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Tree Diversity Enhance Species Richness of Beneficial Insect in Experimental Biodiversity Enrichment in Oil Palm Plantation

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ABSTRACT

Integrating plantation landscape with vegetation/tree diversity has been proposed as a strategy to maintain crop production (for livelihood) while increasing biodiversity, habitat complexity and ecological functions. The objective of this research was to investigate the influence of tree biodiversity in experimental biodiversity enrichment in oil palm plantation to beneficial insects, especially ants and parasitoid wasps in the EFForTS-BEE research plot. Beneficial insects in experimental enrichment oil palm plantation are very important to be studied so that ecosystem services that are related with the changes of the plant structures over time can be understood better. Insect collections were done in two years, 2018 and 2019. Direct sampling was used to collect actual insects, pitfall traps to trap ground dwelling insects, yellow pan traps and malaise trap to trap low-flying insects, and sweep net to collect general insects. Overall, we collected 76 species of 6423 individual ants, and 174 morphospecies of 867 parasitoid wasps in this research. Abundance of ants and parasitoid wasps were not influenced either by tree diversity level in the plot nor the various plant diversity. In contrast, tree diversity level has strongly influenced species richness of ants and partially affected species richness of parasitoid wasps. In conclusion, there are positive correlation between ants' and parasitoid wasps' species richness and vegetation abundance.

Key words: *ants, conservation, ecosystem services, landscape, parasitoid*

INTRODUCTION

Increasing palm oil demands can threaten the existence of biodiversity since land use change to oil palm plantations has been shown to decrease species richness of many insects and birds (Prabowo *et al.* 2016; Grass *et al.* 2020; Nazarreta *et al.* 2020). Indonesia has the highest deforestation rate on tropical region in recent decades with an estimated 0.78% of total forest cover was lost between 2010 and

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2020 with primary forest cover loss mostly occurred in Sumatra Island (Margono *et al.* 2014; FAO 2020). Land-use transformation to oil palm plantation has affected the ecosystem services such as pollinations, pest controls, and carbon-nitrogen retention. Rainforest transformation to simplified oil palm monoculture has been shown to result in the decline of species richness in many insect taxa, such as ants (Nazarreta *et al.* 2020; Rizqulloh *et al.* 2021), parasitoid wasps (Tawakkal *et al.* 2020), and butterflies (Panjaitan *et al.* 2020). Furthermore, the loss of ecosystem services will certainly take human well-being at peril (Dislich *et al.* 2017).

Integration between maintaining crop production and biodiversity-friendly management is needed to accomplish sustainable oil palm management. Monoculture habitat modification into agroforestry has been proposed as a strategy to increase habitat complexity that may enhance biodiversity and ecological functions (Koh *et al.* 2009). Land-sharing strategy in agroecosystem by establishing an agroforestry ecosystem are crucial in a large-scale dominated agriculture landscape. The land sharing concept can maintain the diversity of ecosystem service while also maintain long-term stability of agriculture yield (Grass *et al.* 2019). Land-sharing strategy could conserve and restore the community and ecological function of pollinator (Hass *et al.* 2018) and natural biological control (Bianchi *et al.* 2006; Sann *et al.* 2018).

Establishing biodiversity island by planting various tree can restore habitat heterogeneity (Chazdon 2008; Koh *et al.* 2009) and also increase habitat complexity while accelerating biodiversity restoration in a large-scale plantation (Zahawi *et al.* 2012, Teuscher *et al.* 2016). The EFForTS Project established a large scale and long-term biodiversity enrichment experiment (EFForTS-BEE) on oil palm plantation in Jambi, Indonesia using six native tree species that were planted in the EFForTS-BEE sites, which includes tree-producing-fruits (*Parkisa speciosa* - Petai, *Archidendron pauciflorum* - Jengkol and *Durio zibethinus* - Durian), timber (*Peronema canescens* - Sungkai and *Shorea leprosula* - Meranti) and natural latex- producing trees (*Dyera polyphylla* - Jelutung) (Teuscher *et al.* 2016). Native fruit tree enrichment on large-scale oil palm plantation in Malaysia has been shown to be a positive impact on improving habitat heterogeneity and bird diversity (Yahya *et al.* 2022). Previous study also reported that biodiversity enrichment in oil palm plantation could enhance diversity on invertebrate community (Teuscher *et al.* 2016), however the results have not present the effect of biodiversity enrichment on beneficial insect community that lived in oil palm dominated landscape. Therefore, we would like to fill in this knowledge gap by investigating the influence of tree biodiversity enrichment in the EFForTS-BEE research plot to beneficial insect diversity, ant, and parasitoid wasp. We hypothesize that tree biodiversity enrichment will affect biodiversity of beneficial insect by increasing its abundance and species richness. We also expected that ant and parasitoid wasp abundance and species richness are affected by the number and type of vegetation that are grown in the plots.

MATERIALS AND METHODS

EFForTS-BEE research plot was established on PT Humusindo Makmur Sejati, Jambi Province, Sumatra - Indonesia and tree enrichment was started in December 2013 by planting six native tree species, including three trees for fruits (*P. speciosa, A. pauciflorum*, and *D. zibethinus*), two species for timber (*P. canescens* and *S. leprosula*), and a species for producing latex (*D. polyphylla*) (Teuscher *et al.* 2016). We used plots with various enrichment tree diversity levels (0, 1, 2, 3, and 6 species) and as many as four plots were chosen for replicates in each diversity level. The four plots varied in plot size (5 m x 5 m, 10 m x 10 m, 20 m x 20 m, and 40 m x 40 m). However, we only used the plots sized 40 m x 40 m on tree diversity level 1 and 2 due to insufficiency of other plot size in this level. We conducted field sampling on July 2018 and October 2019.

We used insect net for direct sampling, pitfall traps, yellow pan traps, and malaise trap to collect insect in the research plots. As many three transects of sweep net were conducted in each plot and we also installed four pitfall traps, four yellow pan traps, and a malaise trap in the plots for two days. The ants and parasitoid wasps were separated from the whole sample collection, then were identified until morphospecies level using morphological characters. We used Nazarreta *et al.* (2019) for ants identification guideline and Goulet and Huber (1993) for the parasitoid wasp. We did the same sampling methods for both 2018 and 2019 sampling campaigns.

The effect of tree diversity and plot size were investigated using generalized linear model (glm) with appropriate family and link functions. The appropriate models with the most important factor were selected using AIC (Aikake Information Criterium). The significant models were further tested using the HSD Tukey test at a 95% level of significance. Correlation between species richness of beneficial insect and number of vegetation was analyzed using Pearson correlation. All statistical analyses were performed using R v.4.0.5 (R Core Team 2020) using the following packages: vegan (Oksanen *et al.* 2019), ggplot2 (Wickham 2016), and multcomp (Hothorn *et al.* 2008).

RESULT AND DISCUSSION

In total, we collected 6423 individual of ants and 867 individuals of parasitoid wasp in this study. *Oligomyrmex* sp. is the most abundant of the ant's group that was found in this study (N=2960), followed by *Crematogaster* sp.1 (N=827) and *Pheidole* sp.1 (N=697). The most abundant parasitoid wasp which we collected was from Ichneumonidae family (N=202), followed by Scelionidae (N=145) and Encyrtidae (N=76). The abundance of ants was not influenced either by tree diversity level in the plot ($F_{4,14}$=1.89; p=0.18) (Figure 1a) nor the various plot size ($F_{3,11}$=0.13; p=0.94). The same pattern was found in parasitoid wasp, i.e., that its abundance was not enhanced by the tree diversity level ($F_{4,13}$=2.14; p=0.15) (Figure 1b) and plot size ($F_{3,10}$=1.19; p= 0.36).

In regards of species richness, we found 76 species of ants and 174 species from 22 families of parasitoid wasp in this research. Tree diversity level strongly influenced species richness of ants ($F_{4,14}$=1.38; p<0.01) (Figure 1c) and at the margin of statistical significance on parasitoid wasp species richness ($F_{4,13}$=3.19; p= 0.06) (Figure 1d). Both ants and parasitoid wasps had the lowest species richness in tree diversity level 0. The research plot that had been enrich with two and six tree species were found having the highest ant species richness. The average of ant species richness on tree diversity level 2 was 2.3 times higher and twice higher on the six-diversity level compared to the plot which had not conducted tree enrichment. In contrast to ant species richness, the highest average of parasitoid wasp

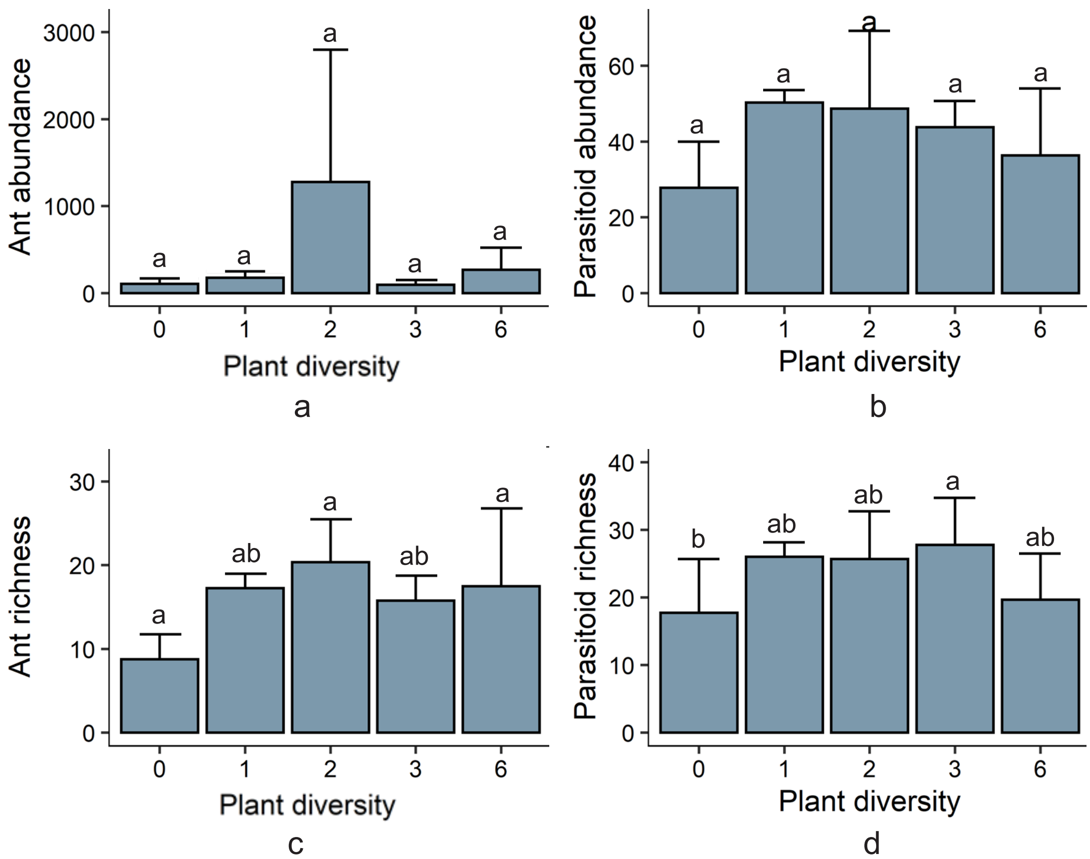

Figure 1 Ant abundance and species richness (a-b) and parasitoid wasp abundance and species richness (c-d) between plant diversity level. Different letters indicate significant differences using Tukey post hoc multiple comparisons at 95% confidence intervals.

richness was found on the plot which been enrich using three different native tree species. The average of parasitoid wasp species richness on the level 3 of tree diversity was 1.5 higher compared to the diversity level 0 plot. Parasitoid wasp species richness on the 1, 2, and 6 tree diversity levels were marginally lower to the tree diversity level, however they were partially higher compared to the level 0 enrichment plot.

We also found that the plot size enhanced species richness of ant ($F_{3,11}$=6.51, p<0.01) (Figure 2a) and parasitoid wasp ($F_{3,10}$=4.66, p<0.01) (Figure 2b). Beneficial insect species richness are higher following the size increase of the enrichment plot size. As beneficial insect species richness was influenced by the plant diversity level factor, we further investigated the correlation between the amount of vegetation in the study plots and species richness of ant and parasitoid wasp. Ant species richness was found significantly correlated with the amount of vegetation in the plots (R^2=0.49, p<0.05) (Figure 3a), in contrast the significant correlation was not find in parasitoid wasp species richness (R^2=0.29, p= 0.26) (Figure 3b). However, a positive trend relation between beneficial insect richness and various plant diversity was shown in this study.

This study investigated the impact of tree biodiversity enrichment on intensively managed oil palm plantation to diversity of ant and parasitoid wasp. The result showed contradict to our earlier hypothesis, the abundance of beneficial insect was not affected by the

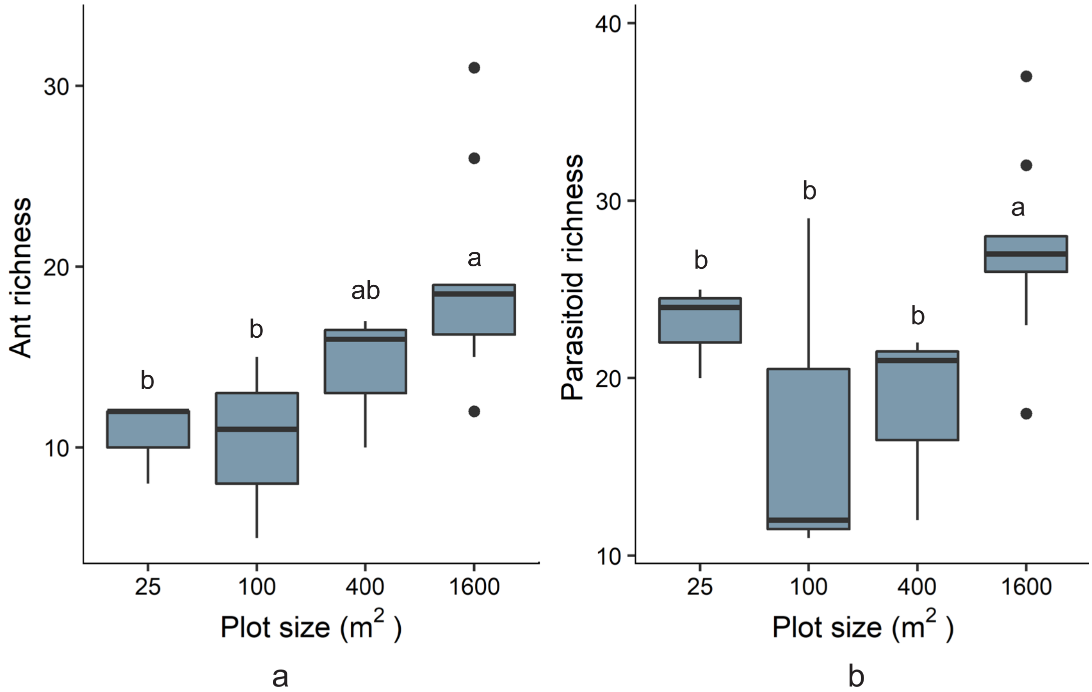

Figure 2 Species richness of ant (a) and parasitoid wasp (b) in various plot size area. Different letters indicate significant differences using Tukey post hoc multiple comparisons at 95% confidence intervals.

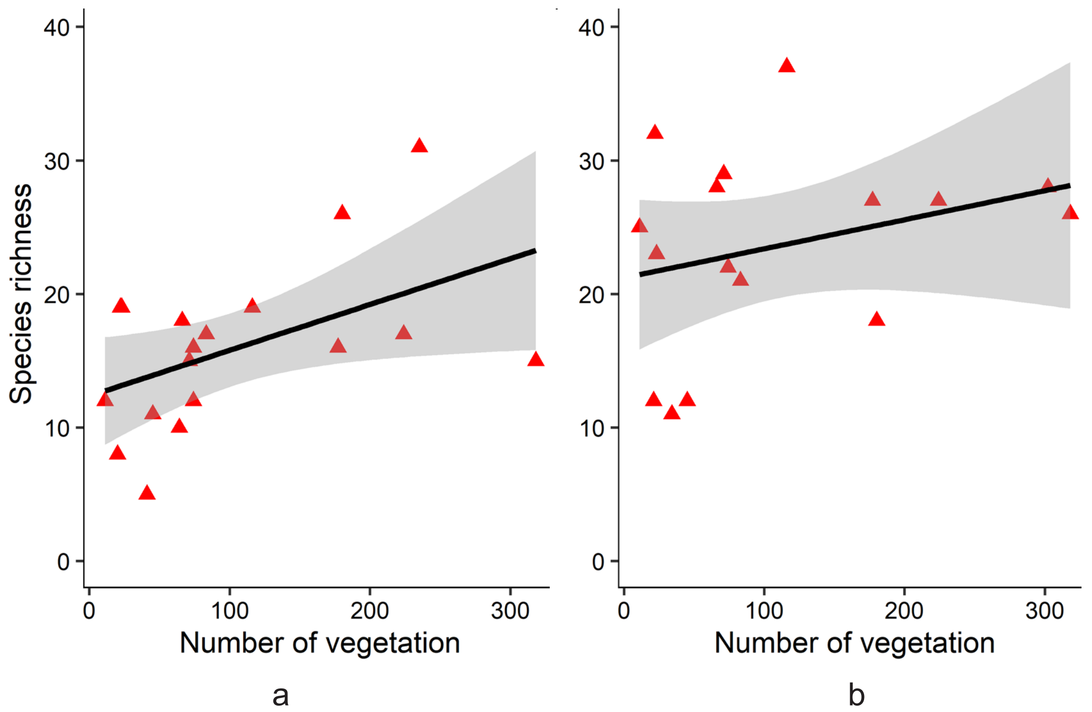

Figure 3 Correlation between species richness of ants (a) and parasitoid wasp (b) with amount of vegetation in biodiversity enrichment experimental plot.

enrichment experimental in oil palm plantation. These findings seems to be related to previous finding that insect abundance and biomass did not have significant effect with tree diversity level (Teuscher *et al.* 2016). In contrast, biodiversity enrichment contributed to increasing of ant and parasitoid wasp species richness. This indicates that tree enrichment could be used in the efforts of restoration and conservation of ant and parasitoid wasp species, as their population were found to be decreasing due to land use conversion to oil palm plantation (Drescher *et al.* 2016; Grass *et al.* 2020). By harboring high species richness of ant and parasitoid wasp, the enrichment plot could contribute to controlling pest population in the plantation. In the diverse system, the increasing natural enemies presence was followed by the decreasing in herbivore population and plant damages (Letourneau *et al.* 2011).

Species richness of ants was influenced by the increasing of habitat complexity and correlated with vegetation occurrence on oil palm plantation. Similar finding was shown on coffee plantation, that ants species richness had positive relation with vegetation complexity and its prey removal (De la Mora *et al.* 2015). Although prey diversity was not measured, we assumed that the missing prey contributed on the lack of ant richness in the plantation without tree biodiversity enrichment. The dominance of generalist nesting and predator ants in this research reminisce the result that shows establishing large scale monoculture oil palm plantation would shift the specialist ants (Luke *et al.* 2014; Kreider *et al.* 2021). Collecting high abundance of *Oligomyrmex* sp., *Crematogaster* sp.1, and *Pheidole* sp1 by using pitfall trap did not surprise us, since all species built their nest in soil. However, the litter leaf nesting species such as Hypoponera sp. were found in the highest tree diversity level plots. It might be explained that the increase of ant richness also correlated with the increase of leaf litter input (Gillison *et al.* 2003; Teuscher *et al.* 2016).

Similar to ant's pattern, the lowest parasitoid species richness was found on the plantation without tree biodiversity enrichment. We assumed the lowest parasitoid richness happened due to the low parasitoid-host interaction in non-diverse plots. Interspecific interaction were highly dependent on the presence or absence of other potential interaction partners (Tylianakis and Binzer 2014). Land use homogenization consequence homogenized network structure and alter the parasitoid and its resource community composition (Laliberté and Tylianakis 2010). Even though parasitoid species richness did not significantly correlate with vegetation number in oil palm plantation, the correlation line was shown a positive trend. It indicated that parasitoid occurrence in crop plantation could be increased by planting non-commodity plants in plantation, the other beneficial population insect will follow indeed.

CONCLUSION

This study represents the impact of having tree biodiversity enrichment in the dominating oil palm landscape. Ants and parasitoid wasp species richness showed an alteration by the enrichment experiment, and they have positive correlation between the species richness and amount of vegetation. Establishing tree island in oil palm dominated landscape could become the promising way of managing sustainable oil palm plantation contributing to biodiversity restoration and conservation. Furthermore, integrating agroforestry system on large-scale plantation will not only support biodiversity but sustainable production as well.

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Supplementary 1 Abundance and species richness of parasitoid wasp and ants collected from various tree diversity levels and plot size.

Diversity levels	Plot size (m^2)	Parasitoid		Ants	
		Abundance	Richness	Abundance	Richness
0	25	32	20	26	8
0	100	16	11	166	5
0	400	20	12	98	10
0	1600	43	12	137	28
1	1600	46	27	120	17
1	1600	51	26	205	15
1	1600	50	28	110	18
1	1600	54	23	269	19
2	1600	54	27	69	16
2	1600	66	32	777	19
2	1600	26	18	2985	26
3	25	36	24	80	11
3	100	48	29	35	15
3	400	40	21	162	17
3	1600	51	37	106	19
6	25	46	25	89	12
6	100	16	12	184	11
6	400	47	22	164	16
6	1600	125	58	641	31
Total		867	174	6423	76

Supplementary 2 Parasitoid wasp family's abundance and species richness across different biodiversity enrichment experiment levels. N= abundance, S= species richness.

Families	Tree diversity levels									
	0		1		2		3		6	
	N	S	N	S	N	S	N	S	N	S
Aphelinidae	1	1	2	2	0	0	0	0	1	1
Bethylidae	1	1	0	0	0	0	1	1	1	1
Braconidae	8	4	11	9	3	2	12	6	3	3
Ceraphronidae	11	6	10	5	5	5	28	7	27	6
Chalcididae	2	1	0	0	0	0	1	1	0	0
Diapriidae	8	1	6	3	15	5	7	4	17	3
Elasmidae	1	1	0	0	0	0	1	1	1	1
Encyrtidae	15	6	17	14	10	7	21	10	32	17
Eucoilidae	0	0	0	0	1	1	1	1	1	1
Eulophidae	17	8	3	3	6	3	14	7	16	8
Eurytomidae	0	0	0	0	1	1	0	0	2	1
Evaniidae	1	1	4	1	5	1	1	1	1	1
Figitidae	0	0	0	0	0	0	0	0	1	1
Ichneumonidae	5	4	99	14	68	12	26	11	26	9
Mymaridae	16	3	4	3	4	3	18	5	36	6
Mymarommatidae	0	0	0	0	0	0	1	1	1	1
Ormyridae	0	0	1	1	0	0	0	0	0	0
Platygastridae	4	3	1	1	1	1	6	5	6	3
Pteromalidae	0	0	1	1	0	0	2	2	4	3
Scelionidae	21	8	38	23	24	14	28	13	52	14
Torymidae	0	0	0	0	0	0	1	1	0	0
Trichogrammatidae	1	1	5	2	1	1	6	3	6	3