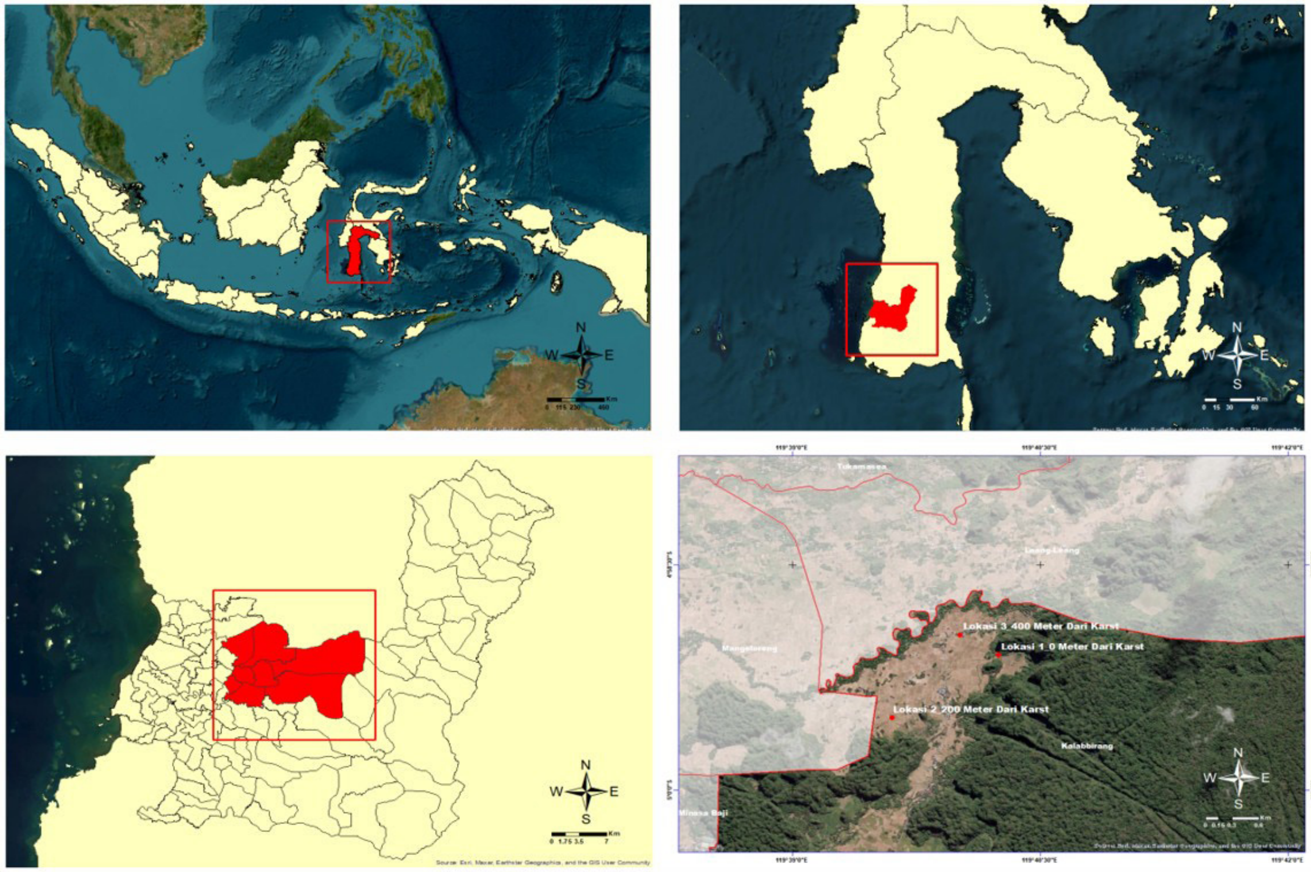

Figure 1. Map of the study area showing the research sites in rice cultivation fields in the Kalabbirang Sub-district, Bantimurung District, Maros Regency, South Sulawesi Province, Indonesia

can strongly influence arthropod abundance. Sampling was conducted during the vegetative (21–35 DAP) and generative (45–75 DAP) stages, as pest-natural enemy interactions are most active during these periods.

2.3.1. Pitfall Trap

The pitfall trap method was used to capture ground-dwelling predatory arthropods in the rice ecosystem in the study (Figure 2). The traps were filled with a mixture of water, detergent, and 70% alcohol in a ratio of 3:1:1. At each sampling site, traps were installed along two 50-m transects, with five pitfall traps per transect (10 traps per site). Pitfall and yellow traps were placed on separate transects to prevent interference between ground-dwelling and flying arthropod sampling.

2.3.2. Yellow Trap

The yellow trap method was used to capture flying pest species in rice ecosystems (Figure 3). The traps were made from yellow map snail sheets cut into 20 × 15 cm rectangles. At each sampling site, traps were installed along two 50-m transects, with five yellow traps per transect (10 traps per site). Pitfall and yellow traps were placed on separate transects to prevent interference between ground-dwelling and flying arthropod sampling.

2.4. Collection of Supporting Data

Supporting field data included measurements of air temperature (°C), relative humidity (%), and altitude (m.a.s.l.). Measurements were performed using a digital thermometer for temperature, a hygrometer for humidity, and an altimeter for altitude. Data were collected at each site in the morning during arthropod sampling.

2.5. Data Analysis

2.5.1 Species Richness Index (S)

The species richness index (S) is a simple measure of biodiversity that indicates the number of species present in a community or a particular area. The formula is as follows (Koneri *et al.* 2019 in Ilhamdi *et al.* 2024).

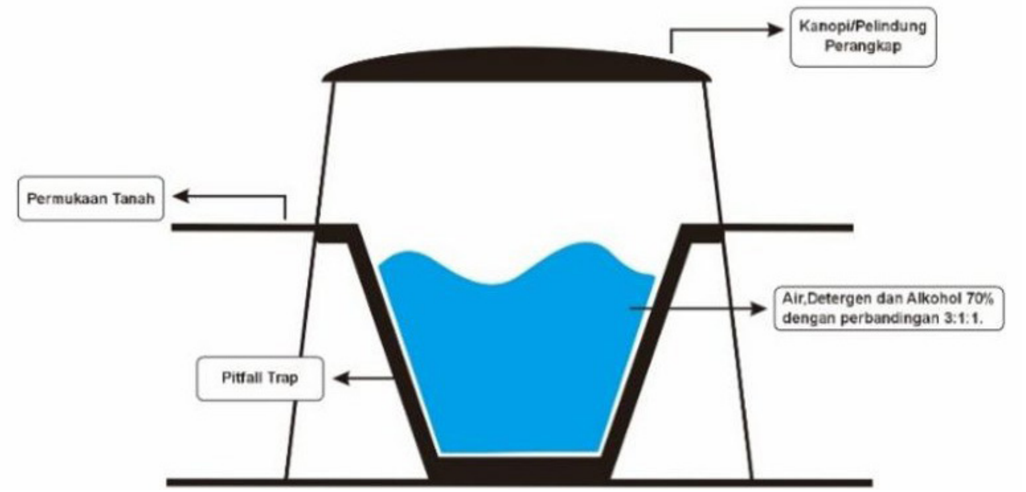

Figure 2. Pitfall Trap

Figure 3. Yellow Trap

$$R=\frac{(s - 1)}{Ln\ (N_0)}$$

Where:
R : margalef’s species richness index
S : total number of species recorded (species richness)
N_0 : total number of individuals of all species
Ln : natural logarithm (base e ≈ 2.718)

2.5.2. Diversity Index (H′)

The Shannon-Wiener diversity index (Odum 1996) was used to assess arthropod species diversity.

$$H' = -\sum_{i=l}^{s} (pi)(ln\ pi)$$

Where:
H' : shannon-wiener diversity index
Pi : proportion of individuals of the i-th species
ni : number of individuals of the i-th species
N : total number of individuals
Interpretation of diversity index values:
H'< 1.0 = Low diversity
1.0<H'<3.0 = Moderate diversity
H'>30 = High diversity

2.5.3. Evenness Index (E)

The evenness index (E) measures the relative distribution of species within a community. The formula is (Magurran 2004):

$$E=\frac{H'}{Ln\ (S)}$$

Where:
E : evenness index
H′ : shannon-Wiener diversity index
S : total number of species
ln : natural logarithm (basis e ≈ 2.718)

Interpretation of evenness index values:
$(0<E<0.4)$ = small and stressed community
$(0.4<E<0.6)$ = moderate and stable community
$(0.6>E>1.0)$ = stable evenness

2.5.4. Dominance Index (D)

The dominance index (D) was used to determine the extent to which one arthropod group dominated the others. It was calculated using Simpson's dominance index (Odum 1996).

$$D = \sum_{i=1}^{n} [\frac{n_i}{N}]^2$$

Where:
C : simpson's dominance index
n_i : number of individuals of each species
N : total number of individuals
Interpretation of dominance index values:
$0<D<0.5$ = low dominance
$0.5<D<0.75$ = moderate dominance
$0.75<D<1$ = high dominance

2.6. Pearson's Correlation and Principal Component Analysis (PCA)

Pearson's correlation analysis was performed in XLSTAT to evaluate relationships among temperature, humidity, and altitude and arthropod abundance, diversity, evenness, and dominance. Furthermore, Principal Component Analysis (PCA) was conducted and visualized as a biplot to describe the relationships among variables and sampling sites.

3. Results

3.1. Species Abundance, Richness (R), Diversity (H′), Evenness (E), and Dominance (D) of Insects Across the Three Study Sites

Various environmental factors, including proximity to karst areas, influence the arthropod community in rice cultivation fields (Table 1). This study aimed to assess the composition and structure of insect communities at three sites along a distance gradient from the exo-karst area (0, 200, and 400 m). Data were collected using yellow and pitfall traps and analyzed for abundance,

Table 1. Abundance, species richness (R), diversity (H′), evenness (E), and dominance (D) of insects recorded at three sites

Species	Location			Total	Role
	0 m from karst	200 m from karst	400 m from karst		
Tetraghnata sp.	6	23	17	46	Predator
Lycosa pseudoannulata	111	112	94	317	Predator
Micraspis discolor	2	1	-	3	Predator
Coccinella repanda	4	-	4	8	Predator
Pheropsophus occipitalis	5	11	9	25	Predator
Coccinella sp.	13	16	205	221	Predator
Stenolophus sp.	-	2	7	9	Predator
Neolema sp.	-	1	-	1	Predator
Gonocephalum sp.	-	-	2	2	Predator
Forficula sp.	5	-	-	5	Predator
Bactrocera dorsalis	125	42	62	229	Pest
Centrotus sp.	2	1	-	3	Pest
Leptocorisa oratorius (Fabricius)	25	71	70	166	Pest
Nephotetix virescens	100	106	10	216	Pest
Brachymeria sp.	2	10	11	23	Parasitoid
Odontomachus sp.	13	-	8	21	Predator
Ischnojoppa luteator	-	11	6	17	Parasitoid
Pelopidas mathias	1	24	19	44	Pest
Tetrigonia viridissima	10	2	1	13	Pest
Gryllus sp.	16	18	14	48	Pest
Oxya sp.	37	6	10	53	Pest
Total Individuals	477	457	549	1483	
Percentage (%)	32.16	30.82	37.02		
Species richness (S)	2.76	2.78	2.69		
Shannon index (H')	2.03	2.15	2.02		
Evenness (E)	0.72	0.76	0.71		
Dominance Index (D)	0.19	0.16	0.2		

species richness (S), diversity (H′), evenness (E), and dominance (D).

A total of 1,483 individual insects were collected from three sampling sites (0, 200, and 400 m from the karst area) using yellow traps and pitfall traps during the rice cultivation period. A total of 21 species were recorded, including pests, predators, and parasitoids. Pest species included *Bactrocera dorsalis, Leptocorisa oratorius, Nephotettix virescens, Pelopidas mathias, Tetrigonia viridissima, Gryllus* sp., *Centrotus* sp., and *Oxya* sp. Predatory species included *Tetragnatha, Lycosa pseudoannulata, Coccinella* sp., *Coccinella repanda, Pheropsophus occipitalis, Micraspis discolor, Stenolophus* sp., *Neolema* sp., *Gonocephalum* sp., *Forficula* sp., and *Odontomachus* sp. The identified parasitoid species were *Brachymeria* sp. and *Ischnojoppa luteator.*

The highest insect abundance was recorded at the 400 m site (549 individuals, 37.02%), followed by the 0 m site (477 individuals, 32.16%) and the 200 m site (457 individuals, 30.82%), which may be related to differences in habitat conditions and resource availability along the karst distance gradient. Although numerical differences were observed among sites, all community indices fell within the same interpretative category. Species richness and diversity values were classified as moderate across all sites, with slightly higher richness (S = 2.78) and diversity (H′ = 2.15) at the 200 m site and lower diversity at the 400 m site (H′ = 2.02), likely reflecting a more balanced distribution of individuals among species at intermediate distances. Evenness values at all sites were considered stable (E>0.6), with the highest evenness at 200 m (E = 0.76). In contrast, dominance values were low at all sites (D<0.5), despite the highest numerical dominance occurring at 400 m (D = 0.20), suggesting a greater influence of a few abundant species at this distance. Overall, the observed gradient highlights how variation in habitat conditions with increasing distance from the karst area primarily shaped patterns of dominance and evenness within the insect community, with intermediate distances favoring a more balanced distribution of individuals. In contrast, greater distances allowed certain species to become numerically prominent.

3.2. Pest Species and Natural Enemies Recorded Across the Three Sites Along the Karst Distance Gradient

Insect communities recorded along the karst distance gradient consisted of pest species and their associated natural enemies, reflecting a complex trophic structure within the rice agroecosystem. These insects belonged to several taxonomic orders, including Araneae, Dermaptera, Hymenoptera, Diptera, Hemiptera, Lepidoptera, and Orthoptera. The composition of pest species, predators, and parasitoids recorded across the three sampling sites is illustrated in Figures 4, 5, and 6.

3.2.1. Pest

A total of eight pest species representing four insect orders were recorded across the study sites (Figure 4). Hemipteran pests such as *Centrotus* sp., *Leptocorisa oratorius*, and *Nephotettix virescens* were commonly observed and are known to cause direct damage to rice plants through sap-sucking activity, which can reduce plant vigor and grain formation. The presence of *Bactrocera dorsalis* (Diptera: Tephritidae) indicates potential risks associated with oviposition and larval feeding, which may affect crop quality.

Lepidopteran pests, such as Pelopidas mathias, cause foliar damage during larval stages. At the same time, orthopteran species, including *Gryllus* sp., *Oxya* sp., and *Tettigonia viridissima*, are associated with leaf chewing and defoliation. The diversity of pest species across different functional feeding groups suggests that rice plants in the karst landscape are exposed to multiple forms of herbivory, potentially influenced by habitat structure and distance from the karst area.

3.2.2. Predators

A diverse assemblage of predatory arthropods was recorded along the karst gradient, comprising 11 species from Araneae, Coleoptera, Dermaptera, and Hymenoptera (Figure 5). Predatory spiders such as *Tetragnatha* sp. and *Lycosa pseudoannulata* play an important role in regulating pest populations by actively preying on various insect stages. Ground-dwelling predators, including *Pheropsophus occipitalis, Stenolophus* sp., *Gonocephalum* sp., *Forficula* sp., and *Odontomachus* sp., reflect strong predatory activity on the soil surface and lower vegetation strata.

Canopy-associated predators such as *Micraspis discolor, Coccinella repanda*, and *Coccinella* sp. are well-known biological control agents, particularly against sap-sucking pests. The coexistence of ground and aerial predators indicates functional complementarity among predator groups, which may enhance natural pest suppression across different microhabitats within the rice field.

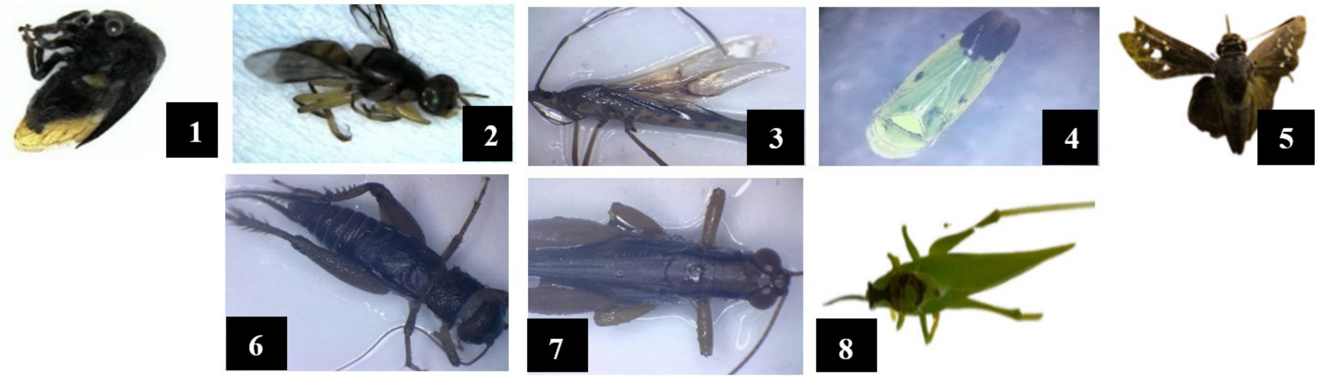

Figure 4. (1) *Centrotus* sp. (Hemiptera: Membracidae), (2) *Bactrocera dorsalis* (Diptera: Tephritidae), (3) *Leptocorisa oratorius* (Fabricius) (Hemiptera: Alydidae), (4) *Nephotettix virescens* (Hemiptera: Cicadellidae), (5) *Pelopidas mathias* (Lepidoptera: Hesperiidae), (6) *Gryllus* sp. (Orthoptera: Gryllidae), (7) *Oxya* sp. (Orthoptera: Acrididae), (8) *Tettigonia viridissima* (Orthoptera: Tettigoniidae)

Figure 5. (1) *Tetragnatha* sp. (Araneae: Tetragnathidae), (2) *Lycosa pseudoannulata* (Aranae: Lycosidae), (3) *Micraspis discolor* (Coleoptera: Coccinellidae), (4) *Coccinella repanda* (Coleoptera: Coccinellidae), (5) *Pheropsophus occipitalis* (Coleoptera: Carabidae), (6) *Coccinella* sp. (Coleoptera: Coccinellidae), (7) *Stenolophus* sp. (Coleoptera: carabidae), (8) *Neolema* sp. (Coleoptera: Chrysomelidae), (9) *Gonocephalum* sp. (Coleoptera: Tenebrionidae), (10) *Forficula* sp. (Dermaptera: Forficulidae), (11) *Odontomachus* sp. (Hymenoptera: Formicidae)

3.2.3. Parasitoid

Two parasitoid species belonging to the order Hymenoptera, *Brachymeria* sp. (Chalcididae) and *Ischnojoppa luteator* (Ichneumonidae), were recorded along the karst distance gradient (Figure 6). These parasitoids contribute to pest regulation by parasitizing host insects, particularly during larval or pupal stages. Although their abundance was relatively lower than that of predators, the presence of parasitoids highlights an additional layer of biological control within the agroecosystem.

The occurrence of both predators and parasitoids across the study sites demonstrates the functional diversity of natural enemies associated with rice cultivation in the exokarst landscape, suggesting their potential role in maintaining ecological balance and supporting sustainable pest management.

The presentation of pest and natural enemy species has been revised from a table format to a graphic format, and information on trap types has been removed, as suggested. However, it was not possible to include a ruler or a direct size reference in the specimen photographs. Although the insect specimens were preserved in alcohol, prolonged storage resulted in tissue degradation, discoloration, and partial decomposition, leading to deformation of body structures. These changes prevented accurate representation of insect body size and morphology in photographs. Therefore, figures are presented without scale indicators to avoid potential misinterpretation, while taxonomic identification and descriptive clarity are maintained.

3.3. Comparison of Pest and Natural Enemy Abundance Across the Three Sites Along the Exo-karst Distance Gradient

The comparative diagrams below illustrate the variation in pest and natural enemy abundance across the three sites along the exo-karst distance gradient (Figure 7).

Figure 6. (1) *Brachymeria* sp. (Hymenoptera: Chalcididae), (2) *Ischnojoppa luteator* (Hymenoptera: Ichneumonidae)

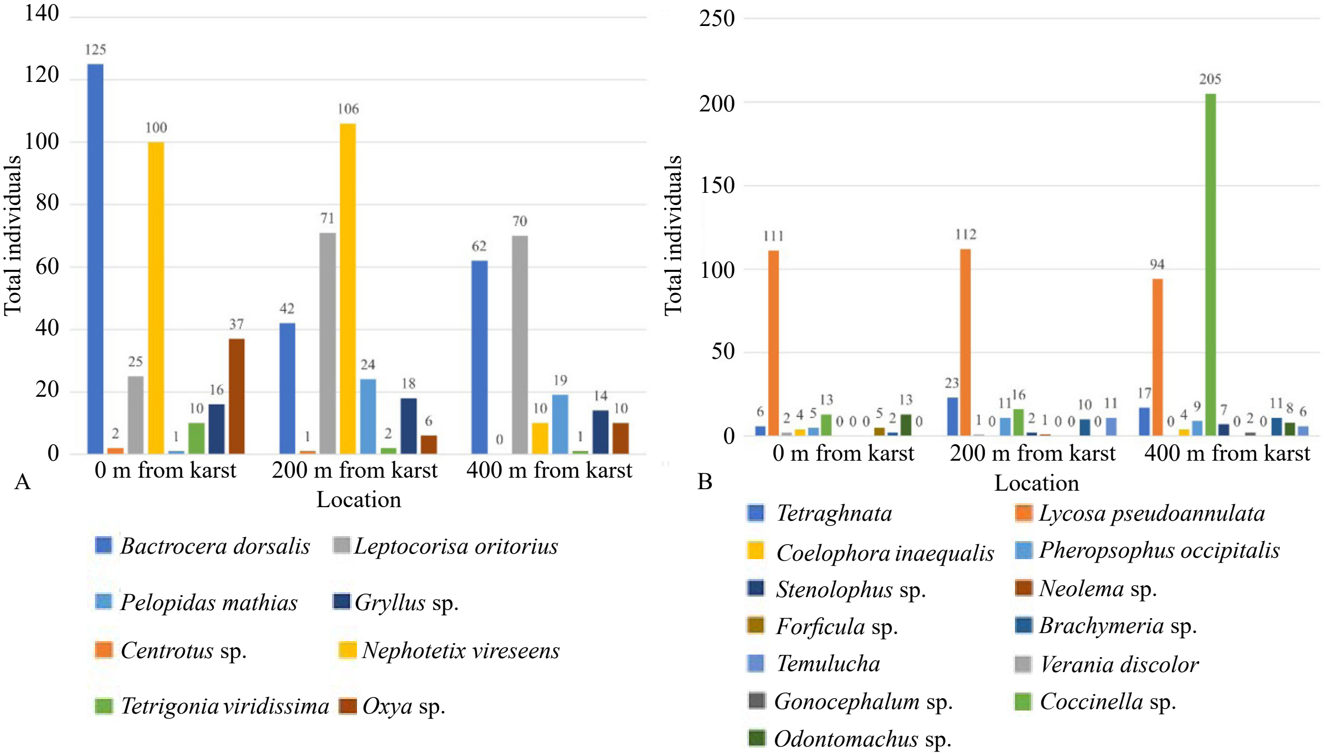

Figure 7. (A) Variation in pest abundance across the three sites along the exo-karst distance gradient, (B) variation in natural enemy abundance across the three sites along the exo-karst distance gradient

The abundance of pest species varied across the karst-distance gradient. *Bactrocera dorsalis* was highest at 0 m (125), declined at 200 m (42), and rose again at 400 m (62). The abundance of *Nephotettix virescens* remained high at 0 (100) and 200 m (106) but dropped sharply at 400 m (10). *Leptocorisa Leptocorisa* abundance increased from 25 individuals at 0 m to a peak of 71 individuals at 200 m, and maintained a similar abundance at 400 m (70 individuals). Several herbivores, such as *Oxya* sp. and *Tetrigonia viridissima*, decreased with increasing distance, whereas species such as Pelopidas mathias and Tetragnatha were more abundant at 200 and 400 m, respectively. A notable spike in *Coccinella* sp. at 400 m (205) indicates strong predator–prey dynamics at this location. Overall, each species showed a distinct response to distance from the karst, reflecting microhabitat- and resource-driven variation.

3.4. Weekly Fluctuations in the Abundance of Pests and Natural Enemies at the Three Observation Sites

To better understand the temporal dynamics of arthropod communities, weekly fluctuations in the abundance of major pest and predator species were monitored at three sites along an exo-karst gradient (0, 200, and 400 m). The fluctuation patterns of pests and natural enemies during the observation period are presented in Figure 8.

Across the karst gradient, predator abundance was consistently dominated by *Lycosa pseudoannulata*, with 31 individuals at 0 m, 30 at 200 m, and 25 at 400 m. At 400 m, *Coccinella* sp. showed the greatest overall numerical increase, reaching 121 individuals, far higher than at the other sites. These high-predator peaks occurred during weeks of elevated arthropod activity, indicating strong predation pressure across all distances from the karst.

This pattern suggests that landscape structure, including the presence of non-crop patches and edge zones, may increase the abundance of natural enemies such as spiders and ladybird beetles, which subsequently suppress pest densities and reduce crop damage. In this study, the karst environment likely functions as a structural landscape features that enhances predator habitat quality, explaining the consistently high population levels of *L. pseudoannulata* at 0 and 200 m and the exceptionally high abundance of *Coccinella* sp. at 400 m.

3.5. Composition of Pests and Natural Enemies at the Three Sites Along the Karst Distance Gradient

The ecological roles of insects in agricultural ecosystems reflect the dynamics of communities influenced by environmental factors, distance from natural habitats, and crop growth stages. A comparison of sites located at different distances from the karst area provides an overview of changes in the balance between pests, predators, and parasitoids.

The diagram shows the effect of distance from the karst on pest and natural enemy abundance in rice fields (Figure 9). At 0 m, pest populations were highest, likely due to greater availability of food resources and host plants near the karst edge, while natural enemies were relatively low. At 200 m, pest numbers decreased, and natural enemy numbers increased, indicating a more balanced ecological condition, with habitat structure and microclimate supporting stronger predator activity. At 400 m, pest levels were at their lowest. In contrast, natural enemies were most abundant, suggesting that areas farther from the karst are more conducive to the stability and effectiveness of predator communities. This pattern occurs because both pests and predators decline with increasing distance from the karst due to reduced habitat complexity. However, predators remain higher than pests because many natural enemies are generalist feeders able to survive on multiple prey types and persist even when pest numbers drop, allowing them to maintain dominance across the gradient. Overall, proximity to the karst promoted higher pest abundance, whereas greater distance supported natural enemy populations that helped suppress pests.

3.6. Pearson Correlation Matrix between Temperature, Humidity, Altitude, and Diversity Indices of Major Pests and Natural Enemies

Correlation analysis was conducted to examine the relationships between abiotic environmental factors (temperature, humidity, and altitude) and insect community structure, as measured by ecological indices such as species richness (S), diversity (H′), evenness (E), and dominance (D). Linear relationships between variables can be quantitatively identified by applying Pearson's correlation test.

The following table presents the Pearson correlation matrix for insect capture data from the yellow-trap method, illustrating the direction and strength of relationships between environmental variables and community indices (Table 2). Significant correlations at the 95% confidence level ($\alpha = 0.05$) are indicated in bold.

The Pearson correlation matrix showed that temperature was strongly negatively correlated with humidity ($r = -0.969$), indicating that warmer conditions coincided with drier microhabitats. Altitude showed a strong positive correlation with the dominance index (D) ($r = 0.812$) but negative correlations with species richness ($r = -0.595$), Shannon diversity (H′) ($r = -0.986$), and evenness (E) ($r = -0.958$), suggesting that higher elevations supported fewer species that were unevenly distributed. Total individuals also correlated positively with dominance ($r = 0.898$) and negatively with richness ($r = -0.990$), showing that a few dominant taxa mainly drove increases in abundance. Overall, humidity and richness were positively related ($r = 0.782$), whereas diversity (H′) and evenness (E) were almost perfectly correlated ($r = 0.993$), reflecting a stable community structure under more humid conditions. These patterns indicate that

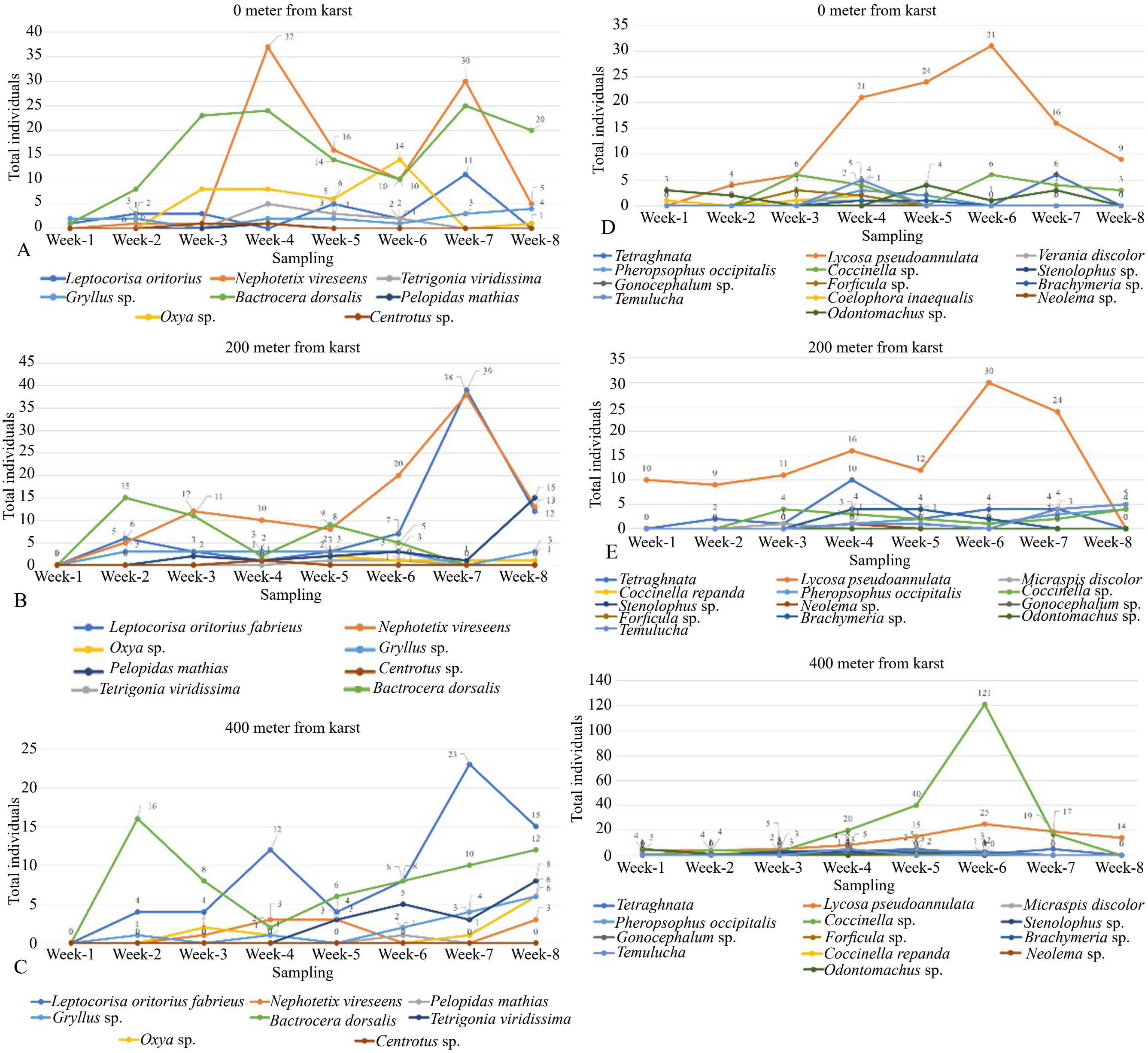

Figure 8. (A) Fluctuation of pest abundance at 0 m from karst, (B) fluctuation of pest abundance at 200 m from karst, (C) fluctuation of pest abundance at 400 m from karst, (D) fluctuation of predator abundance at 0 m from karst, (E) fluctuation of predator abundance at 200 m from karst, and (F) fluctuation of predator abundance at 400 m from karst

the karst landscape influences microclimate, especially humidity and altitude, which then shapes dominance, richness, and overall arthropod community balance.

3.7. Biplot of Principal Component Analysis (PCA) between Microclimate and the Abundance, Diversity, Evenness, and Dominance of Major Pest and Natural Enemy Insects

To better understand the multivariate relationships between microclimatic factors and insect community parameters, Principal Component Analysis (PCA) was applied (Figure 10). This analysis helped identify the distribution patterns of observations by distance from the karst area, as well as the contribution of each variable to variation in community structure.

The PCA shows a clear gradient. The 0 m site was associated with higher humidity and species richness. The 200 m site had higher diversity and evenness. The 400 m site showed higher temperatures, total individuals, altitude, and dominance. This pattern indicates that areas closest to the karst support richer

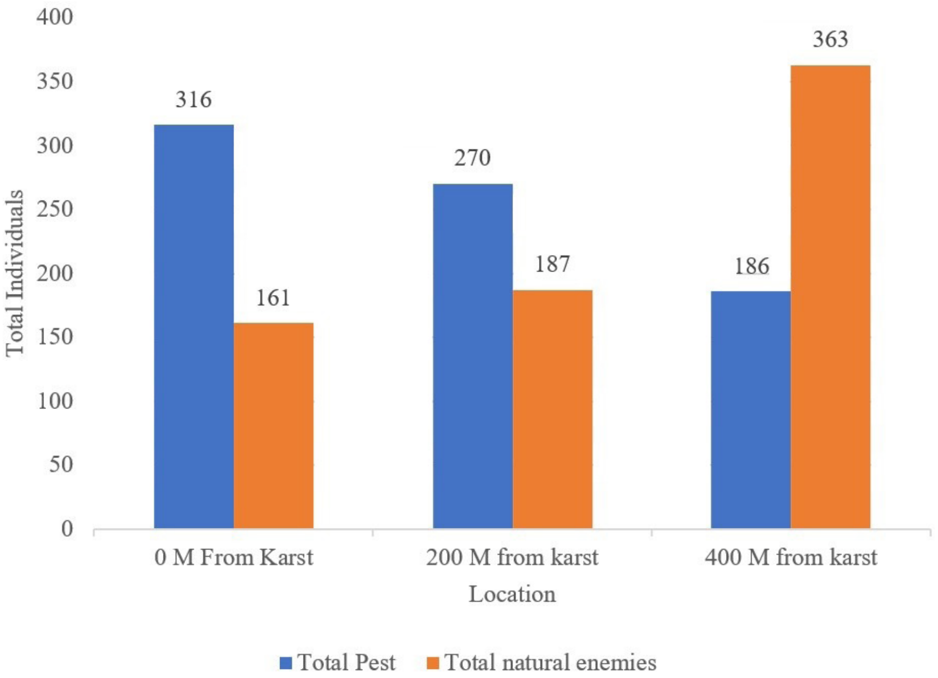

Figure 9. Abundance of pests and natural enemies at the three locations

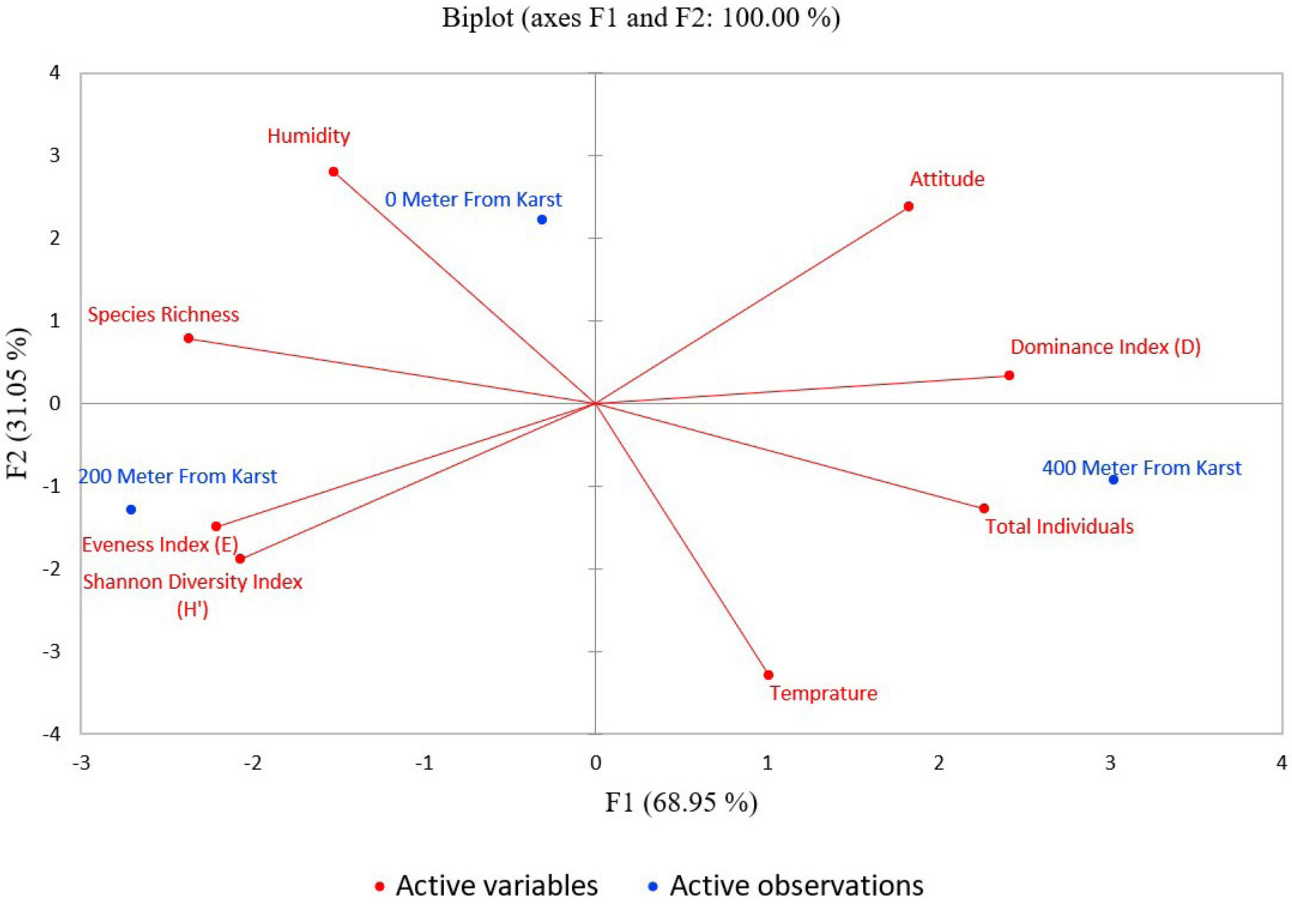

Figure 10. Biplot of principal component analysis (PCA) between microclimate and the abundance, diversity, evenness, and dominance of major pest and natural enemy insects

Table 2. Headmap matrix korelasi pearson (n) metode yellow trap

Variables	Temprature	Humidity	Altitude	Total individuals	Species richness	Shannon diversity index (H')	Dominance index (D)	Eveness Index (E)
Temprature	1							
Humidity	-0.969	1						
Altitude	-0.283	0.035	1					
Total individuals	0.712	-0.864	0.473	1				
Species richness	-0.603	0.782	-0.595	-0.990	1			
Shannon diversity index (H')	0.118	0.133	-0.986	-0.614	0.722	1		
Dominance index (D)	0.330	-0.555	0.812	0.898	-0.952	0.899	1	
Eveness Index (E)	-0.003	0.252	-0.958	-0.705	0.800	0.993	-0.945	1

Pearson's corerelation
-1 -0.5 0 0.5 1

Values in bold are different from 0 with a significance level alpha = 0.05

and more balanced arthropod communities, whereas sites farther away experience hotter conditions and stronger species dominance.

4. Discussion

Vegetation habitats surrounding the observation points differed along the distance gradient from the karst area and likely influenced the abundance and composition of insect pests and their natural enemies. The 0 m site, located adjacent to the karst ecosystem, was characterized by heterogeneous karst-associated vegetation and semi-natural habitats. The 200 m site was predominantly surrounded by extensive rice fields, creating a relatively uniform agricultural habitat. In contrast, the 400 m site was also dominated by rice fields but bordered by residential areas, resulting in a more disturbed landscape with reduced vegetation complexity. These differences in vegetation structure and land use may have played an important role in shaping insect community structure by affecting habitat availability, resource diversity, and interactions between pest insects and their natural enemies. These patterns are consistent with findings that landscape complexity and the presence of semi-natural habitat structures influence insect diversity and community composition in agricultural landscapes, with higher species richness associated with more heterogeneous habitats surrounding crop fields (Rizali *et al.* 2018).

Microclimatic conditions during the observation period showed a clear but moderate gradient among the three study locations. Location 0 m from the karst exhibited cooler and more humid conditions, with temperatures ranging from 24.2–24.8°C (mean 24.41°C) and relative humidity between 94.4–96.8% (mean 95.96%). Location 200 m from the karst was characterized by slightly higher temperatures (24.9–25.9°C, mean 25.20°C) and moderately high humidity (93.9–96.3%, mean 94.65%), indicating transitional microclimatic conditions. In contrast, Location 400 m from the karst recorded the warmest and least humid environment, with temperatures of 25.2–25.9°C (mean 25.60°C) and relative humidity ranging from 91.8–95.5% (mean 93.01%). This gradual shift from cooler, more humid conditions near the karst to warmer and relatively drier conditions at greater distances likely influenced arthropod community dynamics by differentially favoring species adapted to specific microclimatic conditions, consistent with Tang *et al.* (2025), who reported that variation in temperature and moisture is a key factor shaping insect community composition across environmental gradients.

A total of 21 arthropod species were recorded across the three study sites along the karst distance gradient (0, 200, and 400 m), representing major taxonomic groups including Araneae, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Orthoptera, and Lepidoptera. The presence of multiple functional groups of pests, predators, and parasitoids indicates that the combination of yellow traps and pitfall traps effectively captured both aerial and ground-dwelling arthropods. Pest species such as *Bactrocera dorsalis, Nephotettix virescens, Leptocorisa oratorius, Pelopidas mathias, Oxya* sp., and *Gryllus* sp. were prominent. At the same time, natural enemies included predatory spiders (*Lycosa pseudoannulata, Tetragnatha* sp.), ground beetles (*Pheropsophus occipitalis, Gonocephalum* sp.), ladybird beetles (*Coccinella* sp., *Coccinella repanda*), and parasitoids (*Brachymeria* sp., *Ischnojoppa luteator*). The diverse natural enemy community highlights the ecological importance of semi-natural habitats in maintaining predator populations, consistent with Lichtenberg *et al.* (2017), who noted that landscapes such as karst environments provide structural complexity that supports beneficial arthropods, which are essential to integrated pest management (IPM).

Arthropod abundance varied substantially across sites. Although the 400 m site recorded the highest total number of individuals (549, 37.02%), it did not exhibit the highest richness or diversity. In contrast, the 200 m site showed the highest species richness (S = 2.78), Shannon diversity (H′ = 2.15), and evenness (E = 0.76), indicating that intermediate distances from the karst promote a more balanced and stable arthropod community structure. This supports the conclusion of Martin *et al.* (2019) that moderately heterogeneous landscapes, such as transitional zones between natural karst vegetation and cultivated rice fields, support greater biodiversity and maintain more stable predator–prey interactions. At the 0 m site, pest populations such as *N. virescens* and *B. dorsalis* were relatively high, likely due to the higher humidity and vegetation density associated with the karst edge. Meanwhile, at 400 m, natural enemies such as *Coccinella* sp. became numerically dominant (205 individuals). Still, overall diversity was lower, and dominance was higher (D = 0.20), suggesting a simplified, potentially less stable ecological community. Tscharntke *et al.* (2021) emphasized that low diversity combined with high dominance in predator communities can reduce ecosystem resilience, making such systems more vulnerable to pest outbreaks.

Weekly fluctuations provide additional insights into the ecological processes that shape arthropod dynamics. At the 0 m site, *Nephotettix virescens* peaked in weeks 4 and 7, whereas the predator *L. pseudoannulata* showed increased abundance in weeks 4–6. Such asynchronous peaks suggest dynamic predator–prey interactions shaped by environmental changes and crop growth stage. Haan *et al.* (2020) similarly observed that vegetation structural shifts and microclimatic variation can drive temporal redistribution of both pests and natural enemies. At the 200 m site, weekly fluctuations were more stable. *N. virescens* peaked in week 7, while *L. Pseudoannulata* peaked in week 6, suggesting a relatively synchronized predator-prey relationship and supporting the notion that intermediate habitats maintain ecological balance. This aligns with Martin *et al.* (2019), who highlighted that natural enemy stability reflects landscapes that are neither highly disturbed nor overly simplified. Conversely, the 400 m site showed unstable fluctuations, with high peaks of *Coccinella* sp. but reduced abundance of *L. pseudoannulata* and *Tetragnatha* sp. These patterns indicate that hotter, drier conditions and reduced vegetation heterogeneity farther from the karst negatively influence natural enemy diversity and presence. Consequently, pest regulation may weaken, allowing certain pest species to dominate temporarily.

The overall arthropod community patterns indicated that the 200 m site, representing moderate proximity to the karst, supported the highest richness, diversity, and evenness compared to the 0 m and 400 m sites. Such environments avoid the extremes of high disturbance (0 m, with strong karst influence) and low disturbance (400 m, with simplified habitat conditions), allowing both dominant and opportunistic species to coexist and maintain a more balanced ecosystem. The Intermediate Disturbance Hypothesis, proposed by Connell (1978) and Osman (2008), states that species diversity is maximized at intermediate levels of disturbance. At this level, both competitively dominant and fast-colonizing species can coexist, thereby increasing the overall species richness within the habitat.

The Pearson correlation matrix revealed strong relationships between the microclimatic factors and arthropod community indices. Temperature showed a strong negative correlation with humidity (r = –0.969), indicating that drier conditions occurred at higher temperatures, particularly at sites farther from the karst. Temperature also correlated positively with dominance (r = 0.330), suggesting that warmer conditions supported fewer, more dominant species. Humidity was positively correlated with richness (r = 0.782) and evenness (r = 0.252), supporting the idea that humid microclimates near karst areas provide suitable habitats for a wider range of arthropods. These patterns align with the findings of Ali *et al.* (2020), who reported that humid agroecosystems favor the abundance and diversity of natural enemies.

References

Ali, M.P., Kabir, M.M.M., Haque, S.S., Afrin, S., Ahmed, N., Pittendrigh, B., Qin, X., 2020. Surrounding landscape influences the abundance of insect predators in rice field. *BMC Zoology.* 5, 8. https://doi.org/10.1186/s40850-020-00059-1

Altieri, M., Nicholls, C., 2018. *Biodiversity and Pest Management in Agroecosystems*. CRC press, Boca Raton.

Aprilia, D., Arifiani, K.N., Sani, M.F., Jumari, J., Wijayanti, F., Setyawan, A.D., 2021. Review: a descriptive study of karst conditions and problems in Indonesia and the role of karst for flora, fauna, and humans. *International Journal of Tropical Drylands*. 5, 61-74. https://doi.org/10.13057/tropdrylands/t050203

[BPS] Badan Pusat Statistika Kab. Maros, 2024. Kabupaten Maros Dalam Angka 2024 / Maros Regency in Figures 2024. Maros: BPS Kabupaten Maros. Katalog: 1102001.7308.

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. *Science*. 199, 1302–1310. https://doi.org/10.1126/science.199.4335.1302

Dainese, M., Martin, E.A., Aizen, M.A., Albrecht, M., Bartomeus, I., Bommarco, R., Steffan-Dewenter, I., 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. *Science Advances*. 5, eaax0121. https://doi.org/10.1126/sciadv.aax0121

Febrian, I., Nursaadah, E., Karyadi, B., 2022. Analisis indeks keanekaragaman, keragaman, dan dominansi ikan di Sungai Aur Lemau Kabupaten Bengkulu Tengah. *Bioscientist: Jurnal Ilmiah Biologi*. 10, 600-612. https://doi.org/10.33394/bioscientist.v10i2.5056

Haan, N.L., Zhang, Y., Landis, D.A., 2020. Predicting landscape configuration effects on the distribution of a native generalist predator. *Trends in Ecology and Evolution*. 35, 175–186. https://doi.org/10.1016/j.tree.2019.10.003

Ilhamdi, M.L., Al Idrus, A., Santoso, D., Hadiprayitno, G., Syazali, M., Hariadi, I., 2024. Species richness and dispersion patterns of Lepidoptera (Rhopalocera) in the Nuraksa Forest Park, Lombok, Indonesia. *Biodiversitas: Journal of Biological Diversity*. 25, 62-70. https://doi.org/10.13057/biodiv/d250108

Kurniawan I.D., Susila I.L.D., Kinasih I., Rahman I.A., Nasrullah R. 2021. Preliminary study on cavernicolous insecta community in Tasikmalaya karst area, West Java. *In: Proceedings of the 1st International Conference on Islam, Science and Technology (ICONISTECH 2019)*. Bandung: EAI. pp. 1-11. https://doi.org/10.4108/eai.11-7-2019.2297622

Lichtenberg, E.M., Kennedy, C.M., Kremen, C., Batáry, P., Berendse, F., Bommarco, R., Bosque-Pérez, N.A., Carvalheiro, L.G., Snyder, W.E., Williams, N.M., Winfree, R., Klatt, B.K., Åström, S., Benjamin, F., Brittain, C., Chaplin-Kramer, R., Clough, Y., Danforth, B., Diekötter, T., Eigenbrode, S.D., Ekroos, J., Elle, E., Freitas, B.M., Fukuda, Y., Gaines-Day, H.R., Grab, H., Gratton, C., Holzschuh, A., Isaacs, R., Isaia, M., Jha, S., Jonason, D., Jones, V.P., Klein, A.M., Krauss, J., Letourneau, D.K., Macfadyen, S., Mallinger, R.E., Martin, E.A., Martinez, E., Memmott, J., Morandin, L., Neame, L., Otieno, M., Park, M.G., Pfiffner, L., Pocock, M.J.O., Ponce, C., Potts, S.G., Poveda, K., Ramos, M., Rosenheim, J.A., Rundlöf, M., Sardiñas, H., Saunders, M.E., Schon, N.L., Sciligo, A.R., Sidhu, C.S., Steffan-Dewenter, I., Tscharntke, T., Veselý, M., Weisser, W.W., Wilson, J.K., Crowder, D.W., 2017. A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. *Global Change Biology*. 23, 4946-4957. https://doi.org/10.1111/gcb.13714

Magurran, A.E., 2004. *Measuring Biological Diversity*. Blackwell Publishing, Oxford.

Maqsood, S., Rana, N., Majeed, W., Nargis, S., 2020. Effect of dawn and dusk on the diversity and abundance of arthropods in a mixed agroecosystem. *Pakistan Journal of Agricultural Sciences*. 57, 975–980. https://doi.org/10.21162/PAKJAS/20.05

Martin, E.A., Dainese, M., Clough, Y., Báldi, A., Bommarco, R., Gagic, V., Garratt, M.P.D., Holzschuh, A., Kleijn, D., Kovács-Hostyánszki, A., Marini, L., Potts, S.G., Smith, H.G., Al Hassan, D., Albrecht, M., Andersson, G.K.S., Asís, J.D., Aviron, S., Balzan, M.V., Steffan-Dewenter, I., 2019. The interplay of landscape composition and configuration: new pathways to manage functional biodiversity and agroecosystem services across Europe. *Ecology Letters*. 22, 1083–1094. https://doi.org/10.1111/ele.13265

Odum, E.P., 1996. *Dasar-Dasar Ekologi, edisi ketiga*. Gadjah Mada University Press, Yogyakarta.

Octaviani, I., Ikawati, S., 2022. Inventarisasi hama dan musuh alami pada tanaman padi di Kecamatan Pulau Laut Timur. *Jurnal Pertanian Terpadu*. 10, 24-36. https://doi.org/10.36084/jpt..v10i1.379

Osman, R.W., 2008. The intermediate disturbance hypothesis, in: Jørgensen, S.E., Fath, B.D. (Eds.), *Encyclopedia of Ecology*. Elsevier, Oxford, pp. 1986–1994. https://doi.org/10.1016/B978-0-12-409548-9.09480-X

Pasaribu, S.M., 2024. Efektivitas Agensia Hayati *Beuveria bassiana* terhadap Hama Walang Sangit (*Leptocorisa oratorius*) pada Tanaman Padi (*Oryza sativa*) [Dissertation]. Jember, Indonesia: Politeknik Negeri Jember.

Rizali, A., Buchori, D., Susilawati, S., Pudjianto, P., Clough, Y., 2018. Does landscape complexity and semi-natural habitat structure affect diversity of flower-visiting insects in cucumber fields?. *AGRIVITA Journal of Agricultural Science*. 40, 107-117. https://doi.org/10.17503/agrivita.v40i0.1722

Rohman, A., Subchan, W., Buana, Y.C., 2025. Butterfly (Lepidoptera) community structure in several habitat types of Tancak Maesan Forest, Bondowoso, East Java, Indonesia. *Biodiversitas: Journal of Biological Diversity*. 26, 651-661. https://doi.org/10.13057/biodiv/d260212

Sari N.I.S., 2025. Analysis of Rice Paddy Field Suitability in Bantimurung District with the Application of Photogrammetry on Digital Elevation Model (DEM) of SPOT-6 Image [Thesis]. Makassar, Indonesia: Universitas Hasanuddin.

Tang, K., Hilal, M.G., Yue, H., Ding, X., Xing, Y., Zhao, J., Liu, Y., Liu, H., He, Z., Lin, K., Wang, N., 2025. Climatic seasonality shapes insect community composition on the Mongolian Plateau. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2025.113595

Triplehorn, C.A., Johnson, N.F., 2005. *Borror and DeLong's Introduction to the Study of Insects,* seventh ed. Brooks/Cengage Learning, Belmont.

Tscharntke, T., Grass, I., Wanger, T.C., Westphal, C., Batáry, P., 2021. Beyond organic farming–harnessing biodiversity-friendly landscapes. *Trends in Ecology & Evolution*. 36, 919–930. https://doi.org/10.1016/j.tree.2021.06.010

Wu, Q., Wang, L., 2024. Suitability of agronomic water saving in karst areas and its enlightenment in the karst desertification control. *Heliyon*. 10, e32568. https://doi.org/10.1016/j.heliyon.2024.e32568

Wulandari, I., Zainuddin, M., Hamrullah, H., Umar, M.R., Ambeng, A., 2023. Keanekaragaman jenis fauna endokarst pada beberapa gua di Kabupaten Maros dan Pangkep. *Jurnal Ilmu Alam dan Lingkungan*. 14, 11-19. https://doi.org/10.13140/RG.2.2.11925.70885