MONITORING PLANT-INSECT INTERACTIONS IN OIL PALM AGROECOSYSTEMS – a report for the Ferrero-SAN program: *Towards a Healthy & Biodiverse Oil Palm Production System*

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Executive summary

This research reveals the association of non-crop vegetation with insect communities in the oil palm landscape. Non-crop vegetation has the potential to increase and maintain beneficial insect populations to improve ecosystem services such as pollination, natural predation, and nutrient cycling. Previous work has highlighted the importance of flowering plants to attract beneficial insect species in the oil palm landscape: mainly parasitoid wasps and reduviid bugs. However, most plant species traditionally used have been non-native that are not locally viable especially as undergrowth vegetation. On the other hand, identifying plant species based on resource offered (shelter, nectar, pollen, alternative prey/host) is crucial to understand insect-plant interactions. Many insects are common inhabitants of oil palm agro-ecosystems and their potential role as biocontrol for herbivorous insects is underestimated. The present study surveyed arthropod communities looking at their assemblage on non-crop vegetation established as plant beds in oil palm smallholdings. In general, ten plant species (*Plectranthus monostachys, Melastoma malabathricum, Urena lobata, Ocimum basilicum, Clerodendrum paniculatum, Cassia tora, Vitex agnus-cactus, Vitex negundo, Euphorbia hirta* and *Duranta erecta*) represent the highest accumulation and extrapolation of beneficial arthropods, such as parasitoids, predators, scavengers, or decomposers in established plant beds. On the other hand, the eight understory plant species *Ageratum conyzoides, Euphorbia hirta, Nephrolepis biserrata, Lindernia crustacea, Ludwigia hyssopifolia, Cleome rutidosperma, Centotheca lappacea* and *Borreria setidens* represent a high accumulation of beneficial arthropods in control plots, demonstrating potential for future integrated understory management practices. A total of 141 families of arthropods belonging to 13 orders were recorded. Across all sites, the orders Diptera and Hymenoptera, represent the highest number of families (27 families) followed by Coleoptera and Hemiptera with 21 families each. Within the group of beneficial insects that support the control of insect pest populations, the potential biocontrol agents Cotesia *metasae* (Braconidae), *Goryphus bunoh* (Ichneumonidae), *Buysmania oxymora* (Ichneumonidae), and *Paraphylax* sp. (Ichneumonidae) were recorded across witness and experimental plots. The predatory insect species of long-legged flies *Dolichopodidae* sp. (Dolichopodidae), assassin bugs *Cosmolestes picticeps* (Reduviidae) and *Zelus* sp. (Reduviidae), robberflies *Ommatius* sp. (Asilidae) and tiger beetles *Neocollyris* sp. (Carabidae) were also registered. The research findings support the establishment of plant beds on oil palm farms with a variety of plant resources (shelter, nectar, pollen, alternative prey/host) and the selected understory management of host plants for beneficial insects, which should form part of a conservation biocontrol program to support greater arthropod biodiversity for an effective pest management in oil palm.

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Introduction

Only few studies have revealed the plant performance in function of maintaining beneficial insect populations. Insects perform crucial environmental tasks in both natural and human modified habitats. Across various agroecosystems, insects aid crop pest management through pollination and natural predation. Plants provide crucial resources in terrestrial food webs and interact with various insect groups. Using suitable plant communities, certain ecological conditions will be established that support the increase of beneficial insect populations. Plant-herbivorous insect interactions are influenced by plants that supplement different resources to insects: nectar, pollen, extrafloral nectaries and refuge. However, plant-herbivorous insect interactions vary considerably depending on offered resources. Intercropping flowering plants is a habitat management that can suppress pests via conservation biological control in agricultural systems, for example, through the establishment of plantings to provide alternative food sources and habitat for parasitoid and arthropod predators. However, the selection of these plants should meet specific traits to provide insect resources for shelter, nectar, alternative prey, and pollen. Thus, habitat management using suitable plant species is crucial to promote beneficial insect populations. In addition, the accurate evaluation of insect diversity and abundance also requires targeted sampling techniques that vary in terms of efficiency and effectiveness.

Objectives

This study assessed the influence of understory plant species on arthropod assemblages in oil palm agroecosystems.

The specific objectives were:

1. To compare the arthropod community composition and assemblage between experimental plots (oil palm cultivations with beneficial plant beds or "insect habitat islands") and witness plots (oil palm cultivations without beneficial plant beds – as control); and
2. To examine the influence of selected understory vegetation species on the beneficial and non-beneficial arthropod assemblages.

Methods

Study sites

The study surveyed eight oil palm monoculture smallholdings, comprised of two categories: four witness plots (Neoh Ah Seng - Plot ID 331, Mat Jailani - Plot ID 1533, Hor Kim Peow - Plot ID 1577, Razali - Plot ID 1691) and four experimental plots (Neoh Ah Seng – Plot ID 332, Chia Voon Hong – Plot ID 172, Razali – Plot ID 1690, Mat Jailani – Plot ID 1618) (Figure 1). All study farms selected for this study are participants of the Wild Asia Group Scheme (WAGS) BIO program which have been adopting agrochemical-free and regenerative agriculture practices. At each experimental plot, nine square block plant beds (3 m x 3 m) or three plant bed strips (3 m x 9 m) of beneficial plants were set up.

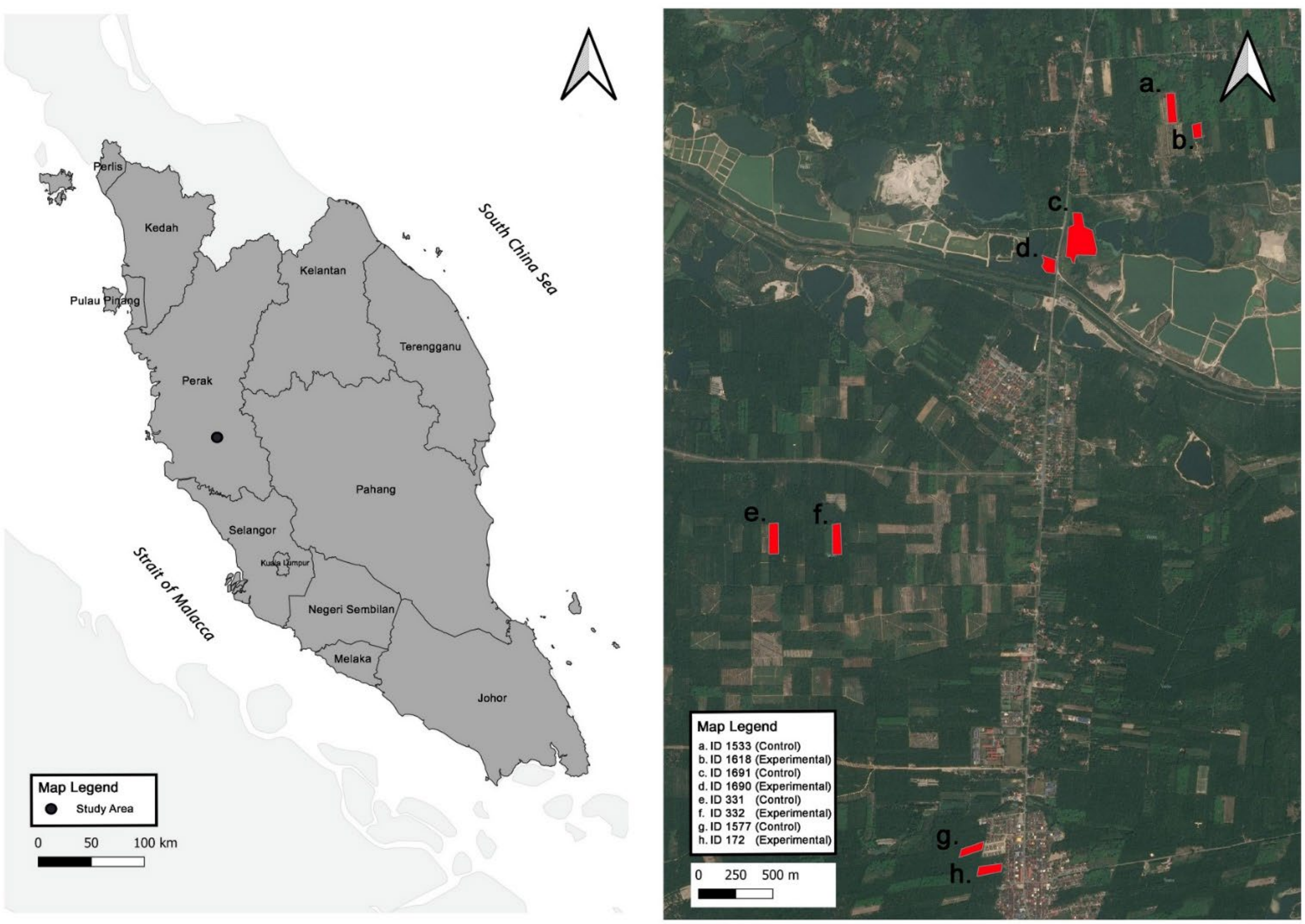


Figure 1. Map of Peninsular Malaysia showing the location of the control (witness) and experimental plots.

Sampling methods

For the current 2022 phase, a combination of active and passive sampling (Figure 2) techniques was carried out to optimize sampling efficiency and effectiveness. Each sampling technique has been carefully selected to increase the capture rates of the targeted insect groups (i.e., beneficial versus pest insects). All sampling methods were carried out on WAGS BIO farms within the plant bed squares and plant bed strips and WAGS BIO farms without plant beds/strips as control plots. Ten sampling squares were established on each farm. Data collection on farms was conducted between August and October 2022.

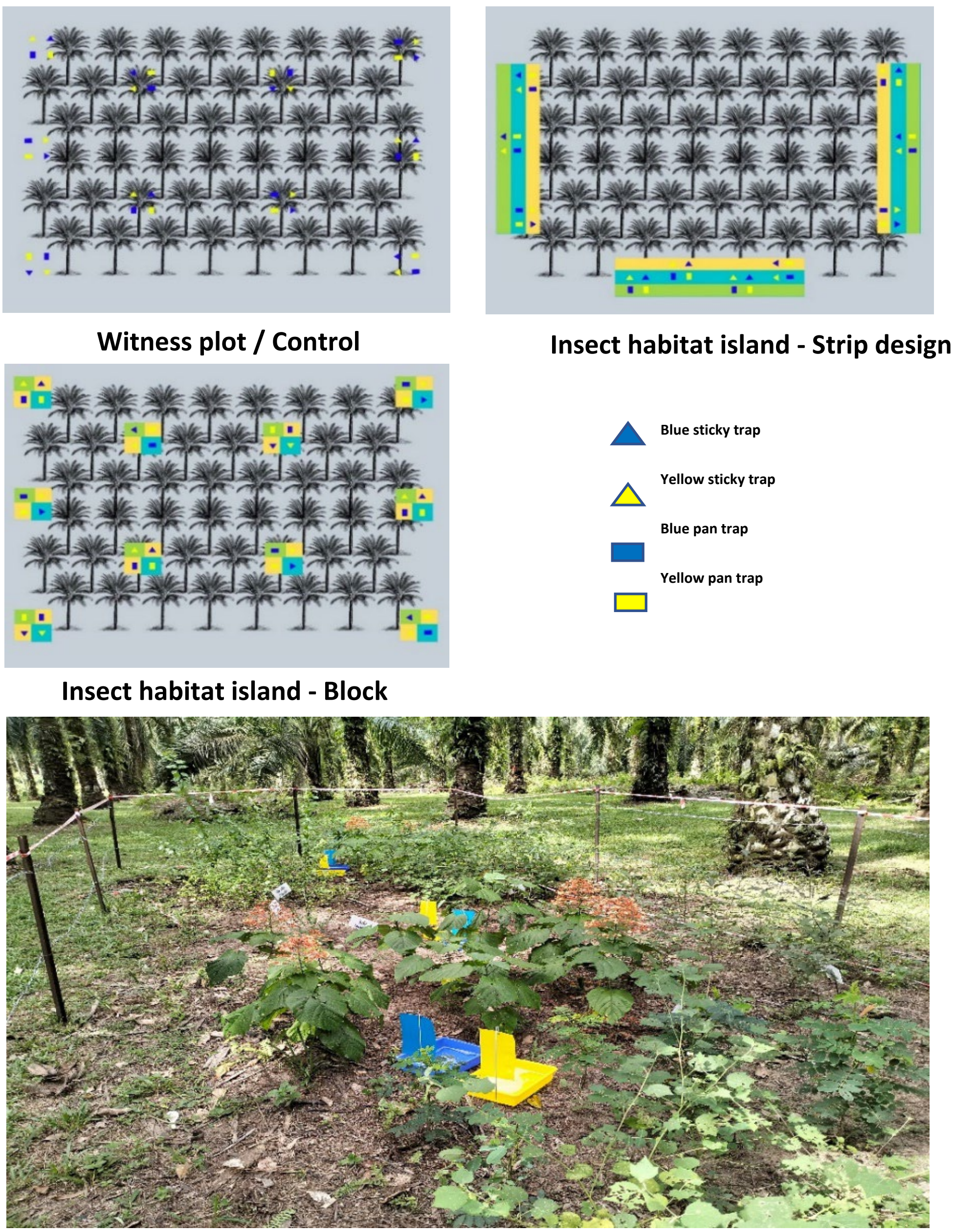


Figure 2: Overview of the sampling design of plant beds and set up for passive sampling (pan traps and sticky traps).

Insect sampling methods (active and passive)

Coloured pan traps

Twenty pan traps (28 cm length x 20 cm width x 6 cm height) were set up at each farm. Two types of pan traps of the same dimension were used to maximise arthropod sampling from different groups: yellow and blue pan traps (Campbell and Hanula, 2007; Vrdoljak and Samways, 2012). Moreira et al. (2016) demonstrated group-specific colour appeal suggesting that wasps are more drawn to the yellow pan traps and bees to the blue ones. In addition, blue pan traps are more attractive to Lepidopteran (e.g., Hesperiidae) and Dipteran (e.g., Syrphidae) insect groups (Campbell and Hanula, 2007), whereas many bee species are known to be attracted to the yellow colour (Leong and Thorp, 1999). Pan traps were laid flat at ground level and filled with 0.5 litre of water. Then, detergent was added to break the surface tension of the water and salt as preservation agent. The applied ratio of water, detergent, and salt is 8:1:1. Each pan trap was active for a period of 24 hours.

Coloured sticky traps

Twenty sticky traps, or glue-coated plastic boards (20 cm length x 12 cm width) were deployed across all treatments and witness farms. Like the pan trap method, yellow and blue sticky traps were utilised to target specific beneficial and pest insect groups (Atakan et al., 2015). Each sticky trap was attached to a galvanized wire and/or hung on oil palm fronds and beneficial plants within the established 3 m x 3 m plots for a period of 24 hours.

Observation on floral visitation

Observation of beneficial insect visits to plant resources were verified based on direct observation. Observation was conducted using binocular, magnification glasses and macro lense photography on beneficial plants within 3 m x 3 m squares established at each farm. Different plant parts (e.g., nectar, pollen, floral tissue (petals and stamen)) were inspected for insect presence. Observations using binocular and magnification lenses were performed by trained entomologists.

Sweep netting

Sweep netting was conducted at point transects established within each farm. For witness farms, the method was performed opportunistically, targeting pest insects within a 20 m radius from the centre of the point transect. In the case of pilot farms with plant beds and strips, sweep netting was performed within the radius of the planted areas.

Collection and rearing of Lepidopteran pupa

Pupa of Lepidopteran were collected at each farm and observed for parasitoid emergence. Pupa were transferred and reared with plant leaves in containers (27 cm × 13.5 cm) and covered with muslin cloth under laboratory conditions. Once parasitoids emerged, images were taken, and specimen were kept for further identification.

Foliage inspection for insect pests

Foliage and insect pest inspections were carried out on oil palms and beneficial plants. Oil palm fronds were selected based on foliage condition using binocular and taken down with the help of a harvester. A wide ground sheet was placed under the fronds prior to dispatch. Inspection of beneficial plants for insect pests was conducted manually by inspecting carefully above and below leaf surface, stem, and flowers. Identified pest insects were photographed and collected using forceps.

Identification of insect specimen

All captured insects were stored in specimen bottles filled with 70% alcohol solution. The specimens were sorted and identified to family level. Each identified insect was assigned to beneficial (e.g., parasitoid, predator, pollinator, scavenger, decomposer) or non-beneficial (e.g., phytophagous) categories.

Figure 3. Examples of active and passive insect sampling techniques used throughout the survey.

Data analyses

Arthropod community composition of experimental and control plots was determined and compared using similarity percentages test (SIMPER) and one-way analysis of similarities (ANOSIM), respectively. To obtain inferential ANOSIM results, a permutation test set at 999 times was performed during each ANOSIM analysis. We visualised arthropod communities on both sites using two-dimensional non-metric multi-dimensional scaling (NMDS) plots. The number of restarts was set at 25, and the minimum stress value was set at 0.01. SIMPER, ANOSIM and NMDS analyses were performed using Primer-e (Primer-e Ltd., Ivybridge, United Kingdom) (Clarke & Gorley, 2006). Arthropod assemblages (i.e., number of beneficial and non-beneficial families) at experimental and control plots were compared using two-sample t-test. T-test was conducted with GenStat (VSN International Ltd., Hemel Hempstead, United Kingdom). We developed coverage-based rarefaction and extrapolation sampling curves (i.e., species accumulation curves) to assess the influence of selected beneficial plant species on the assemblage of beneficial and non-beneficial arthropods across all treatments. Coverage-based rarefaction and extrapolation sampling curves were developed using iNEXT online (Colwell et al., 2012; Chao et al., 2016).

Results

General results

A total of 141 families of arthropods belonging to 13 orders were recorded. The Diptera and Hymenoptera orders represent the highest number of families (27 families) across all sites, followed by Coleoptera and Hemiptera with 21 families. The order Blattodea, Ephemeroptera, Isopoda, and Mantodea were represented by a single family. In general, the greater number of arthropod families were recorded in witness plots (126 families) compared to experimental plots (109 families). Similarly, the number of beneficial arthropods in witness plots (82 families) exceeded the experimental plots (70 families). In contrast, non-beneficial arthropods were less diverse in the experimental plots (39 families) compared to the witness plots (44 families) (Table 1). The beneficial arthropod diversity in experimental plots represent more than 80% of the total arthropods recorded throughout the study which indicates the plant bed capability to maintain these beneficial arthropod populations in the understory plant strata of oil palm farms.

Table 1: List of arthropod families recorded at experimental and control plots.

No.	Order	Family	Guild	Category
1	Araneae	Araneidae	Predator	Beneficial
2		Clubionidae	Predator	Beneficial
3		Corinnidae	Predator	Beneficial
4		Lamponidae	Predator	Beneficial
5		Lycosidae	Predator	Beneficial
6		Oxyopidae	Predator	Beneficial
7		Salticidae	Predator	Beneficial
8		Sparassidae	Predator	Beneficial
9		Tetragnathidae	Predator	Beneficial
10		Thomisidae	Predator	Beneficial
11	Blattodea	Ectobiidae	Scavenger	Beneficial
12	Coleoptera	Anthribidae	Decomposer	Beneficial
13		Aphodiidae	Scavenger	Beneficial
14		Cantharidae	Predator	Beneficial
15		Carabidae	Predator	Beneficial
16		Cerambycidae	Phytophagous	Non-beneficial
17		Chrysomelidae	Phytophagous	Non-beneficial
18		Coccinellidae	Predator	Beneficial
19		Cryptophagidae	Scavenger	Beneficial
20		Curculionidae	Phytophagous	Non-beneficial
21		Dryophthoridae	Phytophagous	Non-beneficial
22		Dytiscidae	Scavenger	Beneficial
23		Endomychidae	Decomposer	Beneficial
24		Latridiidae	Scavenger	Beneficial
25		Lycidae	Pollinator	Beneficial
26		Melolonthidae	Phytophagous	Non-beneficial
27		Mordellidae	Pollinator	Beneficial
28		Nitidulidae	Phytophagous	Non-beneficial
29		Scarabaeidae	Scavenger	Beneficial
30		Scolytidae	Phytophagous	Non-beneficial
31		Scraptiidae	Scavenger	Beneficial
32		Tenebrionidae	Phytophagous	Non-beneficial
33	Dermaptera	Labiduridae	Scavenger	Beneficial
34		Spongiphoridae	Scavenger	Beneficial
35	Diptera	Anisopodidae	Decomposer	Beneficial
36		Anthomyiidae	Scavenger	Beneficial

No.	Order	Family	Guild	Category
37		Asilidae	Predator	Beneficial
38		Calliphoridae	Scavenger	Beneficial
39		Celyphidae	Scavenger	Beneficial
40		Ceratopogonidae	Scavenger	Beneficial
41		Chironomidae	Scavenger	Beneficial
42		Culicidae	Scavenger	Beneficial
43		Dolichopodidae	Predator	Beneficial
44		Drosophilidae	Scavenger	Beneficial
45		Lonchopteridae	Decomposer	Beneficial
46		Micropezidae	Scavenger	Beneficial
47		Muscidae	Scavenger	Beneficial
48		Neriidae	Scavenger	Beneficial
49		Phoridae	Scavenger	Beneficial
50		Pipunculidae	Parasitoid	Beneficial
51		Platypezidae	Scavenger	Beneficial
52		Rhinophoridae	Decommposer	Beneficial
53		Sarcophagidae	Scavenger	Beneficial
54		Sciomyzidae	Scavenger	Beneficial
55		Sepsidae	Scavenger	Beneficial
56		Stratiomyidae	Scavenger	Beneficial
57		Syrphidae	Pollinator	Beneficial
58		Tachinidae	Parasitoid	Beneficial
59		Tephritidae	Phytophagous	Non-beneficial
60		Tipulidae	Scavenger	Beneficial
61		Ulidiidae	Scavenger	Beneficial
62	Ephemeroptera	Ephemeridae	Scavenger	Beneficial
63	Hemiptera	Alydidae	Phytophagous	Non-beneficial
64		Aphididae	Phytophagous	Non-beneficial
65		Aphrophoridae	Phytophagous	Non-beneficial
66		Blissidae	Phytophagous	Non-beneficial
67		Cercopoidea	Phytophagous	Non-beneficial
68		Cicadellidae	Phytophagous	Non-beneficial
69		Coreidae	Phytophagous	Non-beneficial
70		Cydnidae	Phytophagous	Non-beneficial
71		Dictyopharidae	Phytophagous	Non-beneficial
72		Flatidae	Phytophagous	Non-beneficial
73		Lygaeidae	Phytophagous	Non-beneficial
74		Membracidae	Phytophagous	Non-beneficial
75		Miridae	Phytophagous	Non-beneficial

No.	Order	Family	Guild	Category
76		Pentatomidae	Phytophagous	Non-beneficial
77		Pseudococcidae	Phytophagous	Non-beneficial
78		Psyllidae	Phytophagous	Non-beneficial
79		Pyrrhocoridae	Phytophagous	Non-beneficial
80		Reduviidae	Predator	Beneficial
81		Rhyparochromidae	Phytophagous	Non-beneficial
82		Ricaniidae	Phytophagous	Non-beneficial
83		Tingidae	Phytophagous	Non-beneficial
84	Hymenoptera	Apidae	Pollinator	Beneficial
85		Braconidae	Parasitoid	Beneficial
86		Ceraphronidae	Parasitoid	Beneficial
87		Chalcididae	Parasitoid	Beneficial
88		Colletidae	Pollinator	Beneficial
89		Crabronidae	Predator	Beneficial
90		Diapriidae	Parasitoid	Beneficial
91		Eucharitidae	Parasitoid	Beneficial
92		Eulophidae	Parasitoid	Beneficial
93		Eumenidae	Predator	Beneficial
94		Eupelmidae	Parasitoid	Beneficial
95		Evaniidae	Parasitoid	Beneficial
96		Formicidae	Scavenger	Beneficial
97		Halictidae	Pollinator	Beneficial
98		Ichneumonidae	Parasitoid	Beneficial
99		Megachilidae	Pollinator	Beneficial
100		Mutilidae	Parasitoid	Beneficial
101		Pompilidae	Predator	Beneficial
102		Pteromalidae	Parasitoid	Beneficial
103		Scoliidae	Predator	Beneficial
104		Sphecidae	Predator	Beneficial
105		Strepsiptera	Parasitoid	Beneficial
106		Tenthredinidae	Phytophagous	Non-beneficial
107		Thynnidae	Parasitoid	Beneficial
108		Tiphiidae	Parasitoid	Beneficial
109		Vespidae	Predator	Beneficial
110		Trichogrammatidae	Parasitoid	Beneficial
111	Isopoda	Philosciidae	Decomposer	Beneficial
112	Lepidoptera	Arctiidae	Phytophagous	Non-beneficial
113		Choreutidae	Phytophagous	Non-beneficial
114		Cosmopterigidae	Phytophagous	Non-beneficial

No.	Order	Family	Guild	Category
115		Crambidae	Phytophagous	Non-beneficial
116		Erebidae	Phytophagous	Non-beneficial
117		Geometridae	Phytophagous	Non-beneficial
118		Hesperiidae	Phytophagous	Non-beneficial
119		Limacodidae	Phytophagous	Non-beneficial
120		Lycaenidae	Phytophagous	Non-beneficial
121		Lymantriidae	Phytophagous	Non-beneficial
122		Noctuidae	Phytophagous	Non-beneficial
123		Nymphalidae	Phytophagous	Non-beneficial
124		Papilionidae	Pollinator	Beneficial
125		Pieridae	Phytophagous	Non-beneficial
126		Psychidae	Phytophagous	Non-beneficial
127		Pterophoridae	Phytophagous	Non-beneficial
128		Sphingidae	Phytophagous	Non-beneficial
129		Yponomeutidae	Phytophagous	Non-beneficial
130	Mantodea	Mantidae	Predator	Beneficial
131	Odonata	Coenagrionidae	Predator	Beneficial
132		Libellulidae	Predator	Beneficial
133	Orthoptera	Acrididae	Phytophagous	Non-beneficial
134		Chorotypidae	Phytophagous	Non-beneficial
135		Gryllacrididae	Phytophagous	Non-beneficial
136		Gryllidae	Scavenger	Beneficial
137		Gryllotalpidae	Scavenger	Beneficial
138		Pyrgomorphidae	Phytophagous	Non-beneficial
139		Tetrigidae	Scavenger	Beneficial
140		Tettigoniidae	Scavenger	Beneficial
141		Trigonidiidae	Scavenger	Beneficial

Arthropod assemblages and composition between plots

T-test performed on pan trap data for the number of beneficial arthropod families was significantly higher ($t(78) = -5.67$, $p < 0.001$) in experimental ($M = 9.350$, $SD = 2.607$) compared to witness ($M = 6.075$, $SD = 2.556$) plots. Similarly, the abundance of beneficial arthropods was also significantly higher ($t(78) = -3.88$, $p < 0.001$) for experimental ($M = 23.20$, $SD = 9.653$) compared to witness ($M = 15.08$, $SD = 9.065$) plots. In contrast, the T-test performed on the number of non-beneficial arthropod families was significantly higher ($t(78) = -2.13$, $p = 0.036$) for experimental ($M = 2.425$, $SD = 1.338$) compared to witness ($M = 1.8$, $SD = 1.285$) plots. We found no significant difference on the number of arthropod families and abundance from the sticky trap method.

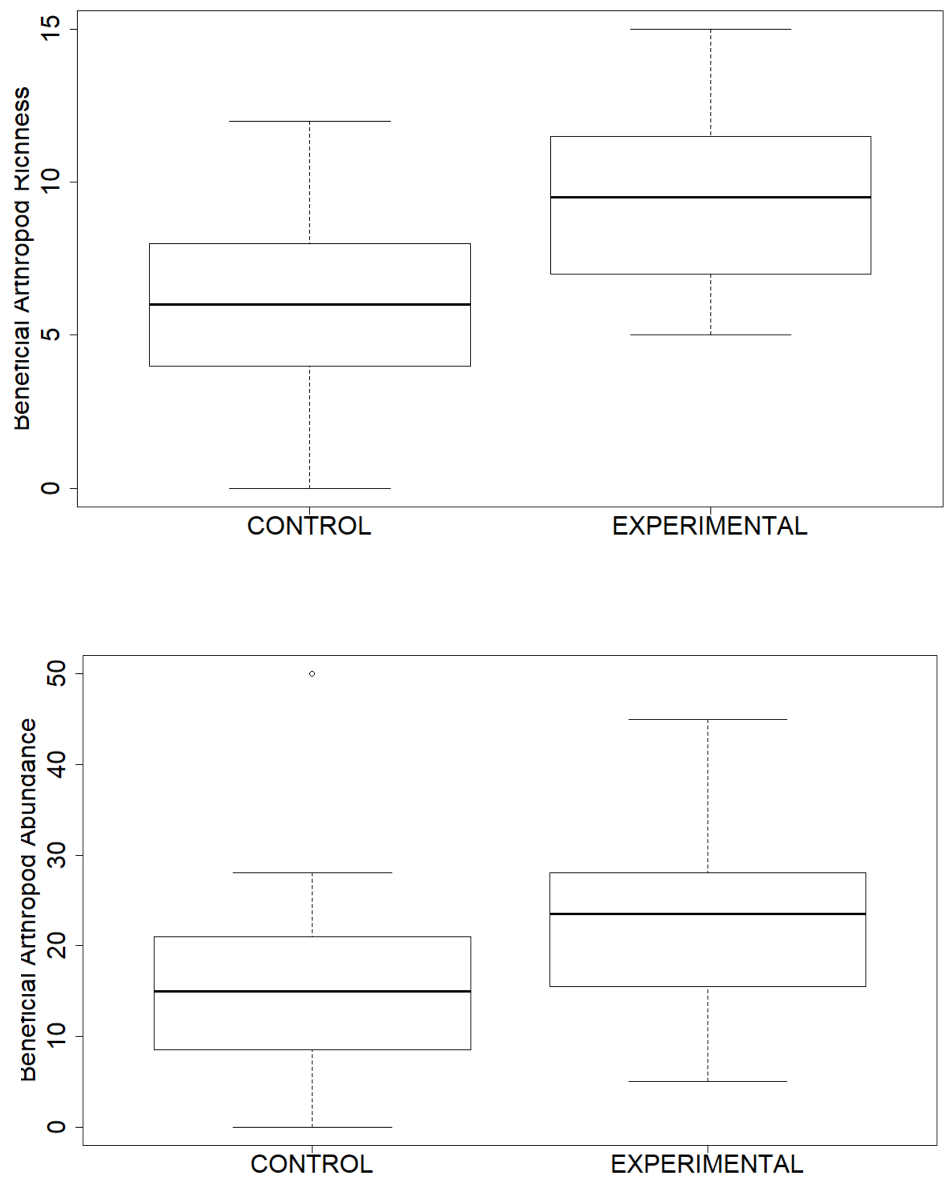
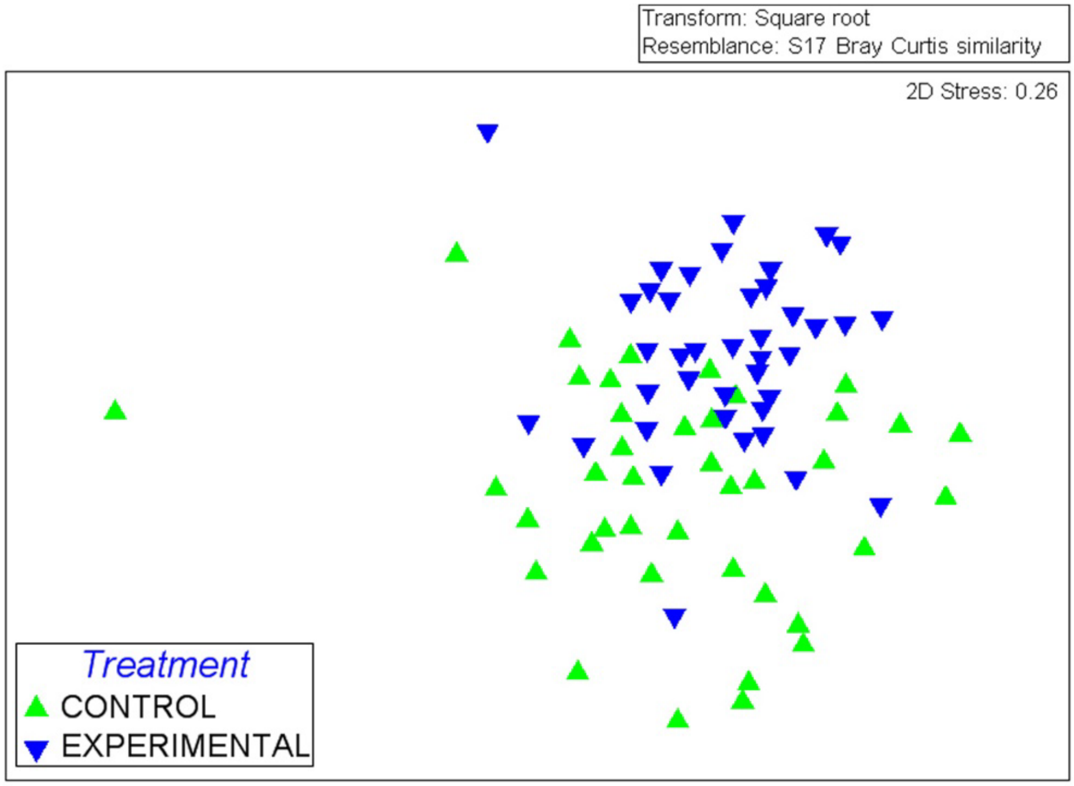


Figure 4: Boxplot showing data distribution for beneficial arthropod family richness (above) and abundance (below) between experimental and witness/control based on pan trap data. The experimental plots represent greater beneficial arthropods diversity and abundance ($p < 0.001$) compared to the control plot.

Data from pan traps indicated that approximately 90% of the arthropod community composition in witness plots were contributed by eight families (i.e., Formicidae, Dolichopodidae, Gryllidae, Rhyparochromidae, Ichneumonidae, Dytiscidae, Tetrigidae, Acrididae), while arthropod community composition in experimental plots were contributed by 14 families (i.e., Dolichopodidae, Formicidae, Drosophilidae, Ichneumonidae, Tetrigidae, Cicadellidae, Diapriidae, Phoridae, Rhyparochromidae, Pompilidae, Aphrophoridae, Anisopodidae, Chironomidae, Gryllidae). Sticky trap data indicated that a total of 12 families (i.e., Cicadellidae, Muscidae, Drosophilidae, Ulidiidae, Anisopodidae, Braconidae, Dolichopodidae, Eupelmidae, Acrididae, Diapriidae, Ichneumonidae) made up approximately 90% of the community composition in witness plots.

SIMPER analysis indicated that arthropod community composition in experimental plots was dominated (approximately 90% of community contribution) by 10 families (i.e, Cicadellidae, Drosophilidae, Muscidae, Dolichopodidae, Anisopodidae, Ulidiidae, Chrysomelidae, Phoridae, Diapriidae, Eupelmidae) (Table 2). SIMPER analysis performed on pan traps data showed that arthropod family composition has similarities of 28.42% in witness plots, while the arthropod family composition in experimental plots shows higher similarities of 36.63%. The lower plant diversity in plant beds may contribute to higher arthropod family similarities in experimental plot. When comparing witness and experimental plots, arthropod family composition differs with 72.28%. This implies that experimental and witness plots vary in terms of arthropod family composition. Similarly, SIMPER analysis performed on sticky traps data showed higher similarities of arthropod family composition in experimental plots with 37.90% compared to witness plots with 32.67%. The arthropod family composition also varies between witness and experimental plots with 65.68% based on sticky trap data. ANOSIM analysis suggests that the community composition obtained from both methods were significantly different, but with high overlapping patterns of arthropod families across treatments (pan traps global R - 0.225, p-value < 0.001; sticky traps global R – 0.046, p-value = 0.014). The Non-Metric Multi-Dimensional Scaling (NMDS) plots visualise the overlapping patterns of arthropod families in witness and experimental plots (Figure 3).



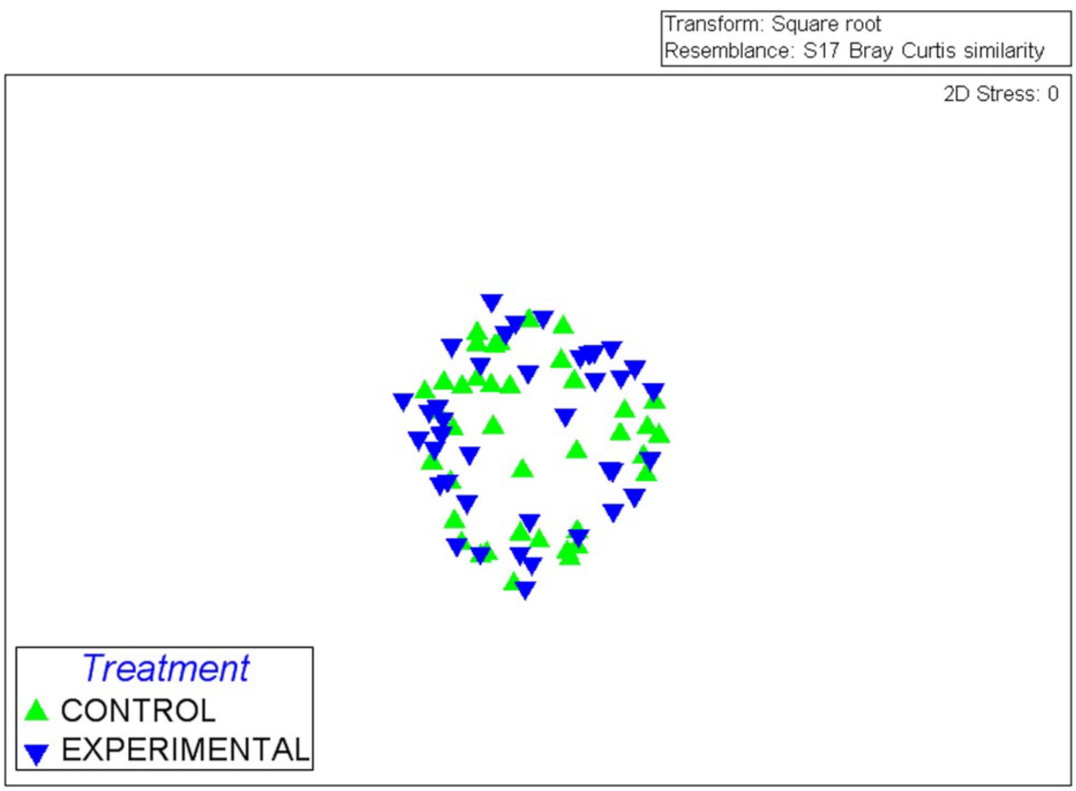


Figure 5. Non-metric multidimensional scaling (MDS) ordination plots developed from pan traps (above) and sticky traps (below) data.

Table 2: Overall arthropod community composition in witness and experimental plots using pan trap (PT) and sticky trap (ST) data with dominant arthropod families of approximately 90% cumulative contribution.

Method	Site	No.	Family	Guild	Contribution (%)	Cumulative contribution (%)
PT	Control	1	Formicidae	Scavenger	41.75	41.75
		2	Dolichopodidae	Predator	19.07	60.82
		3	Gryllidae	Scavenger	8.18	69.00
		4	Rhyparochromidae	Phytophagous	6.25	75.25
		5	Ichneumonidae	Parasitoid	6.05	81.30
		6	Dytiscidae	Scavenger	5.16	86.47
		7	Tetrigidae	Scavenger	2.21	88.68
		8	Acrididae	Phytophagous	1.67	90.35
PT	Experimental	1	Dolichopodidae	Predator	25.57	25.57
		2	Formicidae	Scavenger	19.17	44.75
		3	Drosophilidae	Scavenger	8.94	53.69
		4	Ichneumonidae	Parasitoid	8.40	62.09
		5	Tetrigidae	Scavenger	4.44	66.53
		6	Cicadellidae	Phytophagous	4.30	70.83
		7	Diapriidae	Parasitoid	3.39	74.23
		8	Phoridae	Scavenger	2.71	76.93
		9	Rhyparochromidae	Phytophagous	2.56	79.49
		10	Pompilidae	Predator	2.35	81.84
		11	Aphrophoridae	Phytophagous	1.99	83.83
		12	Anisopodidae	Decomposer	1.96	85.79
		13	Chironomidae	Scavenger	1.96	87.75
		14	Gryllidae	Scavenger	1.93	89.69
ST	Control	1	Cicadellidae	Phytophagous	40.04	40.04
		2	Muscidae	Scavenger	11.22	51.26
		3	Drosophilidae	Scavenger	9.62	60.89
		4	Ulidiidae	Scavenger	6.74	67.63
		5	Anisopodidae	Decomposer	5.94	73.57
		6	Braconidae	Parasitoid	4.83	78.40
		7	Dolichopodidae	Predator	4.46	82.86
		8	Eupelmidae	Parasitoid	2.04	84.90
		9	Chrysomelidae	Phytophagous	1.67	86.57
		10	Acrididae	Phytophagous	1.59	88.15
		11	Diapriidae	Parasitoid	1.45	89.60

Method	Site	No.	Family	Guild	Contribution (%)	Cumulative contribution (%)
		12	Ichneumonidae	Parasitoid	1.28	90.88
ST	Experimental	1	Cicadellidae	Phytophagous	51.00	51.00
		2	Drosophilidae	Scavenger	10.56	61.56
		3	Muscidae	Scavenger	5.20	66.76
		4	Dolichopodidae	Predator	4.64	71.39
		5	Anisopodidae	Decomposer	4.39	75.78
		6	Ulidiidae	Scavenger	4.36	80.14
		7	Chrysomelidae	Phytophagous	3.22	83.36
		8	Phoridae	Scavenger	2.66	86.02
		9	Diapriidae	Parasitoid	2.18	88.20
		10	Eupelmidae	Parasitoid	1.75	89.95

Association between cultivated plant species with arthropod assemblages

This section provides results on plant association with arthropod diversity and abundance in experimental and control plots using rarefaction/extrapolation accumulation curves based on pan trap and sticky trap data. Overall results reported plant-insect associations for 13 plant species in plant beds and 8 understory species from control plots.

Table 3: All plant species in experimental (planted) and control (understory) plots and its association with beneficial and non-beneficial arthropod families based on rarefaction/ extrapolation data.

Family	***Plant species***	**Common name**	**Category**	**Associated beneficial arthropod families**	**Associated non-beneficial arthropod families**
Asteraceae	*Ageratum conyzoides*	Billygoat weed	Understory	63.3	24.5
Lamiaceae	*Plectranthus monostachys*	Monkey's Potato	Planted / Understory	61.0	21.0
Melastomataceae	*Melastoma malabathricum*	Common Senduduk	Planted / Understory	56.3	18.8
Poaceae	*Centotheca lappacea*	Rumput Lilit Kain	Understory	54.3	14.8

Family	*Plant species*	Common name	Category	Associated beneficial arthropod families	Associated non-beneficial arthropod families
Nephrolepidaceae	*Nephrolepis biserrata*	Broad Sword Fern	Understory	53.1	20.6
Linderniaceae	*Lindernia crustacea*	Malaysian False Pimpernel	Understory	49.5	15.8
Malvaceae	*Urena lobata*	Caesarweed	Planted / Understory	47.7	16.8
Verbenaceae	*Stachytarpheta indica*	Brazilian Tea	Understory	45.5	13.6
Cleomaceae	*Cleome rutidosperma*	Fringed Spiderflower	Understory	43.2	18.7
Lamiaceae	*Ocimum basilicum*	Great basil	Planted	40.9	14.3
Lamiaceae	*Clerodendrum paniculatum*	Pagoda Flower	Planted	39.9	16.2
Rubiaceae	*Borreria setidens*	Broadleaf buttonweed	Understory	38.6	17.7
Fabaceae	*Cassia tora*	Sicklepod	Planted	38.4	15.1
Lamiaceae	*Vitex agnus-cactus*	Chaste tree	Planted	37.8	15.7
Verbenaceae	*Duranta erecta*	Golden dewdrop	Planted	37.6	14.4
Dilleniaceae	*Tetracera indica*	Mempelas	Understory	35.4	12.1
Fabaceae	*Cassia cobanensis*	Senna	Understory	34.7	10.6
Onagraceae	*Ludwigia hyssopifolia*	Seedbox	Understory	29.0	6.9
Malvaceae	*Sida rhombifolia*	Arrowleaf sida	Planted	26.9	9.3
Euphorbiaceae	*Euphorbia hirta*	Asthma-plant	Planted	26.9	7.4
Lamiaceae	*Vitex negundo*	Five-leaved chaste tree	Planted	19.1	11.0

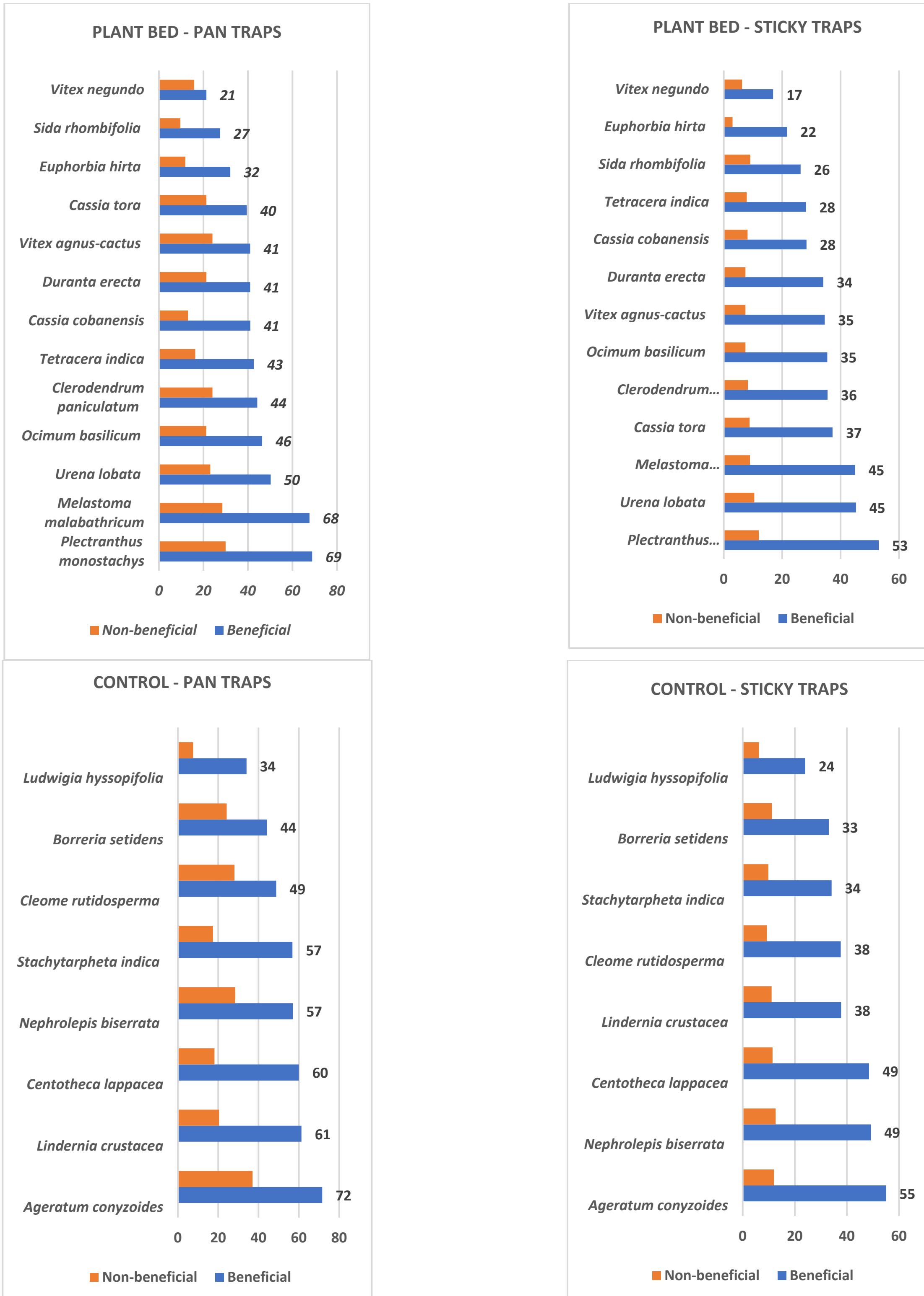


Figure 48. Bar plot showing the number of beneficial and non-beneficial arthropod families based on rarefication/ extrapolation data in experimental (above) and control plots (below) according to sampling methods.

Discussion

Our findings confirm the potential of beneficial plant beds to enhance arthropod biodiversity within oil palm cultivations. The results indicate that the experimental plots improve the diversity (i.e., number of families) and abundance (i.e., number of individuals) of beneficial arthropod populations. Such findings may indicate that the establishment of beneficial plant beds, particularly with specific plant species can improve or enhance the provision of certain ecosystem services, such as natural predation or nutrient cycling within oil palm cultivations. Similar findings have reported positive effects of flowering plants in agricultural landscapes to enhance pollination, natural predation, and nutrient cycling (Karamaouna et al., 2019; Calvert et al., 2019; Zhang et al., 2022). Specifically, *Plectranthus monostachys, Melastoma malabathricum, Urena lobata, Ocimum basilicum, Clerodendrum paniculatum, Cassia tora, Vitex agnus-cactus,* and *Duranta erecta* represent the highest accumulation and extrapolation of beneficial arthropods (e.g., parasitoids, predators, scavengers, decomposers) in plant beds. For understory plants in control plots, *Ageratum conyzoides, Centotheca lappacea, Nephrolepis biserrata, Lindernia crustacea, Cleome rutidosperma,* and *Borreria setidens* showed the highest accumulation and extrapolation of beneficial arthropods. The findings suggest the capability of understory plant beds to attract and maintain existing beneficial arthropods populations. In addition, established plant beds promote and sustain beneficial arthropod populations based on the offered resources. The research findings support the establishment of plant beds on oil palm farms with a variety of plant resources (shelter, nectar, pollen, alternative prey/host) and the selected understory management of host plants for beneficial insects, which should form part of a conservation biocontrol program to support greater arthropod biodiversity for an effective pest management in oil palm.

Insect biodiversity requires understanding of plant-insect interactions. Previous studies indicate that insect biodiversity requires enhancing "the right biodiversity at the right time" (Cahenzli et al., 2017). Plant species need to be carefully selected to offer many diverse resources, which are attractive and accessible to natural enemies (Campbell et al., 2017). Resources, including shelter, nectar, alternative prey/hosts, and pollen offered by flowering plants are used for insects to increase their survival that leads to better population size and function (i.e., predation) in adjacent crops (Penalver-Cruz et al., 2020). Flowering plants used in the present study provide floral resources as alternative foods to prolong insect survival. In addition, specific structures of inflorescences also provide favourable shelter for beneficial insects from adverse conditions (Yang et al., 2021).

Parasitoid and predatory arthropod associations with flowering plants

Flowering plants on oil palm farms or estates increase the potential habitat for natural enemies. According to our results, plants with open floral structures have a higher number of visits by beneficial insects. More specifically, flowering plants with open floral structures such as *Clerodendrum paniculatum*, *Euphorbia hirta*, *Ocimum basilicum*, *Vitex negundo*, *Vitex agnus-cactus, Ludwigia hyssopifolia* and *Duranta erecta* showed greater abundance of parasitoid and predatory arthropods (26 - 30% of total encounters) compared to other plant species (Table 25). Flowering plants with open floral structures offer higher glucose and fructose levels (Campbell et al., 2012). This suggests that the floral structure of plant species has a great influence on the assemblage of natural enemies. Flowering plants can influence parasitoid and predatory insect richness and abundance through plant volatiles (Dotterl & Vereecken 2010), visual cues (Begum et al., 2004), and floral resources (Tscharntke et al., 2005). Thus, intercropping or maintaining plants with open floral structures can be considered as a well-practiced habitat management measure that plays a positive role in biological pest control (Lu et al., 2014). Although greater assemblage of parasitoids and predators were found in these plant species, evidence to reduce pests was not yet determined in the present study.

Most parasitoid and predatory insects found in the flowering plants are potential biological control agents for insect pests of oil palm. Parasitoid species such as *Cotesia metasae* (Halim et al., 2017), *Goryphus bunoh* (Thaer et al., 2021), *Buysmania oxymora* (Halim et al., 2018) and *Paraphylax* sp. (Sahari et al., 2019) have been reported as potential biocontrol agents for bagworm and were recorded throughout the study. Other predatory species such as long-legged flies *Dolichopodidae* sp. (Dolichopodidae), assassin bugs *Cosmolestes picticeps* (Reduviidae), *Zelus* sp. (Reduviidae), robberflies *Ommatius* sp. (Asilidae) and tiger beetles *Neocollyris* sp. (Carabidae) were also recorded. During the next sampling phases, more emphasis should be given on sweep-netting and visual observations of these biocontrol agents together with more frequent sampling periods to match with peak flourishing times of plant beds and the selected plants for integrated understory management. In addition, the number of parasitoid visits at each plant and the floral characteristics preferred by natural enemies should be determined. This is important to understand the biological network of the most important natural enemies in oil palm agroecosystems.

Table 4: Percentage of total parasitoid and predatory arthropod assemblages for all plant species (plant bed and understory). Most frequented plant species (>25% encounter) are highlighted in **bold** font.

Category	Family	Species	Parasitoid and predatory arthropods (%)
Planted	Lamiaceae	*Plectranthus monostachys*	20
Planted	**Lamiaceae**	***Clerodendrum paniculatum***	**28**
Planted	**Lamiaceae**	***Vitex agnus-cactus***	**29**
Planted	**Lamiaceae**	***Vitex negundo***	**30**
Planted	Dilleniaceae	*Tetracera indica*	21
Planted	**Euphorbiaceae**	***Euphorbia hirta***	**31**
Planted	Fabaceae	*Cassia tora*	25
Planted	Fabaceae	*Cassia cobanensis*	18
Planted	**Lamiaceae**	***Ocimum basilicum***	**29**
Planted	Malvaceae	*Urena lobata*	18
Planted	Malvaceae	*Sida rhombifolia*	21
Planted	Melastomataceae	*Melastoma malabathricum*	25
Planted	**Verbenaceae**	***Duranta erecta***	**28**

Category	Family	Species	Parasitoid and predatory arthropods (%)
Understory	Asteraceae	*Ageratum conyzoides*	20
Understory	Cleomaceae	*Cleome rutidosperma*	24
Understory	Linderniaceae	*Lindernia crustacea*	18
Understory	Nephrolepidaceae	*Nephrolepis biserrata*	21
Understory	**Onagraceae**	***Ludwigia hyssopifolia***	**26**
Understory	Poaceae	*Centotheca lappacea*	15
Understory	Rubiaceae	*Borreria setidens*	23
Understory	Verbenaceae	*Stachytarpheta indica*	15

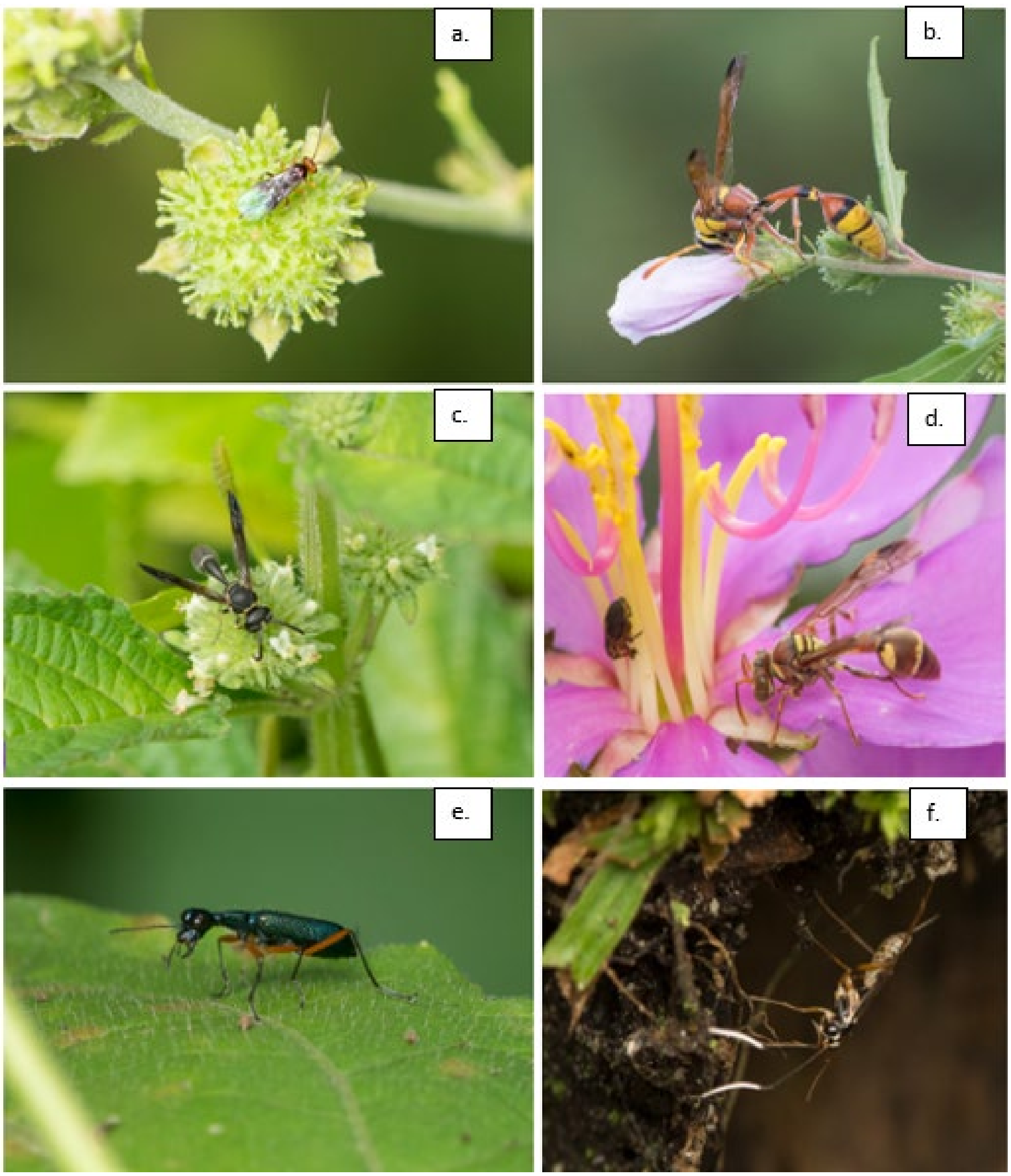


Figure 49. a. Braconid wasp, *Cotesia* sp. and b. Potter wasp (Eumenidae) on *Urena lobata*, c. Potter wasp, *Eumenes* sp. on *Borreria stidens,* d. Potter wasp, *Polistes stigma* (Eumenidae) on *Melastoma malabathricum*, e. Tiger beetle, Neocollyris sp. (Carabidae) on *Tetracera indica* and f. Ichneumonid wasp, *Paraphylax* sp.

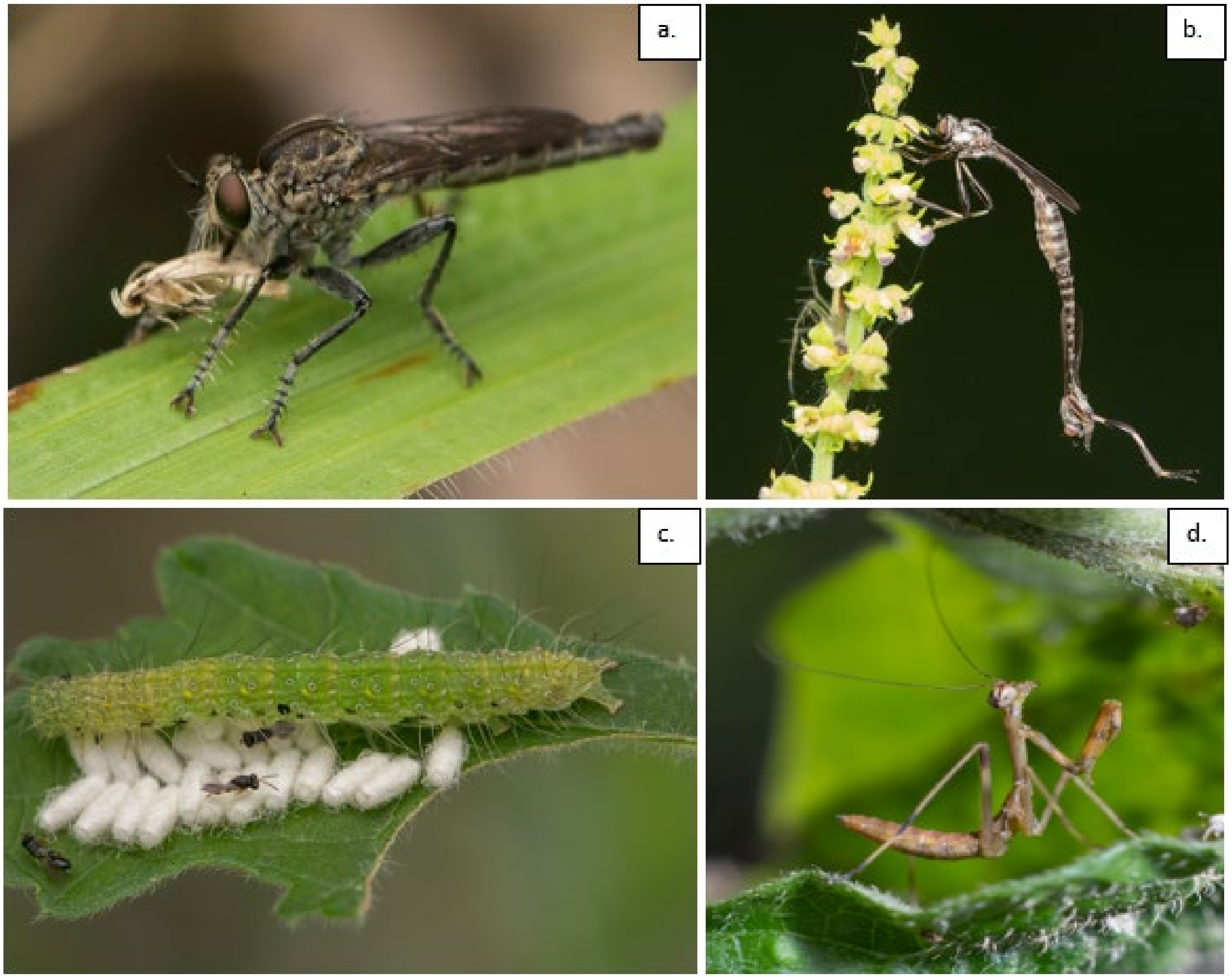


Figure 50. a. Robber flies, *Ammophila* sp. (Asilidae) feeding on moth, b. Robber flies (Asilidae) courtship behaviour on *Plectranthus monostachys,* c. Pteromalid wasp (Pteromalidae) on Braconid cocoon parasitizing *Eurema* sp., d. Mantids (Mantidae) spotted at understory vegetation in control plot.

Insect Pest Occurrence

In this study, we recorded a total of 51 phytophagous insect families with nine species of economic importance. Lepidopteran pests such as bagworms (*Metisa plana* Walker), nettle caterpillars (*Setora nitens*), and tussock moth, *Orgyia* sp. (Lymantriidae) were recorded on oil palm. Bagworm *M. plana* has been reported to cause severe yield losses to oil palm plantations during outbreak at larval stages (Rhainds and Ho, 2002; Foster et al., 2011). Other leaf defoliaters such as hawk moth, *Theretra* sp. (Sphingidae), common grass yellow, *Eurema hecabe* (Pieridae), and pumpkin beetle, *Aulocophora* sp. were found to infest plant beds mostly on *Urena lobata*. Phloem-sucking pest insects such as broad-headed bug *Leptocorisa* sp. (Alydidae), leaf-footed bug *Mictis longicornis* (Coeridae), and mealy bug *Pseudococcus* sp. (Psedococcidae) also caused minor infestations on different plant species in plant beds.

Observation for insect pests did not assess the damage intensity due to the low number of pests encountered especially on bagworms.

Table 5: List of insect pests recorded for oil palm and established plant beds

No.	Species	Family	Common name	Occurrence	Pest Category
1.	*Leptocorisa* sp.	Alydidae	Broad-headed bug	Plant bed	Phloem-sucking
2.	*Mictis longicornis*	Coreidae	Leaf-footed bug	Plant bed	Phloem-sucking
3.	*Pseudococcus* sp.	Pseudococcidae	Mealy bug	Oil palm / Plant bed	Phloem-sucking
4.	*Metisa plana*	Psychidae	Bagworm	Oil palm	Leaf defoliater
5.	*Setora nitens*	Lymantriidae	Nettle caterpillar	Oil palm	Leaf defoliater
6.	*Theretra* sp.	Sphingidae	Hawk moth	Plant bed	Leaf defoliater
7.	*Aulocophora* sp.	Chrysomelidae	Pumpkin beetle	Plant bed	Leaf defoliater
8.	*Eurema hecabe*	Pieridae	Common grass yellow	Plant bed	Leaf defoliater
9.	*Orgyia* sp.	Lymantriidae	Tussock moth	Oil palm / Plant bed	Leaf defoliater

Figure 51. Image of insect pests a. pupae of bagworm, *Metisa plana,* b. larvae of tussock moth, *Orgyia* sp., mealybug, *Pseudococcus* sp. (Pseudococcidae) on c. oil palm and d. *Urena lobata* leaves, e. pumpkin beetle, *Aulocophora* sp. (Chrysomelidae) at plant bed and f. broad-headed bug, *Leptocorisa* sp. (Alydidae) at plant beds.

Conclusion

Complex insect interactions with distinct niches can reduce interspecific competition and enhance biodiversity benefits, such as pest management. To maintain a diverse insect community, it is vital to grow plant species that provide diverse resources. The findings support the establishment of plant bed patches in oil palm smallholdings with selected plant resources (shelter, nectar, pollen, alternative prey/host) by cultivating beneficial plant strips using the following species: *Plectranthus monostachys, Melastoma malabathricum, Urena lobata, Ocimum basilicum, Clerodendrum paniculatum, Cassia tora, Vitex agnus-cactus, Vitex negundo, Euphorbia hirta* and *Duranta erecta*. While, the plant species to be selected and conserved within integrated understory vegetation management activities to promote a sustainable insect habitat in oil palm agroecosystem are: *Ageratum conyzoides, Euphorbia hirta, Nephrolepis biserrata, Lindernia crustacea, Ludwigia hyssopifolia, Cleome rutidosperma, Centotheca lappacea* and *Borreria setidens.* The plant species highlighted in the study have the potential to support the population size and function of parasitoids (Ichneumonidae, Braconidae) and predatory insects (Reduviidae, Carabidae, Asilidae). In addition, these plants also support a variety of Lepidopteran species that serve as hosts or prey for predatory insects and parasitoids.

Based on this research, the SAN-Ferrero project team will carefully select plant species to achieve the optimal plant community combination that is attractive and accessible to predatory insects and parasitoids. Incorporating indirect pollination services provided by insect pollinators into the role of these habitats can also become an added ecosystem value besides biological control. As demonstrated in the study, a successful establishment of insect habitat should combine planting materials from native plant populations for a successful establishment of plant beds and to reduce genetic erosion.

Additional efforts will also be undertaken to keep monitoring the insect pest populations within the same experimental design of this study to track the effect of the plant beds and integrated understory management on pest insect populations over time.

Recommendation

To date, the conservation value of understory vegetation species on oil palm farms is poorly acknowledged. The benefit of persevering understory vegetation species, particularly native species, is yet to be recognised by oil palm growers. Understory vegetation has traditionally been treated as weeds in oil palm cultivation and are usually controlled vigorously through weeding and herbicide application. The present findings suggest that understory vegetation should be integrated as part of a conservation biocontrol program to support more arthropod biodiversity for an effective pest management strategy in the oil palm agroecosystem.

References

Atakan, E., & Pehlivan, S. (2015). Attractiveness of various colored sticky traps to some pollinating insects in apple. Turkish Journal of Zoology, 39(3), 474-481.

Begum, M., Gurr, G. M., Wratten, S. D., & Nicol, H. I. (2004). Flower color affects tri-trophic-level biocontrol interactions. Biological Control, 30, 584–590.

Cahenzli, F., Pfiffner, L., Daniel, C., 2017. Reduced crop damage by self-regulation of aphids in an ecologically enriched, insecticide-free apple orchard. Agron. Sustain Dev. 37, 1–8.

Calvert, F., Hollingsworth, R. G., Wall, M., & Follett, P. A. (2019). Survey of flowering plants in Hawaii as potential banker plants of anthocorid predators for thrips control. Journal of Asia-Pacific Entomology, 22(3), 638–644.

Campbell, A. J., Biesmeijer, J. C., Varma, V., & Wäckers, F. L. (2012). Realising multiple ecosystem services based on the response of three beneficial insect groups to floral traits and trait diversity. Basic and Applied Ecology, 13(4), 363–370.

Campbell, A.J., Wilby, A., Sutton, P., W¨ackers, F., 2017. Getting more power from your flowers: Multi-functional flower strips enhance pollinators and pest control agents in apple orchards. Insects 8, 101.

Campbell, J. W., & Hanula, J. L. (2007). Efficiency of Malaise traps and colored pan traps for collecting flower visiting insects from three forested ecosystems. *Journal of Insect Conservation*, *11*(4), 399-408.

Chao, A., Ma, K. H., & Hsieh, T. C. (2016). User's guide for iNEXT online: Software for interpolation and Extrapolation of species diversity. *Institute of Statictics. Recuperado de http://chao. stat. nthu. edu. tw/wordpress/software_download*.

Clarke, K. R., and R. N. Gorley. "Primer." PRIMER-e, Plymouth 866 (2006).

Colwell, R. K., Chao, A., Gotelli, N. J., Lin, S. Y., Mao, C. X., Chazdon, R. L., & Longino, J. T. (2012). Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. *Journal of plant ecology*, *5*(1), 3-21.

Dotterl, S., & Vereecken, N. J. (2010). The chemical ecology and evolution of bee-flower interactions: A review and perspectives. Canadian Journal of Zoology-Revue Canadienne de Zoologie, 88, 668–697.

Foster, W.A., Snaddon, J.L., Turner, E.C., Fayle, T.M., Cockerill, T.D., Ellwood, M.F., Broad, G.R., Chung, A.Y., Eggleton, P., Khen, C.V., Yusah, K.M., 2011. Establishing the evidence base for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia. Phil. Trans. R. Soc. B 366 (1582), 3277–3291.

Halim, M., Aman-Zuki, A., Syed Ahmad, S. Z., Mohammad Din, A. M., Abdul Rahim, A., Mohd Masri, M. M., Badrul, B. M., & Yaakop, S. (2018). Exploring the abundance and DNA barcode information of eight parasitoid wasps species (Hymenoptera), the natural enemies of the important pest of oil palm, bagworm, *Metisa plana* (Lepidoptera: Psychidae) toward the biocontrol approach and it's application in Malaysia. Journal of Asia-Pacific Entomology, 21(4), 1359–1365.

Halim, M., Muhaimin, A. M. D., Syarifah Zulaikha, S. A., Nor Atikah, A. R., Masri, M. M. M., & Yaakop, S. (2017). Evaluation of infestation in parasitoids on *Metisa plana* Walker (lepidoptera: Psychidae) in three oil palm plantations in peninsular Malaysia. Serangga, 22(2), 135–149.

Karamaouna, F., Kati, V., Volakakis, N., Varikou, K., Garantonakis, N., Economou, L., Birouraki, A., Markellou, E., Liberopoulou, S., & Edwards, M. (2019). Ground cover management with mixtures of flowering plants to enhance insect pollinators and natural enemies of pests in olive groves. Agriculture, Ecosystems and Environment, 274(June 2018), 76–89.

Leong, J. M., & Thorp, R. W. (1999). Colour-coded sampling: the pan trap colour preferences of oligolectic and nonoligolectic bees associated with a vernal pool plant. *Ecological Entomology*, *24*(3), 329-335.

Moreira, E. F., Santos, R. L. D. S., Penna, U. L., Angel-Coca, C., de Oliveira, F. F., & Viana, B. F. (2016). Are pan traps colors complementary to sample community of potential pollinator insects?. *Journal of Insect Conservation*, *20*(4), 583-596.

Penalver-Cruz, A., Alvarez, D., Lavandero, B.J., 2020. Do hedgerows influence the natural biological control of woolly apple aphids in orchards? J. Pest Sci. 93, 219–234.

Rhainds, M., Ho, C.T., 2002. Size-dependent reproductive output of female bagworms (Lepidoptera: Psychidae): Implications for inter-generational variations of population density. Appl. Entomol. Zool. 37 (3), 357–364.

Sahari, B., Nurmansyah, A., Manuwoto, S., & Buchori, D. (2020). Pattern of Hymenopteran Parasitoid Community in Oil Palm Plantations: Effects of Age Gradient or Sampling Methods? 8(Iccesi 2019), 75–82.

Thaer, S., Kassim, F. A., Hasbullah, N. A., & Al-Obaidi, J. R. (2021). Evaluation of Bagworm, *Metisa plana* (Lepidoptera: Psychidae) Infestation and Beneficial Parasitoid in an Oil Palm Plantation, Perak, Malaysia. Journal of Science and Mathematics Letters, 9(1), 19–35.

Toennisson, T. A., Klein, J. T., & Burrack, H. (2019). Measuring the effect of non-crop flowering plants on natural enemies in organic tobacco. Biological Control, 137(July).

Tohiran, K. A., Nobilly, F., Zulkifli, R., Ashton-Butt, A., & Azhar, B. (2019). Cattle-grazing in oil palm plantations sustainably controls understory vegetation. *Agriculture, ecosystems & environment*, *278*, 54-60.

Tohiran, K. A., Nobilly, F., Zulkifli, R., Maxwell, T., Moslim, R., & Azhar, B. (2017). Targeted cattle grazing as an alternative to herbicides for controlling weeds in bird-friendly oil palm plantations. *Agronomy for sustainable development*, *37*(6), 1-11.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. Ecology Letters, 8, 857–874.

Vrdoljak, S. M., & Samways, M. J. (2012). Optimising coloured pan traps to survey flower visiting insects. *Journal of Insect Conservation*, *16*(3), 345-354.

Yang, Q., Men, X., Zhao, W., Li, C., Zhang, Q., Cai, Z., Ge, F., Ouyang, F., 2021. Flower strips as a bridge habitat facilitate the movement of predatory beetles from wheat to maize crops. Pest Manag. Sci. 77, 1839–1850.

Zhang, X., Ouyang, F., Su, J., Li, Z., Yuan, Y., Sun, Y., Sarkar, S. C., Xiao, Y., & Ge, F. (2022). Intercropping flowering plants facilitate conservation, movement and biocontrol performance of predators in insecticide-free apple orchard. Agriculture, Ecosystems and Environment, 340(April), 108157.