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Predatory arthropod diversity and community structure in maize-intercropped immature and mature monoculture oil palm plantations in East Aceh, Indonesia

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ABSTRACT

Monoculture oil palm reduces arthropod biodiversity, including predatory natural enemies of pests. This study compared diversity and community composition of predatory arthropods in two cropping systems in East Aceh, Indonesia: immature oil palm (TBM, 2–3 years) intercropped with maize (*Zea mays* L.) and mature oil palm (TM, ≥10 years) under monoculture. Pitfall traps, yellow pan traps, and sweep nets were deployed across five plots per system (March–May 2023). Specimens were identified to family level and analysed using the Shannon–Wiener index (H′), Pielou's evenness (E), Simpson's dominance (C), and Hutcheson's t-test. Ten predatory arthropod families from five orders were recorded. The TBM system had higher abundance (1,767 individuals) but lower diversity (H′ = 1.57), driven by Coccinellidae dominance (52.63%) linked to aphid outbreaks on maize. The TM monoculture showed higher diversity (H′ = 1.98), evenness (E = 0.86), and lower dominance (C = 0.18). Diversity differed significantly between systems ($p < 0.001$). Understory vegetation density and litter depth were the main microenvironmental variables correlated with community composition. Maize intercropping enhances predator abundance, while mature monoculture supports greater diversity and stability. Integrating maize during the TBM phase is recommended as a natural enemy conservation strategy within integrated pest management in smallholder oil palm systems.

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INTRODUCTION

Indonesia is the world's leading producer of crude palm oil (CPO), with a plantation area of approximately 16.83 million hectares, of which around 40% is managed by smallholder farmers. However, the dominance of monoculture management in oil palm plantations has been widely reported to negatively affect biodiversity, particularly arthropod communities ([6]; Outhwaite *et al*. 2022).

Vegetation simplification reduces habitat complexity, limiting ecological niches, alternative food resources, and microclimatic variation, thereby suppressing the diversity and abundance of natural enemies (Gurr *et al*. 2017). Pest infestations remain a major constraint on oil palm production systems. Key pest species include the nettle caterpillar Setothosea asigna, the rhinoceros beetle *Oryctes rhinoceros* L., and the bunch borer Tirathaba mundella Walker. Severe infestations during the immature oil palm stage can substantially reduce fresh fruit bunch yields. Pest management strategies on many plantations still rely heavily on broad-spectrum insecticides, which reduce populations of beneficial arthropods, including predators essential for ecological balance. Therefore, conserving predatory arthropods is a key component of sustainable Integrated Pest Management (IPM) strategies.

Research on predatory arthropod diversity in Indonesian oil palm ecosystems has increased in recent years, yet its spatial coverage remains limited. Previous studies in West Sumatra reported considerable diversity of predatory arthropods across different plantation systems (Yenti *et al*. 2020). However, most studies have focused on taxonomic composition and diversity indices without incorporating microenvironmental variables. As a result, the ecological mechanisms underlying differences in predator communities among cropping systems remain poorly understood. Intercropping is widely recognised as an effective agroecological approach to enhancing biodiversity in agricultural

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systems. Adding intercrops increases vegetation complexity, providing additional habitats, food resources, and favourable microclimatic conditions for natural enemies (Järvinen *et al*. 2023; Rizali *et al*. 2023). Crop diversification has been shown to promote ecological intensification and improve biological control services in tropical agricultural systems (Gurr *et al*. 2017). In East Aceh, maize (*Zea mays* L.) is commonly used as an intercrop in immature oil palm plantations due to its short growth cycle and economic value. In addition, maize contributes to structural vegetation diversity, which may support predatory arthropod communities (Rizali et al. 2023).

Despite its potential, comparative studies examining predatory arthropod diversity between immature oil palm intercropped with maize (TBM) and mature monoculture oil palm (TM), particularly those incorporating microenvironmental measurements, remain limited in East Aceh. Therefore, this study aimed to: (i) analyse the diversity and family composition of predatory arthropods in maize-intercropped immature oil palm and in mature monoculture oil palm systems; (ii) compare diversity indices between the two systems using Hutcheson's t-test; and (iii) evaluate the relationship between microenvironmental variables and predatory arthropod community structure.

Figure 1. Sampling location map of predatory arthropod study in Alur Duren Village, Birem Bayeun District, East Aceh Regency, Aceh Province, Indonesia (04°26'-04°30' N; 97°50'-97°55' E). Triangles (▲) = TM monoculture; squares (■) = TBM intercropped.

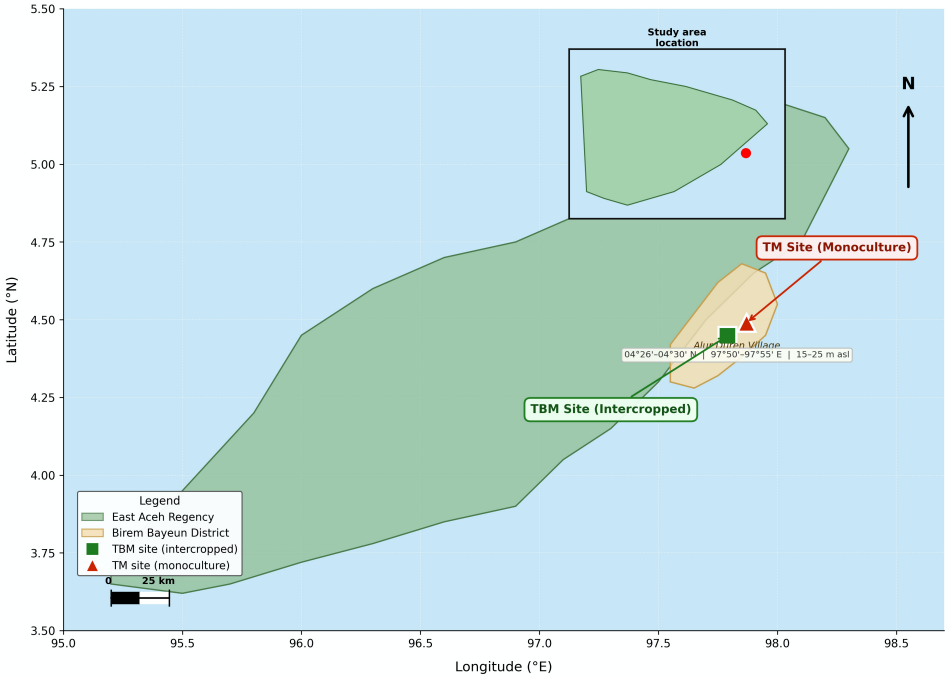


Figure 1. Sampling location map of predatory arthropod study in Alur Duren Village, Birem Bayeun District, East Aceh Regency, Aceh Province, Indonesia (04°26′–04°30′ N; 97°50′–97°55′ E). Triangles indicate TM monoculture sites; squares indicate TBM intercropped sites.

METHOD

Study area and period

The study was conducted in smallholder oil palm plantations in Alur Duren Village, Birem Bayeun District, East Aceh Regency, Aceh Province, Indonesia (04°26′–04°30′ N; 97°50′–97°55′ E; 15–25 m asl). The area is characterised by a humid tropical climate (Köppen Af) with annual rainfall of 1,800–2,200 mm and average daily temperatures ranging from 24 to 32°C.

Two cropping systems were investigated: (i) immature oil palm (TBM, 2–3 years old) intercropped with maize (*Zea mays* L. var. BISI-18), and (ii) mature oil palm (TM, ≥10 years old) managed under monoculture. The two sites were located approximately 500 m apart to reduce potential overlap of arthropod populations (Yenti *et al*. 2020). Field sampling was conducted from March to May 2023. Specimen identification was carried out at the Plant Pest and Disease Laboratory, Faculty of Agriculture, Universitas Bengkulu. Voucher specimens (AA-2023-001 to AA-2023-010) were deposited at Universitas Almuslim.

Ethical consideration

Sampling was conducted on private smallholder plantations with prior consent from landowners. No protected or vertebrate species were involved. All procedures complied with Indonesian regulations on biodiversity conservation (Government Regulation No. 7 of 1999).

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Sampling design

A total of five 20 × 20 m plots were established in each cropping system using a systematic transect design. Sampling was conducted over three periods at two-week intervals: late March (SP1), mid-April (SP2), and early May 2023 (SP3), yielding 30 sampling units (5 plots × 2 systems × 3 periods). The minimum distance between plots was 50 m, and all plots were at least 10 m from plantation edges to minimise edge effects.

Arthropod sampling

Predatory arthropods were collected using three complementary methods to capture ground, aerial, and vegetation-associated taxa. Pitfall traps, consisting of five plastic cups (10 cm diameter, 12 cm depth) installed flush with the soil surface, were filled with 70% ethanol and soapy water (3:1, v/v) and operated for 48 hours (Yenti et al. 2020). Yellow pan traps (five per plot; 25 cm diameter) were placed at 40–70 cm above the ground and filled with the same solution, also for 48 hours. Sweep netting was conducted using a 30 cm diameter net, with 50 double sweeps per plot performed twice daily (06:00–09:00 and 15:00–17:00). Collected specimens were euthanized with ethyl acetate and preserved in 70% ethanol.

Microenvironmental variables

Environmental variables were measured in each plot during each sampling period. Air temperature and relative humidity were recorded with a digital thermohygrometer at 1.5 m above the ground. Light intensity was measured at the plot centre using a lux meter. Litter depth was measured at five random points per plot. Understory vegetation density was estimated using three 1 × 1 m quadrats per plot. All measurements were averaged per sampling period for each cropping system.

Specimen identification

Specimens were sorted and identified to the family level under a stereo microscope. Identification followed standard references: Borror et al. (1996) and Kalshoven (1981) for Coleoptera and Orthoptera; and Barrion and Litsinger (1995) for Araneae and other taxa. Araneae were included as predatory arthropods due to their ecological role in pest control. Culicidae were excluded because they are not predatory on agricultural pests. In the tables, Araneae were indicated with an asterisk (*) to distinguish them from insects.

Data analysis

Predatory arthropod diversity was quantified using the Shannon-Wiener diversity index (H′), Pielou's evenness index (E), and Simpson's dominance index (C). Diversity categories followed Odum (1971), while evenness categories followed Pielou (1966).

Differences in diversity between cropping systems were tested using Hutcheson's t-test at $\alpha = 0.05$ ([9]). Relationships between microenvironmental variables and arthropod community parameters were assessed using Spearman's rank correlation. All analyses were conducted in R version 4.3.1.

Table 1. Ecological indices used in data analysis

Index	Formula	Description	Reference
Shannon-Wiener (H′)	$H' = -\Sigma(pi \ln pi)$	pi = ni/N; ni = number of individuals of family i; N = total individuals	Shannon (1948)
Pielou's evenness (E)	$E = H' / \ln S$	S = total number of families	Pielou (1966)
Simpson's dominance (C)	$C = \Sigma(ni/N)^2$	Indicates dominance level of taxa	Simpson (1949)
Hutcheson t-test	$t = (H'_1 - H'_2) / \sqrt{(\text{var } H'_1 + \text{var } H'_2)}$	Comparison of diversity indices	Hutcheson (1970)

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RESULTS AND DISCUSSION

Figure 2. Predatory arthropod diversity indices per sampling period in maize-intercropped immature oil palm (TBM) and mature monoculture oil palm (TM), Alur Duren Village, East Aceh (September–November 2025)

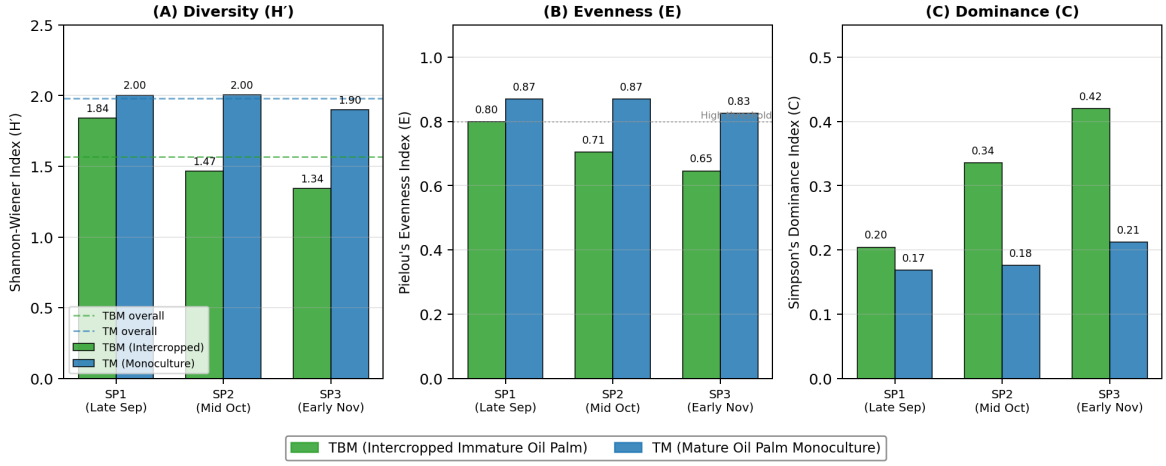


Figure 2. Predatory arthropod diversity indices per sampling period in maize-intercropped immature oil palm (TBM) and mature monoculture oil palm (TM), Alur Duren Village, East Aceh (March–May 2023). (A) Shannon-Wiener diversity index (H′); (B) Pielou's evenness index (E); (C) Simpson's dominance index (C). Dashed lines in panel A indicate overall H′ values.

Table 2. Microenvironmental variables in maize-intercropped immature oil palm (TBM) and mature oil palm (TM) monoculture at Alur Duren Village, East Aceh, Indonesia (March–May 2023; mean ± SD, n = 5 plots × 3 sampling periods)

Parameter	TBM + Maize Intercrop	TM Monoculture	Unit
Mean air temperature	28.4 ± 1.2	29.1 ± 0.9	°C
Mean relative humidity	82.3 ± 4.5	75.6 ± 3.8	%
Mean light intensity	8,240 ± 620	12,580 ± 890	lux
Litter depth	2.1 ± 0.4	5.8 ± 0.7	cm
Understory vegetation density	4.3 ± 0.6	1.8 ± 0.3	individuals m^{-2}
Number of vegetation strata	2 (oil palm + maize)	1 (oil palm only)	—
Dominant canopy height	3.5–4.5	9–12	m

Note: TBM = immature oil palm (Tanaman Belum Menghasilkan, 2–3 years old); TM = mature oil palm (Tanaman Menghasilkan, ≥10 years old).

Table 3. Family composition and abundance of predatory arthropods in maize-intercropped immature oil palm (TBM) at Alur Duren Village, East Aceh, Indonesia (March–May 2023)

Order	Family	Representative species	SP1	SP2	SP3	Total	(%)
Coleoptera	Coccinellidae	*Verania lineata*, *Micraspis crocea*	113	364	453	930	52.63
Odonata	Coenagrionidae	*Agriocnemis femina*, *A. pygmea*	102	87	74	263	14.88
Araneae*	Tetragnathidae	*Tetragnatha maxillosa*	55	87	55	197	11.15
Orthoptera	Gryllidae	*Metioche vittaticollis*	9	67	31	107	6.06
Orthoptera	Tettigoniidae	*Conocephalus longipennis*	23	22	36	81	4.58
Araneae*	Araneidae	*Araneus inustus*	26	23	21	70	3.96
Coleoptera	Carabidae	*Ophionea nigrofasciata*	22	9	25	56	3.17

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Araneae*	Oxyopidae	*Oxyopes javanus*	6	—	25	31	1.75
Araneae*	Linyphiidae	*Atypena formosana*	6	17	—	23	1.30
Odonata	Libellulidae	*Diplocodes trivialis*	9	—	—	9	0.51
Total			**371**	**676**	**720**	**1,767**	**100.00**

Note: SP = sampling period; (%) = percentage abundance relative to total individuals; — = not recorded in that period; * = Araneae (Class Arachnida, not Insecta).

Table 4. Family composition and abundance of predatory arthropods in mature oil palm (TM) monoculture at Alur Duren Village, East Aceh, Indonesia (March–May 2023)

Order	Family	Representative species	SP1	SP2	SP3	Total	(%)
Coleoptera	Coccinellidae	*Verania lineata*, *Micraspis crocea*	87	128	145	360	34.35
Odonata	Coenagrionidae	*Agriocnemis femina*, *A. pygmea*	67	54	48	169	16.13
Araneae*	Tetragnathidae	*Tetragnatha maxillosa*	38	52	41	131	12.50
Araneae*	Araneidae	*Araneus inustus*	29	35	27	91	8.68
Orthoptera	Gryllidae	*Metioche vittaticollis*	18	31	22	71	6.77
Orthoptera	Tettigoniidae	*Conocephalus longipennis*	21	19	28	68	6.49
Araneae*	Oxyopidae	*Oxyopes javanus*	15	22	19	56	5.34
Coleoptera	Carabidae	*Ophionea nigrofasciata*	12	18	16	46	4.39
Araneae*	Linyphiidae	*Atypena formosana*	9	14	11	34	3.24
Odonata	Libellulidae	*Diplocodes trivialis*	8	9	5	22	2.10
Total			**304**	**382**	**362**	**1,048**	**100.00**

Note: SP = sampling period; (%) = percentage abundance relative to total individuals; * = Araneae (Class Arachnida, not Insecta).

Table 5. Shannon-Wiener diversity index (H′), Pielou's evenness index (E), and Simpson's dominance index (C) of predatory arthropods in maize-intercropped immature oil palm (TBM) at Alur Duren Village, East Aceh (March–May 2023)

Period	N	S	H′	H′ category	E	E category	C
SP 1	371	10	1.8401	Moderate	0.7992	High	0.2043
SP 2	676	8	1.4668	Moderate	0.7054	Moderate	0.3359
SP 3	720	8	1.3435	Moderate	0.6461	Moderate	0.4199
Overall	**1,767**	**10**	**1.5687**	**Moderate**	**0.6813**	**Moderate**	**0.3204**

Note: N = number of individuals; S = number of families; C = Simpson dominance index; H′ categories (Odum 1971): low <1, moderate 1–3, high >3; E categories (Pielou 1966): low <0.60, moderate 0.60–0.80, high >0.80; SP = sampling period.

Table 6. Shannon-Wiener diversity index (H′), Pielou's evenness index (E), and Simpson's dominance index (C) of predatory arthropods in mature oil palm (TM) monoculture at Alur Duren Village, East Aceh (March–May 2023)

Period	N	S	H′	H′ category	E	E category	C
SP 1	304	10	2.0034	Moderate	0.8701	High	0.1690
SP 2	382	10	2.0043	Moderate	0.8704	High	0.1757
SP 3	362	10	1.9007	Moderate	0.8255	High	0.2119
Overall	**1,048**	**10**	**1.9794**	**Moderate**	**0.8596**	**High**	**0.1822**

Note: N = number of individuals; S = number of families; C = Simpson dominance index; SP = sampling period.

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Table 7. Spearman's rank correlation coefficients (ρ) between microenvironmental variables and predatory arthropod community parameters

Environmental variable	ρ	p-value	Interpretation
Understory vegetation density vs. Coccinellidae abundance	+0.82	0.03	Positive correlation: Coccinellidae abundance in TBM plots
Litter depth vs. Araneae abundance	+0.89	0.008	Positive correlation: Araneae proportional abundance in TM plots
Relative humidity vs. Tetragnathidae abundance	+0.74	0.04	Positive correlation: Tetragnathidae abundance (TBM)
Light intensity variation vs. abundance fluctuation	−0.71	0.04	Negative correlation: abundance fluctuation in TM plots
Understory vegetation density vs. H′	−0.68	0.04	Negative correlation: high density → Coccinellidae dominance reduces H′
Litter depth vs. H′	+0.79	0.02	Positive correlation: thick litter supports diverse Araneae
Relative humidity vs. H′	+0.65	0.05	Marginally positive correlation with overall H′

Note: H′ = Shannon-Wiener diversity index; TBM = maize-intercropped immature oil palm; TM = mature oil palm monoculture; p-values based on Spearman's rank correlation, n = 6 (3 periods × 2 systems).

Table 8. Summary comparison of predatory arthropod community parameters between maize-intercropped immature oil palm (TBM) and mature oil palm (TM) monoculture at Alur Duren Village, East Aceh

Parameter	TBM + Maize Intercrop	TM Monoculture	Interpretation
No. of predatory arthropod families	10	10	Identical; dominance patterns differ
Total individuals (N)	1,767	1,048	Intercrop higher (+68.6%)
Overall H′	1.5687 (Moderate)	1.9794 (Moderate)	TM higher (Δ = +0.41)
Overall E	0.6813 (Moderate)	0.8596 (High)	TM more even (Δ = +0.18)
Overall C	0.3204	0.1822	Lower dominance in TM
Dominant family	Coccinellidae (52.63%)	Coccinellidae (34.35%)	Dominance proportion significantly different
Araneae proportion	21.18%	29.77%	Greater spider contribution in TM
Abundance fluctuation (SP1→SP3)	+94.1%	+19.1%	Intercrop more fluctuating
Hutcheson t-test	t = −11.43; df = 2,708	p < 0.001	H′ significantly different between systems

Note: H′ = Shannon-Wiener index; E = Pielou's evenness index; C = Simpson's dominance index; Δ = difference between systems; SP = sampling period; df = degrees of freedom.

Microenvironmental conditions

Microenvironmental variables differed consistently between the two cropping systems across all sampling periods (Table 2), indicating that vegetation structure strongly regulates local abiotic conditions. The maize-intercropped immature oil palm (TBM) plots had higher relative humidity (82.3 ± 4.5%) and lower air temperature (28.4 ± 1.2°C) than the mature oil palm (TM) monoculture (75.6 ± 3.8% and 29.1 ± 0.9°C, respectively). This pattern reflects the buffering effect of a multi-strata vegetation system, in which the maize canopy reduces solar radiation penetration and evapotranspiration rates, thereby stabilising the microclimate. Such microclimatic moderation has been widely reported to enhance arthropod survival, particularly for soft-bodied prey and humidity-sensitive predators such as spiders and Odonata ([8]; [14]). In contrast, the more open structure of TM monoculture increases light penetration (12,580 ± 890 lux), resulting in greater thermal fluctuation and lower humidity, conditions that may constrain certain predator guilds.

Litter depth was substantially higher in TM plots (5.8 ± 0.7 cm), reflecting long-term accumulation of palm fronds. Litter plays a crucial ecological role as refugia and a hunting substrate for ground-dwelling and web-building predators, particularly Araneae (Widhiono et al. 2016; [14]). Meanwhile, understory vegetation density was significantly

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higher in TBM plots (4.3 ± 0.6 individuals m^{-2}), driven by maize and associated weeds, which provide additional trophic and structural resources. Overall, these results confirm that the cropping system determines habitat complexity, which in turn regulates microenvironmental gradients and the ecological niches available to predatory arthropods.

Predatory arthropod composition and abundance

A total of 10 predatory arthropod families from five orders were recorded in both systems, indicating comparable taxonomic richness but contrasting community structures. The maize-intercropped TBM system supported 1,767 individuals, substantially more than the TM monoculture (1,048 individuals). This difference aligns with the resource concentration and habitat heterogeneity hypotheses, in which diversified vegetation enhances prey availability and predator colonisation ([2]; Rizali et al. 2023).

The TBM system provided a two-stratum habitat, facilitating the coexistence of multiple functional predator guilds: (a) aerial predators (Odonata), (b) foliage-associated predators (Coccinellidae, Oxyopidae), (c) web-building spiders (Tetragnathidae, Araneidae), and (d) ground predators (Carabidae, Gryllidae).

This vertical and horizontal diversification of habitat is known to increase encounter rates between predators and prey, thereby enhancing the efficiency of biological control ([13]; [23]).

Dominance of Coccinellidae in an intercropped system

Coccinellidae dominated the TBM system (52.63%), with a marked increase across sampling periods. This pattern is associated with the presence of the maize aphid (Rhopalosiphum maidis), a key prey resource. The positive correlation between understory vegetation density and Coccinellidae abundance ($\rho = +0.82$; $p = 0.03$) confirms that plant diversification indirectly enhances predator populations by enriching their prey. This trophic linkage aligns with findings from diversified agroecosystems, where aphidophagous predators respond rapidly to prey outbreaks ([1]). However, this dominance also reflects numerical aggregation, in which a single predator group exploits abundant prey, thereby reducing community evenness.

Role of Odonata and Araneae

Coenagrionidae (14.88%) was the second most abundant group in TBM plots. Odonates are highly mobile predators sensitive to habitat structure and water availability, often associated with semi-humid microhabitats (Astuti et al. 2022). Their presence suggests that intercropping systems may enhance landscape permeability for flying predators. Araneae, particularly Tetragnathidae, showed a strong association with relative humidity ($\rho = +0.74$; $p = 0.04$). Web-building spiders are known to respond to microclimatic stability and structural support, both of which are enhanced in intercropped systems ([14]).

Community structure in mature monoculture

Although TM monoculture supported fewer individuals, it exhibited a more balanced predator community, with Araneae contributing 29.77% of total abundance. The strong correlation between litter depth and spider abundance ($\rho = +0.89$; $p = 0.008$) highlights the importance of detrital habitat in sustaining predator diversity. Litter-rich environments enhance: (1) shelter availability, (2) microclimate stability, (3) prey diversity (detritivores and secondary consumers). These findings are consistent with studies showing that structurally complex ground layers increase spider richness and functional diversity (Widhiono et al. 2016; [14]).

Diversity indices and ecological interpretation

The TBM system exhibited moderate diversity ($H' = 1.5687$) but showed a declining temporal trend, driven by the increasing dominance of Coccinellidae. This illustrates a classic ecological trade-off: high abundance is not the same as high diversity. Dominance reduces Shannon diversity because the index is sensitive to evenness rather than richness alone (Magurran and McGill 2011). Similar patterns have been reported in agroecosystems experiencing prey-driven predator outbreaks ([1]). In contrast, TM monoculture exhibited: (1) higher diversity ($H' = 1.9794$), (2) high evenness ($E = 0.8596$), and (3) low dominance ($C = 0.1822$), indicating a stable and functionally diverse predator assemblage. This stability is characteristic of systems approaching ecological equilibrium, where resource distribution is more homogeneous, and no single taxon monopolises ecological niches (Odum 1971; [12]).

Functional implications for biological control

From an applied ecological perspective, the two cropping systems play contrasting yet complementary roles in biological control. The maize-intercropped immature oil palm (TBM) system is characterised by high predator abundance, which enhances its capacity to rapidly and effectively suppress pest populations, particularly during periods of peak infestation. This elevated abundance is largely driven by prey availability and habitat complexity. However, this system also shows relatively low evenness, indicating a strong dependence on a limited number of dominant predator taxa, especially Coccinellidae, which may reduce functional redundancy within the community.

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In contrast, the mature oil palm (TM) monoculture system exhibits high evenness and a more balanced distribution of predator taxa, resulting in a stable, functionally diverse predator assemblage. This community structure supports sustained, broad-spectrum pest control across multiple pest groups. Nevertheless, the lower overall predator abundance in this system may limit its capacity to suppress rapidly increasing pest populations. These contrasting characteristics support the concept of complementary ecosystem services, in which different cropping systems play distinct yet synergistic roles in pest regulation. Intercropping systems primarily enhance predator abundance and short-term control efficiency, whereas mature monoculture systems provide long-term stability and resilience in biological control (Gurr et al. 2017; [13]).

Microenvironment–community relationships

Spearman's rank correlation analysis (Table 7) revealed that microenvironmental variables play a decisive role in shaping predatory arthropod community structure through both trophic and habitat-mediated mechanisms. Understory vegetation density showed a strong positive correlation with Coccinellidae abundance, indicating that higher plant density indirectly enhances predator populations by increasing aphid prey availability. This finding suggests that vegetation complexity in the maize-intercropped system functions primarily as a bottom-up driver, with prey enrichment supporting numerical increases in dominant predator taxa. Litter depth was positively correlated with Araneae abundance, underscoring the importance of accumulated organic matter as a structural habitat component. Thick litter layers provide suitable microhabitats for web attachment, shelter, and prey interception, thereby facilitating the persistence of spider assemblages, particularly in the mature oil palm system. Similarly, relative humidity showed a positive association with Tetragnathidae abundance, emphasising the sensitivity of web-building spiders to microclimatic stability, particularly the moisture conditions required for web integrity and physiological functioning.

In contrast, understory vegetation density was negatively correlated with the Shannon-Wiener diversity index (H′). This inverse relationship indicates that although vegetation complexity increases total predator abundance, it may also promote dominance by a single highly responsive group, particularly Coccinellidae, thereby reducing overall community evenness. Conversely, litter depth was positively correlated with H′, suggesting that structurally complex ground habitats contribute to a more balanced distribution of taxa by supporting a wider range of predator guilds. Overall, these relationships show that microenvironmental factors regulate predator communities through interacting bottom-up (resource-driven) and habitat-structural pathways, ultimately shaping the abundance and diversity patterns observed across cropping systems. These results reinforce the principle that habitat heterogeneity operates through multiple ecological pathways, including trophic interactions, microclimate regulation, and structural complexity ([2];Rizali et al. 2023).

Comparative system performance and ecological implications

Hutcheson's t-test confirmed a highly significant difference in diversity between systems ($p < 0.001$), indicating that the observed patterns are not due to sampling variation but reflect true ecological differentiation. The intercropping system increased predator abundance by 68.6%, demonstrating its effectiveness as a conservation biological control strategy. This aligns with global meta-analyses showing that crop diversification enhances natural enemy populations ([19]). However, the monoculture system maintained higher diversity and stability, highlighting the importance of long-term habitat features such as litter accumulation and reduced disturbance.

CONCLUSION

Cropping system significantly influences predatory arthropod communities in smallholder oil palm plantations in East Aceh. Both systems supported the same number of families, but differed in structure and function. The maize-intercropped immature oil palm (TBM) system showed higher predator abundance driven by increased habitat complexity and prey availability, but lower diversity due to dominance of Coccinellidae. In contrast, mature oil palm (TM) monoculture exhibited lower abundance but higher diversity and evenness, indicating a more stable predator community. Microenvironmental factors, particularly understory vegetation density and litter depth, played key roles in shaping these patterns. Overall, the two systems provide complementary biological control functions: intercropping enhances short-term pest suppression, while monoculture supports long-term stability. Therefore, maize intercropping during the TBM phase is recommended to strengthen Integrated Pest Management (IPM) in smallholder oil palm systems.

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CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

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