

## Microhabitats Utilization by Solitary Parasitoids and Predatory Insects as Indicators of Oil Palm Agroecosystem's Capacity to Support Insect Species Diversity

(Penggunaan Mikrohabitat oleh Parasitoid Tunggal dan Serangga Pemangsa sebagai Penunjuk Kapasiti Agroekosistem Kelapa Sawit dalam Menyokong Kepelbagaian Spesies Serangga)

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### ABSTRACT

*Microhabitats capacity to support insect species diversity and persistence were evaluated implementing solitary parasitoids and predatory insects according to different phases of herbicide and chemical fertilizer applications. Two species of the genus Xanthopimpla (Ichneumonidae) and one species of the genus Pompilus (Pompilidae) showed relationships on vegetation-type microhabitats, notably natural weeds, leguminous cover crops, and the beneficial plant *Turnera subulata*, while two species of the genus *Evania* (Evaniiidae) showed relationships with chipped oil palm trunks. One species from the genus *Odontomachus* (Formicidae) as an exclusive predatory ant was related to both chipped oil palm trunks and the beneficial plant *T. subulata*. *Xanthopimpla* parasitoids exhibited abundance fluctuations difference around natural weeds during herbicide application phases between three- and six-years old oil palm stands, with decreased and increased abundance patterns of the former and the latter, respectively. 18 years old oil palm stand showed increased abundance patterns only along with the different phases of chemical fertilizer applications. The importance of natural weeds diversity, restrictions of leguminous cover crops, frequency of herbicide applications, and the arrangements between beneficial plants and wood-based microhabitats that benefited insect parasitoids and predators were discussed.*

*Keywords: Microhabitats; oil palm; parasitoid; predator; utilization*

### ABSTRAK

*Kapasiti mikrohabitat untuk menyokong kepelbagaian dan pengekalan spesies serangga telah dinilai dengan menggunakan parasitoid tunggal dan serangga pemangsa berdasarkan kepada fasa penggunaan racun rumpai dan baja kimia yang berbeza. Dua spesies daripada genus *Xanthopimpla* (Ichneumonidae) dan satu spesies daripada genus *Pompilus* (Pompilidae) menunjukkan perhubungan terhadap mikrohabitat berasaskan vegetasi, melibatkan rumpai liar, tanaman legum penutup bumi, serta tumbuhan berguna *Turnera subulata*, manakala dua spesies daripada genus *Evania* (Evaniiidae) menunjukkan perhubungan dengan batang kelapa sawit yang diracik. Satu spesies daripada genus *Odontomachus* (Formicidae) sebagai satu semut pemangsa khas berkaitan dengan batang kelapa sawit yang diracik dan tumbuhan berguna *T. subulata*. Parasitoid *Xanthopimpla* menunjukkan perbezaan terhadap perubahan kelimpahan pada rumpai liar semasa penggunaan racun rumpai antara ladang kelapa sawit berumur tiga dan enam tahun, masing-masing dengan corak penurunan dan peningkatan kelimpahan. Ladang kelapa sawit berumur 18 tahun menunjukkan peningkatan corak kelimpahan hanya pada fasa penggunaan baja kimia yang berbeza. Kepentingan kepelbagaian rumpai liar, kekangan tanaman legum penutup bumi, kekerapan penggunaan racun rumpai dan susunan antara tumbuhan berguna dan mikrohabitat berasaskan kayuan yang memberikan manfaat kepada serangga parasitoid dan pemangsa dibincangkan.*

*Kata kunci: Kelapa sawit; mikrohabitat; parasitoid; pemangsa; penggunaan*

### INTRODUCTION

Diversity statuses of organisms within oil palm agroecosystem have been in arguments since more than a decade ago (Edwards et al. 2010; Fitzherbert et al.

2008; Koh 2008; Koh & Wilcove 2008, 2007), with more emphasized given to the groups of vertebrates than invertebrates (Aratrakorn et al. 2006; Maddox et al. 2007), although extensive biodiversity and ecological studies have been done on invertebrates, primarily to insect

groups (Bong et al. 2012; Brühl & Eltz 2010; Chung et al. 2000; Liow et al. 2001). Most studies done were related to different taxa and of different oil palm plots, focusing on any existing forest-related microhabitats within oil palm plantations that could support diversity and species persistence (Fayle et al. 2010; Turner & Foster 2009).

Since the formation of the Roundtable on Sustainable Palm Oil (RSPO) in 2004 for the purpose of monitoring management processes related to producing a more sustainable palm oil globally, there are eight main principles and related criteria updated annually, and the fifth principle is related to the environmental responsibility and conservation of natural resources and biodiversity (RSPO 2013). Furthermore, in recent years, Malaysia has formed the Malaysian Sustainable Palm Oil (MSPO), supporting the smallholders to have official certifications in the production and exportation of palm oils (Ng 2016), and similar to RSPO, has one of the principles related to the maintenance of biodiversity.

However, the least comprehend aspect is the overlapping between oil palm plantations' management practices and impacts on biodiversity, as for both RSPO and MSPO, management practices for growers and the maintenance of biodiversity are listed separately, making direct comparisons between the two to be unclear and imprecise (Azhar et al. 2015, 2011). The findings from researchers concerned with forest-specific microhabitats, while for managers and growers more concerned about management practices, has formed a large gap in understanding the exact nature of management impacts on diversity, and microhabitat as an element that connected the two factors (Mehrabi et al. 2014).

The most quintessential step in understanding the influences of general oil palm plantations' management practices is to search for key indicator species (Lindenmayer et al. 2000). Some insect species are more sensitive to environmental changes than others, becoming important ecological indicators for many ecologists (Idris et al. 2003; Ng & Idris 2015). Apart from focusing on any existing or remnants of forest-related microhabitats, or at least any importation of forest-related structures into oil palm agro-ecosystem landscapes (Chung et al. 2000), it is more crucial to delve in-depth pertained to oil palm specific microhabitats (Ahmad Bukhary et al. 2017a). Hence, this study is done to elucidate the impacts of oil palm management practices exclusively to parasitoid and predator insects inhabiting oil palm-specific microhabitats as key indicators, and related microhabitats' capacity to sustain diversity through species persistence.

## MATERIALS AND METHODS

Field samplings were done at Felda Sungai Tekam oil palm plantations, Jerantut, Pahang, from February 2013 to February 2014. Five oil palm age stand types were chosen, viz., less than a year old (N03°54'592" E102°31'502"), three years old (N03°54'052" E102°32'062"), six years old (N03°54'253" E102°32'184"), 18 years old (N03°53'592" E102°31'482"), and 23 years old (N03°55'024" E102°30'482"). Total area (m<sup>2</sup>) covered by one oil palm age stand was 100 m length × 100 m width. Each age stand has four plot replicates of similar total area covered. Collection of insect parasitoids and predators involved the employment of the Malaise trap (MT), the passive pit-fall trap (PPT), and the newly modified pit-light trap (MPLT) (Ahmad Bukhary et al. 2017b) from earlier designs invented by Heap (1988) and redesigned by Hébert et al. (2000). Four MT and MPLT units, as well as 100 PPT units were employed per one plot replicate per oil palm age stand type. Samplings were done in two sessions per sampling month, with one sampling session equal to one week. Additional sampling sessions were done to any sampling months with heavy rainfalls, related to either severely damaged traps (MTs) or samples missing due to heavy flooding (PPTs and MPLTs).

Insect samples were brought to the entomological laboratory for sorting purposes. Predators from all known orders were sorted first, then followed by hymenopteran and dipteran parasitoids. Insect predators and dipteran parasitoids were identified based on Borror and White (1970), Hashimoto (2003), and Triplehorn and Johnson (2005). Hymenopteran parasitoids were identified based on Goulet and Hubert (1993). Several unidentified species were assigned as morpho-species following known subfamilies (Krell 2004). Five insect predators and parasitoids per species or morpho-species were pinned by implementing entomological pins and referred as the representative sample. Microhabitats were categorized as either vegetation-type (natural weeds, leguminous cover crops, beneficial plants) or wood-based (chipped oil palm trunks, empty fruit bunches, rotting fronds).

Natural weeds (NW) and leguminous cover crops (LCC) were quantitatively measured using a standard 1 m × 1 m quadrat (Dodd 2011; Krebs 1999), 50 quadrat units per oil palm plot per age stand type, arranged in a systematic grid (5 quadrat units per row grids of 7 m apart, and 10 quadrat units per column grids; 9 m apart) with total area covered of 49 m length × 108 m width. Standard measuring tape was used to measure the area covered by both NW and LCC for each quadrat unit. Beneficial

plants were measured in two ways; a. based on standard volume formula ( $m^3$ ) and b. floral structures density per length covered (Eberhardt 1978). Piles of chipped oil palm trunks, empty fruit bunches, and rotting fronds followed the standard volume formula ( $m^3$ ).

Relationships of parasitoid and predator communities with respective microhabitats were assessed implementing parametric Canonical Correspondence Analysis (CCA) using PC-ORD software version 6.0 (McCune & Mefford 2011), with prior monotonic fourth-root ( $^{0.25}\sqrt{\phantom{x}}$ ) transformation of main matrix species abundance data using IBM SPSS software version 24.0 (IBM Corp. 2016). Appropriate ordination axes were selected based on percentage of variance in distance matrix. Correlations with the main and second matrices were paralleled to observe relationships between species and variables of similar axes (McCune & Mefford 2011; Peck 2010). Abundance differences of selected insect parasitoid and predator

species per different management activity phases were evaluated based on One-Way ANOVA with Tukey's *post hoc* tests separately for herbicides and chemical fertilizers with abundance transformed following the formula  $\log_{10}(x + 1)$  using Minitab software version 17.1.0 (Minitab 2013).

## RESULTS

A total of 11 families, 20 subfamilies, and 41 species recorded for insect parasitoid, and 12 families, 22 subfamilies, and 40 species recorded for insect predators. Relationships among solitary parasitoids with vegetation-type microhabitats according to CCA for Axis 1 showed that *Xanthopimpla*-sp1 (Figure 1), *Xanthopimpla*-sp2 (Figure 2), and *Pompilus*-sp1 (Figure 3) were related to natural weeds, leguminous cover crops, and the beneficial plant *T. subulata*, while for Axis 2, *Pompilus*-sp2 was correlated to the beneficial plant *A. leptopus* (Table 1).



FIGURE 1. *Xanthopimpla*-sp1 (Ichneumonidae: Pimplinae)

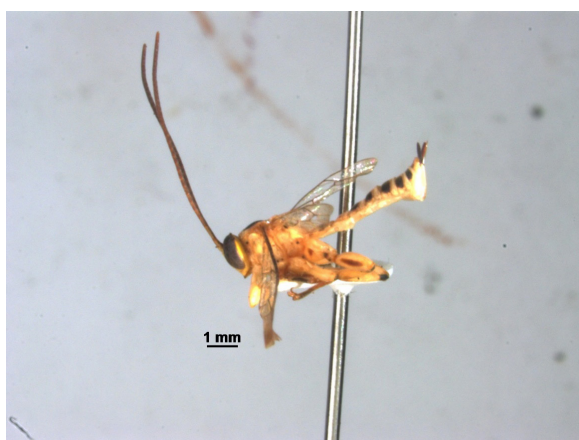


FIGURE 2. *Xanthopimpla*-sp2 (Ichneumonidae: Pimplinae)

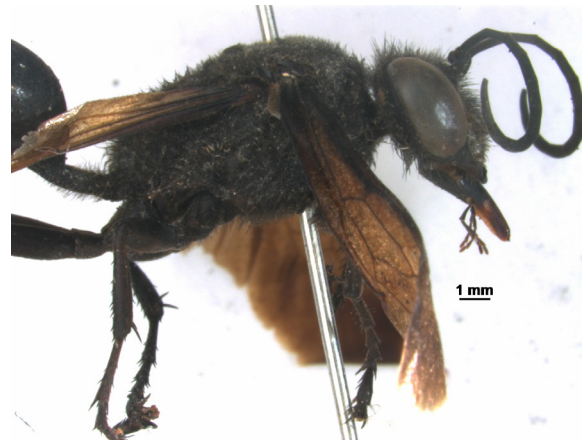
FIGURE 3. *Pompilus*-sp1 (Pompilidae: Pompilinae)

TABLE 1. Canonical Correspondence Analysis (CCA) for insect parasitoid community to vegetation-type microhabitats within different oil palm age stands

Species	Axis 1			Axis 2		
	r	r <sup>2</sup>	τ	r	r <sup>2</sup>	τ
<i>Xanthopimpla</i> -sp1	<b>0.775</b>	<b>0.723</b>	<b>0.544</b>	0.308	0.095	-0.166
<i>Xanthopimpla</i> -sp2	<b>0.751</b>	<b>0.873</b>	<b>0.641</b>	0.462	0.214	-0.230
<i>Pompilus</i> -sp1	<b>0.781</b>	<b>0.739</b>	<b>0.617</b>	0.079	0.006	0.102
<i>Pompilus</i> -sp2	0.047	0.002	-0.088	<b>-0.725</b>	<b>0.888</b>	<b>-0.573</b>
Microhabitat(s)						
NW‡	<b>-0.739</b>	<b>0.709</b>	<b>-0.533</b>	-0.366	0.134	-0.047
LCC‡	<b>0.783</b>	<b>0.713</b>	<b>0.583</b>	-0.458	0.210	-0.120
ANTlep‡	0.157	0.025	0.285	<b>-0.839</b>	<b>0.704</b>	<b>-0.712</b>
TURsub‡	<b>0.817</b>	<b>0.768</b>	<b>0.597</b>	0.458	0.210	0.489

Note: Bold letters and numbers showed highly correlated species to respective microhabitat(s)

‡NW: natural weeds; LCC: leguminous cover crops; ANTlep: *Antigonon leptopus*. TURsub: *Turnera subulata*

For predatory insects, *Odontomachus*-sp1 (Figure 4) was the only one predatory ant species, related to natural

weeds and the beneficial plant *T. subulata* as of CCA in Axis 2 (Table 2).

TABLE 2. Canonical Correspondence Analysis (CCA) for insect predator community to vegetation-type microhabitats within different oil palm age stands

Species	Axis 2			Axis 3		
	r	r <sup>2</sup>	τ	r	r <sup>2</sup>	τ
<b><i>Odontomachus</i>-sp1</b>	<b>0.888</b>	<b>0.746</b>	<b>0.657</b>	-0.097	0.009	-0.014
Microhabitat(s)						
<b>NW</b> ‡	<b>-0.736</b>	<b>0.742</b>	<b>-0.583</b>	0.155	0.024	0.259
<b>LCC</b> ‡	0.232	0.054	0.005	<b>-0.754</b>	<b>0.868</b>	<b>-0.748</b>
<i>ANTlep</i> ‡	-0.283	0.080	-0.227	0.339	0.115	0.035
<b><i>TURsub</i></b> ‡	<b>0.865</b>	<b>0.748</b>	<b>0.562</b>	-0.504	0.254	-0.398

Note: Bold letters and numbers showed highly correlated species to respective microhabitat(s)

‡NW: natural weeds; LCC: leguminous cover crops; *ANTlep*: *Antigonon leptopus*. *TURsub*: *Turnera subulata*



FIGURE 4. *Odontomachus*-sp1 (Formicidae: Ponerinae)

For wood-based microhabitats and relationships among solitary parasitoids, *Casinaria*-sp1, *Evania*-sp1 (Figure 5) and *Evania*-sp2 (Figure 6) were related to oil

palm chipped trunks as in Axis 2, and *Xanthopimpla*-sp3 was related to empty fruit bunch piles as of CCA in Axis 3 (Table 3).

TABLE 3. Canonical Correspondence Analysis (CCA) for insect parasitoid community to wood-based microhabitats within different oil palm age stands

Species	Axis 2			Axis 3		
	r	r <sup>2</sup>	τ	r	r <sup>2</sup>	τ
<i>Xanthopimpla</i> -sp3	-0.063	0.004	-0.081	<b>0.723</b>	<b>0.836</b>	<b>0.624</b>
<i>Casinaria</i> -sp1	<b>0.817</b>	<b>0.867</b>	<b>0.525</b>	-0.118	0.014	0.085
<i>Evania</i> -sp1	<b>0.739</b>	<b>0.722</b>	<b>0.543</b>	-0.144	0.021	-0.115
<i>Evania</i> -sp2	<b>0.808</b>	<b>0.771</b>	<b>0.664</b>	-0.096	0.009	-0.013
Microhabitat(s)						
OPCT‡	<b>0.704</b>	<b>0.896</b>	<b>0.585</b>	-0.168	0.028	0.339
EFBP‡	-0.042	0.002	-0.067	<b>0.999</b>	<b>0.997</b>	<b>0.614</b>
RFP‡	0.273	0.074	0.365	-0.015	0.000	-0.510

Note: Bold letters and numbers showed highly correlated species to respective microhabitat(s)  
‡OPCT: oil palm chipped trunks. EFBP: empty fruit bunch piles. RPF: rotting frond piles



FIGURE 5. *Evania*-sp1 (Evaniiidae: Evaniinae)

FIGURE 6. *Evania*-sp2 (Evaniidae: Evaniinae)

For predatory insects, *Odontomachus*-sp1 and *Paederus*-sp1 both were related to oil palm chipped trunks as of CCA in Axis 2 (Table 4).

TABLE 4. Canonical Correspondence Analysis (CCA) for insect predator community to wood-based microhabitats within different oil palm age stands

Species	Axis 2			Axis 3		
	r	r <sup>2</sup>	τ	r	r <sup>2</sup>	τ
<b><i>Paederus</i>-sp1</b>	<b>0.728</b>	<b>0.894</b>	<b>0.598</b>	0.033	0.001	0.076
<b><i>Odontomachus</i>-sp1</b>	<b>0.776</b>	<b>0.702</b>	<b>0.578</b>	-0.074	0.005	-0.025
Microhabitat(s)						
<b>OPCT‡</b>	<b>0.989</b>	<b>0.977</b>	<b>0.614</b>	-0.049	0.002	0.044
<b>EFBP‡</b>	-0.155	0.024	0.093	<b>0.925</b>	<b>0.855</b>	<b>0.602</b>
RFP‡	-0.351	0.123	0.176	0.242	0.059	0.395

Note: Bold letters and numbers showed highly correlated species to respective microhabitat(s)

‡OPCT: oil palm chipped trunks. EFBP: empty fruit bunch piles. RFP: rotting frond piles

One-way ANOVA showed that only three solitary parasitoid species, viz., *Xanthopimpla*-sp1 (NW; three years old; F = 7.32, d.f. = 2, p = 0.013; six years old; F = 4.70, d.f. = 2, p = 0.040; LCC; less than one year old; F =

5.67, d.f. = 2, p = 0.026; *TURsub*; less than one year old; F = 5.67, d.f. = 2, p = 0.026), *Xanthopimpla*-sp2 (LCC; less than one year old; F = 8.04, d.f. = 2, p = 0.010; *TURsub*; less than one year old; F = 8.04, d.f. = 2, p = 0.010) and

*Pompilus*-sp1 (NW; three years old;  $F = 8.10$ , d.f. = 2,  $p = 0.010$ ; LCC; less than one year old;  $F = 6.31$ , d.f. = 2,  $p = 0.019$ ; *TURsub*; less than one year old;  $F = 6.31$ , d.f. = 2,  $p = 0.019$ ), significantly have fluctuating abundance related to vegetation-type microhabitats as mentioned, according to different herbicide application phases (Table 5).

*Evania*-sp1 (OPCT; less than one-year-old;  $F = 11.98$ , d.f. = 2,  $p = 0.003$ ) and *Evania*-sp2 (OPCT; less than one year old;  $F = 5.53$ , d.f. = 2,  $p = 0.027$ ) showed fluctuated abundances specifically related to oil palm chipped trunks (Table 5).

*Odontomachus*-sp1 was the only predatory ant species showing abundance fluctuations related to *T. subulata* (*TURsub*; less than one year old;  $F = 11.12$ , d.f. = 2,  $p = 0.004$ ) and oil palm chipped trunks (OPCT; less than one year old;  $F = 11.12$ , d.f. = 2,  $p = 0.004$ ) (Table 5). For different phases of chemical fertilizer applications, *Xanthopimpla*-sp1 showed fluctuated abundance related to natural weeds of 18 years old oil palm stand (NW; 18 years old;  $F = 6.52$ , d.f. = 2,  $p = 0.018$ ), while *Pompilus*-sp1 showed fluctuated abundance related to *T. subulata* (*TURsub*; less than one year old;  $F = 4.79$ , d.f. = 2,  $p = 0.038$ ) (Table 6).

TABLE 5. Abundance differences based on microhabitat utilizations by solitary wasp and predatory ant species according different phases of herbicide application

Microhabitat(s)	Species	Management type: Herbicide application		
		Management phases		
	Parasitoid	pre-	during-	post-
<b>NW‡</b>				
Three years old	<i>Xanthopimpla</i> -sp1	20.18 ± 2.46a	6.49 ± 3.74b	5.25 ± 2.83b
	<i>Pompilus</i> -sp1	21.81 ± 6.36a	2.75 ± 2.75b	1.18 ± 0.91b
Six years old	<i>Xanthopimpla</i> -sp1	3.05 ± 1.69a	2.00 ± 0.82a	7.81 ± 1.61b
<b>LCC‡</b>				
< One year old	<i>Xanthopimpla</i> -sp1	6.06 ± 0.61a	1.25 ± 0.95b	5.42 ± 1.53a
	<i>Pompilus</i> -sp1	45.96 ± 4.47a	5.50 ± 5.17b	24.30 ± 12.20a
Three years old	<i>Xanthopimpla</i> -sp2	28.07 ± 2.05a	3.64 ± 2.11b	29.17 ± 7.16a
<b>TURsub‡</b>				
< One year old	<i>Xanthopimpla</i> -sp1	6.06 ± 0.61a	1.25 ± 0.95b	5.42 ± 1.53a
	<i>Xanthopimpla</i> -sp2	32.07 ± 3.07a	4.75 ± 2.95b	32.12 ± 8.65a
	<i>Pompilus</i> -sp1	45.96 ± 4.47a	5.50 ± 5.17b	24.30 ± 12.20a
<b>OPCT‡</b>				
< One year old	<i>Evania</i> -sp1	14.25 ± 1.25a	12.24 ± 3.39b	0.75 ± 0.48a
	<i>Evania</i> -sp2	26.37 ± 2.82a	4.00 ± 3.67b	14.76 ± 6.81a

Note: Mean ± S.E. abundance values with different letters were significantly different from each other, based on One-Way ANOVA and Tukey's *pos hoc* tests at 95% confidence level

‡NW: natural weeds; LCC: leguminous cover crops; *TURsub*: *Turnera subulata*; OPCT: oil palm chipped trunks



TABLE 6. Abundance differences based on microhabitat utilizations by solitary wasp species according different phases of chemical fertilizer application

Microhabitat(s)	Species	Management type: Chemical fertilizer application		
		Management phases		
	Parasitoid	pre-	during-	post-
<b>NW‡</b>				
18 years old	<i>Xanthopimpla</i> -sp1	1.81 ± 0.28a	1.75 ± 0.89a	3.29 ± 0.61b
<b>TURsub‡</b>				
< One year old	<i>Pompilus</i> -sp1	45.96 ± 4.47a	5.50 ± 5.17b	24.30 ± 12.20a

Note: Mean ± S.E. of abundance values with different letters were significantly different from each other, based on One-Way ANOVA and Tukey's *post hoc* tests at 95% confidence level

‡NW: natural weeds; TURsub: *Turnera subulata*

#### DISCUSSION

Five out of 41 parasitoid (12.20%) insect species and one out of 40 predatory (2.50%) insect species showed definite utilization on oil palm agroecosystem-specific microhabitats, verifying the notion that most insect species found within oil palm plantations were migrated temporarily from any nearest primary or secondary forest ecosystems (Lucey & Hill 2012; Lucey et al. 2014), of the fact that most resources for eusocial wasps in the form of flowering plants that produced nectar and pollen sources (Marino & Landis 1996) were much limited within oil palm plantations compared to forest ecosystems (Beggs 2001; Frost et al. 2015). This study emphasized two characteristics of insects' behavioural ecological aspects, primarily described as the ability to adapt to oil palm agroecosystem-specific microhabitats, and secondly the capacity to adapt to introduced environmental disturbances of oil palm-specific management activities of such microhabitats, reflected by most *Xanthopimpla* wasp species (Idris et al. 2003, 2001). The former notion however, is resource-dependent, and marked some characteristics of particular insect species that have the higher capacity to rapidly utilize any available resources and able to compete successfully with other less abundant species, increasing the pressure of inter-specific competitions, hence reducing overall species diversity (Fayle et al. 2010; Turner & Foster 2009; Wang & Foster 2016), reflected by *Odontomachus* ant species (Fowler 1980; Oliveira et al. 2011).

Solitary wasps other than *Xanthopimpla* sp., viz. *Pompilus* sp. and *Evania* sp. are more host-oriented (Klassen & Sharanowski 2014; Punzo 2005), with several physiological restrictions (Tee & Lee 2015), where the disturbance on vegetation structures around the epigeal level of oil palm plantations and the available piled wood-based microhabitats promoted the fluctuations in the abundances of host spiders (Bell et al. 2001; Churchill 1997) and wood cockroaches (Horn & Hanula 2002), respectively. Ensign wasps of the family Evaniidae, although not a specific parasitoid of any known oil palm herbivorous pests, were found to be highly abundant within oil palm plantations as egg parasitoids of wood cockroaches (Bandung et al. 2019). Both *Odontomachus* sp. and *Xanthopimpla* spp. served as non-host-oriented environmental indicators, which is an essential characteristic as ecological indicators (Lindenmayer et al. 2000).

According to Norman and Othman (2016), *Xanthopimpla* spp. parasitoids can only be found around the oil palm plantations but not specifically found on beneficial flowering plants, where most chalcids (*Brachymeria lasus*, *B. carinata*, and *B. lugubrious*), along with braconids (*Apanteles aluella* and *Dolichogenidea metesae*), parasitoids of the bagworm pest, dominating the beneficial plants, hence further proving that *Xanthopimpla* spp. wasps were not host-oriented in utilizing the oil palm microhabitats, as well as depicting avoidance behaviour from other more highly abundant and social wasps. It is

important to note that during the duration of this study, all the selected oil palm plantations were not infested by the bagworm pest, hence explaining why *Xanthopimpla* spp. wasps were significantly related to the available microhabitats. This study also not recording any individuals of the subfamily Microgastrinae, justifying the absence of the desired host species, and hence reducing the probability that bagworm specific parasitoids to utilize any available microhabitats. However, one species of the subfamily Chalcidinae, although not related to any of the oil palm-specific microhabitats based on the statistical analyses, was present with moderate in abundance, suggesting that this either could be any of the species of the genus *Brachymeria* (Norman & Othman 2016).

Other studies also showed that *Xanthopimpla* spp. could be possible minor parasitoid regulating the bagworm pest populations, along with other major parasitoids such as *Brachymeria* sp., *Apanteles* sp., and *Pediobius* sp. (Kalidas 2012; Sankaran & Syed 1972), suggesting that no record on the infestation of bagworm pest during the duration of this study could explain the significant relationships between *Xanthopimpla* spp. with other available microhabitats. It is important to note that this study was not design to assess the microhabitats' utilizations of any specific parasitoids or predators of particular oil palm insect pests, rather to evaluate the microhabitat utilizations of predators and parasitoids neutrally and naturally without the presence of specific desired pest species that could produce the 'pulling' effect on the parasitoids and predators. The findings of this study suggested that *Xanthopimpla* spp., with the dual nature of becoming the solitary parasitoid of bagworm pest, and avoiding other more abundant bagworm parasitoids, could be one of the essential species that indicate the presence-absence of bagworm infestations, along with the novel additional attribute as an indicator for the readiness of oil-palm specific microhabitats, such as beneficial flowering plants, to be utilized by other insects not specific as predators and parasitoids of bagworm pest. There is a possibility that most of major bagworm's parasitoids to be dispersed to nearest secondary forest habitats with higher nectar productivity, and presence of any lepidopteran larval forest defoliators, driving the dispersal activities (Frost et al. 2015), providing *Xanthopimpla* spp. wasps available opportunity to utilize available oil palm-specific microhabitats.

The microhabitat types and their arrangements currently existing within oil palm plantations are primarily focused on oil palm plantations' management feasibility

and productivity (Samedani et al. 2015, 2014), such as providing natural organic fertilizers (Abu Hassan 2006) and increasing efficacy of biological control agents (Basri et al. 1999). Unfortunately these management-oriented microhabitats do not necessarily to be pragmatically habitable to most other wasps species unless under circumstances of the presence of certain specific host pest species (Heimpel & Jervis 2004; Lewis et al. 1998), or preferred nectar-producing vegetation structures (Idris & Grafius 1995; Idris & Zaneedarwaty 2000), different from *Xanthopimpla* spp. wasp with the characteristics to adapt to environmental disturbances. This study proved that the presence-absence patterns of other wasps' species within oil palm agroecosystem to be of ephemeral in nature, and no clear stable wasps' community can be observed to be significantly adapting and utilizing the existing microhabitats. In fact, the beneficial plants *A. leptopus* has not exhibit any abundance fluctuations according to different phases of herbicide and chemical fertilizer applications, yet on the other hand *T. subulata* has been observed from this study as to be dominated by *Odontomachus* sp., recording the highest abundance during herbicide spraying processes, departed from empirical expectations of any active flying wasps' species to be the more desired indicators.

*Xanthopimpla* sp. as solitary wasp is an essential environmental indicator to quantify the capacity of oil palm agroecosystem in supporting insect species diversity and persistence, marked by the differential fluctuations of *Xanthopimpla* sp. abundances according to different oil palm age stands paralleled to different microhabitat structures and management activities, as of previous studies showed the capacity of *Xanthopimpla* sp. as primary indicators for disturbed forest ecosystems (Idris & Kee 2002; Ng & Idris 2015). Another essential characteristic of *Xanthopimpla* sp. evident from this study is that this wasp species has the ability to be an indicator for different management activities related to different oil palm age stand types, notably the 18 years old oil palm age stands, with increased abundance after chemical fertilizer applications, while for three and six years old oil palm stands are more specific to the herbicides applications, with opposing directions of *Xanthopimpla* sp. abundance fluctuations.

Furthermore, one fascinating finding of this study is that dominant predatory ant *Odontomachus* sp., utilized both closely arranged vegetation-type and wood-based microhabitats, compared to previous researches that showed the primary importance of most wood-based

microhabitats (Ahmad Bukhary et al. 2017a) or vegetation-type microhabitats as the drivers for inter-specific competitions among ant species in disturbed areas (Fayle et al. 2010). Suitability of beneficial plant species as an element of vegetation-type microhabitats is essential in alleviating the rapid colonisations of highly dominant ant predators, promoting the persistence of other less dominant species (Ahmad Bukhary et al. 2017a; Mehrabi et al. 2014). *Odontomachus* sp. has been recorded to be existed in oil palm plantations (Nor Rasidah et al. 2010), and to be one of the ant species known to be highly abundant within oil palm plantations, and the sole species existed in most oil palm plantations is *Odontomachus simillimus* (Darmi et al. 2015; Nor Rasidah et al. 2010).

This study emphasized the importance between two inter-related factors that determined the stability of natural weeds community, the coverage of the canopy level, related to light penetration to the plantations' floors and overlapping of frond complexes, and spatial restrictions, related to the interactions of natural weed species with the planted leguminous cover crops. The oil palm of the age six years old has no spatial restrictions, referring to the absence of overlapping leguminous cover crops and expected to have higher weed species diversity, hence attracting more wasp species. However, since *Xanthopimpla* sp. showed higher abundance after the application of herbicides, it can be noted that the oil palm of the age six years old has lower natural weeds diversity compared to three years old oil palm stand, even with the presence of spatial restrictions by the leguminous cover crops (Mohamad et al. 2010). It can be hypothesized that, with the adequate amount of sunlight penetrating the plantations' floors, even with spatial restrictions, could promote natural weed species to diversify further compared to the plantations with fully covered canopy layers, with less capacity to diversify even without spatial restrictions (Essandoh et al. 2011). From the two factors mentioned, light penetration to the plantations' floors is superior to any spatial restrictions for promoting weed species diversity. Highly diverse weed species community alleviating inter-specific competitions, hence enabling any solitary wasps that are not adapted to the presence of other more abundant wasp species, including eusocial wasps, to persist and utilizing nectar resources without confined interactions.

The oil palm of the age 18 years old, although with overlapped frond complexes, but higher trunks' height, enabling sunlight to penetrate the plantations' floors diagonally, producing higher capacity for weed species diversification, marked by increased *Xanthopimpla* sp.

abundance, and by the application of chemical fertilizers that might have accidental leaching process to the other parts of the plantations' floors, giving higher capacity and additional nutrients for the natural weeds' population growth. Marino and Landis (1996) had stressed about the importance of maintain vegetation complexes and diversity levels for the sustenance of wasps' species, reducing inter-specific competitions and promoting species co-occurrence, referring to the combination of all vegetation-type microhabitats in supporting insect species. This notion included that the presence of natural weeds as an important element for the long-term sustainable management of insect species diversity within oil palm plantations, and at the same time marking for actual insect species adapted to oil palm-specific microhabitats.

The combination of the right beneficial plant species, natural weeds, and leguminous cover crops collectively are all contributed to structural vegetation diversity, enhancing the probability to increase insect species diversity. The importance of each microhabitat with respective threshold and capacity measured as total surface area per volume to support differential species presence and persistence (Ranius & Fahrig 2006). It is suggested from this study that, oil palm managers and workers should set new rules and regulations in managing existing natural weeds, where focusing on centralized or topical spraying patterns with least drifting effects as to conserve more flowering weeds on area-wide spatial scales. Similarly, spraying of herbicides must not depend on the thickness or volume of the natural weeds, but must paired with qualitative assessments and observations for the existing natural flowering weed species before spraying processes can be commenced as to achieve the balance between natural weeds management and conservation. Attractive and supportive microhabitats are important for stable assemblages of species, hence increasing the stability of food webs and species persistence, naturally rectifying diversity statuses (McCann 2000).

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