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Diversity and Distribution of Predatory Insects in Non-outbreak and Post-outbreak Estates of an Oil Palm Plantation in Beluran District, Sabah, Malaysia

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ABSTRACT

Hemipteran predator species from the families Reduviidae and Pentatomidae are a group of insects that play a crucial role as natural enemies of leaf-eating pests in oil palm plantations by maintaining the population of pests below the economic threshold. The promotion of natural enemies can be an effective and sustainable approach to pest management. A census was conducted between June and August 2022 in nine plantations in Beluran district, Sabah to compare the species composition between recent leaf-eating pest in outbreaks and non-outbreak estates using sweep nets and active visual surveys. A total of 355 individuals from seven species of two different families were recorded, with Reduviidae being the most abundant family: *Sycanus annulicornis, S. affinis, Cosmolestes picticeps, Velinus nigrigenu, Campsolomus* nr. sp. (Hemiptera: Reduviidae), *Platynopus melanoleucus* and *Eocanthecona furcellata* (Hemiptera: Pentatomidae). The diversity indices of the predatory insects were significantly higher ($p<0.01$) in non-outbreak estates (H' = 1.682, 1-D = 0.763) compared to post-outbreak estates (H' = 1.344, 1-D = 0.683), which recorded a higher dominance value (D = 0.32) of a single species, leading to a decrease in the diversity indices. The Pentatomidae family was only found at non-outbreak estates, while the other Reduviidae species were highly abundant and distributed throughout all study locations. The *S. annulicornis* and *S. affinis* were only found on beneficial plants, while *E. furcellata* and *P. melanoleucus* were highly abundant within the oil palm planting area. These findings provide insights into the importance of maintaining the beneficial plant and reducing the impact of pest outbreaks on the diversity and abundance of predatory insects in oil palm plantations.

Keywords: Assassin bugs, asopin bugs, bagworm predators, biological control, species abundance

INTRODUCTION

Malaysia is known as the second leading producer of palm oil worldwide (Mohan *et al.*, 2021), the Malaysia Peninsular has the largest of Malaysia's palm oil plantations, followed by the state of Sarawak and Sabah. A total of 5.74 million hectares of oil palm plantations were planted throughout Malaysia as of December 2022, whereas Sabah recorded around 1.51 million hectares of palm oil plantations (MPOB, 2022). Bagworms (Lepidoptera: Psychidae) and nettle caterpillars (Lepidoptera: Limacodidae) are common leaf-eating pests in oil palm plantations, which can cause defoliation and yield losses if not effectively managed (Sudharto *et al.*, 2003; Sulaiman, 2021). *Metisa plana* remain the most common species of bagworm infesting the oil palm plantations, followed by *Pteroma pendula*, while *Mahasena corbetti*, a major defoliator, is found throughout eastern Sabah and some areas of Peninsular Malaysia (Norman & Basri, 2007; Sankaran & Syed, 1972; Wood & Kamarudin, 2019). Bagworm infestation in Sabah was first reported in 1972 by Sankaran & Syed (1972). Bagworm prevalence was highest in Sabah (30%), with *M. corbetti* being the species that is most frequently found there as opposed to *M. plana* and *P. pendula* (Norman *et al.*, 2007).

Nettle caterpillars are easily identified by their vivid body color, sometimes with stripes, and their distinctive stinging spines, which can be painful when in contact with the skin (Mohd Basri *et al.*, 1994; Ali *et al.*, 2003). Outbreak of this insect pest have occurred in several states in Malaysia but it was first recorded in Sabah on 1974 (Kimura, 1978; Lay, 1996; Wood & Kamarudin, 2019). The *S. nittens* was identified as the most common nettle caterpillar present during an outbreak in oil palm plantations in Sandakan, Sabah (Lim *et al.*, 2001). Other nettle caterpillar species found in Sabah include the *S. cupreistriga*, *S. cupreiplaga*, *S. tamsi* (Chung, 2016), *Thosea vetusta*, *Darna trima*, *D. diducta*, and *Setothosea asigna* (Darus *et al.*, 2000; Ali *et al.*, 2003; Pujiastuti *et al.*, 2014).

In Malaysia oil palm plantations, the leaf-eating pest outbreaks are intermittent because of the natural enemies like insect predators, parasitoids, and viruses that frequently control the pest population (Cheong *et al.*, 2010; Ali *et al.*, 2013; Loong *et al.*, 2017). Five hemipteran species, including *Cosmolestes picticeps* (Yusdayati, 2008), *Andrallus spinidens* (Khoo & Chan, 2000), *Platynopus melachantus*, *Cantheconidea furcellata* (Wood & Kamarudin, 2019), and *Sycanus dichotomus* (Syari *et al.*, 2011), have been identified as predatory insects for bagworms and nettle caterpillars. These hemipterans such as *Sycanus* sp. (Poopat & Maneerat, 2021), *C. picticeps* (Jamian *et al.*, 2017), *P. melachantus*, *C. furcellata* (Azlina & Tey, 2011) and *Eucanthecona furcellata* (Rustam & Gani, 2019) are general feeders with a wide host range where peculiarly the sharp proboscis of the predator insects penetrates the body of prey insects to siphon the body fluids. One of the future management strategies may include a mass-rearing program of predator insects to increase biological control in oil palm plantations to reduce outbreaks of leaf-eating pests. Therefore, the objective of this research paper was to determine and identify the hemipteran species that could be mass-reared and released as predators in oil palm plantations.

MATERIALS AND METHODS

The sampling has been conducted between June to August 2022 in nine IOI oil palm plantations in Beluran District (Figure 1). The sampling location was divided into four recent leaf-eating pest non-outbreak (NOE) (Estate 1 – 4) and five post-outbreak estates (POE) (Estate 5 – 9) covering an area of 12.24 ha. The sampling sites are shown in Table 1. The sampling was conducted in a specific plot of young matured palm trees, which were planted between 2016 to 2018. The sampling area includes the beneficial plants (*Cassia cobanensis*, *Antigonon leptopus* and *Turnera subulata*) and within the oil palm planting area (palm circle, interrow and harvesting path). The hemipteran insect was sampled using sweep nets and active visual surveys (Azhar *et al.*, 2022; Razali *et al.*, 2015). Sampling was conducted between 10 am to 3 pm for two days in each estate. All samples were kept in 70% ethanol solution for preservation before the identification process in the laboratory.

The hemipteran was morphologically identified up to the level of the genus and species by referring to digital references collections in The Biodiversity of Singapore by the Lee Kong Chian Natural History Museum (LKCNHM, 2022) and available taxonomic key references for hemipteran species (Reduviidae and Pentatomidae) (Gil-Santana *et al.*, 2015; Dass *et al.*, 2016). The photographs were taken by using a RaxVision stereomicroscope with DinoCapture 2.0 software.

Collective data of the individuals captured were used to compute the diversity indices and rarefaction curves analysis (Colwell *et al.*, 2012; Gotelli & Chao, 2012) by using PAST 3.26 (PAleontological STatistics software) (Hammer *et al.*, 2001). These diversity indices include Dominance (D), Simpson diversity index (1-D), Shannon-Wiener diversity index (H’) and Shannon evenness index (E’) (Morris *et al.*, 2014). Cluster analysis was used to distinguish the species composition's similarity in the nine locations, using the Euclidean (Pythagorean) distance measure. The Pc-Ord Version 6 program (Grandin, 2006) was used for two-way cluster analysis.

Table 1. List of hemipteran species found in both non-outbreak and post-outbreak oil palm plantations, as well as in two distinct sampling areas

Family	Species	Non-Outbreak Estates				Post-Outbreak Estates					Total (N)	Relative abundance (%)	Sampling Area	
		Estate 1	Estate 2	Estate 3	Estate 4	Estate 5	Estate 6	Estate 7	Estate 8	Estate 9			Beneficial Plants	Planting Row
Reduviidae	*Sycanus annulicornis*	0	17	0	2	75	5	1	0	0	100	28.17	74	26
	Sycanus affinis	7	3	0	0	14	20	0	0	0	44	12.39	15	29
	Cosmolestes picticeps	25	24	13	15	5	4	7	7	6	106	29.86	58	48
	Campsolomus nr. sp.	0	2	9	1	2	2	1	1	3	21	5.92	16	5
	Velinus nigrigenu	0	2	6	27	3	2	0	3	6	49	13.8	40	9
Pentatomidae	*Eocanthecona furcellata*	18	2	0	0	0	0	0	0	0	20	5.63	0	20
	Platynopus melanoleucus	0	0	15	0	0	0	0	0	0	15	4.23	0	15
	Total	50	50	43	2	99	33	9	11	15	355	100	202	153

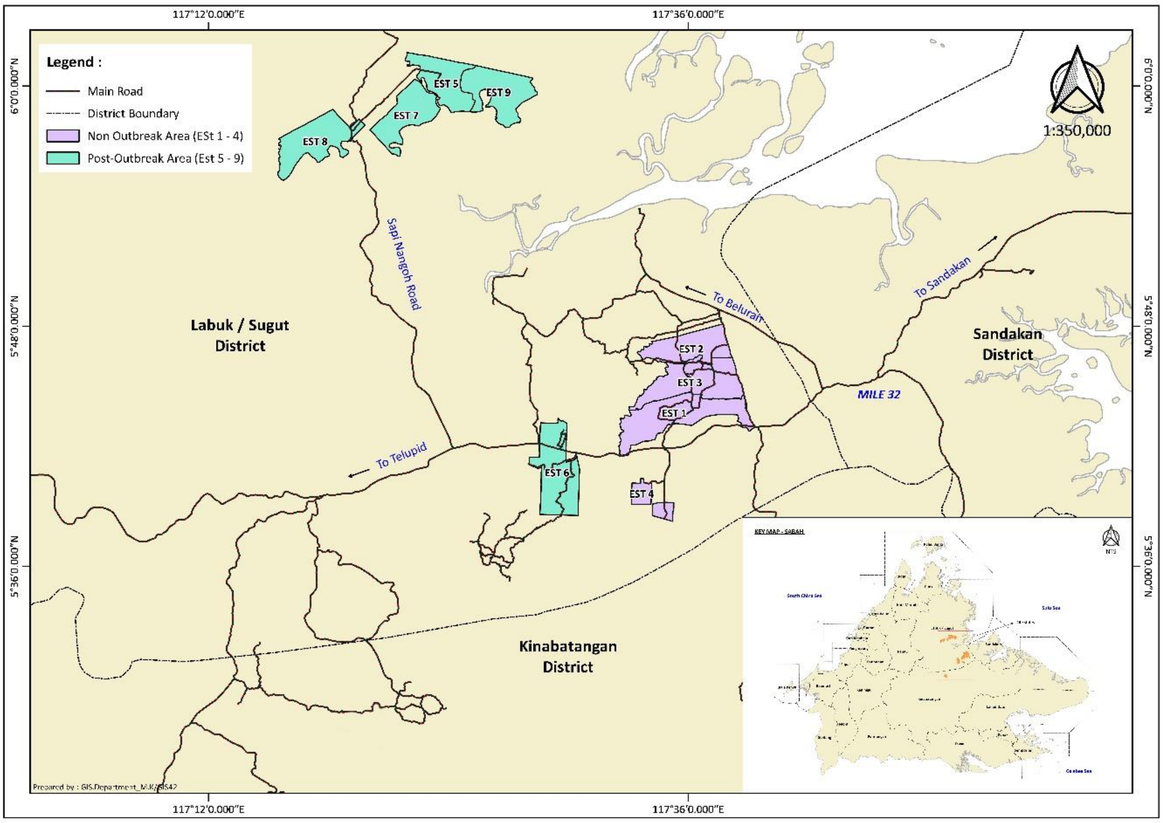

Figure 1. Sampling locations at Beluran district, Sabah. Est - Estate

RESULTS

A total of 355 individuals have been recorded in this sampling from seven species of two different families: *Sycanus annulicornis, S. affinis, Cosmolestes picticeps, Velinus nigrigenu, Campsolomus nr.* sp. (Hemiptera: Reduviidae), *Platynopus melanoleucus* and *Eocanthecona furcellata* (Hemiptera: Pentatomidae) (Figure 2). Table 1 provides information on the hemipteran species recorded in non-outbreak (NOE) and post-outbreak (POE) estates, as well as two sampling areas with their relative abundance percentages.

In the family Reduviidae, *S. annulicornis* was found in POE with a relative abundance of 28.17% (N = 100). This species was most abundant in Estate 5, with 75 individuals recorded. *Sycanus affinis*, another member of the same family, showed a relatively lower abundance (12.39%, N = 44) and was distributed across multiple estates. *Cosmolestes picticeps* exhibited a relatively high abundance (29.86%, N = 106) in both NOE (N = 77) and POE (N = 29). *Campsolomus nr*. sp. and *V. nigrigenu* showing a higher abundance in NOE with 12 and 35 individuals, respectively. Among the species recorded in the Pentatomidae family, *E. furcellata* was primarily found in NOE, with a relative abundance of 5.63% (N = 20). This species was most abundant in Estate 1, with 18 individuals observed. Another member of the Pentatomidae family, *P. melanoleucus* was exclusively found in POE, constituting 4.23% (N= 15) of the total relative abundance.

Among the species observed, *S. annulicornis* had the highest abundance at the beneficial plants, with a total of 74 individuals recorded. Conversely, *S. affinis* exhibited a lower abundance in the beneficial plants (N = 15) compared to the planting rows (N = 29). *Cosmolestes picticeps* displayed higher abundances in both the beneficial plants (N = 58) and the planting rows (N = 48). *Campsolomus nr*. sp. and *V. nigrigenu* were predominantly abundant in the beneficial plant area, with 16 and 40 individuals, respectively, but had limited presence in the planting rows, with only 5 and 9 individuals, respectively. In contrast, *E. furcellata* and *P. melanoleucus* did not show any associations with the beneficial plants. However, they were relatively abundant in the planting rows, with 20 and 15 individuals, respectively. Overall, the recorded hemipteran species showed a total of 203 individuals associated with beneficial plants and 152 individuals on planting rows. The rarefaction curve in Figure 3, indicates that sufficient sampling effort has been achieved in this sampling.

The diversity analysis of the predator insects between the NOE showed a significantly ($t = 4.42$, $p<0.01$) higher score of Shannon-Wiener diversity index (H') = 1.682 and Simpson diversity index (1-D) = 0.763 compared to POE (H'= 1.344, 1-D = 0.683). Comparatively, POE recorded 167 individuals from only five species of predatory insects which excluded *E. furcellata* and *P. melanoleucus*, compared to seven hemipteran species in NOE with a total of 188 individuals (Table 2). The high dominance (D) value in POE (D = 0.32) of a single species, *S. annulicornis* led to a low in the diversity indices score on the study site. The species evenness between the NOE and POE bagworm areas was not significantly different ($t = 0.007$, $p>0.05$) with a score of E' = 0.75 and E' = 0.76, respectively.

According to the two-way clustering dendrogram (Figure 4), *Sycanus* sp. was most abundant and dominant at POE (n = 81), whereas it was least frequent at NOE (n = 19). Both of *E. furcellata* and *P. melanoleucus* belongs to the Pentatomidae family were found only at the NOE (n = 35), whereas the other Reduviidae species (*C. picticeps, Campsolomus nr.* sp., and *V. nigrigenu*) were highly abundant and distributed throughout all the study locations. The clustering analysis revealed that *Campsolomus nr*. sp. was grouped together with *E. furcellata* and *P. melanoleucus,* with over 80% of information remaining. On the other hand, *S. annulicornis* was found to have 0% similarity with other species, while *C. picticeps* (>60%) and *V. nigrigenu* (75%) formed separate clusters with high percentages of information remaining.

In this study, two distinct sampling areas were examined, revealing notable differences in the abundance of certain species. Specifically, *E. furcellata* and *P. melanoleucus* were found to be highly abundant within the oil palm planting row of the estate. These species were predominantly observed beneath the leaflets and at the frond basal of the oil palm trees. On the other hand, *S. annulicornis* and *S. affinis* were exclusively discovered on a beneficial plant known as *Cassia cobanensis*. This information highlights the specific habitat preferences of these species and emphasizes their association with different plant species within the study area. Meanwhile *Campsolomus nr*. sp., *V. nigrigenu*, and *C. picticeps* can be found in planting areas as well as in areas within the vicinity of the beneficial plants. The diversity indices of the hemipteran populations were found to be significantly different (t = 2.819, p<0.01) between the beneficial plant-planted areas and the oil palm planting area. The diversity indices were higher within the oil palm planting area (1-D = 0.795, H' = 1.728) when compared to the beneficial plant area (1-D = 0.735, H' = 1.439). The species evenness between the beneficial plant and oil palm planting area was found to be significantly different (t = 2.819, p<0.01). The evenness score in the beneficial plant area was higher (E' = 0.843) compared to within the oil palm planting area (E' = 0.804). This suggests that the beneficial plant area has a more balanced distribution of species abundance, while the oil palm planting area may have a more uneven distribution of species abundance.

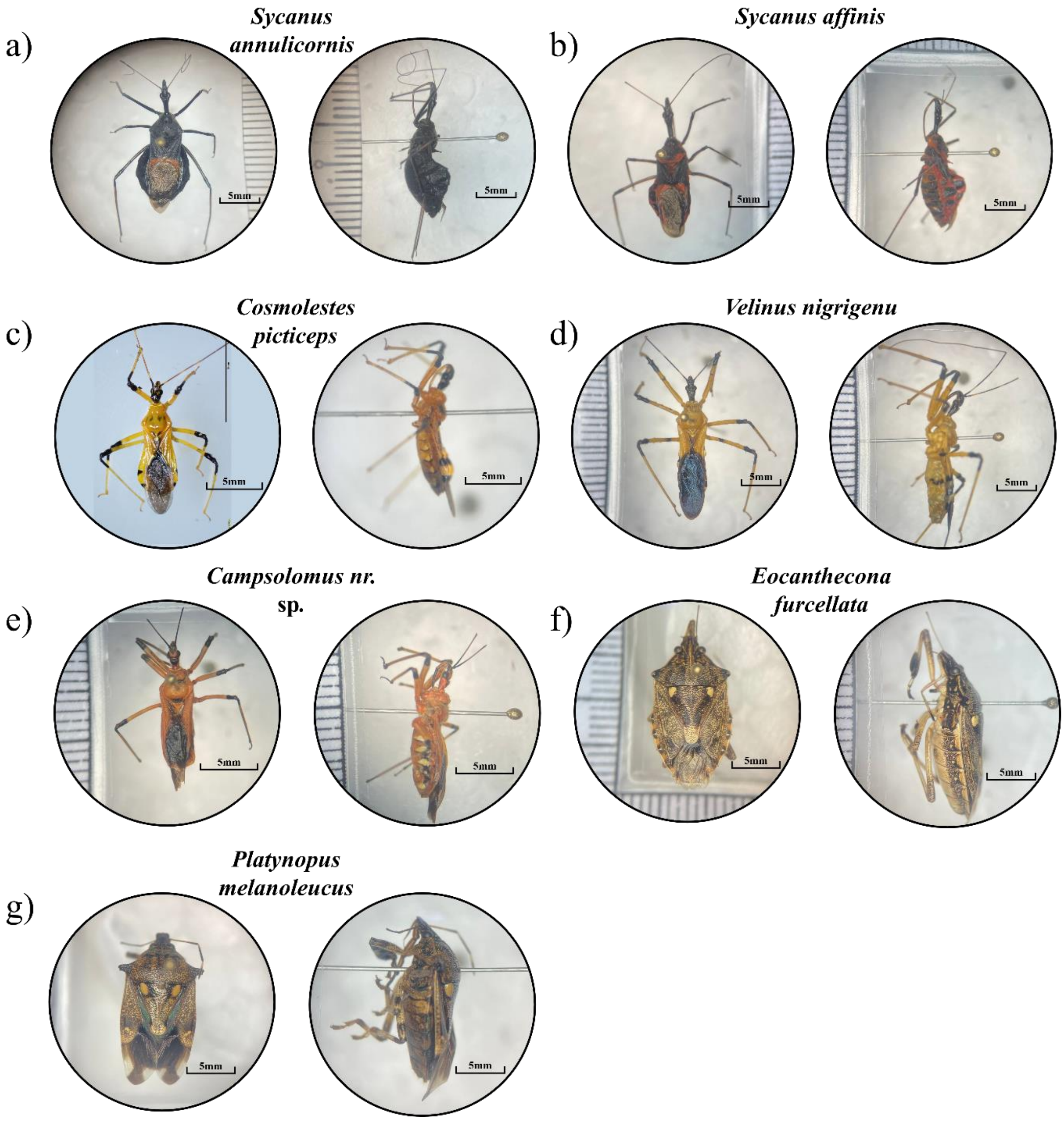

Figure 2. Dorsal and lateral view of collected predator hemipteran species

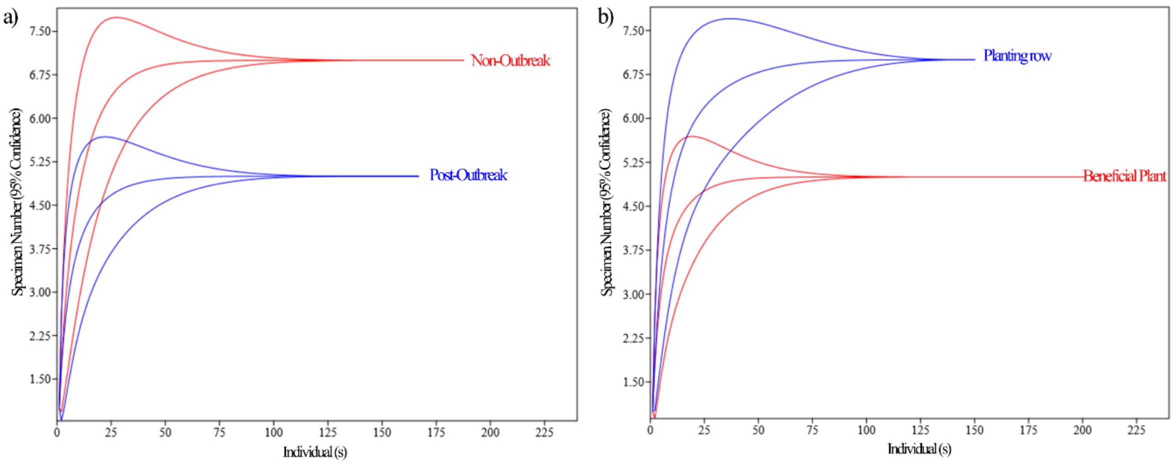

Figure 3. The rarefaction curve of the hemipteran species richness was recorded between a) Non-outbreak estates and post-outbreak estates b) Beneficial plants and within the planting area

Table 2. Diversity indices of the hemipteran predatory insects were recorded at the bagworm non-outbreak and post-outbreak oil palm plantations and two sampling areas

Indices	Estates		Sampling area	
	Non-Outbreak	Post-Outbreak	Beneficial plant	Planting Area
Number of species	7	5	5	7
Individuals	188	167	202	153
Dominance (D)	0.237	0.317	0.265	0.205
Simpson (1-D)	0.763*	0.683*	0.735*	0.795*
Shannon (H’)	1.682*	1.344*	1.439*	1.728*
Evenness (E’)	0.768	0.767	0.843	0.804

*significant difference (p<0.01) within group in each indices

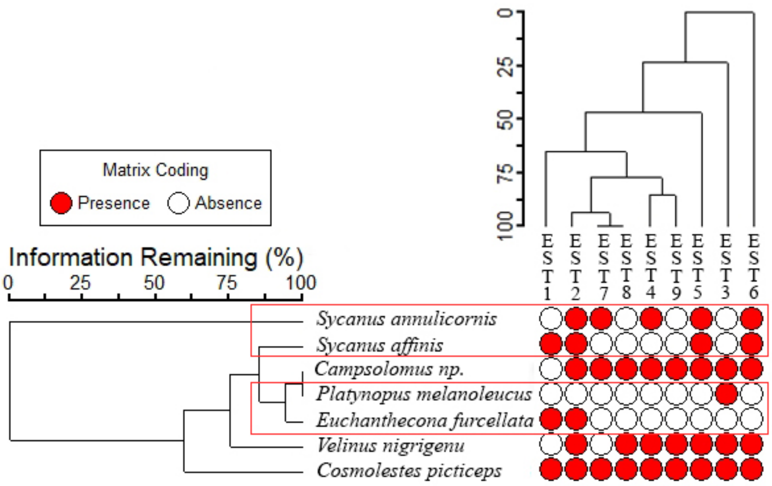

Figure 4. Two-way cluster analysis based on the presence and absence of the hemipteran predator insect assemblage at each locality in oil palm

DISCUSSION

The present study investigated the diversity and distribution of predatory insects in non-outbreak and post-outbreak estates of an oil palm plantation in Beluran district, Sabah, Malaysia. The rarefaction curve shows that all samples have reached asymptote, indicating that a thorough sampling of the species has been accomplished. At this point, only the rarest species remain to be sampled, as suggested by Chiarucci *et al.* (2009). The analysis of diversity in this study unveiled a notable difference between non-outbreak and post-outbreak estates. Specifically, the non-outbreak estates exhibited significantly higher diversity indices (H' and 1-D) compared to the post-outbreak estates. This discrepancy can be attributed to the high dominance by a single species observed in the post-outbreak area known as *Sycanus* sp., which led to a decrease in diversity indices of the predatory insects. Interestingly, these findings contrast with a previous study by Jamian *et al.* (2017), which established a correlation between bagworm and predator populations. In their research, a significantly higher number of insect predators were found in oil palm plantations experiencing an outbreak compared to fields that were not affected. The contrasting results highlight the complexity of ecological dynamics and the importance of considering specific contexts and factors when examining predator-prey relationships in different environments. As there were only a few bagworm hosts present in the oil palm plantations, the insect predators redirected their activities towards beneficial plants, *Tunera subulata* (Jamian *et al.*, 2016).

Furthermore, the results of the clustering analysis indicated a distinct pattern regarding the abundance of the dominant species in different areas. Specifically, *Sycanus* sp. was found to be most abundant in the post-outbreak estate (POE), particularly at the beneficial plant *C. cobanensis*, while it was least frequently observed in the non-outbreak estate (NOE). This observation suggests that the bagworm outbreak may have triggered changes in the structure of the predator community (Wood & Kamarudin, 2019), potentially leading to an increase in the population of certain predator species, such as *Sycanus* sp. These findings emphasize the dynamic nature of predator-prey interactions and highlight the potential impact of ecological disturbances on the composition and abundance of predator species within an ecosystem.

Controlling the bagworm population in oil palm plantations is of utmost importance and natural enemies play a significant role in this regard (Wood & Kamarudin, 2019; Fuat *et al.*, 2022). However, it is vital to exercise caution in the use of synthetic chemical insecticides, as their broad-spectrum activity can have negative consequences on natural enemies and non-targeted species, which are often more susceptible to these insecticides (Cheong & Tey, 2013). To ensure proper control, insecticide application should be carried out at the correct dosage and timing, specifically when the bagworm outbreak reaches the threshold (Lelana *et al.*, 2022). Interestingly, in the current study, a higher number of predator species were observed exclusively at the beneficial plant rather than in the planting row of the post-outbreak estate (POE). This finding may be attributed to the chemical control program implemented in the POE before the sampling period. The program involved the use of cypermethrin, a pyrethroid insecticide (Mat *et al.*, 2020; Sulaiman *et al.*, 2020), applied through spraying methods.

Hence, as previously mentioned, it is conceivable that the utilisation of insecticides might have influenced the distribution and variety of predator species in the planting row, leading to a reduced presence of predator species compared to the beneficial plant. This underscores the significance of adopting alternative selective chemical insecticides that are specific to the target species, such as chlorantraniliprole (Kok *et al.*, 2010). Chlorantraniliprole has been shown to have minimal effects on most natural predatory insects, parasitoids (Brugger *et al.*, 2010), and pollinators (Asib & Musli, 2020). By using selective insecticides, the negative impact on natural enemies and non-targeted species can be minimised, allowing for a more balanced predator-prey relationship in oil palm plantations.

In this study, all the predator insect species identified for controlling leaf-eating pests have been previously documented in various studies, except for *Campsolomus nr*. sp. and *V. nigrigenu*. These species include *Sycanus* sp. (Sahid & Natawigena, 2018; Poopat &

Maneerat, 2021; Pratama, 2021), *C. picticeps* (Jamian *et al.*, 2017), *P. melanoleucus* (Khoo *et al.*, 1999; Azlina & Tey, 2011), and *E. furcellata* (Rustam & Gani, 2019). Notably, the assassin bug, *S. dichotomus,* which is recognised as one of the key predators for bagworms and nettle caterpillars in Peninsular Malaysia oil palm plantations, was not recorded in this study (Jamian *et al.*, 2017; Ahmad *et al.*, 2020). Another study discovered that hemipteran predators were responsible for the highest rate of bagworm mortality (46%) within the plantation, surpassing other natural enemies (Cheong *et al.*, 2010). These hemipterans puncture the bagworm casings with their proboscis and extract their bodily fluids (Bakri & Rahim, 2015).

The effectiveness of different predator insect species in controlling bagworms was assessed, revealing that *S. dichotomus, P. melacanthus,* and *E. furcellata* exhibited higher killing efficiency compared to *C. picticeps* (Azlina & Tey, 2011). Despite *C. picticeps* being abundant and widely distributed in oil palm plantations, its smaller body size limits its ability to prey on larger bagworms during their late instar stage. In contrast, *Sycanus* sp. possesses a narrower and longer proboscis, which enhances its capacity to attack bagworms at all stages of development (Zulkefli *et al.*, 2004). Additionally, cannibalistic behavior was observed in *C. picticeps*, indicating that this species feeds on members of its own genus as a supplementary part of its diet.

Mass rearing and release programs of predatory insects can be a promising long-term preventive strategy for leaf-eating pests. Significant progress has been seen in the laboratory rearing of *S. dichotomous* (Muhamad *et al.*, 2018; Syari *et al.*, 2011), *S. annulicornis* (Sahid & Natawigena, 2018), *S. collaris* (Poopat & Maneerat, 2021) and *E. furcellata* (Rustam & Gani, 2019), with more than 100 folds fecundity rate with a simple and low-cost setup. However, several factors need to be considered before undertaking mass rearing in a laboratory setting. These factors include the long life cycle of certain predator insects, the quality of parent individuals, potential reduction in fecundity, risks associated with inbreeding, the cost of production, and the availability of expertise (Ahmad *et al.*, 2020).

A diverse ecosystem encompassing a variety of understory vegetation and nectar-producing plants provides favourable conditions for natural enemies to thrive and access essential resources (Russell, 1989; O'Rourke & Petersen, 2017; Syahlan, 2021; Lelana *et al.*, 2022). Beneficial plants refers to non-pestiferous plants that produce nectar and act as hosts for the natural enemies of crop insect pests (Ali *et al.*, 2013). Example of such plants include *C. cobanensis, T. subulata, T. ulmifolia, Euphorbia heterophylla* and *Antigonon leptopus* has been proven to provide a suitable environment in attracting and supporting the predator insect and parasitoid in oil palm plantations (Tuck *et al.*, 2003; Jamian *et al.*, 2017). To maintain a balanced agricultural ecosystem in oil palm plantations, it is crucial to preserve the weed-growing areas and add more beneficial plants to the fields (Luke *et al.*, 2020). The present study reveals that the diversity of predator hemipterans was the highest in the samples taken from planting plot areas compared to samples collected from beneficial plants. The Reduviidae species dominated the areas with beneficial plants, while Pentatomidae species were only found under the leaflets of oil palm trees in the weed-growing area. Hence, both beneficial plants and weed-growing areas are vital for sustaining the life cycle of natural enemies that prey on leaf-eating pests (Denan *et al.*, 2020).

CONCLUSION

In conclusion, this study found that the diversity indices of predatory insects were significantly higher in non-outbreak estates compared to post-outbreak estates, with a higher abundance of hemipteran species belonging to the Pentatomidae family in non-outbreak estates. In the context of mass rearing and control of leaf-eating pests in oil palm plantations, the findings of this study suggest that two species, *Sycanus* sp. and *E. furcellata*, hold particular promise. *Sycanus* sp., with its high abundance and ability to prey on bagworms at all stages, emerges as a promising candidate for mass rearing and release programs. Similarly, *E. furcellata* has demonstrated significant killing efficiency against bagworms in previous research. These species hold promise for developing effective biological control strategies to mitigate the impact of leaf-eating pests. Further research is warranted to investigate their life cycles, fecundity rates, and cost-effective production methods. By focusing on these abundant and suitable species, we can pave the way for sustainable and environmentally friendly pest management practices in oil palm plantations.

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REFERENCES

Ahmad, S.N., Mohamad, S.A. & Masri, M.M.M. (2020). A simple laboratory system for rearing of the predator, *Sycanus dichotomus* (Hemiptera: Reduviidae): A promising biocontrol agent for bagworm management. *Oil Palm Bulletin*, 80: 6-14.

Ali, S.R.A., Kamarudin, N., Moslim, R. & Wahid, M. B. (2013). Bioprotection in oil palm. In *Further Advances in Oil Palm Research 2000-2010* (2nd ed.). Malaysian Palm Oil Board (MPOB). pp. 358-406.

Ali, S.R.A., Wahid, M.B. & Mahadi, N.M. (2003). IPM of bagworms and nettle caterpillars using *Bacillus thuringiensis*: Towards understanding and increasing efficacy. *Proceedings of the PIPOC 2003 International Palm Oil Congress : Palm Oil, the Power-House for the Global Oils & Fats Economy*, 1-29.

Asib, N. & Musli, N.N. (2020). Effect of six insecticides on oil palm pollinating weevil, *Elaeidobius kamerunicus* (Coleoptera: Curculionidae). *Serangga*, 25(2): 1-9.

Azhar, A., Tawakkal, M.I., Sari, A., Rizali, A., Tarigan, S.D., Nazarreta, R. & Buchori, D. (2022). Tree diversity enhance species richness of beneficial insect in experimental biodiversity enrichment in oil palm plantation. *International Journal of Oil Palm*, 5(2): 39-49.

Azlina, Z. & Tey, C.C. (2011). Killing efficiency of selected insect predator species against bagworm, *Metisa plana*. *Proceeding of Agriculture, Biotechnology and Sustainability Conference*, 46-59.

Bakri, A. & Rahim, F. (2015). Hemipteran diversity in Endau-Rompin plantation. *AIP Conference Proceedings*, 1678(1): 20006.

Brugger, K.E., Cole, P.G., Newman, I.C., Parker, N., Scholz, B., Suvagia, P., Walker, G. & Hammond, T.G. (2010). Selectivity of chlorantraniliprole to parasitoid wasps. *Pest Management Science*, 66(10): 1075-1081.

Cheong, Y.L., Sajap, A.S., Hafidzi, M.N., Omar, D. & Abood, F. (2010). Outbreaks of bagworms and their natural enemies in an oil palm, *Elaeis guineensis*, plantation at Hutan Melintang, Perak, Malaysia. *Journal of Entomology*, 7(3): 141-151.

Cheong, Y.L. & Tey, C.C. (2013). Environmental factors which influence bagworm outbreak. *Proceedings of the 5th MPOB Dan IOPRI International Seminar: Sustainable Management of Pests and Disease in Oil Palm*, 1-15.

Chiarucci, A., Bacaro, G., Rocchini, D., Ricotta, C., Palmer, M.W. & Scheiner, S.M. (2009). Spatially constrained rarefaction: Incorporating the autocorrelated structure of biological communities into sample-based rarefaction. *Community Ecology*, 10(2): 209-214.

Chung, A.Y.C. (2016). An overview of insect pests of rattans & other palms in Sabah, Malaysia. *Symposium and Training Course on Forest Invasive Pests, Haikou, Hainan*, 18-22.

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.

Darus, A., Wahid, M.B. & Basri, M.W. (2000). Intensive IPM for management of oil palm pests. *Oil Palm Bulletin*, 41: 1-14.

Dass, A.D., Yaakop, S. & Ghani, I.A. (2016). Taxonomic notes on assasin bugs (Hemiptera: Heteroptera) from Malaysia. *AIP Conference Proceedings*, 1784(1): 60004.

Denan, N., Wan Zaki, W.M., Norhisham, A.R., Sanusi, R., Nasir, D.M., Nobilly, F., Ashton-Butt, A., Lechner, A.M. & Azhar, B. (2020). Predation of potential insect pests in oil palm plantations, rubber tree plantations, and fruit orchards. *Ecology and Evolution*, 10(2): 654-661.

Fuat, S., Adam, N.A., Hazmi, I.R. & Yaakop, S. (2022). Interactions between *Metisa plana*, its hyperparasitoids and primary parasitoids from good agriculture practices (GAP) and non-gap oil palm plantations. *Community Ecology*, 23(3): 429-438.

Gil-Santana, H.R., Forero, D. & Weirauch, C. (2015). Assassin bugs (Reduviidae Excluding Triatominae). In *True bugs (Heteroptera) of the neotropics*. Springer. pp. 353-393.

Gotelli, N. & Chao, A. (2012). *Measuring and estimating species richness, species diversity, and biotic similarity from sampling data.* In *The Encyclopedia of Biodiversity*. New York: Elsevier.

Grandin, U. (2006). PC-ORD version 5: A user-friendly toolbox for ecologists. *Journal of Vegetation Science*, 17(6): 843-844.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D. (2001). PAST: paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, 4(1): 9.

Jamian, S., Adam, N.A., Azhar, B., Noor, H.M. & Muhamad, R. (2016). Relationship between bagworm and predatory insect species in oil palm plantation of Peninsular Malaysia. *Conference: 9th International Conference on Plant Protection in the TropicsAt: Kuching, Sarawak, Malaysia*, 34-37.

Jamian, S., Norhisham, A., Ghazali, A., Zakaria, A. & Azhar, B. (2017). Impacts of 2 species of predatory Reduviidae on bagworms in oil palm plantations. *Insect Science*, 24(2): 285-294.

Khoo, K.C. & Chan, Y.C. (2000). The Honolulu creeper, *Antigonon leptopus*, as a supplementary food resource for the predatory bug *Andrallus spinidens* (Hemiptera: Pentatomidae, Asopine). *Plant Health 2000 Conference on Crop Protection and Biotechnolgy Toward Improved Plant Health*, 45-47.

Khoo, K.C., Sri Ulina, E., Ng, P.L. & Ibrahim, Y. (1999). The role of predatory insects in the pest management of leaf-eating caterpillars of oil palm. In *Research Report. The Research Unit, Universiti Putra Malaysia, Serdang, Selangor.*

Kimura, N. (1978). A new nettle caterpillar of oil palm in Sabah, Malaysia. *Japan Agricultural Research Quarterly*, 12(1): 53-55.

Kok, C., Eng, O., Abdul, R.R., Marcon, P.G. & Loong, L. (2010). Chlorantraniliprole: a novel insecticide for bagworm (*Metisa plana*) control in oil palm plantation. *Planter*, 86(1009): 223-235.

Lay, T.C. (1996). Integrated pest management of leaf-eating caterpillars of oil palms in Sabah. *Planter*, 72(844): 395-405.

Lelana, N.E., Utami, S., Darmawan, U.W., Nuroniah, H.S., Haneda, N.F., Darwiati, W. & Anggraeni, I. (2022). Bagworms in Indonesian plantation forests: Species composition, pest status, and factors that contribute to outbreaks. *Diversity*, 14(6): 471.

Lim, G., Lim, K. & Fook, K. (2001). New records of alternative host plants for oil palm nettle caterpillar Setora nitens Walker in Sabah, Malaysia. In *Cutting-Edge Technologies for Sustained Competitiveness. Proceedings of the 2001 PIPOC International Palm Oil Congress, Agriculture Conference*, 20-22 August 2001, Kuala Lumpur, Malaysia. pp. 609-611.

LKCNHM, Lee Kong Chian Natural History Museum. (2022). *The Biodiversity of Singapore*. National University of Singapore. https://singapore.biodiversity.online/taxon/A-Arth-Hexa-Hemi

Loong, C.Y., Shamsudin, S.H. & Chong, T.C. (2017). The efficacy of entomopathogenic virus for the control of oil palm nettle caterpillar. *Proceeding of Agriculture, Biotechnology and Sustainability Conference, Kuala Lumpur*, 121-124.

Luke, S.H., Advento, A.D., Aryawan, A.A.K., Adhy, D.N., Ashton-Butt, A., Barclay, H., Dewi, J.P., Drewer, J., Dumbrell, A.J. & Edi (2020). Managing oil palm plantations more sustainably: Large-scale experiments within the Biodiversity and Ecosystem Function in Tropical Agriculture (BEFTA) Programme. *Frontiers in Forests and Global Change*, 2: 75.

Mat, M.D., Latip, S.N.H.M., Manan, C.A.H.C. & Razali, A.C. (2020). Toxicity of selected insecticides on late stage instar of bagworm, *Metisa plana*. *Scientific Research Journal*, 17(2): 163-175.

Mohan, D., Essam, Y., Katman, H.Y.B., Ahmed, A.N. & Shamsuddin, A.H. (2021). Potential environment and socio-economic impact of biofuel production in Malaysia: A preliminary review. *IOP Conference Series: Earth and Environmental Science*, 708(1): 12068.

Mohd Basri, W., Siti Ramlah, A.A. & Norman, K. (1994). Status report on the use of *Bacillus thuringiensis* in the control of some of oil palm pests. *Elaeis (Malaysia)*, 6(2): 82-101.

Morris, E.K., Caruso, T., Buscot, F., Fischer, M., Hancock, C., Maier, T.S., Meiners, T., Müller, C., Obermaier, E. & Prati, D. (2014). Choosing and using diversity indices: Insights for ecological applications from the German biodiversity exploratories. *Ecology and Evolution*, 4(18): 3514-3524.

MPOB, Malaysia Palm Oil Board. (2022). *Overview of The Malaysian Oil Palm Industry 2022*.

Muhamad, F., Dzulhelmi, M.N., David, A.D. & Idris, A.G. (2018). The effectiveness of rearing *Sycanus dichotomous* (Hemiptera: Reduviidae) in the laboratory using larvae *Tenebrio molitor* as alternative food source. *Serangga*, 23(2): 155-169.

Norman, K. & Basri, M.W. (2007). Status of common oil palm insect pests in relation to technology adoption. *Planter*, 83(975): 371-385.

O'Rourke, M.E. & Petersen, M.J. (2017). Extending the 'resource concentration hypothesis' to the landscape-scale by considering dispersal mortality and fitness costs. *Agriculture, Ecosystems & Environment*, 249: 1-3.

Poopat, P. & Maneerat, T. (2021). Prey preference and predation efficacy of *Sycanus collaris* (F.) (Hemiptera: Reduviidae) on *Tenebrio molitor* (L.)(Coleoptera: Tenebrionidae). *Khon Kaen Agriculture Journal*, 49(4): 1047-1058.

Pratama, Y. (2021). Penggunaan predator (*Sycanus annulicornis*) tanaman kelapa sawit (*Elaeis guineensis* Jacq.) dalam mengendalikan hama pemakan daun (*Setothosea asigna*). *Jurnal Ilmiah Mahasiswa Pertanian [JIMTANI]*, 1(4): 1-10.

Pujiastuti, Y., Bando, H. & Asano, S. (2014). Serial dilution of Nettle Caterpillar viruses applied as bioinsecticide against *Setothosea asigna* van Ecke (Lepidoptera: Limacodidae) the important pest of oil palm. *Journal of Advanced Agricultural Technologies*, 1(2).

Razali, R., Yaakop, S., Abdullah, M., Ghazali, S.Z. & Zuki, A.A. (2015). Insect species composition in an under SRI management in Tanjung Karang, Selangor, Malaysia. *Malaysian Applied Biology*, 44(4): 59-66.

Russell, E.P. (1989). Enemies hypothesis: A review of the effect of vegetational diversity on predatory insects and parasitoids. *Environmental Entomology*, 18(4): 590-599.

Rustam, R. & Gani, M.A. (2019). Biology of *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae) Predator Nettle Caterpillar *Setora nitens* Walker Origin from Riau. *IOP Conference Series: Earth and Environmental Science*, 347(1): 12009.

Sahid, A. & Natawigena, W.D. (2018). Laboratory rearing of *Sycanus annulicornis* (Hemiptera: Reduviidae) on two species of prey: Differences in its biology and efficiency as a predator of the nettle caterpillar pest *Setothosea asigna* (Lepidoptera: Limacodidae). *European Journal of Entomology*, 115: 208-216.

Sankaran, T. & Syed, R.A. (1972). The natural enemies of bagworms on oil palms in Sabah, East Malaysia. *Pacific Insects*, 14(1): 57-71.

Sudharto, P., Desmier de Chenon, P. & Poeloengan, Z. (2003). Biological control of oil palm nettle caterpillars in Indonesia: Review of research activities in Indonesia Oil Palm Research Institute (IOPRI). *Proceedings of the PIPOC 2003 International Palm Oil Congress (Agriculture)*, 362-371.

Sulaiman, M.N. (2021). Sustainable control of bagworm (Lepidoptera: Psychidae) in oil palm plantation: A review paper. *International Journal of Agriculture*, 11(1988): 47-55.

Sulaiman, N., Yeoh, C.B., Ahmad Bustamam, F.K., Khairuddin, N.S.K. & Muhamad, H. (2020). Fate of cypermethrin in Malaysian oil palm plantation. *Drug Testing and Analysis*, 12(4): 504-513.

Syahlan, A. (2021). The role of planting media and mulch in the growth of *Leptopus antigonon* as a beneficial plant on oil palm plantation. *IOP Conference Series: Earth and Environmental Science*, 694(1): 12029.

Syari, J., Muhamad, R., Norman, K. & Idris, A. . (2011). Pemeliharaan *Sycanus dichotomus* Stal.(Hemiptera: Reduviidae) serangga pemangsa ulat bungkus tanaman sawit, *Metisa plana* (Lepidoptera: Psychidae) Walker di makmal. *Sains Malaysiana*, 40(10): 1129-1137.

Tuck, H.C., Chong, K.K., Ibrahim, Y. & Omar, D. (2003). Comparative studies on the use of beneficial-plants for natural suppression of bag worm infestation in oil palm. *Proceedings of PIPOC 2003 International Palm Oil Congress (Agriculture)*, 372-424.

Wood, B.J. & Kamarudin, N. (2019). A review of developments in integrated pest management (IPM) of bagworm (Lepidoptera: Psychidae) infestation in oil palms in Malaysia. *Journal of Oil Palm Research*, 31(4): 529-539.

Yusdayati, R. (2008). *Biological and ecological aspects of bagworms (Lepidoptera: Psychidae) in Ladang FELDA, Sungkai, Perak emphasizing on increasing efficiency of natural enemies through* *planting of beneficial plants*. Master Thesis. Malaysia: Universiti Sains Malaysia.

Zulkefli, M., Norman, K. & Basri, M.W. (2004). Life cycle of *Sycanus dichotomus* (Hemiptera: Pentatomidae) a common predator of bagworm in oil palm. *Journal of Oil Palm Research*, 14: 50-56.