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Research Article

Soil Macroinsect Diversity and Soil Properties in a High Conservation Value Area of Oil Palm Plantation, Pulau Carey, Selangor, Malaysia

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ABSTRACT

High Conservation Value (HCV) areas in oil palm plantations are designated to protect biodiversity in the plantation landscape. However, few assessments have been conducted of the area's HCV potential to maintain soil biota. This preliminary study compared the abundance, species richness, and community structure of soil macroinsects between an HCV area and a typical oil palm plantation (OPP) plot. The soil physicochemical properties (pH, organic matter, moisture, and particle size) in both areas were also examined. Soil macroinsects were sampled using pitfall traps and excavated soil samples. A total of 1,197 soil macroinsect individuals, consisting of 15 families and 38 morphospecies, were collected. Species richness and abundance were higher in the HCV area, though Shannon diversity was higher in the OPP, driven by greater evenness. Non-metric Multidimensional Scaling (NMDS) ordination indicated differentiation of macroinsect communities between habitats. Higher soil organic matter in the HCV area supported decomposer taxa, while pH and soil moisture shaped the prevalence of disturbance-tolerant taxa in OPP. This preliminary assessment suggests that the HCV area has the potential to conserve rich soil macroinsect groups. However, extended studies are needed for longer monitoring that includes other environmental variables to strengthen the understanding of the role of HCV habitats in sustaining soil biodiversity in plantation landscapes.

Keywords: Soil biota; soil physicochemistry; insect diversity; ants; sustainable agriculture.

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INTRODUCTION

Currently, oil palm (*Elaeis guineensis*) is one of the most important global crops, supplying approximately 40% of the world's vegetable oil trade (Murphy et al., 2021). Palm oil fruits are available year-round, allowing for the extraction of palm oil and palm kernel oil, which are used in a range of industrial sectors. Due to the widespread consumption of palm oil and its non-food applications, such as in cleansing and sanitising products, approximately 19 million hectares of land worldwide are dedicated to its cultivation. Malaysia and Indonesia together account for most of the world's palm oil supply, producing approximately 26% and 58% respectively (Mohd Hanafiah et al., 2022). However, as both countries lie within biodiversity-rich tropical regions, the expansion of oil palm plantations has raised environmental concerns due to their impact on biodiversity and ecosystem services (Vijay et al., 2016).

To balance economic progress with ecological integrity, Malaysia's palm oil sector must embrace sustainable approaches that protect biodiversity and ecosystem services. To uphold this goal, every oil palm plantation, regardless of ownership or size, must adhere to the national certification scheme. The Malaysian Sustainable Palm Oil (MSPO) Certification Scheme embeds the High Conservation Value (HCV) principle to safeguard areas of ecological and cultural importance (Bois D'enghein, 2024). The HCV areas are natural sites with significant environmental, social, or cultural value and therefore require careful management and protection (Areendran et al., 2020). In Malaysia, as part of efforts to conserve biodiversity, the MSPO certification mandates all stakeholders in the oil palm plantation sector, including plantation owners, mill operators, and government agencies, to identify and manage HCV areas.

Soil insects are fundamental to terrestrial ecosystems, performing services such as nutrient cycling, soil aeration, and the decomposition of organic matter. These insects also act as natural enemies of crop pests. Because they are closely associated with the soil environment, soil insects are highly responsive to changes in soil quality and therefore serve as reliable indicators of soil health (Menta & Remelli, 2020). Commonly monitored groups include Hymenoptera, Coleoptera, and Diptera. For example, ground beetles (Carabidae) are frequently used to signal heavy metal contamination associated with agrochemical practices, as their physiological condition and population dynamics can reflect the degree of soil pollution (Naccarato et al., 2020). Therefore, assessing the diversity and composition of soil insect communities in oil palm landscapes offers valuable information on the environmental impacts and sustainability of current management practices in Malaysia.

Although the HCV concept has been widely adopted to encourage sustainable oil palm management, its actual effectiveness in biodiversity conservation remains unclear (Senior et al., 2015). Moreover, assessments of HCV sites have been dominated by research in Indonesia and have largely focused on larger taxa such as birds, mammals, and reptiles, leaving other taxa understudied (Kissinger et al., 2020). In contrast, there is a lack of studies on the benefits of HCV areas within Malaysia's oil palm plantation landscapes, particularly regarding their impact on soil biota and soil properties. Therefore, this preliminary study aims to assess the abundance, species richness and community structure of soil macroinsects in the HCV area in comparison to the oil palm plantation plot in Pulau Carey, Selangor, Malaysia and to explore the influence of soil properties on the macroinsect communities.

MATERIAL & METHODS

Study area

This study was conducted from 3rd to 5th March 2024 at SD Guthrie plantation, located in Pulau Carey, Selangor, Malaysia (Fig. 1). Pulau Carey is situated along the western coast of Malaysia and is known for its extensive plantations, managed primarily by large agro-industrial companies like SD Guthrie Berhad (Er et al., 2012).

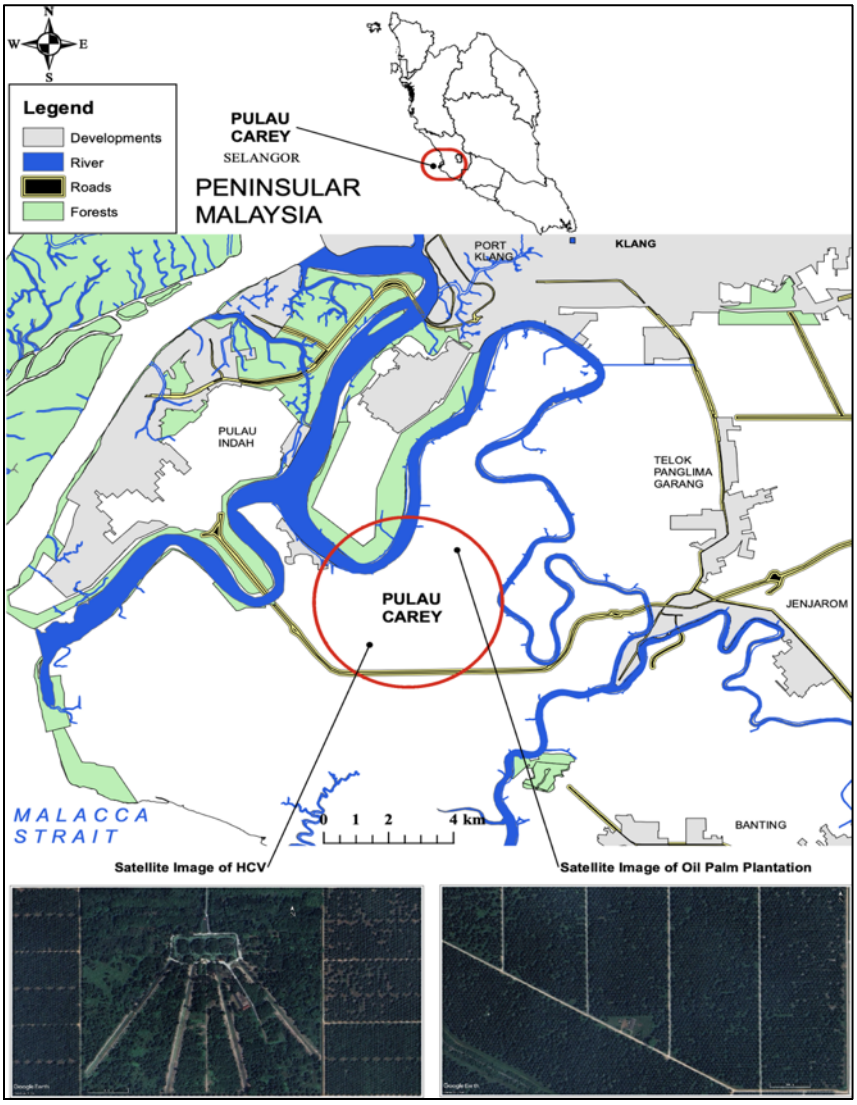

Figure 1: Sampling locations in the SD Guthrie Plantation in Pulau Carey, Selangor, Peninsular Malaysia. The circled area indicates the study site with inset satellite images contrasting different habitat types, the High Conservation Value (HCV) and oil palm plantation (OPP) areas.

The HCV area (2.876389° N, 101.376389° E) within the plantation consists of a designated 42-hectare zone embedded within a 4000-hectare oil palm plantation (2.912222° N, 101.393889° E). It was established to safeguard native flora and fauna within the managed landscape. The area encompasses several natural habitats such as remnant forest patches, riparian corridors, and areas with secondary vegetation that offer vital resources for a range of native plant and animal species. In comparison, the neighboring oil palm plantation (OPP) is dominated by mature palms planted in dense rows, forming a largely uniform monocultural landscape.

Sample collections and identification

Sampling of soil macroinsects was conducted in two areas of the study site, which are the HCV area and a nearby mature OPP, representing different habitat types. At each site, three transect lines, each 45 meters long, were established. Along every transect, ten pitfall traps were positioned at 5-meter intervals (Larsen & Forsyth, 2005). Each trap consisted of a plastic cup about 7 cm wide and 10 cm deep, inserted into the soil surface until the rim was level with the ground to allow insects to fall freely. A small amount of water mixed with a few drops of detergent was placed in each trap to reduce surface tension and prevent captured insects from escaping (Leather, 2005). All traps were left for 48 hours to ensure uniform sampling duration and to minimize variation caused by differences in insect activity across time (Southwood & Henderson, 2000). After each 48-hour sampling period, the contents of the pitfall traps were collected.

All samples were then transported to the laboratory and preserved in 70% alcohol. Samples with a body length larger than 2 mm were sorted according to morphology and identified to morphospecies level within families and genera, using references from Triplehorn & Johnson (2005), Pfeiffer & Deufel (2009), Cigliano et al. (2024), and other relevant, published keys. Functional group assignment at the family level followed classification synthesised from published literature on insect ecological traits, such as Basset et al. (2008) and Potapov et al. (2022). Taxa were placed in the group that best represents their dominant feeding role in tropical soil ecosystems.

Soil sampling

Following the same line transect, four quadrats of 25 cm × 25 cm (Arp & Krause, 1984) were used to extract soil samples at a depth of 30 cm in 10-meter intervals. The soil macroinsects with a body length larger than 2 mm were sorted out manually using forceps. After the soil insects had been sorted out, the soil samples were then combined to create composite samples per transect for physical soil analysis (Schroth & Kolbe, 1994; Carter & Gregorich, 2008). In the laboratory, the soil samples were air-dried, ground, sieved, and stored in a dry state until analysis (Jones, 2001). Soil moisture content was determined by measuring the weight difference between fresh and oven-dried soil samples (dried at 105°C). Total soil organic matter was estimated using the loss-on-ignition (LOI) method, where oven-dried samples (105°C) were ashed at 400°C. The reduction in weight between 105°C (221°F) and 400°C (752°F) represented the organic matter content (Jones, 2001). Soil texture was analysed using the mechanical method (Carter & Gregorich, 2008), and soil pH was measured with a water-to-soil ratio of 1:2.5 (Jones, 2001).

Data analysis

To ensure an adequate sample size for data analysis while retaining replications, data were pooled at the transect level, given the low number of specimens captured per individual pitfall trap and soil extraction unit. The normality test was conducted using the Shapiro-Wilk analysis of homogeneity. As the data were not normally distributed, differences in soil macroinsect abundance between the HCV and OPP areas were analysed using the Mann-Whitney U test.

Species richness was quantified based on morphospecies using species richness estimators (Chao1 and ACE) to account for potential effects of rare taxa. As there were unequal numbers of individuals in each HCV and OPP, rarefactions were conducted to standardize comparisons of soil macroinsect richness between habitats (Chao & Chiu 2016). Excluding ants (Formicidae) from the dataset, an additional rarefaction analysis was performed to evaluate the influence of a high number of ants on richness patterns. This was done as ants are eusocial, where worker abundance may not reflect true population size (Gotelli et al., 2011). The diversity of soil macroinsects in the habitat was measured using the Shannon-Wiener (H) Diversity Index. The Dominance Index (D') and Evenness Index (e^H/S) were also calculated.

Community similarities between habitat types were analysed using two-way cluster analysis. Cluster analysis was first conducted based on the Bray-Curtis dissimilarity on abundance-based data. Additional cluster analysis using the Sorensen dissimilarity with presence-absence data was conducted to account for the potential influence of high ant abundance. Another complementary cluster analysis was also performed on abundance-based data, with the exclusion of ants. These analyses assist in distinguishing community patterns driven by relative abundance and dominance from those driven by occurrence. Dendograms were then generated to exhibit any similarities or differences throughout the soil macroinsect community in the HCV and OPP. The difference was further visualised in the Non-metric Multidimensional Scaling (NMDS) ordination plot. The environmental variables were then fitted onto the ordination using permutation tests to assess their correlation with community structure. Both cluster and NMDS were analysed using data of soil macroinsects at the family level. Data at the family level has been shown to retain sufficient ecological signal to detect changes in environmental gradients while ensuring consistent taxonomic resolution across samples (Timms et al., 2013). All statistical analyses were conducted using 'iNEXT' (Hsieh et al., 2020) and 'vegan' (Oksanen et al., 2013) packages in R v4.4.0.

RESULTS

The result of this study gathered a total of 1,197 individuals from the HCV and OPP areas in Pulau Carey, Selangor, Malaysia. The results comprised six insect orders (Blattodea, Coleoptera, Dermaptera, Diptera, Hymenoptera, and Orthoptera) across 15 families (Table 1) with differing diversity indices between the two habitats (Table 2). The most abundant macroinsect orders recorded were Hymenoptera (92%, 1,102 individuals), Orthoptera (4.23%, 51 individuals) and Blattodea (2.16%, 26 individuals).

The total abundance of soil macroinsects was significantly higher ($z = 2.1529$, $p < 0.05$) in the HCV (927 individuals) in comparison to the OPP areas (270 individuals) (Table 1). Several ant taxa accounted for a large proportion of individuals in HCV, including *Anoplolepis gracilipes* (305 individuals), *Pheidologeton* sp. (370 individuals), *Crematogaster* (116 individuals) and *Nylanderia* sp. (6 individuals). Together, these represented nearly 70% of all individuals collected. The HCV area was observed to record higher species richness with 28 morphospecies, in contrast to 22 morphospecies in the OPP area. However, Chao1 and ACE indicated that the observed richness in both habitats was underestimated, with more species expected to be encountered with additional sampling effort, particularly in the HCV area (Table 2).

Table 1: Abundance of soil macroinsects in High Conservation Value (HCV) area and Oil Palm Plantation (OPP) in Pulau Carey, Selangor, Malaysia. D: Decomposer, H: Herbivore, P: Predator, G: Generalist, Pa: Parasitoid.

Order	**Family**	**Morphospecies**	**Functional group**	**HCV**	**OPP**
Blattodea	Ectobiidae	*Blatella germanica*	D	3	0
	Termitidae	*Macrotermes* sp.	D	0	22
		Termitidae sp.	D	0	1
Coleoptera	Carabidae	*Tachys* sp.	P	0	1
	Chrysomelidae	Galerucinae sp.	H	1	0
	Cicindellidae	*Cicindela* sp.	P	1	1
	Elateridae	Cardiophorinae sp.	D	0	1
	Staphylinidae	*Hesperus* sp.	P	0	1
		Lispinus sp.	P	1	0
		Paederus sp.	P	0	2
		Staphylinidae sp.	D	1	0
Dermaptera	Labiidae	Labiidae	H	1	1
Diptera	Drosophilidae	*Drosophila melanogaster*	D	0	1
		Drosophilidae sp.	D	2	0
		Scaptodrosophila sp.	D	3	0
Hymenoptera	Ceraphronidae	Ceraphronidae sp.	Pa	1	0
	Formicidae	*Dolichederus* sp.	P/D	40	0
		Dorylinae sp.	P	0	2
		Anoplolepis gracilipes	P/D	305	85
		Camponatus sp.	P/D	5	0
		Centromyrmex hamulatus	P/D	6	5
		Centromyrmex sp.1	P/D	28	42
		Centromyrmex sp.2	P/D	4	0
		Crematogaster sp.1	G	97	0
		Crematogaster sp.2	G	19	1
		Nylanderia sp.1	G	6	2
		Odontomachus simillimus	P	1	14
		Oecophylla smaragdina	P	3	0
		Pheidologeton sp.	P/D	370	60
		Pheidole sp.	G	5	0
		Tetheamyrma sp.	P/D	1	0
Orthoptera	Gryllidae	*Gryllodes sigillatus*	G	16	12
		Loxoblemmus appendicularis	P/D	2	0
	Gryllotalpidae	Gryllotalpidae sp.1	H/D	0	2
		Gryllotaplidae sp.2	H/D	0	1
	Tetrigidae	*Bolivaritettix convergens*	H/D	2	10
		Lamellitettigodes contractus	H/D	2	3
	Trigonidiidae	Trigonidiidae sp.	H/D	1	0
			TOTAL	**927**	**270**

Table 2: Soil macroinsect diversity indices at High Conservation Value (HCV) area and oil palm plantation (OPP) in Pulau Carey, Selangor, Peninsular Malaysia.

	HCV	**OPP**
Richness (S)	28	22
Chao1	35	29
ACE	43	36
Shannon (H')	1.70	2.10
Dominance (D)	1.278	0.183
Evenness (e^H/S)	0.193	0.371

The individual-based rarefaction and extrapolation analysis curve of HCV showed higher expected richness in HCV compared to OPP at a comparable sampling effort (Fig. 2). The extrapolation curve for HCV approached higher asymptotic richness. In contrast, the OPP curve exhibited a steeper initial slope. Additional rarefaction analysis conducted with the exclusion of Formicidae from the dataset resulted in the same pattern of richness and diversity (Appendix I). Despite the observed higher abundance and morphospecies richness in the HCV area, the Shannon diversity of soil macroinsects was lower in comparison to the OPP (Table 2).

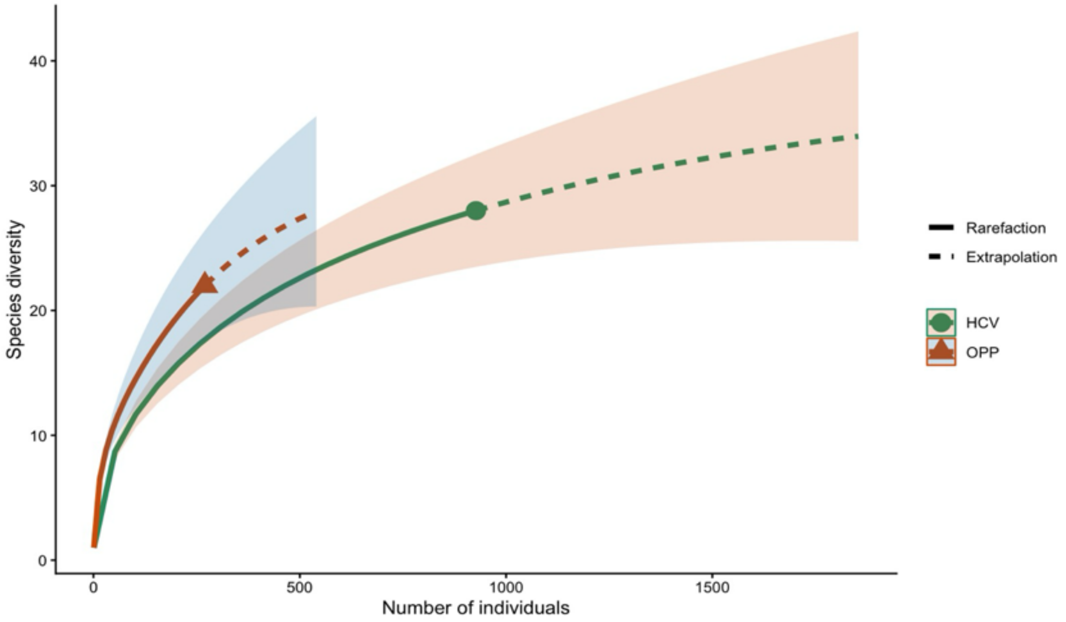

Figure 2: Individual-based rarefaction and extrapolation curves of soil macroinsect richness in High Conservation Value (HCV) and oil palm plantation (OPP) areas of SD Guthrie Plantation in Pulau Carey, Selangor, Peninsular Malaysia. Curves are standardised by sampling effort for comparable expected richness between habitats. The solid lines represent rarefaction, dashed lines represent extrapolation and shaded areas indicate confidence intervals at 95%.

A clear separation of the soil macroinsect community between HCV and OPP was shown following a two-way cluster analysis (Fig. 3). However, clustering among taxa was weak with overlaps in the occurrence of soil macroinsects across the HCV and OPP. When presence-absence data were used (Appendix II), or when Formicidae were excluded from abundance data (Appendix III), no clear separation between habitat types was observed.

Based on the soil texture analysis, both HCV and OPP were classified as sandy loam. Despite the similarity, several soil physicochemical properties differ significantly between HCV and OPP (Table 3). Consistent with the cluster analysis based on abundance data, the NMDS plot (stress <0.05) reflected a distinct separation of the soil macroinsect community between HCV and OPP areas (Fig. 4). However, soil physicochemical properties fitting showed no significant correlation (p > 0.05) with macroinsect community composition.

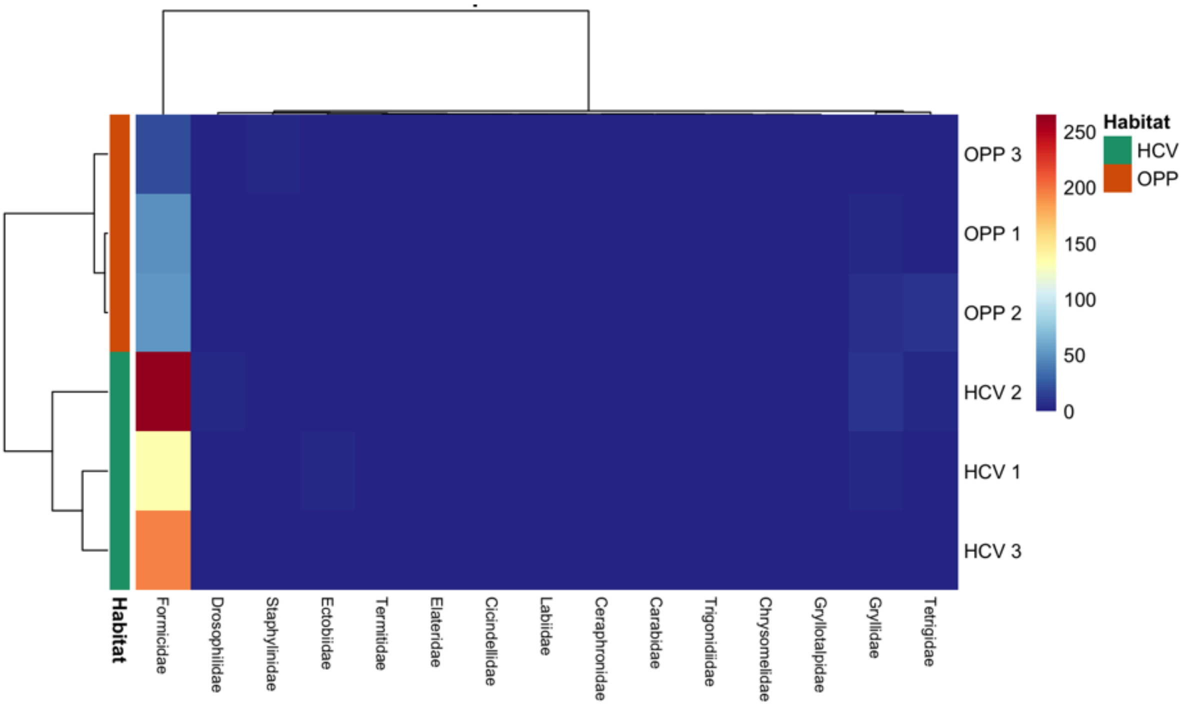

Figure 3: Dendrogram from two-way cluster analysis of soil macroinsects in High Conservation Value (HCV) area and oil palm plantation (OPP) in Pulau Carey, Selangor, Peninsular Malaysia, based on Bray-Curtis dissimilarity on abundance data at the family level. Samples shown to cluster by habitat type, suggesting differences in community structure driven by relative abundance and dominance.

Table 3: Mean (±SE; n = 5) of the soil properties analysed in High Conservation Value (HCV) and Oil Palm Plantation (OPP) areas of SD Guthrie Plantation, Pulau Carey, Selangor, Malaysia.

Soil properties	HCV	OPP	t	p-value
pH	3.6 ± 0.02	3.9 ± 0.02	24.191	< 0.05
Moisture	21.08 ± 0.276	22.38 ± 0.092	4.467	< 0.05
Organic matter	2.00 ± 0.132	0.94 ± 0.058	7.339	< 0.05
Sand %	65.57	53.71		
Silt %	22.33	29.45		
Clay %	12.09	16.84		

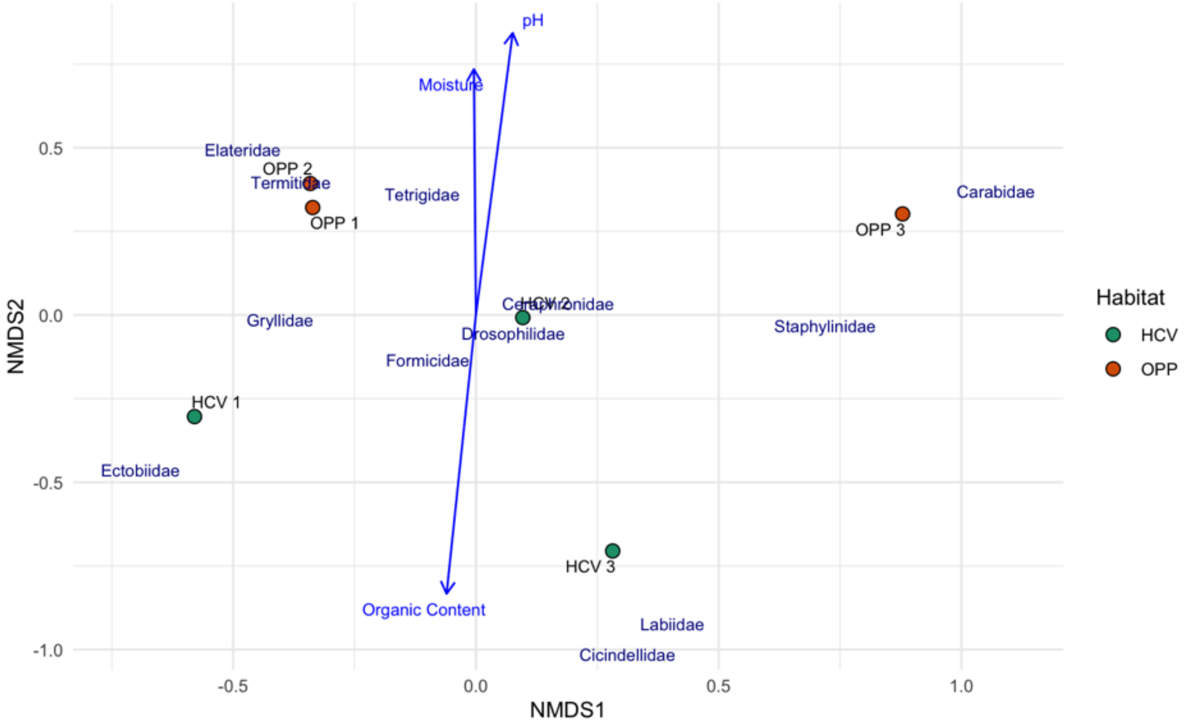

Figure 4: Non-metric multidimensional scaling (NMDS) ordination plot of soil macroinsect communities' composition in High Conservation Value (HCV) and oil palm plantation (OPP), Pulau Carey, Selangor, Malaysia. The ordination plot was based on Bray-Curtis dissimilarity of family-level abundance data with a stress value of <0.05, indicating a good representation of community dissimilarity in two dimensions. Each point represents a sampling transect with colours representing habitat type (green= HCV, and orange = OPP). Vectors represent fitted environmental variables (soil organic content, pH, and moisture).

DISCUSSION

Soil macroinsect diversity and community composition across HCV and OPP areas

The result of our study showed that the HCV has a larger soil macroinsect species pool compared to the OPP, as reflected by higher observed richness, greater abundance, and higher asymptotic estimates from rarefaction analyses. These are consistent with previous studies showing that structurally complex and less disturbed habitats sustain a wider range of macroinsects (Wale & Yesuf, 2022). Although the OPP exhibited higher Shannon diversity, this was driven by greater evenness rather than larger species pool. These highlight the importance of maintaining high conservation value patches within plantation landscapes, fitting the aim of the Malaysian Sustainable Palm Oil certification in protecting habitats aside from the customary plantation site (Bois D'enghein, 2024).

However, the numerical dominance of ants in the HCV area warrants further monitoring as it may suppress the functional roles of other taxa through competitive exclusion (Parr & Gibb 2010). The *A. gracilipes* is known to form super colonies with its ability for rapid recruitment and aggressive defence mechanism (Lee & Yang, 2022), while the *Pheidologeton* (Fischer et al., 2014) and *Crematogaster* (Hamidi et al., 2017) can also establish extensive colonies in habitats with dense canopy cover, abundant litter, and high organic matter, such as the HCV. The numerical dominance of these ant taxa in the HCV area appears to have suppressed the presence and relative abundance of other insect groups. This had caused lower Shannon diversity despite higher richness in the HCV areas. This phenomenon was also reported in other arthropod systems where competitively superior species monopolize resources and suppress subordinate taxa (Fayle et al., 2010; Arnan et al., 2012).

Accordingly, the separation of the soil macroinsect community between the HCV and OPP areas was strongly influenced by the numerical dominance of Formicidae rather than complete taxa turnover. Nevertheless, rarefaction analysis excluding Formicidae retained the pattern of higher richness in HCV, indicating that ant dominance alone does not explain the larger species pool. Instead, the difference in richness is more likely due to variation in habitat characteristics associated with structural complexity between HCV and OPP areas. Therefore, it is deduced that while dominance may explain differences in diversity indices and assemblage separation, habitat filtering better explains differences in species pool size between the areas.

Consistent with the lack of separation observed when presence-absence data were used, most functional groups were represented in both HCV and OPP assemblages. However, the hymenopteran parasitoid, Ceraphronidae was recorded only in the HCV and was absent from the OPP. While parasitoids can occur across a wide range of habitats (Kishinevsky & Ives, 2024) and are not exclusive to high conservation value areas, the detection of this group in the HCV suggests greater compositional breadth with the availability of host resources and heterogeneous microhabitats (Tscharntke et al., 2012). Nevertheless, this pattern is interpreted cautiously and does not imply habitat specialisation, given the low abundance of this group and the short sampling period.

In contrast to the assemblage in HCV that is dominated by ants, the OPP was characterised by a more even distribution of disturbance-tolerant taxa such as termites, *Macrotermes* sp. (Saputra et al., 2016; Tuma et al., 2019), ants, *Odontomachus simillimus* (Hashim et al., 2010), rove beetles (*Paederus* sp., *Hesperus* sp.) (Twardowski et al. 2020), and tiger beetles (*Cicindela* sp.) (Stia et al., 2020). These differences reflect the changes in relative representation of functional groups rather than a definite change of functional group composition across the habitat.

Variation in soil physicochemical parameters

The HCV area has substantially higher soil organic matter than the OPP, which typically has low soil organic matter because of soil disturbance from extensive planting activities (Noirot et al., 2022). The HCV area of the SD Guthrie plantation is planted with various types of trees, resulting in a more diverse litter layer on the soil surface. Visually, the HCV area showed a higher leaf density than the OPP in this study. Within the HCV area, soil organisms can actively decompose the dense leaf litter into organic matter (Liebmann et al., 2020; Prescott & Vesterdal, 2021), resulting in higher organic content compared to the surrounding OPP. This observation aligns with the findings of Kooch et al. (2020), who noted that areas with greater structural complexity and dense canopy cover, such as forests, tend to retain more organic material. The accumulation of organic matter further enhances the diversity and activity of soil fauna (Moraes Sá & Lal, 2009), which is evident from the higher abundance of soil macroinsects recorded in this study. Protecting HCV areas within the SD Guthrie plantation is vital for maintaining soil organic matter levels that are often diminished in intensive agricultural environments.

The pH values of both HCV and the OPP areas in SD Guthrie are slightly more acidic than the average soil pH in oil palm estates in Malaysia, which is 4.3 (Mahmud & Chong, 2022). The acidity of soil may be influenced by many factors, such as the use of fertilisers, rainfall and leaching, biological activity, crop type, and soil texture (Tao et al., 2019; Agegnehu et al., 2021). As high-yielding crops take cations from the soil during harvest, intensive plantations can cause soil acidity over time. Apart from that, the soil in the SD Guthrie plantation is of a sandy type with low buffering capacity against acidification (Desie et al., 2020). This is typical for agricultural areas located in coastal regions (Mohd Yusoff et al., 2017), such as Pulau Carey. Despite the low pH value, SD Guthrie plantations sustain the growth and production of the oil palm trees.

The soil within the HCV area was found to be slightly more acidic and contained lower moisture compared to that of the OPP site. This difference could be influenced by the composition of plant species present, as certain species produce litter with higher acidity (Desie et al., 2020). The lower pH could also be linked to the build-up of decomposed litter from tree species that decompose slowly, resulting in a thicker organic layer (Kooch et al., 2020).

The SD Guthrie plantation's soil moisture content was lower in comparison to moisture levels found in other peat-based plantations (Ngau et al. 2022). The soil texture in the SD Guthrie plantation is of sandy loam with a larger pore size than the peat soil. As the pore size is larger, the sandy loam soil of SD Guthrie is not as effective in retaining moisture when compared to peat soil. Besides soil texture, soil moisture is also affected by climate and topography (Tang et al., 2022), apart from vegetation (Cai et al., 2022). A higher rate of transpiration might occur in the HCV area following denser vegetations of greater plant diversity. Each plant species in the HCV area will also have varying root depths that affect water uptake and lead to difference in soil moisture balance. As vegetation characteristics, plant diversity and litter input were not quantified, their potential influence on the soil parameters remains beyond the scope of the present analysis.

Influence of soil properties on the soil macroinsect community

In the HCV areas, higher organic matter appears to support decomposer taxa such as the Blattodea (Ectobiidae), Diptera (Drosophilidae), and Dermaptera (Labiidae) (Ball et al. 2022; Li et al. 2020). The feeding and interaction of soil fauna, including these decomposers with microbial communities, help to stimulate microbial activity, which enhances nutrient cycling (Angst et al. 2024). Organic matter provides a resource base for decomposers by promoting microbial biomass and functional diversity, accelerating litter decay in less disturbed soils (Elias et al. 2020), such as the HCV.

In contrast, community composition in the OPP may be primarily influenced by soil moisture and pH, with taxa such as Termitidae and Elateridae that are more tolerant to soil disturbance. Some species of termites were reported to have been influenced by soil pH, impacting nutrient cycles differently in comparison to undisturbed forest soils (Li et al. 2017). The result of this study also showed that soil moisture may shape the soil macroinsect communities, which have also been reported in Eckert et al. (2023) and Li et al. (2024).

However, there is no significant correlation ($p > 0.05$) between all soil properties and the insect communities, indicating that the pH, moisture, and organic matter do not fully explain the observed community variation, especially without considering multiple other environmental factors. Apart from that, the low sample size may reduce the ability of permutation tests to detect relationships. Following these constraints, the NMDS presented in this study is considered an exploratory visualisation that only gives initial insights into the ecological patterns. Extended sampling and inclusion of other environmental variables are needed for future confirmation.

Collectively, the results of this study indicate that the difference in habitat type is primarily shown as changes in relative abundance, dominance, and structure of the soil macroinsect assemblage, rather than differences in functional taxa. While the OPP supported higher diversity due to greater evenness, the HCV maintained higher species richness and distinct assemblage characteristics associated with higher soil organic matter and lower disturbance. These findings highlight the importance of maintaining HCV patches within plantation landscapes, as higher diversity values in plantations do not necessarily reflect greater ecological or conservation value.

CONCLUSIONS

This study indicates that although OPP showed higher Shannon diversity due to greater evenness, HCV areas supported a larger species pool and distinct soil macroinsect assemblage characteristics. The differences between these two habitat types are primarily driven by variation in relative abundance and dominance rather than by the presence of habitat-exclusive functional groups. Ordination showed that variation in soil organic content, moisture, and pH likely influences the assemblage composition, although these relationships were exploratory. Therefore, the findings demonstrate that diversity indices alone may not be adequate to reflect ecological differences between habitats. HCV patches within oil palm landscapes may retain important compositional and structural attributes to soil macroinsect assemblages in tropical agroecosystems. We suggest a longer study period to collect enough data to support the role of HCV habitats in sustaining soil biodiversity in plantation landscapes.

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DECLARATIONS

Research permit(s). The study was conducted in a privately managed area with permission from the company. One co-author is affiliated with this company. A Material Transfer Agreement (MTA) was signed to regulate the transfer and use of research materials and to allow publication of the findings. The authors declare that this affiliation and agreement did not influence the study design, data collection, analysis, or interpretation of the results.
Ethical approval/statement. Not applicable.
Generative AI use. The author (s) declare that an AI-based language checker was used solely for grammar, spelling, and clarity improvements. All content has been reviewed and verified by the author(s), who take full responsibility for the final manuscript.

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Supplementary material 1

Appendix I

Authors: Abdullah et al.
Data Type: PDF
Explanation note: Individual-based rarefaction and extrapolation curves of soil macroinsect richness in High Conservation Value (HCV) and Oil Palm Plantation (OPP) areas, excluding Formicidae to assess richness patterns independent of ant dominance. Curves are standardized by sampling effort for comparable expected richness between habitats. The solid lines represent rarefaction, dashed lines represent extrapolation and shaded areas indicate confidence intervals at 95%.
Link: https://doi.org/10.51200/jtbc.v23i.6166.g4669

Supplementary material 2

Appendix II

Authors: Abdullah et al.
Data Type: PDF
Explanation note: Two-way cluster dendogram of soil macroinsect assemblages in High Conservation Value (HCV) and oil palm plantation (OPP) areas based on Sorensen dissimilarity of family level presence-absence data. The lack of separation between HCV and OPP suggests that variation between habitats is caused by difference in relative abundance and assemblage structure rather than by the presence of habitat-exclusive taxa.
Link: https://doi.org/10.51200/jtbc.v23i.6166.g4670

Supplementary material 3

Appendix III

Authors: Abdullah et al.
Data Type: PDF
Explanation note: Two-way cluster dendogram of soil macroinsect assemblages in High Conservation Value (HCV) and oil palm plantation (OPP) areas based on Bray-Curtis dissimilarity of family-level abundance data after exclusion of Formicidae. There is a lack of distinct clusters by habitat, indicating that a high number of ants plays a role in influencing the difference in soil macroinsect community structure in HCV and OPP.
Link: https://doi.org/10.51200/jtbc.v23i.6166.g4671