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A PRELIMINARY CHECKLIST OF LEPIDOPTERA IN OIL PALM AREA AND REMNANT FOREST AT SANDAKAN BAY ESTATES, SABAH, MALAYSIA

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ABSTRACT

Oil palm plantations have been frequently reported with a low insect diversity. However, having a conservation area within the oil palm estate might create a sanctuary for the insects. This study documented and compared the Lepidoptera diversity (butterfly and moths) between a remnant forest and a 30-year-old mature oil palm area within the Sandakan Bay Estates. The Lepidoptera were sampled using Van Someren-Rydon traps and aerial nets from 30 September to 4 October 2022 in the remnant forest and 5 to 9 October 2022 in the oil palm area. The remnant forest recorded 184 individuals of 28 Lepidoptera species while the oil palm area recorded 172 individuals of 19 species. The T-test result showed that there was no significant difference in species richness (P = 0.108) between both sites due to differences of nine species recorded. There was also no significant difference in species abundance (P = 0.577) between both sites, with differences of 12 individuals recorded. The remnant forest recorded slightly higher Lepidoptera diversity (H' = 2.6415) compared to the oil palm area (H' = 2.2316). The remnant forest has a higher species richness indicated by the Margalef index, (Dmg = 5.1774). On the other hand, the oil palm area recorded a lower species richness value (Dmg = 3.4968) indicating a low Lepidoptera species richness in the area. The similarity index of both sites was 0.3380, sharing 10 butterfly species and two moth species. This preliminary assessment highlighted the importance of having a conservation area to support biodiversity within a monoculture environment.

Keywords: Butterflies and moth, species richness, conservation area, monoculture environment

ABSTRAK

Serangga di kawasan ladang sawit sering kali dilaporkan mempunyai kepelbagaian yang rendah. Walau bagaimanapun, kewujudan kawasan pemuliharaan di dalam kawasan ladang sawit adalah penting dan berfungsi sebagai habitat perlindungan untuk spesies serangga. Kajian ini mendokumentasikan dan membandingkan kepelbagaian Lepidoptera (kupu-kupu dan rama-rama) di antara hutan tinggalan dan kawasan kelapa sawit yang telah diusahakan selama 30

tahun dalam ladang sawit Teluk Sandakan. Pensampelan Lepidoptera telah dijalankan dari 30 September hingga 4 Oktober 2022 di hutan tinggalan dan dari 5 hingga 9 Oktober 2022 di kawasan kelapa sawit, dengan menggunakan kaedah perangkap *Van Someren-Rydon* dan jaring serangga. Hasil kajian ini merekodkan sebanyak 184 individu dari 28 spesies Lepidoptera di hutan tinggalan, manakala sebanyak 172 individu dari 19 spesies di kawasan kelapa sawit. Keputusan analisis ujian-T menunjukkan bahawa tidak terdapat perbezaan yang signifikan pada kekayaan spesies (P = 0.108) di antara kedua-dua kawasan kerana terdapat perbezaan sembilan spesies yang direkodkan. Kelimpahan spesies di antara kedua-dua kawasan turut tidak terdapat perbezaan ketara (P = 0.577) kerana hanya terdapat perbezaan 12 individu sahaja. Hutan tinggalan mencatatkan kepelbagaian Lepidoptera yang lebih tinggi (H' = 2.6415) berbanding kawasan kelapa sawit (H' = 2.2316). Indeks Margalef menunjukkan bahawa hutan tinggalan mempunyai kekayaan spesies yang lebih tinggi (Dmg = 5.1774), berbanding kawasan kelapa sawit (Dmg = 3.4968). Indeks kesamaan spesies antara kedua-dua kawasan ialah 0.3380 kerana terdapat persamaan 10 spesies kupu-kupu dan dua spesies rama-rama. Kajian awal ini menekankan kepentingan mempunyai kawasan pemuliharaan untuk menyokong kepelbagaian biologi serangga yang terdapat di dalam persekitaran pertanian jenis monokultur.

Kata kunci: Kupu-kupu dan rama-rama, kekayaan spesies, kawasan pemuliharaan, persekitaran monokultur

INTRODUCTION

Oil palm plantation development has been alleged to reduce biodiversity including insect diversity when one heterogeneous structure is converted into a monoculture-dominant environment (Murphy et al. 2021), especially in the beginning stage of land clearing and planting preparation, followed by various pollutions from the whole planting management. Despite the controversies brought up along the plantation development, Fitzherbert et al. (2008) suggested that oil palm plantations might be beneficial or better at providing certain ecosystem services and supporting biodiversity than grassland. Throughout the minimum 25 years of commercial lifespan, oil palm can develop complex understory and epiphyte community as discussed in Luskin & Potts (2011). It was also pointed out that old and mature plantations had more buffered microclimates and taller understory vegetation compared to young plantations. Eventually, such ecosystem and environment become suitable to support arthropod diversity (Dzulhelmi et al. 2022; Pashkevich et al. 2021).

In balancing biodiversity and economic growth, there are suggestions such as having high conservation value areas (HCVA) inside the plantation (Brown et al. 2013), using Integrated Pest Management (IPM) and intercropping (Ashraf et al. 2018). With the involvement of the Roundtable on Sustainable Palm Oil (RSPO) and Malaysian Sustainable Palm Oil (MSPO), even degraded HCVA is advised to be restored (Lucey et al. 2018). One approach is to encourage understory plant growth, in which highly diverse understory plants can support many insect communities (Hood et al. 2020; Reiss-Woolever et al. 2023a).

Malaysia has a very high Lepidoptera species richness, with 950 butterfly species found in Borneo (Otsuka 2001), of which 81 species are Borneo endemic (Gohun et al. 2021). Johor also recorded 396 butterfly species, representing 37.57% of the butterfly species of Peninsular Malaysia (Aqilah et al. 2018). Moreover, the moth species richness in Malaysia is much more abundant, for example, the Pasoh Forest Reserve in Negeri Sembilan has recorded 413 moth

species solely from Geometridae family (Holloway & Intachat 2003). Among the insect orders, Lepidoptera is one of the bioindicators to be observed due to several factors such as easy to identify and its sensitivity to ecological changes (Dar & Jamal 2021; Hill et al. 2021). Another factor is that Lepidoptera has a very strong host-plant relationship, as each species has its preferred host plants to feed on during the larvae stage (Dyer et al. 2007). Thus, having records of Lepidoptera species in one place also could act as evidence to infer one place's plant diversity. There are many recent Lepidoptera studies in Malaysian oil palm plantations conducted around Malaysia such as in Sarawak (Mohd-Azlan et al. 2023) and in Selangor (Harianja et al. 2024). However, more research is needed to support and update these studies in line with the current industry demands and environmental requirements.

In the year 2022, Yayasan Sime Darby collaborated with Universiti Malaysia Sabah to restore about 102 Ha of forest and riparian buffer zones within the five oil palm estates in Sandakan Bay, Sabah, Malaysia (Media Yayasan Sime Darby 2022). There has been no insect diversity study done before in these five estates, which brought up the opportunity to record first-hand data and use this data as baseline information for continuous recording of the Lepidoptera community throughout the restoration process. This study aimed to record and compare the Lepidoptera (both butterfly and moth) diversity in an oil palm area and a remnant forest within the Sandakan Bay estates.

MATERIALS AND METHODS

Study Sites

The Lepidoptera sampling was conducted within the Sime Darby Plantation Sdn. Bhd. Strategic Operating Unit (SOU 26) Sandakan Bay, which is situated at Sandakan, Sabah, Malaysia. Two types of landscapes were selected for the early stage of the restoration project, including remnant forest and mature oil palm area. Thus, these two landscapes were also selected for the Lepidoptera survey study before the restoration commenced (Figure 1).

The remnant forest is also known as "Sentosa Bird Sanctuary" and is surrounded by oil palm compartments. This place was set aside as a conservation area (land size 13.51 Ha) and serves as a habitat for migratory birds and other wildlife species. The forest was sampled from 30 September to 4 October 2022. As for the mature oil palm area, the oil palms in the sampled area were reaching the maximum 30-year cycle since being planted in 1994. Furthermore, this area is located along a river, with around 20 meters of riparian buffer that was retained for restoration. This area was sampled from 5 to 9 October 2022.

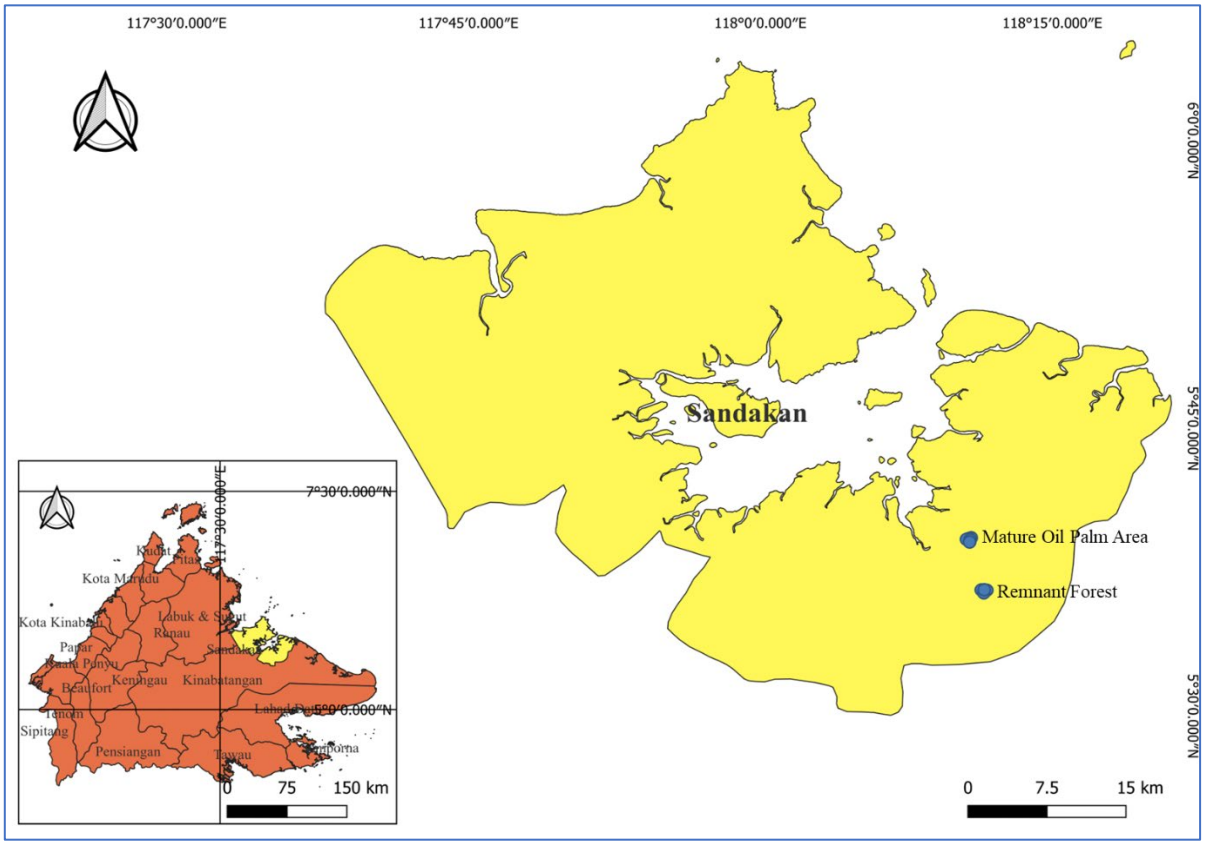

Figure 1. Location of the sampling sites (Source: Natural Earth 2024)

Insect Sampling Methods

Van Someron-Rydon traps and manual net sweeping were done in this study. Due to the safety policy of the plantation estates, which does not allow travelling around the estates at night, light trapping which targets the nocturnal Lepidoptera was not conducted. Thus, Van Someron-Rydon traps were employed in this study to capture possible nocturnal Lepidoptera as the traps can function for 24 hours. Each site was sampled using eight Van Someren-Rydon traps, where each trap was distanced 10 – 15 meters away from each other (as shown in Figure 2). The traps were hung at an approximate height of 1.5 meters above ground, with four traps under the canopy of trees or oil palms and another four traps placed under open canopy areas. The traps were baited with fermented bananas (fermented for at least 48 hours before usage) (Freitas et al. 2014) and were checked every 24 hours followed by adding new bait every day.

In addition, manual sweeping with aerial net was conducted on three 300-meter Pollard walk transects (Viliani et al. 2022), with some modifications to suit the existing trails and roads. These transects were walked twice a day at 9 – 11 am and 2 – 4 pm to maximise the sampling effort of recording diurnal Lepidoptera. The sampling time was conducted in two sessions due to frequent stormy weather in the noon time, which happened almost every day. All the sampling transects happened to be located on main roads around the sampling areas because the trails entering to the centre of remnant forest were overgrown by vegetation and there were many ditches built in the oil palm area.

Specimen Preservation and Species Identification

All caught specimens were euthanised by pinching the thorax part, then placed into triangle glassine paper envelopes. All specimens were then brought back to the Entomology Laboratory at the Faculty of Tropical Forestry, Universiti Malaysia Sabah for sorting, preservation, and deposition. Identification was done to the species level, if possible, based on available reference materials such as Abang (2006), Otsuka (1988), Maruyama & Otsuka (1991), Barlow (1982), Robinson et al. (1994) and The Moths of Borneo website by Holloway (n.d.).

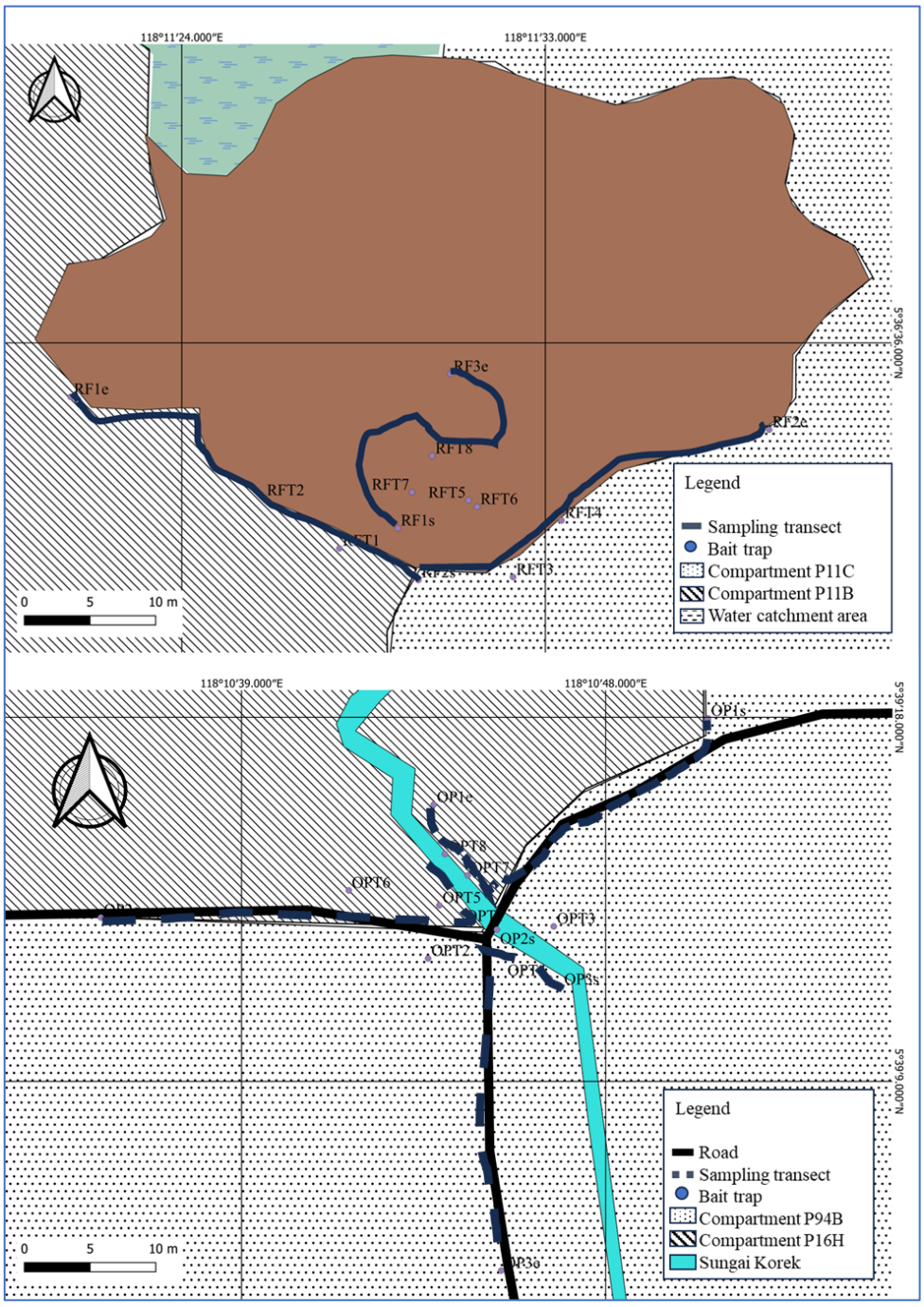

Figure 2. Locations of sampling trails and bait traps in remnant forest (above) and oil palm area (below)

Data Analysis

All data were analysed in Species Diversity and Richness version 2 software (PISCES Conservation Ltd. 1999) for Shannon Wiener diversity index (H'), Margalef's species richness index (Dmg), Pielou's evenness index (J), Simpson's index (D) and Chao 1 species estimation (Chao 1). Sorensen similarity index was used to calculate the index of shared species between both sampling sites. Rarefaction curves were generated using iNEXT Online, developed by Chao et al. (2016) and referring to Chao et al. (2014). Normality test was conducted in R Statistical Software (v4.3.1; R Core Team 2023), then followed by Student's T-tests, performed to determine if there were any differences in species richness and species abundance between both sites. Hutcheson's T-test was performed to compare the Shannon Wiener diversity index of both sites.

RESULTS AND DISCUSSION

There were five butterfly families recorded from both sites, namely Nymphalidae, Pieridae, Papilionidae, Hesperiidae and Lycaenidae (Figure 3). Nymphalidae were the most common butterflies found in both sites. Most of the Nymphalidae species are frugivorous species (Krenn et al. 2001), and most of the recorded species in this study were attracted to the fermented banana bait. However, only four moth families (Crambidae, Erebidae, Noctuidae and Geometridae) were recorded in both sites. All moth species were attracted to the bait due to their fruit feeding behaviour except *Eumelea ludovicata* (the only recorded Geometridae species) which was caught manually using sweep net. The *E. ludovicata* has a behaviour of staying near to the ground and grasses, which is easily disturbed and starts to fly around.

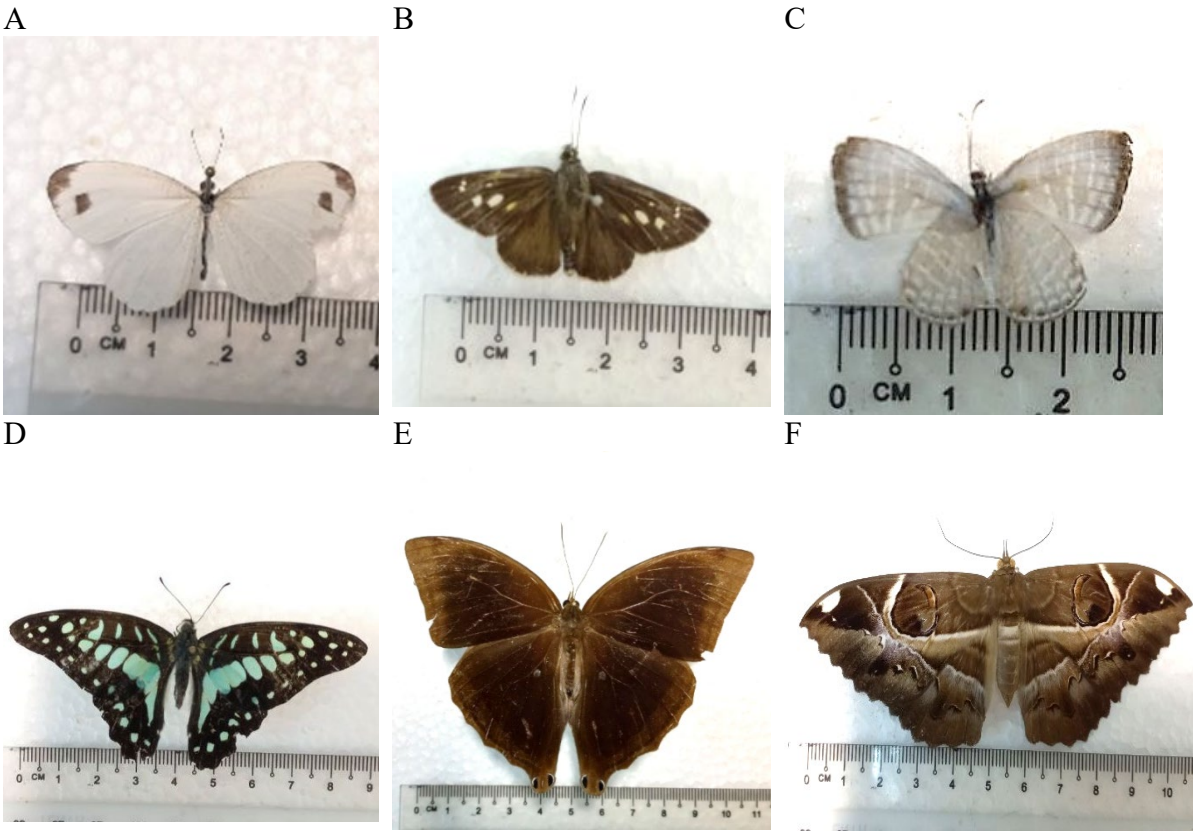

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Figure 3. Representative species from each family, A: *Leptosia nina* (Pieridae), B: *Suastus gremius* (Hesperiidae), C: *Jamides pura* (Lycaenidae), D: *Graphium doson* (Papilionidae), E: *Amathusia phidippus* (Nymphalidae), F: *Erebus ephesperis* (Erebidae), G: *Eumelea ludovicata* (Geometridae), H: *Ischyja inferna* (Noctuidae), I: *Cirrhochrista fulmipalpis* (Crambidae)

Throughout the sampling period of this study, no pest species were recorded. In addition, no endemic species was recorded within the small remnant forest area of 13.51 Ha. Benedick et al. (2006) also noted a similar trend. They reported that remnant forests smaller than 4000 Ha hardly harbour Borneo endemic species, where even the smallest remnant in their study (120 Ha) only recorded species that were restricted to Sundaland. The absence of endemic species in this current study could be associated to the small forest size. The species abundance rank and the full listing of species in each site were shown in Figure 4 and Table 1. In the remnant forest, the top three dominant species recorded were *Amathusia phidippus* (34 individuals), *Elymnias nesaea* (26 individuals) and *Leptosia nina* (23 individuals). While in the oil palm area, the top three dominant species were *A. phidippus* (54 individuals), *E. nesaea* (27 individuals) and *Elymnias panthera* (21 individuals). The *A. phidippus*, *E. neseae* and *E. panthera* have been recorded to utilize oil palm as a host plant (Egonyu et al. 2022; Howard et al. 2001; Wei et al. 2017), which explains the abundance of these species in both sites. Although these species were seen feeding on the oil palms' leaves, no pest outbreak caused by these species was reported in the estates. However, the potential of these species as native pollinators for oil palm is yet to be investigated.

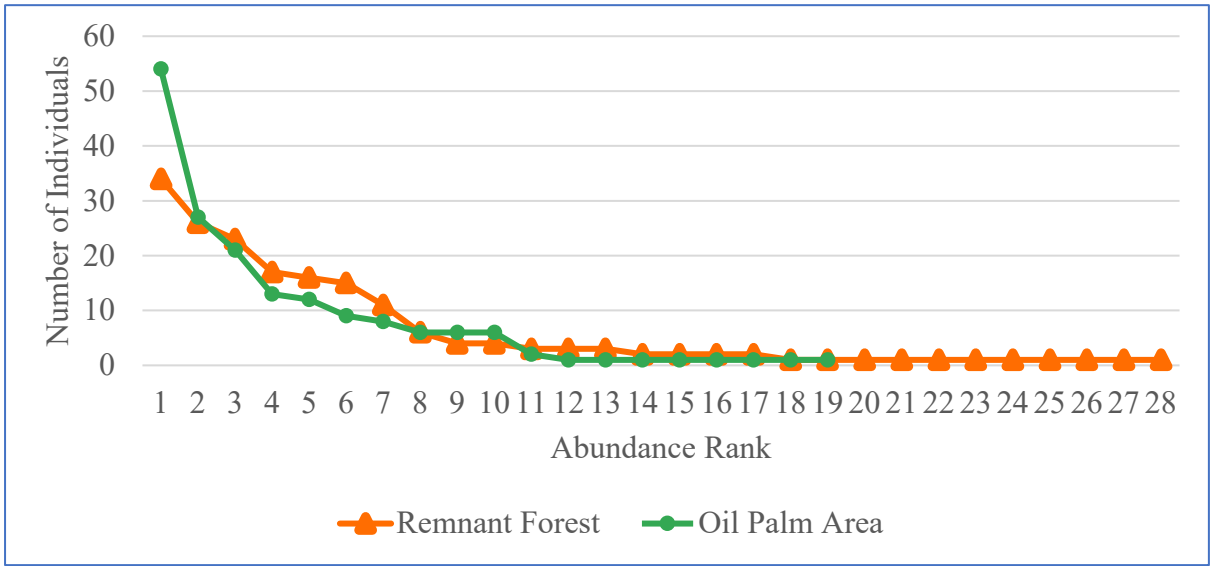

Figure 4. Species abundance rank in remnant forest and oil palm area

Table 1. Species abundance rank list in remnant forest and oil palm area

Rank Abundance	Remnant Forest	Oil Palm Area
1	*Amathusia phidippus*	*Amathusia phidippus*
2	*Elymnias nesaea*	*Elymnias neseae*
3	*Leptosia nina*	*Elymnias panthera*
4	*Neptis hylas*	*Leptosia nina*
5	*Mycalesis* sp. 1	*Mycalesis* sp. 1
6	*Ypthima baldus*	*Neptis hylas*
7	*Elymnias panthera*	*Melantis leda*
8	*Melantis leda*	*Appias libythea*
9	*Eumelea ludovicata*	*Hypolimnas bolina*
10	*Erebus ephesperis*	*Ypthima baldus*
11	*Hypolimnas bolina*	*Junonia atlites*
12	*Asota subsimilis*	*Catopsilia scylla*
13	*Ischyja inferna*	*Jamides pura*
14	*Euthalia aconthea*	*Suastus gremius*
15	*Mycalesis* sp. 2	*Mycalesis* sp. 2
16	*Eurema* sp. 2	*Asota heliconia*
17	*Anomis* sp.	*Bastilla fulvotaenia*
18	*Moduza procris*	*Bastilla arcuata*
19	*Graphium doson*	*Ophisma gravata*
20	*Pandita sinope*	
21	*Athyma nefte*	
22	*Papilio memnon*	
23	*Eurema* sp. 1	

24	*Bastilla fulvotaenia*
25	*Ophisma gravata*
26	*Mocis undata*
27	*Bertula* sp.
28	*Cirrhochrista fulmipalpis*

This study has collected a total number of 356 individuals belonging to 35 lepidopteran species. Overall, the remnant forest recorded 28 lepidopteran species from seven families and 184 individuals (as shown in Table 2), which was slightly more than in the oil palm area that recorded 19 species from six families and 172 individuals. The Student's T-test result revealed no significant difference in species richness ($t = 1.812$, $df = 8$, $P = 0.108$), between remnant forest (mean±SD = 14±3.2) and oil palm area (11.4±0.5), even though both sites have differences of nine species recorded. There was also no significant difference in species abundance ($t = 0.582$, $df = 8$, $P = 0.577$) between remnant forest (36.8±7.9) and oil palm area (34.4±4.7), due to only a difference of 12 individuals recorded.

The Shannon-Wiener Index shows that the remnant forest ($H' = 2.6415$) has a higher diversity index value than the oil palm area ($H' = 2.2316$), and the Hutcheson's t-test showed a highly significant difference between the two sites' Shannon-Wiener index values ($t = 3.682$, $df = 354$, $P = 0.0003$). The significance of diversity difference is related to the differences in the evenness of the Lepidoptera communities in both sites. According to the classification scheme of diversity indices by Ulfah et al. (2019), both sites would still be considered as moderately diverse (moderate range: $1 \leq H' \leq 3$).

The Pielou's Evenness Index of the oil palm area ($J = 0.7579$) was found to be slightly lower compared to the remnant forest ($J = 0.7927$). However, both sites are considered to have a uniform distribution of individuals among species (stable community range: $0.75 \leq J \leq 1.00$). Although *A. phidippus* was the most abundant species in both sites, the Simpson's index showed that both sites have a low dominance of a species (low dominance range: $0 \leq D \leq 0.5$). There were 12 Lepidoptera species (10 butterfly species and two moth species) found at both sites, accounting for 33.80% of species similarity between both sites.

Table 2. Lepidoptera diversity indices in the remnant forest and oil palm area

Index	**Remnant forest**	**Oil Palm Area**
Number of Species	28	19
Number of Individuals	184	172
Shannon-Wiener Index (H')	2.6415	2.2316
Margalef' Index (Dmg)	5.1774	3.4968
Pielou's Evenness (J)	0.7927	0.7579
Simpson's Index (D)	0.0996	0.1577
Chao 1 Species Estimation	30	20
Similarity	12 species (33.80%)	

The recorded species richness in both sites did not reach asymptote (as shown in Figure 4), indicating more species to occur, where the Chao-1 index estimated 30 species in the remnant forest and an estimated of 20 species in the oil palm area. The rarefaction based on recorded abundance showed that the sampling coverage had reached near asymptote (Figure 5), suggesting sample completeness is near complete, but longer sampling days are still recommended especially having the possibility of recording Lepidoptera species that are active at different times of the year. Moreover, as the restoration project started in these sampling sites, there is a possibility for the Lepidoptera community to change over time, which can be monitored through a series of samplings over a longer period.

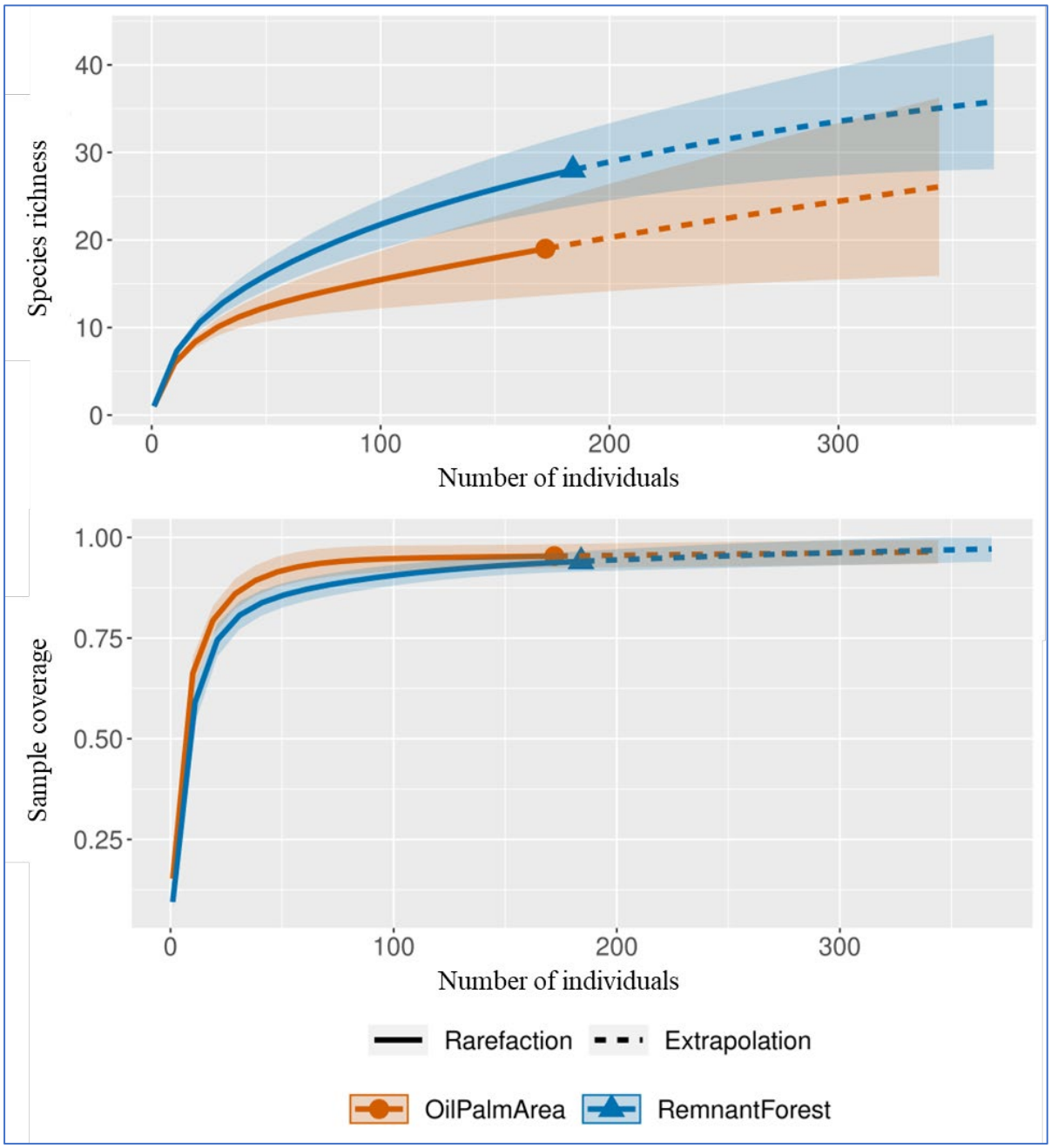

Figure 5. Species richness (above) and sample coverage (below) rarefaction curve derived from Lepidoptera abundance samples

The species richness and species abundance in both sites were found to be slightly similar can be related to the sampling transects applied on existing road paths that are wide open in both areas. Most butterfly species prefer open canopy spaces and edges where sunlight is available for sun basking (Barton et al. 2014; Ohwaki et al. 2017). During the field sampling and observation, more butterflies were seen flying at the forest edge and oil palm edge as compared to under the dense canopy of oil palm and forest. Moreover, the estates had planted small islands of coral vine (*Antigonon leptopus*) along all main roads. The coral vine is perennial and can flower throughout the year thus, providing constant nectar sources to the insects.

In the remnant forest, besides the coral vine, several plants were seen utilised by the Lepidoptera community for nectar resources such as Chinese violet (*Asystasia gangetica*) and Indian rhododendron (*Melastoma malabathricum*). These plants provide flower nectar throughout the year, which helps to sustain the Lepidoptera community in the area. Moreover, complex plant diversity also helps to support more Lepidoptera species with more plants to provide nectar and larvae food source (Swarnali et al. 2019; Reiss-Woolever et al. 2023b). Thus retaining more native forest vegetation is important as pointed out by Mohd-Azlan et al. (2023) when they researched the value of these conservation forest habitats as native pollinators refugia inside the oil palm plantations.

Certain areas of the oil palm area in this study are to be retained and restored as riparian. Increasing the abundance of flowering plants is recommended not just to support the existing Lepidoptera with food sources, but also to aid the movements of these flying insects based on a study by Gray et al. (2019) in one Sabah oil palm plantation. The study was able to record that the moths were utilising the forested riparian reserves for travelling instead of into adjacent oil palm areas. Hence it is encouraged to increase non-crop flowering vegetation in oil palm areas to mimic a similar environment to remnant forest as part of the sustainable management for oil palm plantation.

The remnant forest recorded 18 butterfly species (163 individuals) and 10 moth species (21 individuals), while the oil palm area recorded 15 butterfly species (168 individuals) and four moth species (four individuals). As illustrated in Figure 6, the T-test results showed that there is no significant difference in terms of butterfly species richness and butterfly abundance between remnant forest and oil palm area with P-value of 0.729 and 0.805 respectively. However, there is a significant difference in moth species richness and abundance between the remnant forest and oil palm area (both P-values = 0.007) as the number of moth species and individuals are higher in the remnant forest compared to the oil palm area.

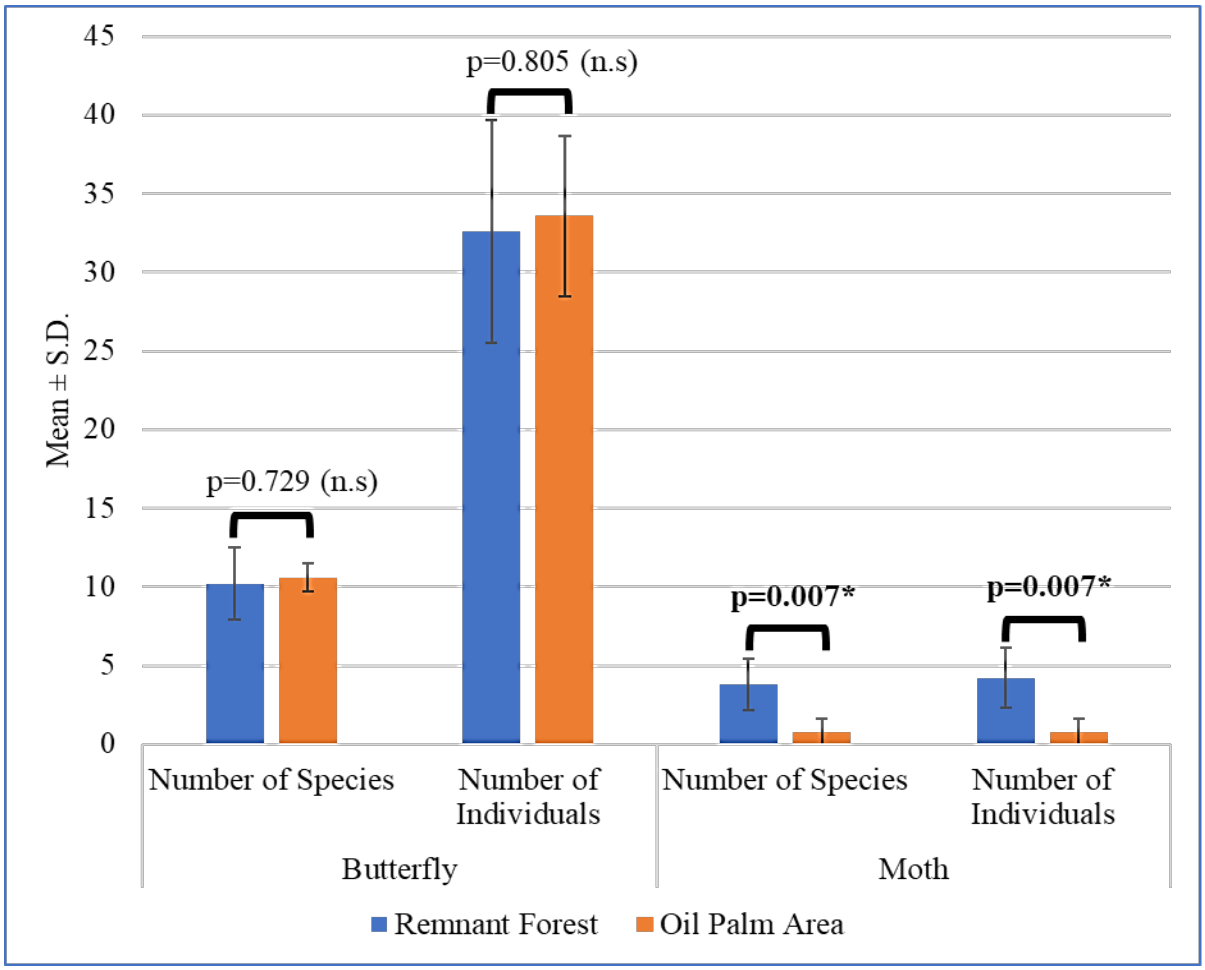

Figure 6. Comparison of species richness and abundance of butterfly and moth between remnant forest and 30-year-old oil palm area [* = Significant ($P<0.05$), n.s. = no significant ($P>0.05$)]

CONCLUSION

In conclusion, the results of this study showed that the overall Lepidoptera assemblages was dominated by generalist and common species. No pest species was recorded. Both remnant forest and oil palm area were found to have moderate Lepidoptera diversity, indicated by the Shannon-Wiener diversity index of 2.6415 and 2.2316 respectively. However, both sites recorded a Lepidoptera species composition with a similarity of 33.80%. Although the remnant forest is very small and surrounded by oil palms, 16 Lepidoptera species were found in this forest only. However, the information recorded in this study is insufficient to determine any significant species due to the short sampling period. Thus, a longer sampling time is suggested, along with other factors to be recorded and related such as surrounding plant diversity. The result of this preliminary study points out the importance of retaining forest areas within a monoculture environment especially for the native forest species to live in. With this study as a reference or example, oil palm plantation management is highly encouraged to set aside forested or buffer zone areas as an act of biodiversity conservation or restore these green patches with enrichment planting to keep the area's ecological functions from degrading. The

management can also plant more flowering plants around the oil palm area to sustain not just the Lepidoptera community, but also other beneficial insect pollinators and predators as part of the Integrated Pest Management system in the plantation.

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AUTHORS DECLARATIONS

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Conflict of Interest

The authors declare that they have no conflict of interest.

Ethics Declarations

No ethical issue is required for this research.

Data Availability Statement

This is part of the undergraduate Final Year Project and the data are currently in the BSc thesis entitled "Comparison of Butterfly Species Diversity in Three Forest Locations in Relation to Canopy Openness" (2021). The authors confirm that the data supporting the findings are available in the article.

Authors' Contributions

Maria Lourdes T. Lardizabal (MLTL) and Alice Atom (AA) conceived this research and designed the experiments; MLTL, AA and Gerald Lee Zheng Yang (GLZY) performed the sampling and data analysis; MLTL, AA and GLZY participated in the design and interpretation of the data; GLZY and MLTL wrote the paper and were involved in the revisions of it. All authors read and approved the final version of the manuscript.

REFERENCES

Abang, F. 2006. *Butterflies of Malaysian Borneo: A Pocket Guide.* Universiti Malaysia Sarawak.

Aqilah, A.A.R., Maryati, M., Ismail, N. & Anas, N.I. 2018. A review of distribution and diversity of butterfly (Lepidoptera: Rhopalocera) fauna in Johor, Malaysia. *Serangga* 23(1): 12-23

Ashraf, M., Zulkifli, R., Sanusi, R., Tohiran, K.A., Terhem, R., Moslim, R., Norhisham, A.R., Ashton-Butt, A. & Azhar, B. 2018. Alley-cropping system can boost arthropod biodiversity and ecosystem functions in oil palm plantations. *Agriculture, Ecosystems & Environment* 260: 19-26.

Barlow, H.S. 1982. *An Introduction to the Moths of South East Asia*. Kuala Lumpur: The Malayan Nature Society.

Barton, M., Porter, W. & Kearney, M. 2014. Behavioural thermoregulation and the relative roles of convection and radiation in a basking butterfly. *Journal of Thermal Biology* 41: 65–71.

Benedick, S., Hill, J.K., Mustaffa, N., Chey, V.K., Maryati, M., Searle, J.B., Schilthuizen, M. & Hamer, K.C. 2006. Impacts of rain forest fragmentation on butterflies in northern Borneo: species richness, turnover and the value of small fragments. *Journal of Applied Ecology* 43: 967-977.

Brown, E., Dudley, N., Lindhe, A., Muhtaman, D.R., Stewart, C. & Synnott, T. 2013. Common guidance for the identification of High Conservation Values. HCV Resource Network. https://www.hcvnetwork.org/library/common-guidance-for-the-identification-of-hcv-english-indonesian-french-portuguese [16 March 2024].

Chao, A., Gotelli, N.J., Hsieh, T.C., Sander, E.L., Ma, K.H., Colwell, R.K. & Ellison, A.M. 2014. Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies. *Ecological Monographs* 84: 45-67.

Chao, A., Ma, K.H. & Hsieh, T.C. 2016. iNEXT (iNterpolation and EXTrapolation) Online: Software for Interpolation and Extrapolation of Species Diversity. Program and User's Guide.
http://chao.stat.nthu.edu.tw/wordpress/software_download/inext-online/ [16 March 2024].

Dar, A.A. & Jamal, K. 2021. Moths as ecological indicators: A review. *Munis Entomology & Zoology* 16(2): 833-839.

Dyer, L.A., Singer, M.S., Lill, J.T., Stireman, J.O., Gentry, G.L., Marquis, R.J., Ricklefs, R.E., Greeney, H.F., Wagner, D.L., Morais, H.C., Diniz, I.R., Kursar, T.A. & Coley, P.D. 2007. Host specificity of Lepidoptera in tropical and temperate forests. *Nature* 448(7154): 696-699.

Dzulhelmi, N., Ishak, R., Nasir, N., Hasi, A., Yap, P., Khasim, N., Gintoron, C.S. & Tohiran, K.A. 2022. Diversity of arthropods in an oil palm plantation in Sabah. *Borneo Journal of Resource Science and Technology* 12: 82-87.

Egonyu, J.P., Baguma, J., Martínez, L.C., Priwiratama, H., Subramanian, S., Tanga, C.M., Anankware, J.P., Roos, N. & Niassy, S. 2022. Global advances on insect pest management research in oil palm. *Sustainability* 14(23): 16288.

Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Bruhl, C.A., Donald, P.F. & Phalan, B. 2008. How will oil palm expansion affect biodiversity? *Trends in Ecology & Evolution* 23(10): 538-545.

Freitas, A.V.L., Iserhard, C.A., Santos, J.P., Carreira, J.Y.O., Ribeiro, D.B., Melo, D.H.A., Rosa, A.H.B., Marini-Filho, O.J., Accacio, G.M. & Uehara-Prado, M. 2014. Studies with butterfly bait traps: An overview. *Revista Colombiana de Entomologia* 40(2): 209–218.

Gohun, M., Dg. Fazrinah, A.D., Nurul Aqidah, I., Japir, R. & Chung, A.Y.C. 2021. *A Compilation of Bornean Endemic Butterflies.* Malaysia: Forest Research Centre, Sabah Forestry Department.

Gray, R.E.J., Slade, E.M., Chung, A.Y.C. & Lewis, O.T. 2019. Movements of moths through riparian reserves within oil palm plantations. *Frontiers in Forests and Global Change* 2: 68.

Harianja, M.F., Stone, J., Mamat, W.Z.W., Hadi, M.A., Luke, S.H., Azhar, B. & Turner, E.C. 2024. How do management decisions impact butterfly assemblages in smallholding oil palm plantations in Peninsular Malaysia? *Journal of Applied Ecology* 61: 759-772.

Hill, G.M., Kawahara, A.Y., Daniels, J.C., Bateman, C.C. & Scheffers, B.R. 2021. Climate change effects on animal ecology: Butterflies and moths as a case study. *Biological Reviews of the Cambridge Philosophical Society* 96(5): 2113-2126.

Holloway, J.D. n.d. "The Moths of Borneo." Southdene Sdn. Bhd. https://www.mothsofborneo.com/ [1 June 2023].

Holloway, J.D. & Intachat, J. 2003. Aspects of the diversity of Geometridae (Lepidoptera) in Pasoh Forest Reserve. In Okuda, T., Manokaran, N., Matsumoto, Y., Niiyama, K., Thomas S.C. & Ashton, P.S. (eds). *Pasoh: Ecology of A Lowland Rain Forest in Southeast Asia*, pp. 293–313. Tokyo: Springer.

Hood, A.S.C., Advento, A.D., Stone, J., Fayle, T.M., Fairnie, A.L.M., Waters, H.S., Foster, W.A., Snaddon, J.L., Ps, S., Caliman, J.-P., Naim, M. & Turner, E.C. 2020. Removing understory vegetation in oil palm agroforestry reduces ground-foraging ant abundance but not species richness. *Basic and Applied Ecology* 48: 26-36.

Howard, F.W., Moore, D., Giblin-Davis, R.M. & Abad, R.G. 2001. *Insects on Palms*, 1st Edition. Oxford: CABI Publishing.

Krenn, H.W., Zulka, K.P. & Gatschnegg, T. 2001. Proboscis morphology and food preferences in nymphalid butterflies (Lepidoptera: Nymphalidae). *Journal of Zoology* 254(1): 17-26.

Lucey, J.M., Barclay, H., Gray, C.L., Luke, S.H., Nainar, A., Turner, E.C., Reynolds, G., Slade, E.L., Snaddon, J.L., Struebig, M. & Walsh, R. 2018. *Simplified Guide: Management and Rehabilitation of Riparian Reserves*. Kuala Lumpur: RSPO Secretariat Sdn. Bhd.

Luskin, M.S. & Potts, M.D. 2011. Microclimate and habitat heterogeneity through the oil palm lifecycle. *Basic Applied Ecology* 12(6): 540–551.

Maruyama, K. & Otsuka, K. 1991. *Butterflies of Borneo Vol. 2, No. 2 – Hesperiidae.* Tokyo: Tobishima Corporation.

Media Yayasan Sime Darby. 2022. Universiti Malaysia Sabah Receives RM2 Million for the Research and Restoration of Forest Biodiversity in Sandakan Bay, May 12, 2022. http://www.yayasansimedarby.com/media/universiti-malaysia-sabah-receives-rm2-million-for-the-research-and-restoration-of-forest-biodiversity-in-sandakan-bay [15 January 2024].

Mohd-Azlan, J., Conway, S., Travers, T.J.P. & Lawes, M.J. 2023. The filtering effect of oil palm plantations on potential insect pollinator assemblages from remnant forest patches. *Land* 12(6): 1256.

Murphy, D.J., Goggin, K. & Paterson, R.R.M. 2021. Oil palm in the 2020s and beyond: Challenges and solutions. *CABI Agriculture and Bioscience* 2: 39.

Natural Earth. 2024. The Natural Earth quick start kit. https://www.naturalearthdata.com/downloads/ [16 March 2024].

Ohwaki, A., Maeda, S., Kitahara, M. & Nakano, T. 2017. Associations between canopy openness, butterfly resources, butterfly richness and abundance along forest trails in planted and natural forests. *European Journal of Entomology* 114: 533-545.

Otsuka, K. 1988. *Butterflies of Borneo Vol. 1*. Tokyo: Tobishima Corporation.

Otsuka, K. 2001. *A Field Guide to the Butterflies of Borneo and South East Asia*. Kota Kinabalu: Hornbill Books.

Pashkevich, M.D., Aryawan, A.A.K., Luke, S.H., Dupérré, N., Waters, H.S., Caliman, J.-P., Naim, M. & Turner, E.C. 2021. Assessing the effects of oil palm replanting on arthropod biodiversity. *Journal of Applied Ecology* 58: 27-43.

PISCES Conservation Ltd. 1999. Species Diversity & Richness. V. 2. PISCES Conservation Ltd. PC.

Reiss-Woolever, V.J., Advento, A.D., Aryawan, A.A.K., Caliman, J.-P., Foster, W.A., Naim, M., Pujianto, Purnomo, D., Soeprapto, Suhardi, Tarigan, R.S., Wahyuningsih, R., Rambe,

T.D.S., Ps, S., Widodo, R.H., Luke, S.H., Snaddon, J.L. & Turner, E.C. 2023a. Understory vegetation supports more abundant and diverse butterfly communities in oil palm plantations. *Frontiers in Forests and Global Change* 6: 1205744.

Reiss-Woolever, V.J., Advento, A.D., Aryawan, A.A.K., Caliman, J.-P., Foster, W.A., Naim, M., Pujianto, Purnomo, D., Snaddon, J.L., Soeprapto, Suhardi, Tarigan, R.S., Wahyuningsih, R., Rambe, T.D.S., Ps, S., Widodo, R.H., Luke, S.H. & Turner, E.C. 2023b. Habitat heterogeneity supports day-flying Lepidoptera in oil palm plantations. *Journal of Tropical Ecology* 39(e24): 1–11.

Robinson, G.S., Tuck, K.R. & Shaffer, M. 1994. *A Field Guide to the Smaller Moths of South-East Asia*. Kuala Lumpur: Malaysian Nature Society.

Swarnali, M., Rudra, D.P., Soumyajit, B., Pathiba, B., Goutam, S.K. & Gautam, A. 2019. Correspondence of butterfly and host plant diversity: Foundation for habitat restoration and conservation. *European Journal of Ecology* 5(1): 49–66.

Ulfah, M., Fajri, S.N., Nasir, M., Hamsah, K. & Purnawan, S. 2019. Diversity, evenness and dominance index reef fish in Krueng Raya Water, Aceh Besar. *IOP Conference Series: Earth and Environmental Science* 348: 012074.

Viliani, L., Bonelli, S., Vercelli, M., Roy, D.B. & Riva, F. 2022. Does a short Pollard walk transect capture butterfly and bee diversity? A test to inform pollinator monitoring and community science initiatives. *Insect Conservation and Diversity* 15(6): 645–654.

Wei, C.-H., Lohman, D.J., Peggie, D. & Yen, S.-H. 2017. An illustrated checklist of the genus Elymnias Hübner, 1818 (Nymphalidae, Satyrinae). *ZooKeys* 676: 47–152.