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FIRST RECORD OF INSECTS IN PULAU TINGGI, JOHOR, MALAYSIA

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Abstract: Species assembly of insects in Pulau Tinggi was extensively studied to obtain the first checklist of insect fauna on the island. Samples were collected from forested areas in Pulau Tinggi on three occasions (20-30 April, 1-10 May and 20-30 June 2019). Various sampling methods were used, including pitfall trap, light trap and active collection using sweep net and forceps. The specimens were dried and curated for identification. A total of 41 families from ten orders of insects representing 90 species and morphospecies were identified. Coleoptera was the most dominant order with 14 families, followed by seven families from the order Hemiptera, three from Hymenoptera, four from Orthoptera, three from Odonata, three from Diptera, two from Blattodea, one from Mantodea and one family from order Phasmatodea. This first inventory study has shown that this relatively unexploited island possesses many insect species. Hopefully, this data will assist policymakers and governing bodies, particularly the private landowners and Johor State Government in making conservation management decisions in the future.

Keywords: Coleoptera, Hemiptera, Mersing, Seribuat Archipelago, Malaysia, South China Sea.

Introduction

Insects are a crucial component for a functional natural and human-modified landscape. They play an important role in several ecosystem services that ensure the quality of agriculture, tourism and natural resources for humans (Saikim *et al*., 2020; Hor *et al*., 2021). Most insects have high survival and reproduction rate. They are a very successful group of organisms that can live in all types of ecosystems. They maintain the nutrient cycle by assisting the degradation of wood and leaf debris and diffusion of fungi, eliminating the decaying flesh and faeces, loosening the soil, disseminating plants or seeds, and being a food source for terrestrial and aquatic lives (Gullan & Cranston, 2010). Insects are also used worldwide as biomonitoring tools to measure diversity and ecosystem health (Rákosy & Schmitt, 2011; Shuey *et al*., 2017). Globally, insect numbers are already in decline (Basset & Lamarre, 2019). If nothing is done to conserve this group of organisms, Malaysia will soon see a significant insect number decline. Malaysia is already well known for its highly diverse fauna and iconic insect species (Nur Atiqah *et al*., 2017; Hor *et al*., 2021; Ridzuan *et al*., 2021). Ranked as one of the most mega-diverse countries in the world, Malaysia is now focused on protecting its natural treasures, as stated in Malaysia's National Policy on Biological Diversity (2016–2025) (NRE, 2016). Within Malaysia, documentation of insect diversity has been carried out extensively in Borneo and some parts of Peninsular Malaysia (Nur Atiqah *et al*., 2017; Chung *et al*., 2020). New species of insects have been discovered quite frequently in recent years (Al-Talafha *et al*., 2018; Gildenkov, 2019; Ng & Mound, 2020). However, knowledge of insect diversity in Malaysian island forests is still lacking. An island ecosystem provides a habitat for migratory, endemic and endangered species (Quek *et al*., 1999; Francini & Ramos,

2014; Mohd-Taib *et al*., 2019). Therefore, it makes sense to pay particular attention to the remarkable biodiversity in an island ecosystem.

Pulau Tinggi (02° 18′ 0″ N, 140° 07′ 0″ E) is located in the middle arc of Seribuat Archipelago, Mersing, Johor (Figure 1). The island has an area of 13.5 km^2 and an elevation of 610 m. Pulau Tinggi has a relatively low human disturbance and is covered with different vegetation types. The archipelago also consists of several main islands including Pulau Tioman, Pulau Pemanggil, Pulau Aur and Pulau Sibu. Prior to the publication of this study, several inventory studies focusing on general insect groups or specific orders have been done in Malaysian islands (Quek *et al*., 1999; Farizawati *et al*., 2014; Rosmidi *et al*., 2017; Mohamed *et al*., 2019; Ridzuan *et al*., 2021). However, none was done in Pulau Tinggi.

To our knowledge, no entomological research has been done on this relatively unexplored island. Therefore, this paper aims to record the various insect groups that inhabit the area. However, insects from the order Lepidoptera were not included in this paper. From the authors' preliminary observation, Lepidoptera of Pulau Tinggi requires a more extensive discussion due to their relatively high abundance in Pulau Tinggi. Therefore, a separate paper will be published focusing on only the island's butterflies and moths.

Materials and Methods

Study Area

The study site is at Gunung Semudu in Tanjung Balang, Pulau Tinggi. Sampling was conducted within three hiking trails. Trail 1 and Trail 2 are located within a secondary forest, Trail 3 is located within a primary forest (Figure 2). The coordinates and elevation of each trail are recorded in Table 1.

Insect samples were collected from the forest area for three months within ten consecutive days each month (20-30 April, 1-10 May and 20-30 June 2019). The sampling was carried out in two replications. The sampling techniques consisted of active collection, pitfall trapping and light trapping. All samples were collected in three separate timings throughout the day: morning (08:00 hours), afternoon (13:00 hours) and evening (17:00 hours), except light trapping, which was conducted at night (20:00 hours) for nocturnal insects.

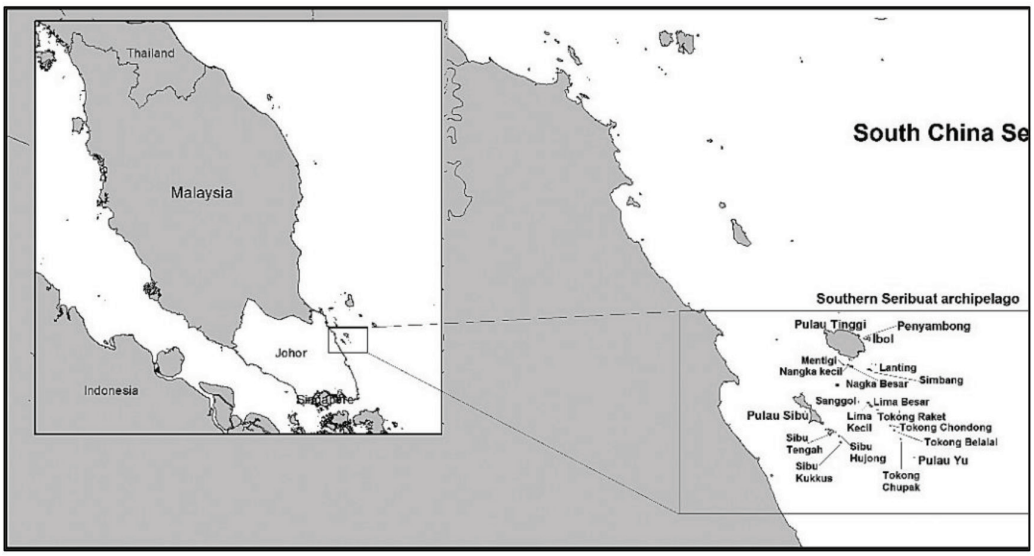

Figure 1: Map of Pulau Tinggi and its location relative to Peninsular Malaysia and the Southern Seribuat Archipelago

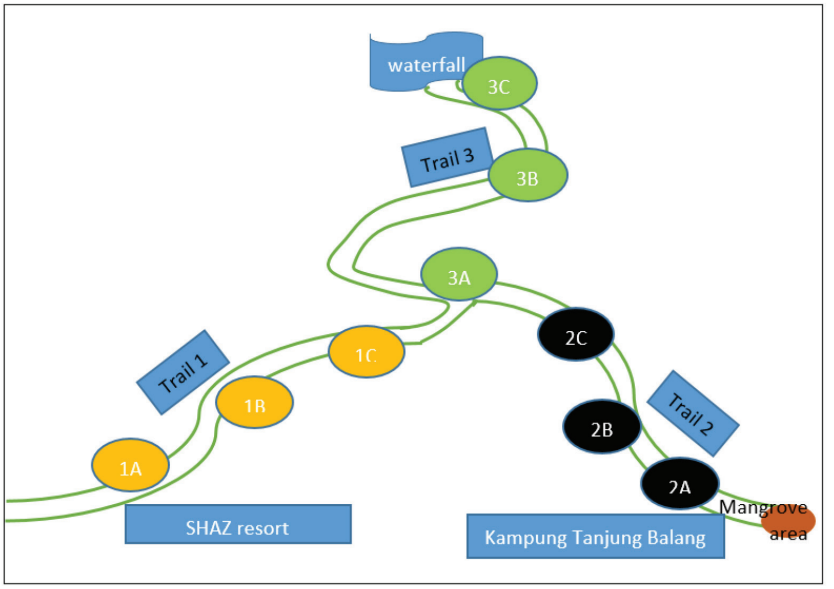

Figure 2: Study trail located in Gunung Semudu

Table 1: Coordinate and elevation of each sampling trail used in this study

Trail	Sub-trail	Coordinates
1	1A	(02° 17′ 06.1″ N, 104° 06′ 55.9″ E, 4 m)
	1B	(02° 17′ 07.7″ N, 104° 06′ 53.1″ E, 19 m)
	1C	(02° 17′ 38.5″ N, 104° 07′ 39.3″ E, 56 m)
2	2A	(02° 17′ 05.4″ N, 104° 07′ 18.9″ E, 6 m)
	2B	(02° 17′ 24.5″ N, 104° 07′ 16.3″ E, 53 m)
	2C	(02° 17′ 18.5″ N, 104° 07′ 05.8″ E, 66 m)
3	3A	(02° 17′ 27.6″ N, 104° 07′ 19.9″ E, 80 m)
	3B	(02° 17′ 42.3″ N, 104° 07′ 38.3″ E, 118 m)
	3C	(02° 17′ 31.1″ N, 104° 07′ 36.0″ E, 142 m)

Sweep Net

The active collection was done opportunistically similar to the method by Chung *et al*. (2020). Flying insects were caught using sweep nets and put in glassine envelopes while crawling insects were sampled using fine-tipped forceps and kept in vials with 75% ethanol.

Light Trapping

Four sets of light traps were installed in light trapping from 20:00 hours until 01:00 hours. A 2 × 2 m white fabric attached to a rope was hung vertically and lit by a 160-watt mercury bulb. The four sets of light traps were employed at three different trails. The traps were placed 300 m from the seashore (1A) at Trail A, at a mangrove area (2A) and shrub area (2B) at Trail 2, the entrance (3A) of Trail 3. Nocturnal insects attracted to the light were collected using a killing jar filled with a tissue soaked with ethyl acetate. The specimens were kept in 75% ethanol prior to drying and pinning.

Pitfall Trapping

In the pitfall trapping method, five sets of pitfall traps were set up randomly at different elevations ranging from 4 meters to 142 meters above sea level. Each set consisted of five traps with different bait types: candy, stone, tofu, whiskey, and salted fish. Cups with a width of 10 cm and depth of 15 cm were buried in the forest floor as traps. Some soapy water was poured into the trap to prevent the insects from escaping. Each pitfall trap was covered with dried leaves to prevent water from leaking into the trap. The five sets of pitfall traps were installed at a shrub area (1B) at Trail 1, at a mangrove area (2C) at Trail 2 and near the waterfall entrance (3A and 3B) at Trail 3.

Species Identification

Specimens were brought back to the taxonomy lab at the Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, for identification using stereo microscopes. Specimens were identified to species level using keys by Romoser and Stoffolano (1998), Borror *et al*. (2005), Buck *et al*. (2009), Choate (2011a), Choate *et al*. (2011), Choate (2011b) and Orr (2014). At the time of publication, identification of doubtful species without comparison with type specimens and museum collections were denoted as 'unknown sp.' in Table 2.

Table 2: Checklist of insects collected in Pulau Tinggi

Order	Family	Subfamily	Species
Coleoptera	Brentidae	Brentinae	Unknown sp. 1
	Lampyridae	Lampyrinae	*Pyrocoelia fumigata* (Gorham, 1880)
	Cantharidae	Silinae	*Laemoglyptus* sp.
	Chrysomelidae	Eumolpinae	*Abirus aeneus* (Wiedemann, 1821) *Abirus elegans* (Baly, 1864) *Basilepta anthracina* (Baly, 1867) *Basilepta lateripunctatum* (Baly, 1867) *Cleorina collaris* (Baly, 1867) *Colaspoides cuprea* (Baly, 1867) *Colaspoides parvula* (Baly, 1867) *Phytorus pinguis* (Baly, 1867) *Platycorynus* sp.
		Alticinae	*Chabria angulicollis* (Clark, 1865)
		Galerucinae	*Hoplosaenidea abdominalis* (Jacoby, 1884)
	Erotylidae	Erotylinae	*Episcapha* sp.
	Carabidae	Cicindelinae	*Cicindela aurulenta* (Fabricius, 1801) *Cylindera viduata* (Fabricius, 1801) *Tricondyla* sp. Unknown sp.
		Lebiinae	*Catascopus phlogops* (Andrewes, 1926)
	Cleridae	Neorthopleurinae	*Allochotes scymnoides* (Westwood, 1875)
	Cerambycidae	Cerambycinae	*Hoplocerambyx spinicornis* (Newman, 1842)

		Lamiinae	*Acalolepta* sp. *Gnoma* sp. *Epepeotes lateralis* (Guerin Meneville, 1831)
	Coccinellidae	Coccinellinae	*Heteroneda billardieri* (Crotch, 1871)
	Elateridae	Elaterinae	*Agonischius* sp.
	Passalidae		*Odontotaenius* sp.
	Scarabaeidae	Rutelinae	Unknown sp. 2
		Scarabaeinae	*Onthophagus* sp. 1 *Onthophagus* sp. 2
		Dynastinae	*Oryctes rhinoceros* (Linnaeus, 1758) *Oryctes* sp. *Xylotrupes gideon* (Linnaeus, 1767)
	Staphylinidae	Aleocharinae	Unknown sp. 3
	Tenebrionidae		Unknown sp. 4 Unknown sp. 5 Unknown sp. 6
Blattodea	Blattidae	Blattinae	*Periplaneta americana* Unknown sp. 7
		Epilamprinae	Unknown sp. 8
	Termitidae	Nasutitermitinae	*Hospitalitermes umbrinus* (Haviland, 1898)
		Macrotermitinae	*Macrotermes carbonarius* (Hagen, 1858)
Diptera	Tephritidae	Trypetinae	*Euphranta maculifemur* (Meijere, 1924)
	Muscidae	Muscinae	*Neomyia* sp.
	Dolichopodidae	Dolichopodinae	*Paraclius* sp.
Hemiptera	Reduviidae	Reduviinae	*Acanthaspis inermis* (Stahl, 1870)
		Harpactorinae	Unknown sp. 9 Unknown sp. 10 *Campsolomus* sp.
		Ectrichodiinae	Unknown sp. 11
		Stenopodainae	*Aulacogenia patalungae* (Miller, 1940)
	Membracidae	Membracinae	Unknown sp. 12
	Pentatomidae	Pentatominae	*Antestiopsis anchora* (Thunberg, 1783)
	Coreidae	Coreinae	*Physomerus grossipes* (Fabricius, 1794)
	Largidae	Physopeltinae	*Physopelta gutta* (Burmeister, 1834)
	Pyrrhocoridae	Pyrrhocorinae	Unknown sp. 13 *Dysdercus decussatus* (Boisduval, 1835)
	Tessaratomidae	Tessaratominae	Unknown sp. 14
Phasmatodea			Unknown sp. 15

Hymenoptera	Formicidae	Formicinae	*Anoplolepis* sp. *Dinomyrmex gigas* (Latreille, 1802) *Camponotus* sp. *Oecophylla smaragdina* (Fabricius, 1775) *Polyrhachis* sp. *Polyrhachis proxima* (Roger, 1863)
		Myrmicinae	*Crematogaster* sp.
		Pseudomyrmecinae	*Tetraponera* sp.
	Vespidae	Eumeninae	*Delta* sp. (Fabricius, 1775)
	Apidae	Apinae	Unknown sp. 16
		Xylocopinae	*Ceratina* sp.
Mantodea	Mantidae	Mantinae	*Rhombodera* sp.
Odonata	Aeshnidae	Aeshninae	*Anax guttatus* (Burmeister, 1839)
	Libellulidae		*Orthetrum testaceum* (Burmeister, 1839) *Orthetrum glaucum* (Brauer, 1865) *Lathrecista asiatica* (Fabricius, 1798) *Neurothemis fluctuans* (Fabricius, 1793) *Neurothemis* sp. *Trithemis festiva* (Rambur, 1842) *Agrionoptera insignis* (Rambur, 1842)
	Argiolestidae	Argiolestinae	Unknown sp. 17
Orthoptera	Acrididae	Gomphocerinae	*Gonista* sp.
	Pyrgomorphidae	Pyrgomorphinae	*Atractomorpha* sp.
	Tettigoniidae	Phaneropterinae	*Ducetia malayana* (Heller, 2017) *Elimaea* sp.
		Conocephalinae	*Euconocephalus varius* (Walker, 1869)
	Gryllidae	Eneopterinae	*Lebinthus* sp.
		Euscyrtinae	*Euscyrtus* sp.
		Landrevinae	*Endodrelanva jimini* (Tan & Kamaruddin, 2016)
		Trigonidiinae	*Amusurgus* sp.

Results and Discussion

The first insect checklist for Pulau Tinggi produced from this study is shown in Table 2. Insects on this island are exceptionally diverse. A total of ten insect orders consisting of 41 families and 90 species were recorded. Most of the insects were collected from light traps.

Beetles (Coleoptera)

Coleoptera was the most dominant order, with 14 families recorded. They are commonly found in an open and disturbed area in Pulau Tinggi. A species of firefly was discovered here, namely *Pyrocoelia fumigata*. *P. fumigata* has also been recorded in Singapore (Jusoh *et al*., 2021)Europe, Africa, Australia, and the Pacific islands. Due to phenotypic similari-ties, species identification using external morphological characters can be unreliable for this group. Consequently, decades of piecemeal taxonomic treatments have resulted in numerous erroneous and contentious classifications. Furthermore, our understanding of the group's evolutionary

history is limited due to the lack of a robust phylogenetic framework that has also impeded efforts to stabi-lize its taxonomy. Here, we constructed molecular phylogenies of Luciola and its allies based on combined mitogenomes and Cytochrome c oxidase subunit 1 (COX1. The presence of firefly species is a good sign for the island as these charismatic insects provide a sense of allurement and wonder for conservation philanthropists. Further studies may evaluate the potential of firefly tourism in Pulau Tinggi. Lewis *et al*. (2021)we provide the first comprehensive review of the geographic scope, magnitude, focal species, and other attributes of the major firefly tourism sites worldwide. Through targeted interviews and surveys, we estimate that in recent years over one million tourists travelled annually to sites located in at least 12 countries for firefly-watching. Rapid proliferation of firefly tourism provides a timely opportunity to examine how such activities may impact local firefly populations, and to highlight the biological factors that make certain species especially vulnerable to tourism-associated threats. We offer science-based best practices for firefly ecotourism that can be tailored to fit local circumstances, including recommendations to: (1 estimated that over one million tourists had travelled annually for firefly watching worldwide in recent years. Several rhinoceros beetles, namely *Xylotrupes Gideon* (brown rhinoceros beetle) and *Oryctes rhinoceros* (coconut palm rhinoceros beetle) were also recorded here. This is not surprising considering *O. rhinoceros* and *X. Gideon* are considered pests in an oil palm plantation which is abundantly available in the mainland of Johor (Pradipta *et al*., 2020; Mat Ripin & Md. Latip, 2021).

True Bugs (Hemiptera)

Hemipterans were the second most abundant insect order discovered here in Pulau Tinggi. A total of seven families were recorded which includes 12 species and morphospecies. Notable species include *Acanthaspis inermis* (Stahl, 1870) and *Aulacogenia patalungae* (Miller, 1940) from the Reduviidae family. These species are well known to be distributed in Peninsular Malaysia, Singapore and Thailand (Tan *et al.,* 2015). Many other species in this order were not identified as species or even genera at the time of publication as no type specimens or museum collections of that particular morphospecies were found for comparison.

Termites and Cockroaches (Blattodea)

Both termites (Termitidae) and cockroaches (Blattidae) were recorded in Pulau Tinggi. One of the termite species recorded was *Macrotermes carbonarius*. While termites are an economical liability due to their ability to cause serious damage to structures in their natural habitat, termites help decompose organic matter, recycle nutrients and improve soil quality (Enagbonma & Babalola, 2019). The discovery of the American cockroach (*Periplaneta americana*) on this island was not shocking, as this species is a common pest in human dwellings (Kamarol Zaman & Omar, 2019).

Ants, Bees and Wasps (Hymenoptera)

Three families of Hymenoptera were recorded, which included ants (Formicidae), bees (Apidae) and wasps (Vespidae). The giant forest ant, known as Dinomyrmex gigas, was recorded in Endau Rompin Johor National Park (Shafiq & Maryati, 2021). This largely nocturnal insect is easily spotted in lowland tropical rainforests due to its large size and colour strikingly different from other ants. On the other hand, a more common ant species, the weaver ant (*Oecophylla smaragdina*) was also recorded here. The weaver ant is widely distributed throughout most of the Oriental region, from India to the Solomon Islands (Greenslade, 1972). On top of that, *O. smaragdina* is known to highly prefer food with higher protein content (Pimid *et al*., 2019). In this survey, tuna was used in the bait traps which attracted the foraging behaviour of the nearby *O. smaragdina* colony.

Dragonfly (Odonata)

Three families from the order Odonata were recorded in Pulau Tinggi. Notable species include *Agrionoptera insignis* and *Neurothemis*

fluctuans which have also been recorded in the forest of Pulau Pangkor (Farizawati *et al*., 2014), Pulau Tioman (Choong *et al*., 2017) and in more than eight localities in Johor mainland (Abdul Aziz *et al*., 2018). It is worth noting that Pulau Tioman is also part of the Seribuat Archipelago. Being a generalist species, *N. fluctuans* is more widespread, with additional records in Pulau Carey, Pulau Langkawi and Pulau Pinang (Farizawati *et al*., 2014). In Pulau Tinggi and Pulau Sibu, *Orthetrum testaceum* and *N. fluctuans* were the most abundant species from the Libellulidae family (Azmi & Haris-Hussain, 2019). *O. testaceum* (Scarlet skimmer) and *N. fluctuans* (Grasshawk dragonfly) have also been reported in three National Parks in Sarawak (Kubah National Park, Lambir Hills National Park and Similajau National Park) (Dow *et al*., 2013). Members from the Libellulidae family are regularly found as the most dominant in tropical and subtropical forests. Additionally, their distribution is common in various habitats due to their ability to breed in open and disturbed habitats (Azmi & Haris-Hussain, 2019).

Other Insect Orders (Diptera, Mantodea, Phasmatodea, Orthoptera)

Pulau Tinggi shares only six similar species with Pulau Sibu, even though they are part of the same Seribuat Achipelago (Azmi & Haris-Hussain, 2019). Overall, Pulau Sibu recorded 35 species of insects belonging to 12 orders and 24 families. The similar species were *Oryctes rhinoceros*, *Camponotus* sp., *Oecophylla smaragdina*, *Orthetrum testaceum*, *Lathrecista asiatica* and *Neurothemis fluctuans*. These are all common species found in human-modified landscapes due to their generalist capabilities (Pimid *et al*., 2019; Mat Ripin & Md. Latip, 2021). It has to be taken into consideration that most insects collected in this study were unidentifiable to the genus or species level. This shows that many studies and fundamental research still need to be done on the fauna of Pulau Tinggi. This is particularly true for insects since approximately one million have been described to date, with an estimated 5 million species left undescribed (Stork *et al*., 2015).

Issues and Implications Affecting Insect Diversity in Pulau Tinggi

Challenges in species-level identification are one of the major reasons why entomological data are not mainly used to justify conservation. The insect group is often considered too large and difficult to use. Any misidentification may compromise conservation research as these may result in overestimating or underestimating insect diversity. Hopefully, unidentified samples from this research will help advance the specific group's taxonomy in the future. This is crucial since to protect a taxon, one must identify and describe it first. It is impossible to protect something that is yet to be described.

Compared to other islands in Peninsular Malaysia, Pulau Tinggi is relatively unexplored. The forested and riverine area of Gunung Semudu is a source of water supply for nearby villages. The pre-existing terrestrial and marine ecosystems show great potential for naturalists and city dwellers to relax and immerse in nature (Akashah *et al*., 2021). As shown in this study, a relatively high insect species richness was recorded. Therefore, we must continue protecting the forest and marine ecosystem in line with the National Policy of Biological Diversity (NPBD 2016-2025) (NRE, 2016).

Conclusion

The diverse forest of Malaysia is a habitat for many insect species. Insects play an important role in maintaining ecosystem balance. Unfortunately, they are the most ignored group due to their small size. This first documentation of insects in Pulau Tinggi is important as it has shown that this relatively unexploited island has many insect species. Conservation action should be taken immediately to preserve the insect diversity in Pulau Tinggi. Any development to be done on the island should consider the health of the ecosystem surrounding it. Consistent monitoring of insect diversity here is crucial to ensure the sustainability of the island's ecosystem. Perhaps, more intensive research on insects in the Seribuat Archipelago can be done

in the future to open up future possibilities in the aspect of biodiversity conservation and tourism.

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