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DIVERSITY AND ABUNDANCE OF HYMENOPTERAN SPECIES IN MIXED-USE AGRICULTURAL LANDSCAPE OF PUSAT PENYELIDIKAN PERTANIAN TUN RAZAK, PAHANG, MALAYSIA

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ABSTRACT

Hymenoptera are ubiquitous insects crucial for ecosystem balance, fulfilling diverse ecological roles as pollinators, parasitoids, and predators, serving as valuable bioindicators of environmental health. While Hymenoptera communities in homogeneous agricultural landscapes have been extensively studied, research on heterogeneous mixed-use systems in Malaysia remains limited. Thus, the objectives of this study are to produce a checklist of Hymenoptera and to compare their diversity and composition across four land cover types namely oil palm plantations (OP), fruits orchards (FO), forest remnants (FR), and urban areas (UA) within the Pusat Penyelidikan Pertanian Tun Razak (PPPTR). A total of 3,455 individuals of Hymenoptera from 22 families and 148 morphospecies were identified during the study period. This study also found a significant difference in the abundance (df = 3, $P<0.05$) and richness (df= 3, $P<0.05$) of Hymenopteran species across different land covers of PPPTR, Pahang. Fruit orchards (H' index = 5.624) and oil palm plantations (H' index = 5.352) support a higher diversity of Hymenoptera in comparison to forest remnant (H' index = 4.398) and urban areas (H' index = 5.107), though in a smaller number of individuals. Forest remnant and urban areas hold different hymenopteran communities, with only 35% similarity from the orchard and oil palm plantation. This preliminary study shows that mixing different land cover patches within an agricultural landscape may promote different diversity and abundance of Hymenoptera. Cropped habitat apparently holds substantial value in providing resources for the Hymenoptera, through good management practices are needed to increase its population size. Additional study is needed to characterize the environmental variations between each cover type for a better understanding of the influence of mixed-use agricultural landscapes on Hymenoptera communities.

Keywords: Landscape pattern; fruit orchards; urban area; oil palm; pollination; parasitoid

ABSTRAK

Hymenoptera adalah serangga yang boleh ditemui di mana-mana serta penting untuk keseimbangan ekosistem. Hymenoptera juga memainkan peranan penting dalam ekologi sebagai pendebunga, parasitoid dan pemangsa serta berfungsi sebagai bioindikator berharga pada kesihatan alam sekitar. Walaupun komuniti Hymenoptera di dalam landskap pertanian homogen telah dikaji secara meluas, penyelidikannya di dalam sistem penggunan campuran heterogen di Malaysia masih terhad. Oleh itu, objektif kajian ini adalah untuk menghasilkan senarai semak Hymenoptera dan untuk membandingkan kepelbagaian dan komposisinya di dalam empat jenis tutupan tanah iaitu ladang kelapa sawit (OP), kebun buah-buahan (FO), hutan (FR), dan kawasan bandar (UA) di Pusat Penyelidikan Pertanian Tun Razak (PPPTR), Pahang. Sebanyak 3,455 individu Hymenoptera daripada 22 famili dan 148 morfospesies telah dikenal pasti sepanjang tempoh kajian. Kajian ini juga mendapati perbezaan ketara dalam kelimpahan (df = 3, $P<0.05$) dan kekayaan (df= 3, $P<0.05$) spesies Hymenopteran merentas liputan tanah PPPTR, Pahang yang berbeza. Kebun buah-buahan (H' indeks = 5.624) dan ladang kelapa sawit (H' indeks = 5.352) menyokong kepelbagaian lebih tinggi Hymenoptera berbanding dengan hutan tinggalan (H' indeks = 4.398) dan kawasan bandar (H' indeks = 5.107), walaupun dalam bilangan individu yang lebih kecil. Kawasan hutan dan bandar mempunyai komuniti hymenopteran yang berbeza sama dengan hanya 35% persamaan daripada kebun dan ladang kelapa sawit. Kajian awal menunjukkan bahawa gabungan pelbagai jenis litupan tanah dalam landskap pertanian berpotensi menyokong kepelbagaian dan kelimpahan Hymenoptera. Kawasan tanaman kelihatan mempunyai nilai yang signifikan dalam menyediakan sumber untuk Hymenoptera, namun amalan pengurusan yang baik diperlukan bagi meningkatkan saiz populasinya. Kajian lanjutan diperlukan untuk mencirikan variasi persekitaran antara setiap jenis litupan tanah bagi memahami dengan lebih mendalam pengaruh landskap pertanian pelbagai guna terhadap komuniti Hymenoptera.

Kata kunci: Corak landskap; kebun buah-buahan; hutan bandar; kelapa sawit; pendebungaan; parasitoid

INTRODUCTION

Malaysia, known for its diverse ecosystems and agricultural landscapes, struggles to balance economic development with environmental conservation. Various studies recorded loss of richness over the loss of habitats due to other land uses, including agricultural activities (Simplício et al. 2022). Local insect extinction was reported, especially among specialist species sensitive to environmental changes (Cardoso et al. 2020). The population reduction mostly occurs following decreased breeding sites, increased resource competition, and reduced prey or hosts (Sánchez-Bayo & Wyckhuys 2021). However, some other insects have shown opposite responses where certain groups have higher tolerance towards environmental changes (Medan et al. 2011; Paiva et al. 2020).

The insect is a good indicator of ecosystem stability and health. Hymenoptera, which encompasses sawflies, wasps, bees, and ants, constitute one of the most diverse insect orders considered excellent bioindicators of habitat quality (Sánchez-Bayo & Wyckhuys 2021). There are an estimated over 153,000 known species within this group, and the number of existing species could exceed one million, including numerous species yet to be described (Peters et al. 2017). Hymenoptera provides multiple services to the ecosystem, such as pollinators (Idris et al. 2023), predators, and parasitoids (Jankielsohn 2018). This insect group included species sensitive to environmental changes and more generalist species that are more tolerant to habitat disturbances. The crucial importance of Hymenoptera and other insects in the pollination process is widely recognized as it is vital to the growth of 87 important food crops that are crucial to the production of the world's food, covering 35 % of agricultural land worldwide (FAO 2018). This group of insects is also crucial in controlling pest populations as it becomes a predator or parasitoid to other insects.

The decline in the Hymenoptera population due to expanding agricultural land has been reported in many parts of the world (Miglani et al. 2020; Volpato et al. 2020). Other studies, however, recorded increased dispersion and abundance of Hymenoptera in agricultural regions (Arnold 2020; Abd Rahman et al. 2017), suggesting a contrasting influence of agricultural activity on the population. While different habitat types have been studied to infer the distribution of Hymenoptera in Malaysia (Hatta et al. 2015; Naser et al. 2021), the impact of agricultural practices on this taxon is still understudied. This is due to the lack of good empirical data with a standardized method for comparable measurements. The existing studies only focus on a homogenous agricultural landscape (Hatta et al. 2012) or rather centered around specialized taxa (Madihah et al. 2019; Razali et al. 2016).

It is important to note that many agricultural landscapes are surrounded by varied proportions of other land cover, including non-crop habitats such as bare lands, water bodies, forests, and urban areas. The non-crop habitats were reported to harbour hymenopteran species that are absent in the crop fields (Neokosmidis et al. 2018; González et al. 2022). Within an intensive agricultural landscape, non-crop habitat types will be sparse and become important in supporting rare plants for insect resources. Following a mixed-use agricultural landscape, hymenopteran species such as bees resorted to different habitat types as nesting sites and floral resources necessary for survival (Mallinger et al. 2016). Surveying non-crop habitats should be included for a more accurate assessment of hymenopteran communities in agricultural landscapes, as Groff et al. (2016) suggested.

Thus, this study collects preliminary data for the assessment of Hymenopteran communities in one of Malaysia's mixed-used oil palm plantation landscapes. The Pusat Penyelidikan Pertanian Tun Razak (PPPTR), Pahang, is a huge research complex with an oil palm plantation surrounded by other land covers. The objective of this study is 1) to prepare a checklist of Hymenoptera in the mixed-use agricultural landscape of Pusat Penyelidikan Pertanian Tun Razak, Pahang, and 2) to compare the abundance, richness, and composition of Hymenoptera across different land cover types. The Hymenoptera community in different land cover areas is hypothesized to have a different composition of species. It is also hypothesized that the diversity and abundance of Hymenoptera will be lower in the homogeneous cropped areas characterized by uniform tree composition. Understanding the influence of mixed-use agricultural landscapes on Hymenoptera could help inform conservation and management practices towards the beneficial use of Hymenoptera in crop fields. This will also provide baseline data for monitoring efforts in Hymenopteran conservation, apart from assessing the capability of the current management practices in PPPTR, Pahang, in supporting the Hymenopteran community.

MATERIALS AND METHODS

Study Area

Pusat Penyelidikan Pertanian Tun Razak (PPPTR) in Sungai Tekam, Pahang, Malaysia (3°52'53.59"N, 102°31'52.87"E) is an intensively mixed-use agricultural research complex with multiple land covers consisted of cropped (oil palm plantation & fruit orchard) and non-cropped (forest remnant and urban area) areas. This site is recognized as a Research and Development Centre (R&D) for agriculture, managed by FGV Holdings Berhad. All land covers are interspersed with each other in a 2,400-hectare area (Figure 1).

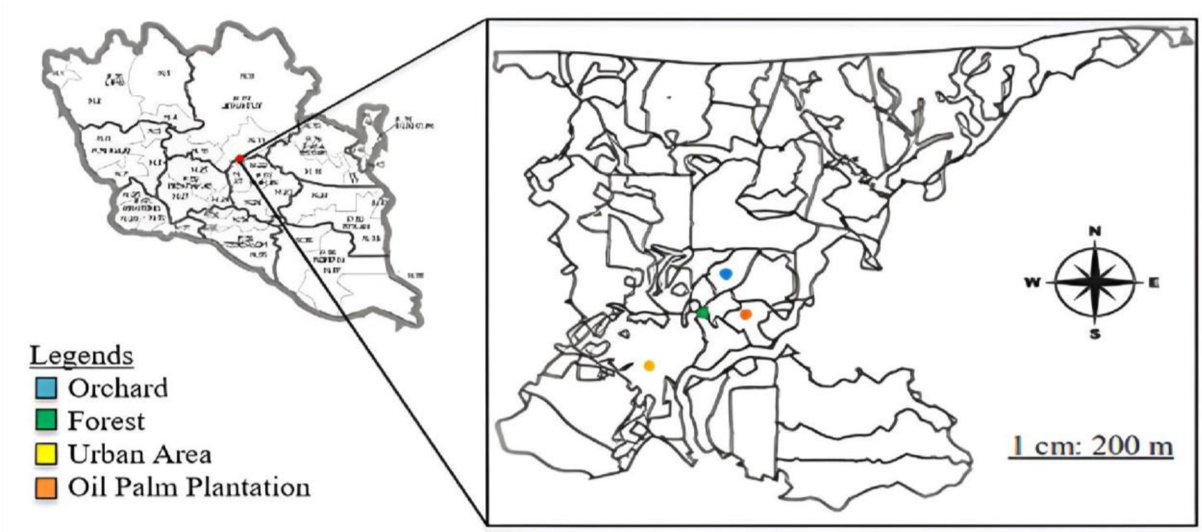

Figure 1. Study sites in Pusat Penyelidikan Pertanian Tun Razak (PPPTR) at Sungai Tekam, Pahang, Malaysia

Field Sampling

Data were collected from March to June 2023. In this study, four sampling sites were established throughout the PPPTR, Pahang, representing different land covers: oil palm plantation, fruit orchard, forest remnant, and urban area. The description of each site is shown in Table 1. At each difference land cover, one Malaise trap was set up to collect Hymenoptera samples. A bottle containing 70% alcohol was suspended beneath each Malaise trap to preserve the samples, and these bottles were replaced every seven days. The distance between land cover was minimum 1 km radius to avoid overlap of the Hymenopteran communities in difference land cover. Each sampling site, the Malaise trap was strategically deployed in the center of the land cover to minimize edge effects. Each site was sampled for six consecutive weeks. The total data collected from this study comprised 26 samples, representing the four land covers. All samples were transported to the laboratory and preserved in 70% alcohol. Samples were sorted morphologically and identified to the lowest taxonomic level possible using references from Triplehorn and Johnson (2005) and Goulet and Huber (1993). All samples were deposited in the Environmental Science and Natural Resources Laboratory at Universiti Teknologi MARA (UiTM), Jengka Campus, Pahang

Table 1. Summary of different ecosystems in Pusat Penyelidikan Pertanian Tun Razak (PPPTR) at Sungai Tekam, Pahang, Malaysia

Sites	Location	Ecosystem Description
Oil Palm Plantation	N 03° 53.105′, E 102° 32.322′	Areas cultivated with oil palm trees with low understorey vegetation spanning 1627 hectares. The plantation area has frond stacks, harvesting paths, and weeded circles. Beneficial plants such as *Turnera subulata* are planted as hedgerows. Pest and disease management take place following a designated schedule.
Fruit Orchard	N 03° 53.450′, E 102° 32.148′	Areas actively cultivated with multiple crops, including jackfruit, pomelo, sapodilla, and rambutan, approximately 227 hectares in size. Pest and disease management take place following a designated schedule.
Urban Area	N 03° 52.852′, E 102° 31.688	Areas consisted of management complex and residential areas, covering approximately 500 hectares. Flowering plants were grown in hedgerows and pots for ornamental purposes.
Forest Remnant	N 03° 53.187′, E 102° 32.072′	Small (<100 hectares) fragmented forest area with shrubs and higherwoody plants.

Data Analysis

The significant differences in Hymenoptera species richness and abundance across various land cover types were assessed using Kruskal-Wallis test. This non-parametric test was chosen as the data did not meet the of normality assumptions, as indicated by a significant Shapiro-Wilk test ($P<0.05$). The Chi-square test was conducted to determine the significant differences in the composition of Hymenoptera amongst the different land covers. Species diversity was estimated using Simpson's diversity index, Shannon's diversity index, Evenness, Margalef's richness index, and Fisher's alpha. Species richness was further estimated using Chao-1 and Abundance-based Coverage Estimator (ACE), following the methodology outlined by Kim et al. (2017). All statistical analyses were conducted using Paleontological Statistics (PAST) version 4.10. Samplesize-based rarefaction and extrapolation sampling curves, with 95% confidence intervals, were generated using the iNEXT online platform (Chao et al. 2014) to evaluate sampling completeness.

To examine community similarity in Hymenoptera functional groups across different land cover types, a two-way cluster analysis was performed. The resulting dendrogram visually represents the clustering of Hymenoptera functional groups according to land cover. A chi-square test was used to determine if significant differences in functional group composition existed between land cover types. Graphs illustrating the distribution of Hymenoptera functional groups were created using Microsoft Excel.

RESULTS

Species Richness, Abundance and Diversity of Hymenoptera.

During a six-week survey at the PPPTR, Pahang, 3,455 individuals of Hymenoptera belonging to 22 families and 148 morphospecies were identified (Table 2). The study found that the family Formicidae was the most abundant, comprising 58.7 % of the total collection with 2028 individuals (23 morphospecies). This is followed by family Ichneumonidae with 435 individuals (12.59%, 33 morphospecies) and Braconidae with 420 individuals (11.92%, 20 morphospecies). Formicidae also had the highest counts across all four land uses: Orchard, Forest Remnant, Urban Area, and Oil Palm Plantation. The remaining families comprised less than 2.5% of the total collection, with five families appearing only as singletons in the study (Megastigmidae, Bethylidae, Leucospidae, Gasteruptidae, Scoliidae) (Figure 2). A comprehensive checklist of the collected Hymenoptera across the cropped and non-cropped areas in the PPPTR, Pahang, is shown in Table 2. Each family's ecological role was classified following reviews of multiple literatures. There is a significant difference in the abundance (df = 3, $P<0.05$) and richness (df= 3, $P<0.05$) of Hymenopteran species across different land covers of PPPTR, Pahang. The non-cropped areas recorded a higher number of individuals with Forests Remnant (1530 individuals) and Urban Areas (1304 individuals) in comparison to the cropped area with Fruit Orchards (412 individuals), and Oil Palm Plantations (209 individuals). The species richness is also higher in the non-cropped area with Urban Area (111 morphospecies) and Forests Remnant (101 morphospecies) in comparison to the cropped areas with Fruit Orchard (84 morphospecies) and Oil Palm Plantation (54 morphospecies) (Table 3). However, the Shannon-Weiner index showed that the cropped areas have a higher diversity index with Fruit Orchard and Oil Palm Plantation followed by the noncropped area with Urban Area and Forest Remnant. Sample-size-based rarefaction and extrapolation below (Figure 3) showed the curve of species diversity in four different land cover and also determine the sample has been sequenced to an extent sufficient to represent its true diversity.

Table 2. The abundance of Hymenoptera in Fruit Orchard (FO), Forest Remnant (FR), Urban Area (UA), and Oil Palm Plantation (OP) of Pusat Penyelidikan Pertanian Tun Razak, Pahang, Malaysia, using Malaise trap from May to June 2023

Family	**Functional Role**	**Genus/Species**	**FO**	**FR**	**UA**	**OP**
Apidae	Pollinator	Apidae sp.1	4	5	3	0
		Apidae sp.2	3	2	13	0
		Ceratina sp.1	1	1	8	0
		Trigona sp.1	0	0	4	0
		Trigona sp.2	0	0	3	0
		Xylocopa sp.1	1	0	0	0
		Xylocopa sp.2	1	0	0	0
Bethylidae	Parasitoid	Bethylidae sp.1	0	1	0	0
Braconidae	Parasitoid	*Aleiodes* sp.1	1	5	1	5
		Aleiodes sp.2	0	1	1	0
		Aleiodes sp.3	0	17	2	0
		Braconidae sp.1	28	1	18	3
		Braconidae sp.2	1	0	0	0
		Braconidae sp.4	0	0	8	4
		Braconidae sp.5	0	1	11	0
		Braconidae sp.6	1	1	0	0
		Chelonus sp.1	17	24	2	0
		Chelonus sp.2	1	13	4	2
		Chelonus sp.3	0	1	1	0
		Cotesia sp.1	3	19	21	0
		Cotesia sp.2	0	3	7	0
		Cotesia sp.3	4	9	34	4
		Cotesia sp.5	6	7	10	3
		Cotesia sp.6	8	19	24	3
		Cotesia sp.7	4	2	0	0

		Orgilus sp.1	1	2	2	6
		Orgilus sp.2	4	7	7	10
		Orgilus sp.3	0	5	0	3
Ceraphronidae	Parasitoid	Ceraphronidae sp.1	0	9	36	16
		Ceraphronidae sp.2	2	1	2	0
		Ceraphronidae sp.3	0	0	1	0
		Ceraphronidae sp.4	1	0	4	0
Chalcididae	Parasitoid	*Brachymeria* sp.1	0	0	1	0
		Chalcedectidae sp.1	8	6	3	2
		Chalcididae sp.1	0	2	0	5
		Chalcididae sp.2	2	1	0	0
		Chalcididae sp.3	0	0	2	3
		Chalcididae sp.4	0	1	0	4
		Chalcididae sp.5	9	1	1	2
		Chalcididae sp.6	19	1	2	0
		Chalcididae sp.7	0	22	5	2
Crabronidae	Predator	Crabronidae sp.1	7	1	6	2
		Crabronidae sp.2	0	0	1	1
		Crabroninae sp.1	1	0	0	0
		Crabroninae sp.2	0	0	0	1
Eucharitidae	Parasitoid	Eucharitidae sp.1	2	0	12	0
Eupelmidae	Parasitoid	Eupelmidae sp.1	0	1	0	0
		Eupelmidae sp.2	0	1	2	0
Evaniidae	Parasitoid	Evanidae sp.1	5	7	2	3
		Evanidae sp.2	2	4	15	3
		Evanidae sp.3	17	3	12	1
		Evanidae sp.4	1	4	5	0
Formicidae	Predator	*Anoplolepis gracilipes*	13	1	1	5
		Camponotus sp.1	28	3	19	9
		Formicidae sp.1	3	3	0	0
		Formicidae sp.2	3	0	0	0
		Formicidae sp.3	6	174	122	0
		Formicidae sp.4	27	515	290	2
		Formicidae sp.5	0	8	3	0
		Formicidae sp.6	3	37	0	5
		Formicidae sp.7	4	8	0	0
		Formicidae sp.8	4	119	132	0
		Formicidae sp.9	5	54	26	5
		Formicidae sp.10	1	0	4	0
		Formicidae sp.11	1	8	3	2
		Formicidae sp.12	0	1	2	4
		Formicidae sp.13	10	21	1	0
		Formicidae sp.14	2	2	6	0
		Formicidae sp.15	0	0	1	0
		Oecophylla sp.1	3	12	20	17
		Oecophylla sp.2	1	31	2	1
		Paratrechina longicornis	39	51	38	9

		Polyharchis shixingensis	0	0	1	0
		Solepnopsis sp.1	11	57	5	24
Gasteruptiidae	Predator	Gasteruptidae sp.1	1	0	0	0
Ichneumonidae	Parasitoid	Cremastinae sp.1	1	3	0	0
		Creamstinae sp.2	0	7	0	0
		Cremastinae sp.3	0	2	3	0
		Diadegma sp.1	1	5	1	0
		Diadegma sp.2	2	3	0	0
		Diadegma sp.3	1	14	18	0
		Diadegma sp.4	0	1	0	0
		Ichneumonidae sp.1	0	4	1	0
		Ichneumonidae sp.2	0	4	1	0
		Ichneumonidae sp.3	0	4	9	0
		Ichneumonidae sp.4	1	0	2	0
		Ichneumonidae sp.5	0	0	1	0
		Ichneumonidae sp.6	2	7	2	1
		Ichneumonidae sp.7	1	7	7	3
		Ichneumonidae sp.8	0	5	2	0
		Ichneumonidae sp.9	1	0	1	0
		Ichneumonidae sp.10	0	0	1	0
		Ichneumonidae sp.11	1	1	5	0
		Ichneumonidae sp.12	1	0	0	2
		Meteorus sp.1	2	20	20	3
		Meteorus sp.2	3	7	2	1
		Ophion sp.1	8	1	6	0
		Ophion sp.2	0	0	1	0
		Pimpla sp.1	0	0	20	0
		Pimpla sp.2	2	1	1	0
		Pimplinae sp.1	0	10	9	4
		Pimplinae sp.2	0	0	8	0
		Pimplinae sp.3	0	1	0	0
		Tryphoninae sp.1	0	7	15	1
		Xanthopimpla sp.1	3	7	39	5
		Xanthopimpla sp.2	2	11	30	0
		Xanthopimpla sp.3	0	3	7	1
		Xanthopimpla sp.4	6	5	24	0
Leucospidae	Parasitoid	*Leucospis* sp.1	0	0	1	0
Megachilidae	Pollinator	Megachilidae sp.1	2	0	0	0
Megastigmidae	Parasitoid	Megastigmidae sp.1	0	1	0	0
Orussidae	Parasitoid	Orussidae sp.1	1	0	0	0
		Orussidae sp.2	1	1	0	0
		Orussidae sp.3	0	2	1	0
Pompilidae	Pollinator	Pompilidae sp.1	0	4	4	1
		Pompilidae sp.2	0	3	2	0

		Pompilidae sp.3	0	0	0	1
		Pompilidae sp.4	1	2	2	0
		Pompilidae sp.5	0	0	2	0
Scoliidae	Parasitoid	Scoliidae sp.1	1	0	0	0
Sphecidae	Predator	*Ammophila* sp.1	7	3	14	2
		Ammophila sp.2	0	0	1	0
		Prionyx sp.1	0	1	0	0
		Sphecidae sp.1	1	0	0	0
		Sphecidae sp.2	9	1	3	0
		Sphecidae sp.3	1	0	0	0
		Sphecidae sp.4	0	1	2	0
		Sphecidae sp.5	1	0	0	0
Tiphiidae	Parasitoid	Tiphiidae sp.1	0	1	3	3
		Tiphiidae sp.2	0	2	3	2
		Tiphiidae sp.3	0	0	1	0
		Tiphiidae sp.4	5	0	1	1
		Tiphiidae sp.5	1	14	8	2
		Tiphiidae sp.6	3	10	5	0
		Tiphiidae sp.7	0	0	3	0
		Tiphiidae sp.8	0	4	1	0
Trigonalidae	Parasitoid	Trigonalidae sp.1	0	6	0	0
Vespidae	Predator	Vespidae sp.1	0	2	5	0
		Vespidae sp.2	0	0	1	0
		Vespidae sp.3	0	0	4	1
		Vespidae sp.4	5	0	6	1
		Vespidae sp.5	3	13	8	1
		Vespidae sp.6	0	0	7	0
		Vespidae sp.7	0	0	1	0
		Vespidae sp.8	0	0	6	2
		Vespidae sp.9	1	0	0	0
		Vespidae sp.10	0	2	0	0
		Vespidae sp.11	1	1	1	0
		Total	412	1530	1304	209
		Grand Total		**3455**		

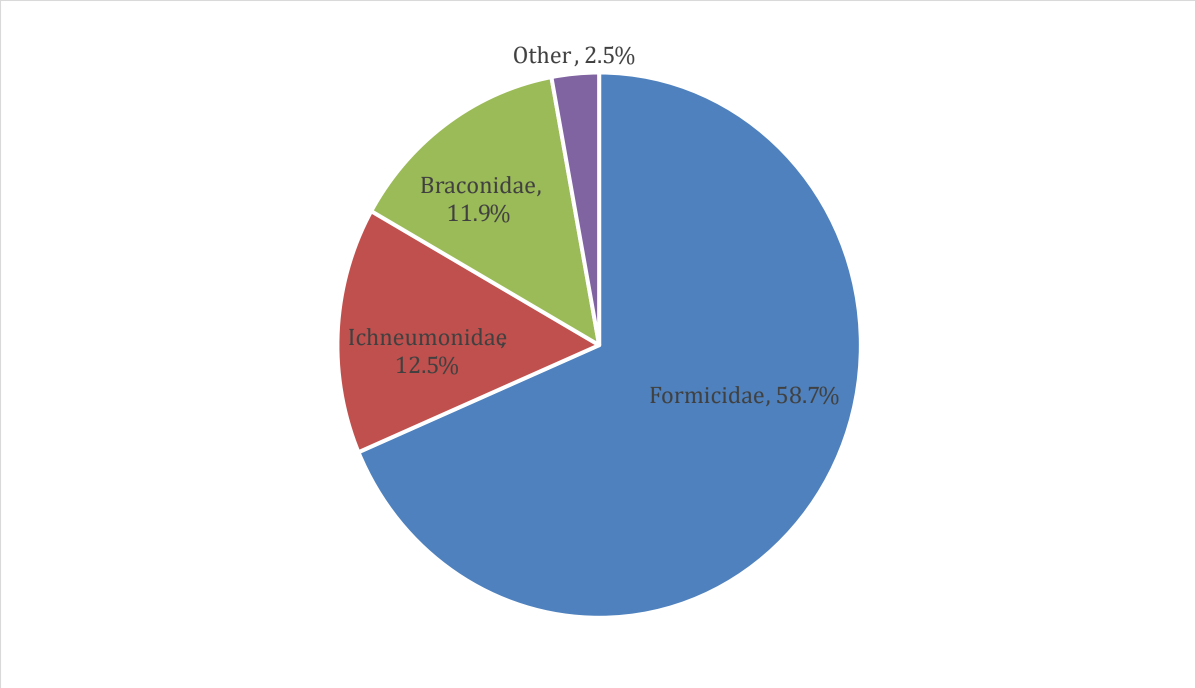

Figure 2. Relative Abundance of the Dominant Hymenopteran Family in Pusat Penyelidikan Pertanian Tun Razak, Pahang, Malaysia

Table 3: Diversity indices in different land cover areas; Fruit Orchard (FO), Forest Remnant (FR), Urban Area (UA), and Oil Palm Plantation (OP) of Pusat Penyelidikan Pertanian Tun Razak, Pahang, Malaysia

		FO	**FR**	**UA**	**OP**
	Taxa species	84	101	111	54
	Individuals	412	1530	1304	209
Estimate species diversity	Dominance	0.03341	0.1388	0.07567	0.03662
	Simpson	0.9666	0.8612	0.9243	0.9634
	Shannon	5.624	4.398	5.107	5.352
	Evenness	0.5871	0.2088	0.3106	0.7563
	Margalef	13.79	13.64	15.33	9.921
	Fisher alpha	31.9	24.29	29	23.6
Estimate species richness	Chao-1	127.9	134.8	130.9	60.97
	ACE	120.9	125.4	133.3	63.68

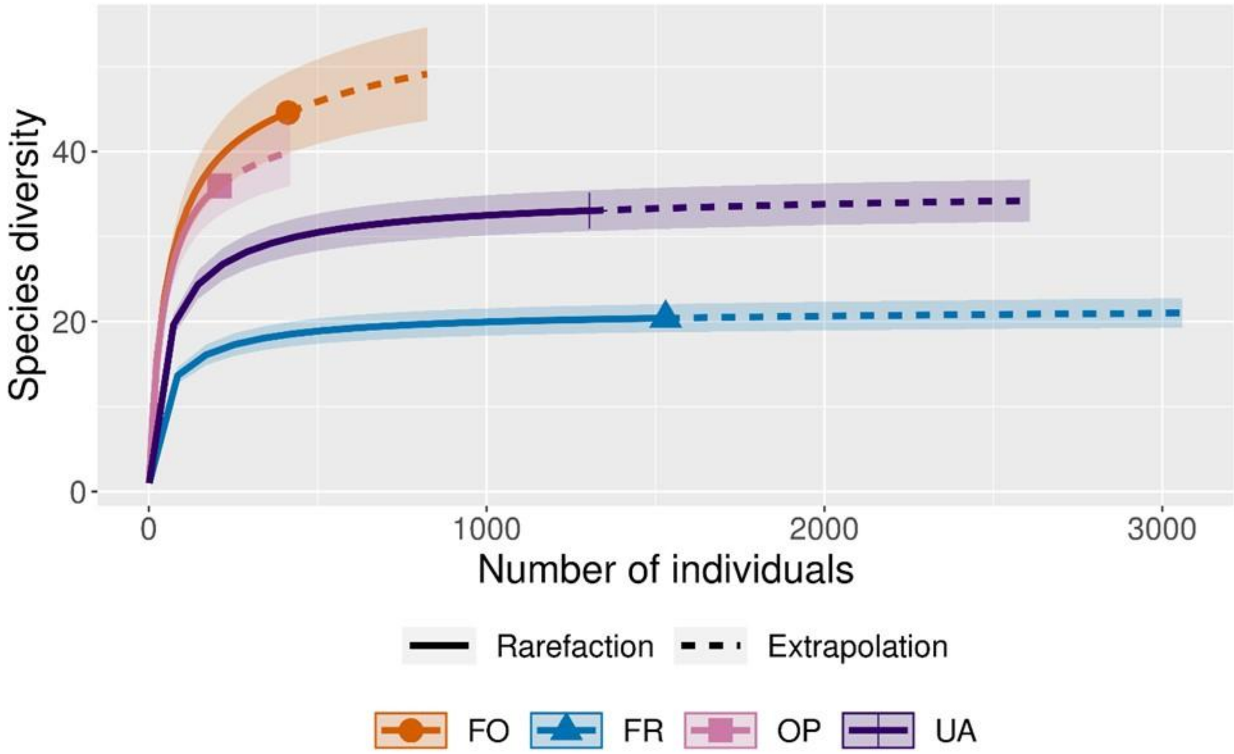

Figure 3. Sample-size-based rarefaction and extrapolation sampling curve. This extrapolation may assuming that existing trends or patterns continue Note: FO- Fruit Orchard, FR- Forest Remnant, OP- Oil Palm Plantation & UA- Urban Area

Functional Group of Hymenoptera In PPPTR

The chi-square test indicated significant differences (χ^2 = 925.06, df = 90, $P<0.05$) in the composition of Hymenoptera among the four study sites. The dendrogram generated from two way cluster analysis revealed the variation in Hymenoptera communities across cropped and noncropped areas of PPPTR (Figure 4). Following cluster analysis, the communities of Hymenoptera in PPPTR, are divergent with different functional groups occupying different land cover types. At 25% similarity, the Hymenoptera can be characterized into five different groups (A, B, C, D, E) according to their feeding group and active time (Figure 4). Communities of Hymenoptera in cropped areas (Oil Palm Plantation and Fruit Orchard) are disparate from the non-cropped areas (Urban Areas and Forest Remnants), particularly with the preeminent presence of group A, which includes the Formicidae, Braconidae, and Ichneumonidae species. Group B and D are both defined by a combination of parasitoid and predatory wasps with varying activity patterns and diets. Group C on the other hand consists of a single unique family, the Leucospidae. The predators and parasitoids are dominant across PPPTR, especially in the Forest Remnant and Urban Areas in comparison to the smaller population of pollinators (Figure 5).

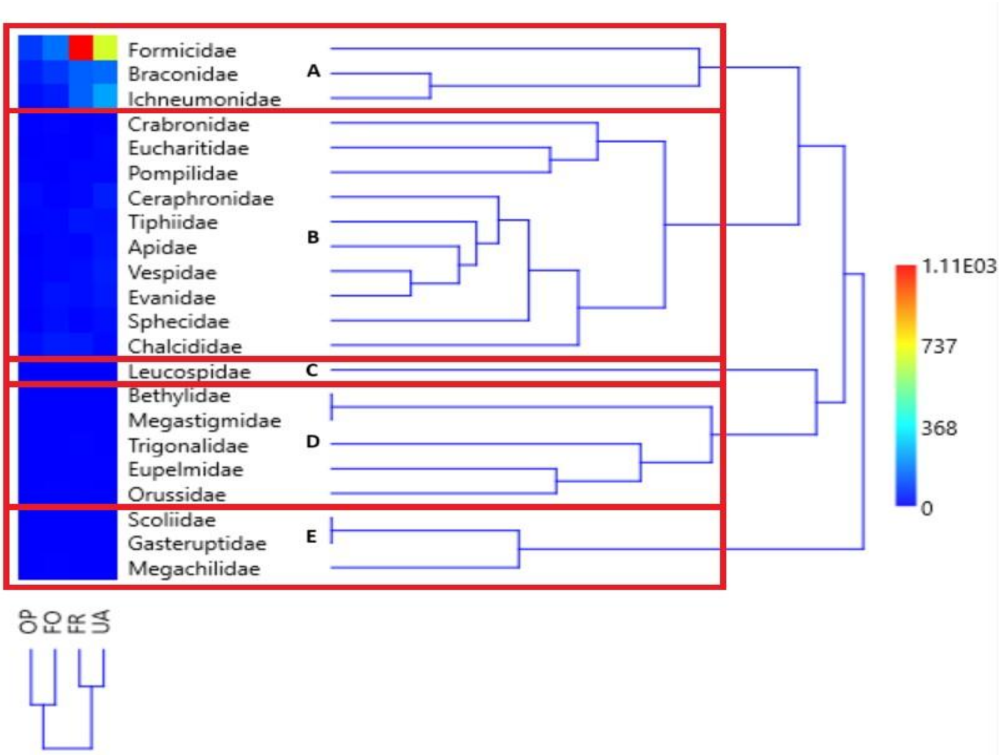

Figure 4. Two-way clustering dendrogram of Hymenoptera community in Pusat Penyelidikan Pertanian Tun Razak, Pahang. Note: FO- Fruit Orchard, FR- Forest Remnant, UA- Urban Area and OP- Oil Palm Plantation

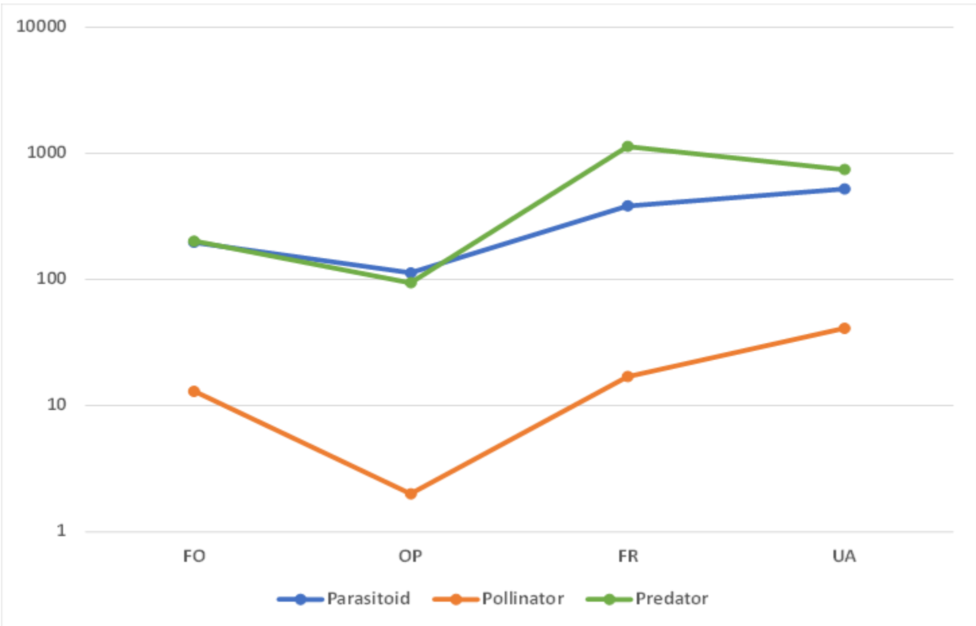

Figure 5. Abundance and distribution of Hymenoptera across Pusat Penyelidikan Pertanian Tun Razak, Pahang following different functional groups. Note: FO- Fruit Orchard, FR- Forest Remnant, OP- Oil Palm Plantation and UA- Urban Area

DISCUSSION

The study documented 3455 Hymenoptera individuals, representing 22 families and 148 morphospecies, over a six-week sampling across four distinct agroecosystem areas with varying land uses in PPPTR, Pahang. Due to the lack of comprehensive species keys, limited taxonomic expertise, and time constraints, identification was primarily conducted at the family and genus levels, categorizing them into morphospecies. This limitation highlights the need for enhanced taxonomic knowledge to accurately identify and understand the ecological roles of Hymenoptera in the region. Accurate identification to a higher taxonomic level is essential for discerning their contributions as beneficial species or potential pests within the ecosystem (Verberk et al. 2013). Nevertheless, family-level identification was also proven effective in insect bioassessment (Godoy et al. 2019).

In this study, Formicidae, Ichneumonidae, and Braconidae are the most abundant families across all study locations, showcasing remarkable adaptability to diverse environments. However, these three families are more prevalent in the non-cropped areas, especially in the forest remnant, leading to distinct communities compared to the cropped area. This result is similar to those of Narváez-Vásquez et al. (2021), reporting forest areas provide suitable areas for nesting sites with ample food supply in comparison to cropped areas with a hotter and drier microclimate (Turner & Foster 2009). Formicidae's predominance is attributed to its social structure, versatile foraging behavior, and varied nesting habits (Mezger & Moreau 2016; Peng et al. 2023). Similarly, Ichneumonidae and Braconidae thrive due to their parasitic lifestyles, broad host ranges, and adaptable foraging behaviors (Quicke 2014; Tschopp et al. 2013). Both Ichneumonoidea families were also abundant in other agricultural ecosystems, such as rice and vegetable fields (Ikhsan & Hamid 2020), proving their ability to withstand environmental changes.

The two-way clustering dendrogram highlights distinct Hymenoptera communities across agroecosystem areas, with differences in community composition between the cropped areas (Oil Palm Plantation and Fruit Orchard) in comparison to the non-cropped areas (Urban Areas and Forest Remnant). While exhibiting the highest hymenopteran abundance among land cover types, the forest remnant unfortunately lacks diversity. This is often the case for fragmented habitats, especially when the patch size is small and isolated (Decocq et al. 2016). The forest remnant, however, could act as a refugia or a 'lifeboat' habitat for species that could not migrate following hotter microclimates due to the agricultural disturbance, explaining the high abundance of Hymenoptera in this land cover. A similar situation was reported for the bumblebee and butterfly communities that resorted to greener sanctuaries when they were affected by farmland activities (Choi et al. 2012; De Montaigu & Goulson 2024). This can also explain the high abundance of Hymenoptera in urban areas. While the urban areas consist of management complexes and residential buildings, they are also incorporated with gardens and ornamental plants, becoming resources for some of the Hymenoptera species. Hence, any agricultural landscape such as the PPPTR, Pahang should still retain these forest patches and ornamental plants to conserve the Hymenoptera, providing crucial ecosystem services as pollinators, predators, and parasitoids.

The low abundance of Hymenoptera in Fruit Orchards and Oil Palm Plantations can be caused by multiple factors such as the lack of structural complexity, changing microclimate, and the use of pesticides (Wang et al. 2019). Agricultural settings typically have higher temperatures and dryer conditions (Braem et al. 2023) due to less structural complexity (Donfack et al. 2021). The result of this study suggests that most Hymenoptera are affected by changes in the microclimate following reduced stand structural complexity from the monocultural settings leading them towards the non-cropped areas as refuge. While several studies have reported an identical response of Hymenopteran species towards the changing microclimate (Ikhsan 2022; Rotondi et al. 2019; Wilson et al. 2020), this hypothesis still needs to be further tested following the absence of seasonal sampling in this study. As the sampling was limited to a single season, changes in microclimatic conditions such as temperature, humidity, and precipitation which can fluctuate considerably were not accounted. Incorporation of microclimatic data will be crucial for a thorough relationship analysis with the whole Hymenoptera communities instead of focusing on single selected taxa, especially in a tropical agricultural setting.

The use of pesticides in the agricultural setting also contributed to the low abundance of Hymenoptera in the cropped areas. The effect of pesticide residues has been shown to affect many Hymenoptera families including the Formicidae (Schläppi et al. 2021), Braconidae (Cheng et al. 2021) and Apidae (Reis et al. 2024). A more environmentally friendly approach should be adopted to control the population of weeds and other insect pests in the area. It is also an added advantage that PPPTR already recorded a high number of Hymenoptera predators and parasitoids. For example, Ichneumonidae, Braconidae, and Chalcididae of many species were proven to have infected the *Metisa plana*, a pest of economic importance in oil palm plantations in Malaysia (Halim et al. 2018). With an improved management practice in agricultural areas, the presence of these beneficial predators and parasitoids can be optimized to control pest populations as alternatives to chemical pest control.

Habitat structures and resource availability influence species distribution (Humphrey et al. 1999; Zemp et al. 2019). Despite the low abundance of Hymenoptera in the cropped areas, it still holds a high diversity value of Hymenoptera. The Fruit Orchard exhibits the highest diversity value, attributed to its diverse array of fruit tree species providing varied microhabitats and food resources (Peñalver-Cruz et al. 2019; Sahito & Sahito 2014). Oil palm plantations also showed a high diversity value of Hymenoptera following the current management practiced by PPPTR which bid to maintain buffer zones apart from having hedgerows of beneficial plants such as the *Turnera ulmifolia* and *Antigonon leptopus* (Azhar et al. 2019; Hakim & Hazmi 2018). The current management practices should be maintained and also improved to increase the low number of pollinators. A larger population of pollinators in PPPTR, Pahang will help to increase the production of the current fruit crops grown in the area.

CONCLUSION

This study provides valuable insights into the composition, abundance, richness, diversity, and ecological roles of Hymenoptera across different land covers in PPPTR, Pahang. The mixed-use agricultural landscape of PPPTR, can support a diverse community of Hymenoptera consisting of various functional roles in the ecosystem including pollinators, predators, and parasitoids. The community of Hymenoptera is different across cropped and non-crop areas. The cropped areas reduced the abundance and richness of Hymenoptera though it provided resources to a more diverse species. This preliminary assessment showed that agricultural landscapes may help in the conservation of Hymenoptera species provided that it is integrated with a management practice that increases habitat connectivity and complexity.

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The authors declare no conflict of interest.

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This research does not include any ethical issues.

Data Availability Statement
The manuscript has no associated data

Authors' Contributions
Muhammad Haziq Aiman Aubaidellah (MHAA) contributed to data collection, formal analysis, and wrote the first draft of the manuscript. Nur Athirah Abdullah (NAA) planned the research framework, assisted with writing, data analysis, and interpretation. NAA reviewed the manuscript with Nur Amalina Mohd Izam (NAMI), Siti Khairiyah Mohd Hatta (SKMH), Dzulhelmi Muhammad Nasir (DMN), and Siti Asmah Muslim (SAM). NAMI and SKMH also provided resources for the research.

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