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Preliminary study on hymenopteran distribution and abundance from island ecosystem of Tuba Island Forest Reserve, Langkawi

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Abstract

The study was performed to determine the diversity and distribution of Hymenoptera across the environmental gradient ranging from fringe forest, mid forest to inner forest. The study was conducted in a selected area of Tuba Island Forest Reserve from 17th to 21st September 2020 using Malaise trap, an insect capturing trap. During this study, a total of 133 individuals of Hymenoptera were sampled from 12 families and 27 morphospecies. Hymenoptera was most abundantly found in the forest fringe with 64 individuals (11 families, 25 morphospecies) and least abundant in the inner forest with 26 individuals (7 families, 8 morphospecies). The top three highest number of individuals recorded were Formicidae (43 individuals), Braconidae (28 individuals) and Ichneumonidae with 27 individuals. Shannon-Weiner Diversity Index (H') showed that the forest fringe had the highest diversity value with H'=1.80 while the lowest was recorded in the mid forest with H'=1.43. The Evenness Index (E′) was highest at mid forest (E′=0.81) and the Margalef Richness Index (R′) value recorded the highest at forest fringe indicating a high species richness with R′=2.40. Kruskal-Wallis test reveals that the distribution of Hymenopterans from the forest fringe to the inner forest did not differ significantly with $P>0.05$. High similarities in microclimate variables (monsoon season, temperature, humidity, and light intensity), resources availability, forest features, hiding places, and the presence of predators are among the factors influencing the homogeneity of the composition and abundance of Hymenoptera in Tuba Island. This study is the first checklist of Hymenoptera in Tuba Island and can be utilised as a baseline dataset for further ecological research at Tuba Island.

1. INTRODUCTION

Insects, which belong to the vast phylum of jointed legs, hardened parts of integument creatures known as the arthropods, make up a significant portion of the terrestrial fauna (Freeman, 2020). They dominate today's land fauna, accounting for about three-quarters of all known animal species, thus have contributed majorly to the emergence of our great biodiversity (Stork, 2018, Samways, 2020). They are known for their ecological function on agriculture, human health and natural resources as well as contributing to nutrient cycling, and ecosystem food webs (Foottit and Adler, 2009). Their morphologically small in size, allow them to inhabit a wide range of habitats and niches (Siti Aisyah et al., 2017). Therefore, from the tropical forest canopy, coastal and marine habitats, even in the island forest, insects can be discovered ubiquitous (Mohamed et al., 2019).

Hymenoptera that include sawflies, bees, wasps and ants is one of the five major orders of insects together with Coleoptera (beetles), Diptera (true flies), Hemiptera (bugs, cicadas, lice and aphids) and Lepidoptera (moths and butterflies) (Gullan and Cranston, 2014; Forbes et al., 2018). Hymenoptera or "membrane-winged" is known to be the largest insect order with 27 superfamilies and 132 families (Aguiar et al., 2013; Forbes et al., 2018). Hymenopterans have unique morphology to distinguish between species from the structure of their body that includes head, antennae, mouth, thorax, legs, abdomen and wings (Siti Khairiyah et al., 2015a). There are two main suborders of Hymenoptera: Symphyta (sawflies) and Apocrite (wasp-waisted). Symphyta is a suborder of leaf insects that are commonly classified as plant pests or sawfly while Apocrita suborder is mostly parasitic types of bees, wasps, and ants (Trianto and Marisa, 2020).

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Within an island ecosystem, Hymenoptera prefers inland forest to coastal forest because inland forest provides more needs, including nectarines from flowering plants, which are necessary for hymenopterans (Salmah et al., 2019). Inland forest vegetation is far more productive compared to coastal forest. Tuba Island likewise an inland forest, so high hymenopterans are predicted. The vegetation grows from the forest fringe through the mid forest to the inner forest. Hymenopterans preferred the inner forest to the forest fringe most likely because the inner forest has a greater quantity food supplies, and the location is safer for them to forage (Siti Khairiyah et al., 2015b).

Knowing the life of insects in isolated environments like an island is interesting because it builds understanding on how the insect population is biologically or evolutionally influenced from the isolated surroundings compared to mainland (New, 2008). According to Gillespie and Roderick (2002), fauna species in an island depend on several aspects including habitat diversity, age of island, climate and extreme isolation. The authors also mentioned that the comprehensive knowledge on arthropods in island ecosystem is limited and deemed for more recent updates. Species richness, phylogenetic diversity and composition are determined by the distance from the mainland and the role of the island area (Portillo et al., 2019). To date, no comprehensive study has been undertaken in assessing the insect diversity and composition in Malaysian island forest specifically in Tuba Island.

This study is designed to establish the first checklist of Hymenoptera's diversity and composition in Tuba Island. Studies of island insects have been widely reported and described in other countries other than Malaysia (Foottit and Adler, 2009). The study may enhance knowledge of insect trends specifically Hymenopteran in the island forest across environmental gradient which are important for the sustainable management of island forest habitats. This research is anticipated to aid Langkawi Development Authority (LADA) to regulate human activities, managing and conserving valuable species of Hymenoptera alongside other fauna species to establish Langkawi as a safe home for island-living biota.

2.0 MATERIALS AND METHOD

2.1 The study area

Langkawi Archipelago located in the Andaman Sea and situated 25 kilometres off the western coast of northern Peninsular Malaysia consists of approximately 99 islands (Kázmér et al., 2015). One of those 99 islands, Tuba Island is the study site of the present work. Tuba Island was named after the tuba plant, a small flowering shrub endemic to the island (Asib and Omar, 2018).

Tuba Island that is located 9.26 km from Marble Jetty, Kuah (Figure 1), with a total area of 504 ha, accumulating 62.78 percent of the island (Laut, 2013). Tuba Island, part of Dayang Bunting Marble Geoforest Park is one out of three Langkawi's Geoforest Park listed under United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Geopark, making it a popular destination for both locals and visitors (Workman, 2019). High level of anthropogenic activities present potentially affects the diversity of insects including Hymenoptera.

The study is performed in a selected inland forest of Tuba Island, which was then classified into into forest fringe, mid forest and inner forest for the present work. In general, inner forest is densely forested compared to mid forest and forest fringe. However, the forest fringe of Tuba Island was loaded with flowering plants which relied by most nectar-feeding hymenopterans as part of their diet. This study is likely to yield unique findings.

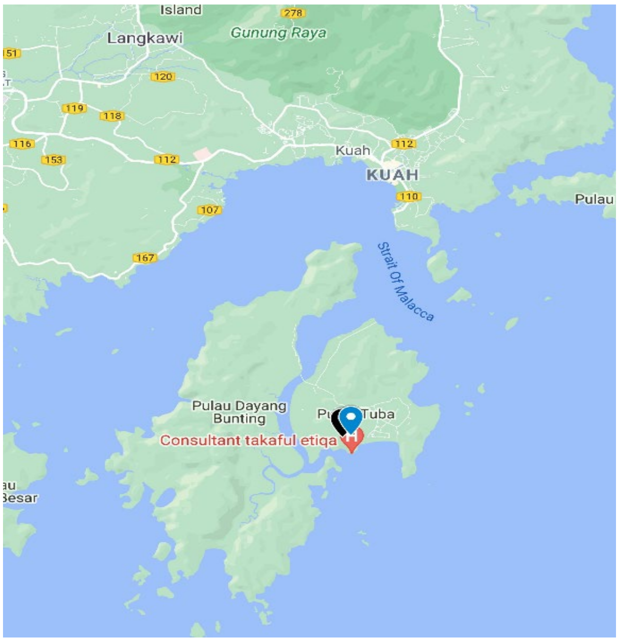

Figure 1:Maps of Tuba island (source: Google Maps) Study site coloured in black

2.2 Sampling method

Samplings were carried out beginning form the forest fringe toward the inner forest. Three trails separated from each other about 100 m distances were established along a census line (Figure 2). Trap 1 represented the forest fringe, Trap 2 represented the mid forest and Trap 3 represented the inner forest.

The forest fringe refers to the forest's outermost borders, which have received the majority of the disturbance and pressure from humans and man-made structures such as roads. Forest fringe of Tuba Island is situated near a walkway for people. The mid forest is 100-metres away from the fringe forest and has received less disturbance from outsiders. Mid forest endowed greater vegetation compared to the forest edge. Inner forest, located 100-metres from mid forest, is more secured from any construction, development or any anthropogenic activities, and is more secluded and less vulnerable for most fauna. Flowering plants appear to be loaded on the forest fringe of Tuba Island but not as much as in the inner forest.

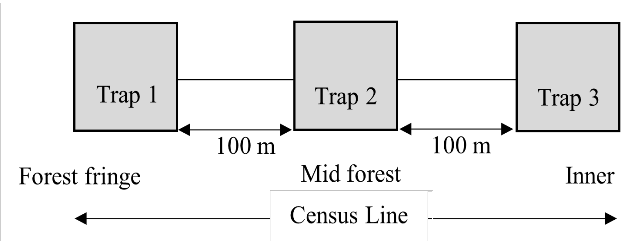

Figure 2: The placement of malaise traps on the census line

Malaise traps were placed along the census line constructed to study the distribution across environmental gradients. The Malaise traps were left unattended for five days from 17th to 21st September 2020. Collecting bottles attached to the Malaise traps contained 70% alcohol to preserve the insect specimen sampled for later identification and classification.

2.3 Hymenoptera identification

All hymenopterans sampled in the collecting bottles were sorted out and dried. Mounting process begin by carefully pinned each of them using minute-size entomological pin onto insect mounting board. The specimens were dried at 38°C to 40°C for about a week to protect them against any possible fungal attack. The specimen was then identified and classified under the guidance and supervision of Dr. Siti Khairiyah of the School of Biology, Faculty of Applied Sciences, UiTM Shah Alam, as well as a reference book titled "Hymenoptera of the World: An Identification Guide to Families".

2.4 Data analysis

Statistical Package for the Social Sciences (SPSS) version 26.0 was utilised. A normality test was performed to determine the normality of distribution. Biodiversity indicators including Shannon-Wiener Diversity Index, Evenness Index, Margalef Richness Index was used to further clarify Hymenoptera families' diversity and distribution in those three sites. Kruskal Wallis test with pairwise comparison was conducted to see the mean differences of insect distribution at three different transects.

3. RESULTS AND DISCUSSION

3.1 Abundance of Hymenoptera

Altogether, 133 individuals belonging to 12 families were successfully sampled from all selected areas in this study. The identified families were Apidae, Braconidae, Colletidae, Evaniidae, Formicidae, Ichneumonidae, Megachilidae, Pompilidae, Pteromalidae, Sphecidae, Tenthredinidae, and Vespidae (Figure 3). All 12 families identified belonged to suborder Apocrita and Symphyta and only family Tenthredinidae belonged to suborder Symphyta.

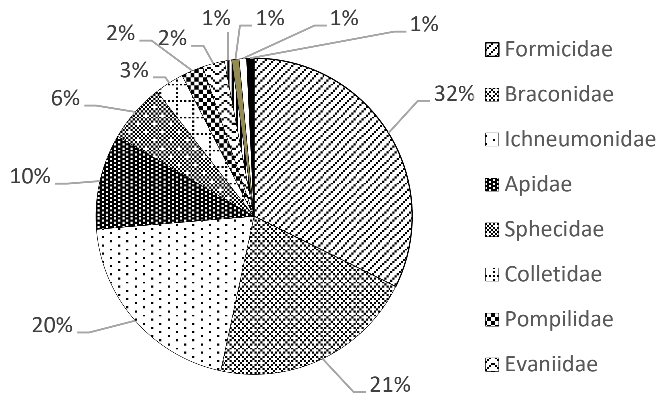

Figure 3: The percentage of families identified under order Hymenoptera collected at Tuba Island

The most abundant Hymenopterans recorded was from family Formicidae with 32% followed by family Braconidae (21%) and family Ichneumonidae (20%). Both families Pompilidae and Evaniidae had a similar percentage of 2% with three individuals per family. Family Megachilidae, Pteromalidae, Tenthredinidae, and Vespidae had the lowest proportion of 1%, with only one individual recorded per family.

Family Formicidae or commonly known as ants was the most widespread family recorded in this study. This particular result correlates with previous study by Siti Khairiyah et al. (2015a) which was also conducted in Langkawi Archipelago (main island) in mountainous areas (Gunung Raya and Gunung Mat Cincang). This family, which accounts for almost 25% of land animal biomass (Indriati et al., 2020) recognized as predators, decomposers, herbivores, and bioindicators for the health of agricultural ecosystems (Ikhsan et al., 2020) as well as cleaners of the forests, stealthily consuming fallen leaves, branches and trees (Siti Khairiyah et al., 2015a). They showed great capability to adapt quickly to environmental changes (Abdar, 2020) which may contribute to the high spread and abundance. However, because the study was conducted during the rainy season, ant populations may have been impacted, thus fewer ants were predicted. Nunes et al. (2011) confirm the findings of this study, which found that ant populations were much lower during the rainy season, with 4,083 individuals during the wet season compared to 15,005 during the dry season. Rainfall is believed to be a mechanical barrier to foragers' foraging activities, particularly for certain ground-dwelling species.

Temperature and humidity changes linked with rainfall have an effect on mobility and activity rates of arthropods include ant foragers (Nunes et al., 2011).

The second highest family recorded, Braconidae, with a total of 28 individuals identified. Braconidae serve a vital role in the ecosystem as parasitoids, assisting in the regulation of herbivore insects and are thus necessary for the preservation of ecological processes and contributing to the diversity of flowering plants (Ruiz-Guerra et al., 2015). High richness of braconid species is due to high availability of microhabitats, resources, nesting sites as well as greater predator protections (Ruiz-Guerra et al., 2015). Prior research done in an inland forest in an island backs up these arguments. They discovered that braconid species are found dominant in inland forests of an island due to the abundance of resources that allow them to dominate (Salmah et al., 2019). According to Lewis and Whitfield (1999), many braconid wasps are drawn to flowering plants, and have been visiting flowers for nectar and pollen. Thus, they are found in abundant because of the presence of flowering vegetation which is part of their important resources.

Ichneumonidae recorded 20% from overall collected Hymenopteran with 27 individuals. Ichneumonidae shows preference over floral plants as they feed on nectar or pollen or resting on leaves whilst vibrating their white-banded antennae, and they are usually only seen flying erratically amongst the forest floor vegetation (Amanda et al., 2011). Both Braconidae and Ichneumonidae which belong to superfamily Ichneumonoidea do exhibit seasonal patterns of activity due to the presence of rainfall despite the fact that the temperature in tropical forests remains constant throughout the year (Shapiro and Pickering, 2000). The authors mentioned that higher activity of insects under this family led by rainfall and humidity levels besides the food availability and forest structure. Thus the abundance of Ichneumonoidea found in this study is potentially contributed by the greater number of morphospecies identified especially Braconidae (Table 1). Aside from the rainfall, the forest features, particularly floral composition at sites, impact their richness. Floral vegetation is required for it nectars, and also provides a wider range of available niches and platform for plant-host-parasitoid interactions (Shapiro and Pickering, 2000).

The least percentage families recorded were Megachilidae, Pteromalidae, Tenthredinidae, and Vespidae with only one percent accounted from overall individuals sampled. Least in proportion probably because the study site was not suited for the species' habitat due to anthropogenic disturbances or temporal factors which are related to the rainy seasons during the sampling duration. Only one individual Megachilidae (pollen and nectar feeders) (Mayr et al., 2020) was discovered in this study although pollinators usually preferred dense vegetation and floral plants (Bishnoi and Dang, 2019). Vespidae with also one individual only sampled is commonly known as family for most solitary wasps and eusocial wasps. Result for Vespidae family against previous finding by (Siti Khairiyah et al., 2015a, 2015b) in which Vespidae was recorded as second highest family. This might be because, as previously stated, it rained during the sampling time and reduced floral vegetation, resulting in fewer individuals being collected.

3.2 Abundance of Hymenoptera between sites

Based on the distribution pattern of Hymenopteran families in three selected transects shown in Table 1, Trap 1 recorded the highest number of Hymenopterans with 64 individuals (48.12%) followed by Trap 2 which collected 43 individuals (32.33%) and Trap 3 was the lowest with 26 individuals (19.55%). Trap 1 consisted of 11 families with 25 morphospecies, Trap 2 with six families and 9 morphospecies while Trap 3 consisted of seven families and 8 morphospecies.

Distribution patterns across the groups of insects are varying and depending on their adaptability in the ecosystem Siti Khairiyah et al., (2011). Trap 1 (forest fringe) recorded the highest number of Hymenopteran individuals, families and morphospecies. The forest fringe accommodates diversified vegetation especially shrubs and flowering plants. The presence of floral plants encourages the Hymenopteran distribution to acquire food in the form of nectars and/or honey (Upadhyay, 2014). Most Hymenopterans especially pollinator bees and wasps are numerously found in the disturbed habitats like forest fringe because it endowed greater understory herbaceous layer (Winfree et al., 2007) and minimal total tree cover (Arnan et al., 2011) and high light intensity (Gossner, 2009). Apart from the great supply of diet nectars, forest fringe also owns the breeding sites for the bees (Winfree et al., 2007). The plant-insect interaction occurs as in return, the flower-visitor Hymenopterans will pollinate those flowers (Whittaker and Fernández-Palacios, 1998; Kyerematen et al., 2014). The co-existence of flower-visitor insects and the flowering vegetation is reinforced as the flowers morphologically adapt in the habitat by possessing vibrant colours of nectar tube and nectarines.

This finding contradicts with a study performed by Siti Khairiyah et al. (2015b), which stated Hymenoptera was found more abundant in the inner forest compared to forest fringe. The author also added that insects require protection from predators and human activity, so Hymenoptera does not choose to establish their nest towards the forest fringe, where there are fewer trees, shrubs, and grass.

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Table 1: Number of Hymenopteran individuals in different traps

Family	Morphospecies	Traps			Total
		1 (forest fringe)	2 (mid forest)	3 (inner forest)	
Formicidae	8	23(8)	10(2)	10(2)	43
Braconidae	6	16(6)	11(1)	1(1)	28
Ichneumonidae	2	8(2)	9(2)	10(1)	27
Apidae	1	1(1)	10(1)	2(1)	13
Sphecidae	3	6(2)	2(2)	0	8
Colletidae	1	4(1)	0	0	4
Pompilidae	1	2(1)	0	1(1)	3
Evaniidae	1	1(1)	1(1)	1(1)	3
Megachilidae	1	1(1)	0	0	1
Vespidae	1	1(1)	0	0	1
Pteromalidae	1	0	0	1(1)	1
Tenthredinidae	1	1(1)	0	0	1
Total individual		64	43	26	133
Percentage		48.12	32.33	19.55	
Total family	12	13	7	10	
Total morphospecies	27	25	9	8	

(The value in the bracket is the total number of morphospecies among families of Order Hymenoptera at the study sites)

However, in the forest fringe of Tuba Island, it was filled with flowering plants which are the food resources for most Hymenoptera.

In contrast to Trap 3 (the inner forest) in which it was densely forested and had fewer flowering plants, recorded the least number of individuals because food resources were limited thus resulting in a lower insect population. Besides, the inner forest is a somewhat closed area and has reduced light intensity, making it unpreferable for most insects (Gossner, 2009).

The total number of individuals in this study was influenced by the duration of sampling activities. Overall, the number of Hymenopteran individuals which successfully sampled (150 individuals) is lower compared to previous study conducted by Siti Khairiyah et al. (2015a) at a selected forest in Langkawi (640 individuals) where both studies using the same sampling traps. This condition is possibly due to the temporal factor. The time frame of sampling performed in Langkawi archipelago is six months which is pronouncedly much longer than the present study. Fraser et al. (2008) experimentally affirms that sampling period significantly affects the abundance and composition of species caught and believes that sampling should continue over several weeks in order to get better coverage.

The efficacy of using the quantified Malaise traps may also be the cause of the unparalleled result. In the previous study, three traps were placed at a single site, however in this study, only one trap is placed at a single site. Malaise traps are widely used to sample insect communities (Matthews and Matthews, 2017) but the best way to utilize them at individual sites is yet unknown (Fraser et al., 2008). Malaise trap is believed to give unbiased catches especially for Hymenoptera and Diptera (Southwood and Henderson, 2000) but several physical factors such as temperature, air flow and weather might influence the efficacy of Malaise trap operation (Matthews and Matthews, 2017). The greatest captures are apparently happening on days that are hot, clear with low air flow after the rain. Height of surrounding vegetation and location of a trap can also materially alter trap performance and efficiency (Matthews and Matthews, 2017). Few traps at one site and short period of sampling led to the outcome but findings supplied can still be helpful and valuable for long-term monitoring (Fraser et al., 2008).

The lower number of individuals collected was because the sampling activities were performed in September, during the southwest monsoon which is associated with intense rains and winds (Loo et al., 2015). Heavy rains can limit the insect movements in finding shelter and foraging activites may lead to fewer insect presences (Pellegreno et al., 2013). The presence of flowering plants, rainfall, humidity levels and habitat structures were few factors that influenced the distribution of Hymenoptera found in Tuba Island.

3.3 Diversity (H’), Evenness (E’) and Richness (R’) of Hymenoptera

The Shannon-Weiner Diversity Index (H’) in forest fringe (Trap 1) has the highest family diversity (H’=1.80), followed by H’=1.59 in mid forest (Trap 2) and H’=1.43 in the inner forest (Trap 3) (Table 2). All the three traps have H’ values less than 2.0. The values indicate that the diversity was low. The typical values of H’ are between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4 (Mohamed et al., 2019). The value of H’ obtained also indicated that the study area has been disturbed and unstable (Manuel, 2008).

The low value of H’ can be influenced by human interference. Ecotourism is a rapidly growing sector in Langkawi Archipelago which encouraged the developments of shelters including hotels and chalets, alongside other activities to attract more tourists for example, insects are captured to feed pigeons (Berger, 2015). These anthropogenic activities potentially disturb

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the insect population. The floral vegetation required by flower-visiting Hymenopterans reduced led to reduced distribution of Hymenoptera (Winfree et al., 2007; Siti Khairiyah et al., 2015a; Bishnoi and Dang, 2019).

Table 2: Table Shannon-Wiener Diversity Index (H'), Evenness Index (E'), and Margalef Richness Index (R')

Trap	H’	E’	R’
1(forest fringe)	1.80	0.55	2.40
2 (mid forest)	1.59	0.81	1.33
3 (inner forest)	1.43	0.60	1.84

Evenness Index, E’ value was the highest in Trap 2 at E’=0.81 compared to Trap 1 (E’=0.55) and Trap 3 (E’=0.60). The highest value of E’ at Trap 2 (E’=0.83) which approaching 1.00 indicated the distribution of species in the mid forest was evenly distributed with no dominating families but lower diversity observed (Manuel, 2008). The lowest Evenness index value was Trap 1 with E’=0.55 with less evenly distributed species observed. The dominant family in Trap 1 is Formicidae (ants). The severity of habitat disturbances was the most important predictor of ecological communities (Idris and Kee, 2002).

The Margalef Richness Index, R’ value in Trap 1 was the highest while Trap 2 recorded the lowest. The highest R’ value in Trap 1 indicates that the species richness was greatest highest at the forest fringe compared to mid forest and inner forest. The lowest value recorded in Trap 2 with R’=1.33 indicated that the mid forest area has the lowest species richness.

Kruskal-Wallis test was used to determine whether there were any significant differences in families’ distribution across the three traps. The distribution of Hymenoptera in this study did not differ significantly across all traps (Kruskal Wallis, X2=0.59, df=2, P>0.05) where the Hymenopteran families are similarly distributed between environmental gradient from the forest fringe towards the inner forest.

4. CONCLUSION

Overall results revealed Hymenoptera was most diverse and abundant in the forest fringe and the least at the inner forest. Microclimate variables such as humidity, temperature and rainfall as well as resources availability (presence of flowering plants), forest features and environment gradients, all of which contributed to abundance of Hymenoptera across the forest fringe, mid forest and inner forest. All in all, Hymenopteran diversity in the island ecosystem is rather low. The weather, sampling duration and how the Malaise traps used in this study potentially contribute to these outcomes. This research is seen as an initial approach to create the first components of a faunal inventory of Hymenoptera on the ecology of the Tuba Island, Langkawi. Such studies could be used to provide an insight on how Tuba Island's famous, fast-growing ecotourism industry affect Hymenoptera presences and finding effective ways to conserve island ecosystems through ecotourism especially after the Movement Control Order (MCO) due to Coronavirus Disease 2019 (COVID-19) pandemic outbreak, which had affected the entire Malaysian travel industry since March 18, 2020.

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