



Research Article

Insect community in riparian zones of Sungai Sepetang, Sungai Rembau and Sungai Chukai of Peninsular Malaysia

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Academic editor: David Bilton

Received: 23 Apr 2019 | Accepted: 02 Sep 2019 | Published: 18 Sep 2019

Citation: Abdullah N-A, Radzi SNF, Asri L-N, Idris NS, Husin S, Sulaiman A, Khamis S, Sulaiman N, Hazmi IR (2019) Insect community in riparian zones of Sungai Sepetang, Sungai Rembau and Sungai Chukai of Peninsular Malaysia. Biodiversity Data Journal 7: e35679. <https://doi.org/10.3897/BDJ.7.e35679>

Abstract

Riparian areas hold vast number of flora and fauna with exceptional contributions to the ecosystem. A study was conducted in Sungai Sepetang, Sungai Rembau and Sungai Chukai to identify the insect community in a riparian zone of Peninsular Malaysia. Sampling was conducted in six consecutive months from December 2017 to May 2018 during both day and night using sweep nets. Twenty sampling stations (S1-S20) had been assembled along the riverbanks with an average distance of 200 m between each station. The 17,530 collected insects were from 11 orders and consisted of Diptera, Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, Neuroptera, Orthoptera, Blattodea, Thysanoptera, Mantodea and Odonata. The three most abundant orders were Diptera (33.84%; 5933 individuals), Coleoptera (28.82%; 5053 individuals) and Hemiptera (25.62%; 4491 individuals). The collected insect community consisted of different guilds such as the

scavenger, predator, herbivore, pollinator and parasitoid. Sungai Sepetang and Sungai Rembau were dominated by mangrove flora, *Sonneratia caseolaris* (Myrtales: Lythraceae), while Sungai Chukai was dominated by *Barringtonia racemosa*. There was a significant difference ($p < 0.05$) in the composition of insects between the three rivers though clustering analysis showed that the insect communities in Sungai Sepetang and Sungai Rembau were 100% similar compared to Sungai Chukai which consisted of a totally different community. There is a significant negative correlation between abundance of insects with salinity and wind speed at Sungai Chukai and Sungai Sepetang.

Keywords

Insect community, Insect-plant interaction, insect guild, plant community, Sungai Sepetang, Sungai Rembau, Sungai Chukai

Introduction

Insects are an important faunal group in terrestrial ecosystems where they play vital roles in stabilising the ecosystem. Based on an estimation of global species richness, there are about 5.5 million species of insects already recorded (Stork 2018). An insect may occupy multiple niches as a pollinator, predator, herbivore, parasite, as well as symbiont. It is important to note that insects live simultaneously creating a stable ecosystem dynamic. In response to any environmental change, each species will behave complementarily to one another, as in one species will increase while the other decreases (Schowalter 2016). This group of organism is also sensitive to changes in environment, thus making it possible to be used as an indicator for conservation planning (Kremen et al. 1993). As a sophisticated group of organisms, insects may adapt to diverse environments including aquatic, semi-aquatic and terrestrial habitat. They also inhabit the most extreme conditions on earth (hot springs, tundra, deserts). Nevertheless, certain individual species may only live in a limited dimension of space (Stewart et al. 2015).

The riparian area, an interface between land and water, becomes the habitat to a wide range of flora and fauna. The riparian vegetation apparently supports both aquatic and terrestrial insects especially in providing space to find food, mating partners, refuge, as well as a resting place (Herrera and Dudley 2003). Some riparian floras recorded as being found in Malaysia are *Sonneratia caseolaris*, *Hibiscus tiliaceus*, *Nypa fruticans*, *Acrotichum aureum*, *Areca cathechu*, *Oncosperma tigillarum* and *Ficus* sp. All of these types of vegetation were commonly found in riparian habitats and are associated with firefly in Peninsular Malaysia (Khoo et al. 2012; Wan Juliana et al. 2012) and Thailand (Prasertkul 2018). However, a different flora community was recorded in the riparian area in Sabah where there were *Rizophora apiculata*, *Clerodendrum inerme*, *Glochidion littorale*, *Bruguiera parviflora* and *Excoecaria indica* (Chey 2004; Dawood and Saikim 2016). Uniquely, one of the riparian vegetation, *Sonneratia caseolaris*, known as Berembang, was

found to be the most preferable display tree by the synchronous firefly, *Pteroptyx tener* in Peninsular Malaysia (Jusoh et al. 2010; Wan Jusoh et al. 2010).

Firefly is a huge commodity for this country as it becomes a centre of attraction in the ecotourism industry. A spectacular flashing pattern is produced through light emitting reaction catalysed by Luciferase in the firefly abdomen (Nur Khairunnisa et al. 2016). The flashing light of firefly is captivating for the tourist visiting the riparian zone as its natural habitat. Multiple studies had been done in monitoring of the firefly population in riverbanks of Malaysia (Sulaiman et al. 2017; Hazmi and Sagaff 2017; Foo and Dawood 2017). However, there is a limited amount of research being undertaken in recording other insect communities coexisting in the same riparian area. It is advantageous to have knowledge of other insect populations living in the same riparian zone as an effort for firefly conservation, as well as the entire riparian ecosystem. We want to emphasise the need to study insect communities besides firefly, thus the data on firefly were not included in this study. Hence, this study is a preliminary assessment done to 1) identify the insect community in the riparian zone, 2) identify riparian vegetation in which the insect community resides and 3) determine changes in the insect community across several environmental parameters (salinity, wind speed, temperature and humidity).

Materials and Method

Samplings were conducted in 20 sampling stations along the riverbanks of Sungai Sepetang, Taping, Perak, (Lat 4.8866–4.9092°N, Lon 100.6311–100.6648°E), Sungai Rembau, Negeri Sembilan (Lat 2.4191–2.4484°N, Lon 102.0654°E) and Sungai Chukai, Kemaman, Terengganu (Lat 4.3076–4.3002°N, Lon 103.3725–103.395°E); see Fig. 1. At each locality, twenty riparian trees along the river with an average distance of 200 m were selected as sampling stations. The sampling stations were assembled at both sides of the riverbanks as shown in Fig. 2. They were labelled as S1- S20 where S1 was located closest to the downstream while S20 was furthest. Samples of insects were collected monthly for six consecutive months (December 2017 to May 2018) during day and night using sweep nets. The net was swept for one minute at each sampling station in the study area. Insect samples were placed in bottles containing ethyl acetate and were then brought to the laboratory for identification up to the lowest taxonomic level possible. Each station was observed from the boat to record the riparian tree and others species composition located within a 5 m radius from the sampling station. Abiotic factors such as temperature (°C), relative humidity (%), salinity (% of NaCl) and wind speed (m/s) were also recorded at each sampling station. Environmental temperature and relative humidity were measured using a thermo hygrometer HI8564 by Hanna Instruments. Salinity was measured using a NaCl meter HI 9835 by Hanna Instruments, while wind speed was measured using an anemometer PCE-007 by PCE instruments.

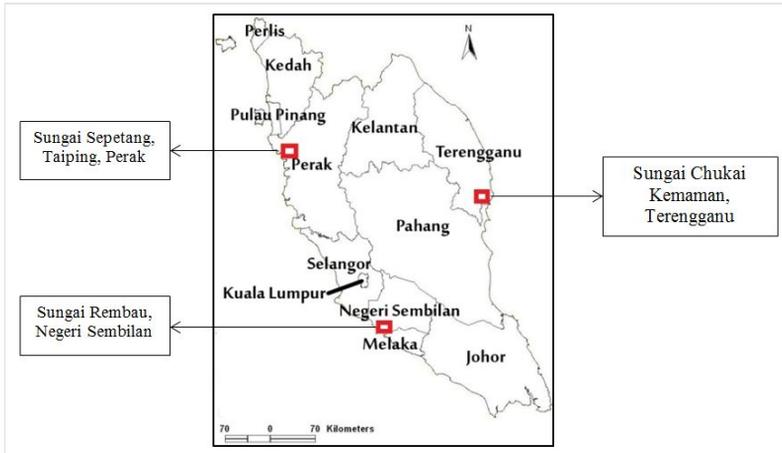


Figure 1. [doi](#)

Location of the study sites in Peninsular Malaysia.

Identification of specimens

The insect specimens were identified to the family level using the key published in Triplehorn and Johnson 2005. All specimens were also compared to the collection of insects in the insect repository of Center of Insect Systematics, The National University of Malaysia. If it were not possible to determine the species, insect specimens were then classified into morphospecies. The specimens collected were then deposited in the Center for Insect Systematics, Universiti Kebangsaan Malaysia.

Data Analysis

Data assessed for normality by the Shapiro–Wilk test ($p < 0.05$) were found to be not normally distributed. Therefore, a non-parametric Kruskal–Wallis test was run to determine whether differences occurred to insect communities in different locations. Spearman's correlation analysis was used to test the correlation between abundance and diversity of insect communities and abiotic factors (salinity, wind speed, temperature and relative humidity). ANOVA is used to test for significant differences of abiotic factors between each study location. The Shapiro–Wilk test was performed using R 3.5.3 while the Kruskal–Wallis test, correlation analysis and ANOVA were performed using Minitab 17. Species diversity was determined by using the Shannon Diversity Index (H'). Cluster analysis, using the Sørensen–Bray Curtis distance measure, was carried out to find the overlapping of the insect community at three different locations. Insect families with a presence of less than five individuals were identified as outliers and excluded from cluster analysis. The PCORD programme (MjM Software, Oregon 2001) was used for both diversity index and cluster analysis.



Figure 2.

Sampling points in all study sites.

a: Sungai Sepetang, Taiping, Perak [doi](#)

b: Sungai Rembau, Linggi, Negeri Sembilan [doi](#)

c: Sungai Chukai, Kemaman, Terengganu [doi](#)

Results and Discussion

Insect and vegetation spatial variability across different locations

A total of 17,530 insect specimens were collected in six consecutive months from three riparian zones in Peninsular Malaysia. The collection consisted of 11 insect orders consisting of Diptera, Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, Neuroptera, Orthoptera, Blattodea, Thysanoptera, Mantodea and Odonata. Three most abundant orders are Diptera (33.84%; 5933 individuals), Coleoptera (28.82%; 5053 individuals) and Hemiptera (25.62%; 4491 individuals) (Fig. 3). There is a significant difference ($H = 11.83$; $df = 2$; $p < 0.05$) between the insect composition in the three locations. Nevertheless,

clustering analysis provided an insight as to how the insect community differed between locations.

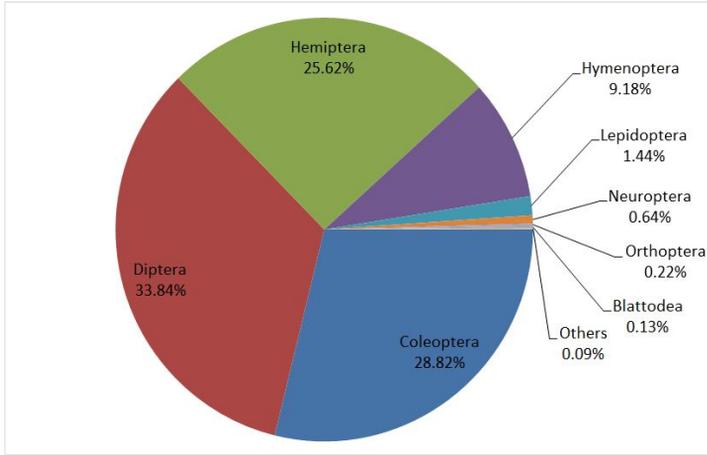


Figure 3. doi

Composition of insect order in riparian zones of Peninsular Malaysia.

The insect community in Sungai Sepetang and Sungai Rembau were 100% similar, while the community in Sungai Chukai was entirely different from the other two sites (Fig. 4). The insects collected in this study consisted of diurnal, nocturnal and crepuscular insects. Through clustering analysis, the insect community collected in this study can be categorised into four groups of different guilds at 75% overlapping value. Group I consisted of diurnal herbivorous insects. Generalist insects, which occupy a wide range of sources, were clustered into Group II. This group consisted of herbivores, predators and scavengers that are active both diurnally and nocturnally. Group III consisted of diurnal predators, herbivores as well as scavengers, while Group IV consisted of diurnal scavenging flies. The community of insects in Sungai Chukai were characterised by the absence of these scavenging flies along with several families of gall-inducing insects and leaf rollers, such as Aprophoridae, Aphididae and Attelabidae with parasitoid groups such as Figitidae and Torymidae. A checklist of insects collected in the riparian zones of Peninsular Malaysia is shown in (Table 1).

Table 1.

List of insect fauna in riparian zones of Sungai Sepetang, Sungai Rembau and Sungai Chukai, Peninsular Malaysia

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
Blattodea	Ectobiidae		Ectobiidae gen. sp.			•
		Anaplectinae	<i>Anaplecta</i> sp.	•		

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
		Blattellinae	<i>Blatella germanica</i>		•	•
			<i>Symploce</i> sp.	•	•	
Coleoptera						
	Anthicidae	Anthicinae	<i>Anthicus</i> sp.1	•	•	
			<i>Anthicus</i> sp.2	•	•	•
		Macratriinae	<i>Macratria</i> sp.		•	
	Anthribidae	Anthribinae	<i>Acorynus</i> sp.	•		
	Attelabidae	Rhynchitinae	<i>Auletobius</i> sp.		•	
	Buprestidae	Agrilinae	<i>Agrillus</i> sp.	•	•	
	Cantharidae	Cantharinae	<i>Cantharis</i> sp.	•	•	•
			<i>Pacificanthia</i> sp.		•	
		Silinae	<i>Silis</i> sp.1	•		
			<i>Silis</i> sp. 2	•		
	Carabidae	Lebiinae	<i>Ophionea indica</i>	•		
	Cerambycidae	Cerambycinae	<i>Ceresium furtivum</i>	•		•
	Chrysomelidae	Eumolpinae	<i>Basilepta multicostata</i>		•	•
			<i>Rhyparida wallacei</i>	•	•	
			<i>Tricliona</i> sp. 1	•	•	•
			<i>Tricliona</i> sp. 2	•		
		Galerucinae	<i>Arthrotus capitata</i>	•	•	
			<i>Dercetisoma</i> sp.	•	•	•
			<i>Mimastra</i> sp.	•	•	
			<i>Monolepta bifasciata</i>	•	•	•
			<i>Monolepta rufipennis</i>	•	•	•
			<i>Monolepta terminata</i>		•	•
			<i>Palpaenidae pallipes</i>	•		•
	Coccinellidae	Chilocorinae	<i>Brumus</i> sp.			•
			<i>Exochamus aethiops</i>	•		
		Epilachninae	<i>Henosepilachna</i> sp.		•	
		Coccinellinae	<i>Heteroneda reticulata</i>	•	•	•
	Curculionidae	Cryptorhynchinae	<i>Rhadinomerus</i> sp.	•		
		Scolytinae	<i>Coccotrypes</i> sp.	•	•	
	Elateridae	Esthesopinae	<i>Priopus</i> sp.			•
		Agrypninae	<i>Pyrophorus</i> sp.		•	
	Lampyridae	Luciolinae	<i>Pteroptyx tener</i>	•	•	•

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
			<i>Pteroptyx malacca</i>	•	•	
			<i>Pteroptyx asymmetria</i>	•		
			<i>Pteroptyx valida</i>			•
	Scarabaeidae	Rutelinae	<i>Adoretus sinicus</i>	•		•
	Scirtidae	Scirtinae	<i>Contacyphon</i> sp.	•	•	•
			<i>Nyholmia collaris</i>	•	•	•
			<i>Ora</i> sp.	•	•	•
			<i>Scirtes flavoguttatus</i>	•	•	•
			<i>Scirtes</i> sp.1	•	•	•
			<i>Scirtes</i> sp.2		•	
			<i>Scirtes</i> sp.3			•
			<i>Scirtes</i> sp.4	•	•	
			<i>Scirtes</i> sp.5	•	•	•
	Staphylinidae	Paederinae	<i>Paederus</i> sp.	•		
			<i>Pinophilus</i> sp.	•		
		Oxytelinae	<i>Carpelimus</i> sp.	•		•
	Tenebrionidae	Lagriinae	Lagriinae gen sp.			•
			<i>Cerogria</i> sp.	•	•	•
Diptera						
	Calliphoridae		Calliphoridae gen. sp.	•	•	
	Cecidomyiidae		Cecidomyiidae gen. sp.		•	
	Culicidae	Anophelinae	<i>Anopheles</i> sp.	•	•	•
		Culicinae	<i>Armigeres</i> sp.	•	•	•
			<i>Culex</i> sp.	•	•	•
	Chloropidae		Chloropidae gen. sp. 1		•	•
			Chloropidae gen. sp. 2			•
		Oscinellinae	<i>Gaurax</i> sp. 1	•	•	•
			<i>Gaurax</i> sp. 2		•	•
	Dolichopodidae	Medeterinae	<i>Acropsilus</i> sp.	•	•	•
			Medeterinae gen. sp. 1	•	•	•
			Medeterinae gen. sp. 2	•	•	
	Drosophilidae	Drosophilinae	<i>Drosophila melanogaster</i>	•	•	•

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
	Hybotidae	Tachydromiinae	<i>Drapetis parillis</i>	•	•	•
			<i>Elaphropeza</i> sp.	•	•	
	Ephydriidae	Discomyzinae	<i>Ceropsilopa</i> sp.	•	•	•
		Gymnomyzinae	<i>Discocerina obscurella</i>	•	•	•
			<i>Allotrichoma alium</i>	•	•	•
	Faniidae	Faniidae gen. sp.	Faniidae gen. sp.		•	
	Lauxaniidae		Lauxaniidae gen. sp.	•	•	
	Muscidae	Atherigoninae	<i>Atherigona</i> sp.	•	•	
		Coenosiinae	<i>Limnophora</i> sp. 1	•	•	•
	Mycetophilidae	Mycetophilinae	<i>Epicypsa</i> sp.	•	•	
	Platystomatidae		Platystomatidae gen. sp.	•	•	
		Platystomatinae	<i>Scholastes</i> sp. 1	•		
			<i>Scholastes</i> sp. 2	•	•	
	Sarcophagidae		Sarcophagidae gen. sp.	•	•	
		Sarcophaginae	<i>Sarcophaga</i> sp.	•	•	
	Sciaridae	Cratyninae	<i>Bradysia</i> sp.	•	•	•
	Sepsidae		Sepsidae gen. sp.	•		
	Stratiomyidae		Stratiomyidae gen. sp.	•	•	
		Pachygastrinae	Pachygastrinae gen. sp.	•	•	
	Tabanidae	Tabaninae	<i>Tabanus</i> sp.	•	•	
	Tephritidae	Tephritinae	Tephritinae gen. sp.		•	
		Trypetinae	<i>Hardyadrama</i> sp.		•	
	Tipulidae		Tipulidae gen. sp. 1	•	•	•
			Tipulidae gen. sp. 2	•	•	•
			Tipulidae gen. sp. 3	•	•	
	Ulidiidae		Ulidiidae gen. sp.	•	•	
Hemiptera						
	Achilidae	Achilinae	Plectoderini gen. sp. 1	•	•	•
			Plectoderini gen. sp. 2	•	•	•
			Plectoderini gen. sp. 3	•		•

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
	Aphalaridae		Aphalaridae gen. sp.	•	•	•
		Spondylaspidinae	Spondylaspidinae gen. sp. 1	•	•	•
			Spondylaspidinae gen. sp. 2	•	•	•
	Aphididae		Aphididae gen. sp	•	•	
	Aphrophoridae		Aphrophoridae gen. sp.	•	•	
	Cicadellidae	Typhlocybinae	Typhlocybinae gen. sp. 1	•	•	•
			Typhlocybinae gen. sp. 2	•		•
	Cixiidae		Cixiidae gen. sp. 1		•	
			Cixiidae gen. sp. 2		•	•
			Cixiidae gen. sp. 3		•	•
			Cixiidae gen. sp. 4			•
			Cixiidae gen. sp. 5			•
	Delphacidae		Delphacidae gen. sp		•	•
	Dictyopharidae	Dictyopharinae	Dictyopharinae gen. sp		•	
	Flatidae	Flatinae	<i>Siphanta</i> sp.		•	•
			<i>Salurnis</i> sp.			•
	Hydrometridae	Hydrometrinae	<i>Hydrometra</i> sp.			•
	Membracidae	Centrotinae	<i>Tricentrus</i> sp. 1	•	•	•
			<i>Tricentrus</i> sp. 2		•	•
			<i>Tricentrus</i> sp. 3	•		
			<i>Gargara</i> sp.			•
	Miridae		Miridae gen. sp.		•	•
		Bryocorinae	<i>Randallopsalus</i> sp. 1		•	•
			<i>Randallopsalus</i> sp. 2	•	•	
			<i>Helopeltis</i> sp.		•	
			<i>Felisacus</i> sp.		•	•
			<i>Michailocoris</i> sp.		•	
		Phylinae	<i>Pilophorus</i> sp.	•	•	•
	Pentatomidae		Pentatomidae gen. sp. 1		•	
		Asopinae	<i>Podisus</i> sp.	•	•	
		Pentatominae	<i>Nezara viridula</i>	•	•	•

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
	Psyllidae	Psyllinae	<i>Cacopsylla</i> sp.	•	•	•
		Spondyliaspidiinae	<i>Boreioglycaspis</i> sp.		•	•
	Pyrrhocoridae	Pyrrhocorinae	<i>Dysdercus decussatus</i>			•
	Reduviidae	Emesinae	Emesinae gen. sp.			•
		Harpactorinae	<i>Isyndus heros</i>			•
			<i>Endochus</i> sp.		•	•
		Salyavatinae	<i>Lisarda inornata</i>			•
	Scutelleridae	Scutellerinae	<i>Calliphara nobilis</i>	•	•	
	Tingidae	Tinginae	<i>Stephanitis</i> sp.		•	
Hymenoptera						
	Andrenidae		Andrenidae gen. sp.	•	•	
	Apidae	Apinae	<i>Apis dorsata</i>		•	
		Xylocopinae	<i>Xylocopa latipes</i>			•
	Bethylidae	Bethylinae	<i>Goniozus</i> sp. 1	•	•	•
			<i>Goniozus</i> sp. 2	•	•	
	Braconidae		Braconidae gen. sp.		•	
		Cheloninae	<i>Phanerotoma</i> sp. 1	•	•	
			<i>Phanerotoma</i> sp. 2	•	•	•
			<i>Phanerotoma</i> sp. 3	•	•	•
			<i>Phanerotoma</i> sp. 4	•	•	•
		Doryctinae	Doryctinae gen. sp.		•	•
		Mesostoinae	Mesostoinae gen. sp.	•	•	•
		Microgastrinae	<i>Cotesia</i> sp.		•	•
	Ceraphronidae		Ceraphronidae gen. sp.	•	•	•
			<i>Ceraphron</i> sp.1	•	•	•
			<i>Ceraphron</i> sp.2	•		
	Chalcididae	Chalcidinae	<i>Brachymeria minuta</i>		•	
	Crabronidae	Pemphredoninae	Psenini gen. sp.	•		
	Eulophidae		Eulophidae gen sp. 1		•	
			Eulophidae gen. sp. 2	•	•	•
		Eulophinae	<i>Euplectrus</i> sp.	•	•	•
	Evaniidae		<i>Evania appendigaster</i>		•	
	Figitidae		Figitidae gen. sp.	•	•	
	Formicidae		Formicidae gen. sp. 1	•		

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
			Formicidae gen. sp. 2	•		
		Dolichoderinae	<i>Dolichoderus</i> sp.	•	•	•
		Formicinae	<i>Anoplolepis</i> sp.			•
			<i>Camponotus festinus</i>			•
			<i>Camponotus</i> sp.	•	•	
			<i>Euprenolepis</i> sp. 1	•	•	•
			<i>Euprenolepis</i> sp. 2	•	•	•
			<i>Formica</i> sp.			•
			<i>Oecophylla smaragdina</i>			•
			<i>Parapatrechina</i> sp.	•		
			<i>Paratrechina</i> sp.	•		
			<i>Plagiolepis</i> sp.	•	•	
			<i>Polyrhachis furcata</i>	•		•
		Myrmicinae	Myrmicinae gen. sp.	•		
			<i>Myrmecina</i> sp.	•	•	
			<i>Creumatogaster</i> sp.		•	•
			<i>Creumatogaster claudiae</i>	•	•	•
			<i>Creumatogaster rogenhoferi</i>			
			<i>Solenopsis</i> sp.	•	•	•
		Pseudomyrmecinae	<i>Tetraponera allaborans</i>	•		•
			<i>Tetraponera extenuata</i>	•	•	
	Halictidae	Nomiinae	<i>Nomia</i> sp.		•	
	Ichneumonidae	Banchinae	Banchinae gen. sp. 1	•	•	•
			Banchinae gen. sp. 2	•		
		Gelinae	<i>Arhytis</i> sp.	•	•	•
			<i>Messatoporus</i> sp.	•	•	•
		Labeninae	Labeninae gen. sp.	•		
		Pimplinae	<i>Xanthopimpla stemmator</i>	•		
		Tryphoninae	Tryphoninae sp.	•		
	Mymaridae		<i>Polynema</i> sp.			•
	Perilampidae	Perilampinae	Perilampinae gen. sp.	•	•	
	Platygastridae	Scelioninae	<i>Macroteleia</i> sp.			•

Order	Family	Sub-family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
	Scelionidae	Telenominae	<i>Telenomus</i> sp.	•	•	•
	Torymidae	Megastiminae	<i>Megastigmus</i> sp.	•	•	
	Vespidae		<i>Donilus orientalis</i>	•		
		Polistinae	<i>Ropalidia malayana</i>	•	•	
			<i>Ropalidia sumatrae</i>	•	•	•
Lepidoptera						
	Blastobasidae		Blastobasidae gen. sp.	•	•	•
	Pyralidae		Pyralidae gen. sp.	•	•	•
Mantodea						
	Mantidae	Mantinae	Mantinae gen. sp. 1	•		•
			Mantinae gen. sp. 2			•
			Mantinae gen. sp. 3	•		
Neuroptera						
	Chrysopidae	Chrysopinae	<i>Chrysoperla</i> sp. 1		•	•
			<i>Chrysoperla</i> sp. 2	•	•	•
			<i>Chrysoperla</i> sp. 3		•	
	Mantispidae	Mantispinae	Mantispinae gen sp. 1	•	•	•
			Mantispinae gen sp. 2		•	
Odonata						
	Chlorocyphidae	Calopteryginae	<i>Libellago</i> sp.		•	
	Coenagrionidae	Pseudostigmatinae	<i>Enallagma</i> sp.	•	•	
Orthoptera						
	Acrididae		<i>Aiolopus thalassinus</i>		•	
	Gryllidae	Gryllinae	Gryllinae gen. sp. 1	•		
			Gryllinae gen. sp. 2	•		
			Gryllinae gen. sp. 3	•	•	•
		Oecanthinae	Oecanthinae gen. sp.		•	
		Trigonidiinae	<i>Anixipha</i> sp.	•	•	•
Thysanoptera						
	Phlaeothripidae		Phlaeothripidae gen. sp. 1	•		•
			Phlaeothripidae gen. sp. 2	•	•	

Family	Species	Sungai Sepetang	Sungai Rembau	Sungai Chukai
Fabacea	<i>Caesalpinia crista</i>	1	5	3
Lamiaceae	<i>Vitex pinnata</i>	0	0	1
Lecythidaceae	<i>Barringtonia racemosa</i>	0	1	18
Lythraceae	<i>Sonneratia caseolaris</i>	19	19	13
Malvaceae	<i>Hibiscus tiliaceus</i>	0	6	8
Melastomataceae	<i>Melastoma malabathricum</i>	0	0	1
Moraceae	<i>Ficus microcarpa</i>	1	0	0
Pteridaceae	<i>Acrostichum aureum</i>	8	3	1
Pteridaceae	<i>Acrostichum speciosum</i>	4	0	0
Rhizophoraceae	<i>Rizophora apiculata</i>	6	1	1
Rhizophoraceae	<i>Bruguiera sexangula</i>	0	0	1

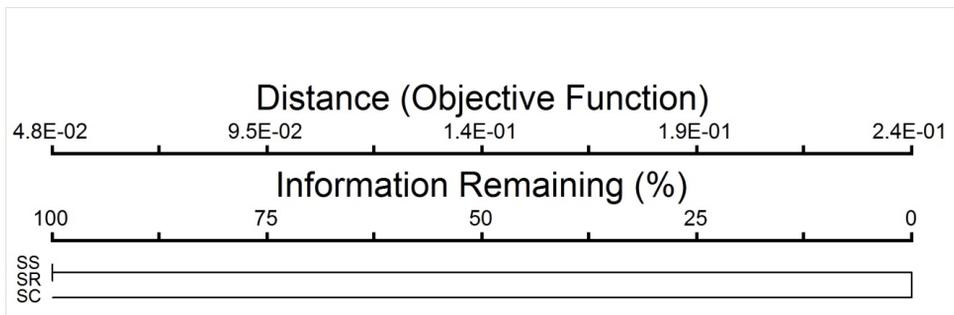


Figure 5. [doi](#)

Dendrogram from one way cluster analysis for vegetation found at Sungai Sepetang-SS, Sungai Rembau- SR and Sungai Chukai-SC.

The diversity of vegetation in Sungai Chukai is 1.998 when compared to Sungai Rembau ($H' = 1.816$) and Sungai Sepetang ($H' = 1.591$). In coherence with this situation, the insect diversity is recorded to be highest in Sungai Chukai ($H' = 3.831$). The diversity of insects in Sungai Rembau is 3.599 and lowest in Sungai Sepetang ($H' = 3.398$). The result supports a positive correlation between plant diversity and insect diversity (Hunter and Price 1992; Morante-Filho et al. 2016). The vegetation structure is a large deciding factor for the insect assemblage presence at each site (Schaffers et al. 2008). Every type of vegetation will have a unique quantity and quality of resources. Variation in quantity and quality of resources between the plant species may be reflected by looking at the plant structure (Randlkofer et al. 2010) and leaf quality (Barber and Marquis 2011), as well as its chemical attributes (Joern and Laws 2013). The chemical content of a plant may act as insect attractants (Yu et al. 2008) or repellants (Maia and Moore 2011). Therefore, we suggest for the study of phytochemical and tree architecture of plant species in the riparian zone of Peninsular Malaysia to be done for a more comprehensive understanding with regards to this matter.

In comparison to the high species richness of insects in Sungai Chukai, the abundance of insects was shown to be lowest out of all three locations. Apparently, *B. racemosa* that dominates the riverbank of Sungai Chukai have insecticidal properties, known as Saponin, which may repel the presence of insects (Izzati Osman et al. 2017). Besides that, the branching structure of *B. racemosa* is simpler when compared to the complex ramification of *S. caseolaris* that dominated both Sungai Sepetang and Sungai Rembau. According to Obermaier et al. 2008), each plant has a different structural architecture which may regulate insects' establishment in an area which is shown in this study. A complex structure of vegetation such as *S. caseolaris* will provide more resources in terms of leaf and litter for the insects to survive on, either as refugees or food source. This is supported by a study done by Li et al. (2012) which highlighted a significant difference in richness and abundance of ground-dwelling arthropods under different species of shrubs. A complex and larger-sized plant may serve as a greater source of feeding area and shelters (Stapp 1997). It is therefore important to take note of the key plant species in the effort of conservation management. This study managed to identify *S. caseolaris* as the key plant species in study sites, as it dominated the riverbanks and supports a wide variety of insects including the invaluable firefly which can be considered as an umbrella species to the area.

Utilisation of resources by insect community

The abundance of insects is very closely related to the quantity of resources available which includes food resources, habitat, mating partners and others. Following cluster analysis, phytophagous insects prevail in the riparian zone. These insects comprised of various orders, such as the Coleoptera, Hemiptera and Lepidoptera, as well as Orthoptera. These orders are known to cause damage to plants in mangrove areas. The true mangrove plants, such as *Sonneratia*, are prone to attack by sap feeders, such as Psyllidae, Membracidae (*Tricentrus* sp.), Flatidae (*Salurnis* sp.) and Cixiidae (Murphy 1990). It was also reported by Murphy (1990) that the Chrysomelid beetle was not a significant foliage grazer of *Sonneratia*. However, our study found substantial numbers of *Monolepta* sp. suggesting possible damage to the tree, caused by this insect family. This is especially true for *S. caseolaris* found in Sungai Chukai that depicts the obvious physical damage to the leaf, affecting its vigour. A further study needs to be undertaken to confirm this circumstance as to whether indeed the Chrysomelid beetle feeds on the leaf of *S. caseolaris* in Sungai Chukai. *Sonneratia* can also be affected by the Pyralidae moth which was also collected in abundance during this study. According to Murphy (1990) and Veenakumari et al. (1997), the Pyralidae moth might destroy both old and young leaves as well as bore into the fruit and flower of *Sonneratia*. This should raise concern about the effort of firefly conservation management. The health of *S. caseolaris* is crucial in maintaining firefly populations in the riparian area since the fireflies are highly associated with this mangrove species (Ayub et al. 2017). Hence, in an effort to maintain the firefly population, it is important to identify all possible factors that may cause damage to its display tree.

Nevertheless, Diptera is recorded to have high abundance at all three sites, especially in Sungai Rembau. Diptera is indeed one of the dominant orders amongst others, as it can be found in abundance within various ecosystems (Daly et al. 1998). In addition to the natural

condition of the sampling area where riverbanks are subjected to water tides making it moist and humid for development of Dipteran larva, the high abundance of Diptera may also be caused by human activity. During the period of the study, there were multiple land uses next to the riverbank. In fact, human activities such as horticulture and livestock farming were common; oil palm plantation, cattle and a chicken farm were found close to the sampling station in Sungai Rembau. Apparently, the minimum buffer zone of 20 m on both sides of the riverbank were exploited for such activities. The minimum buffer zone of 20 m was proposed in 2016 to overcome water pollution problems (Lokman 2016). However, the regulations were infringed as oil palm plantation areas and a livestock farm were erected up to the water edge. Livestock farming such as a cattle farm and a chicken farm in Sungai Rembau may contribute to the high number of scavenging fly individuals which have been attracted to the animal waste. Besides that, the high abundance of Diptera were fixed upon the natural habitats for Chironomidae, Ephydriidae and Hybotidae which were all commonly found in shores and marsh areas (Grootaert and Shamshev 2012, Triplehorn and Johnson 2005). There is a strong presence of *Acropsilus* sp., *Drosophila* sp. as well as *Hardyadrama* sp. on the other hand, due to the rotten *S. caseolaris* fruits that become their source of food.

The predator and parasitoid insect groups were also recorded in the riparian zone of our study. This insect group assists in stabilising the insect community in the riparian zone by keeping the population of herbivorous insects at an optimum level. Parasitoid wasps, such as Bethyliidae, *Goniozus* sp., Braconidae; *Cotesia* sp., *Phanerotoma* sp., Ceraphronidae; *Ceraphron* sp., Eulophidae; *Euplectrus* sp. and Ichneumonidae; *Arhytis* sp. are known to have a beneficial use in agriculture, such as oil palm. *Cotesia* sp., for instance, is an important natural enemy to bagworm (Psychidae; *Metisa plana*), an important pest to the oil palm plantations of Peninsular Malaysia (Halim et al. 2018). As the location of study sites in Sungai Rembau and Sungai Sepetang are located next to oil palm plantations, these beneficial insects may move across the boundaries and colonise the adjacent plantations and then exert their beneficial effects upon the pests in the agricultural plantations. The predator group, such as Reduviidae, also acts the same way as the parasitoid wasps in maintaining a balanced ecosystem. It is also important to note that Reduviidae might take firefly species as a prey. A species of the assassin bug, *Zelus luridus* has been observed to feed on firefly species, *Photinus carolinus* (Lewis et al. 2012). This ecological relationship should be highlighted in the process of firefly conservation.

It is interesting to document a family of soldier beetle, Cantharidae in this study as *Cantharis* sp. and *Pacificanthia* sp. seem to resemble the morphological character and colouration of the firefly, *Pteroptyx tener*. There is a potential mimicry of the soldier beetle to the firefly species, based on this encountered record. The soldier beetle of different species was also found to mimic other species of firefly, *Pteroptyx effulgens* in Papua New Guinea (Ohba and Meyer-Rochow 2012). Cantharidae is also involved in the mimicry complexes with fireflies as recorded by Lloyd 1973. A possible explanation to this occurrence is of Batesian mimicry with the basic principle that the mimics must be less common compared to the model (Ohba and Meyer-Rochow 2012). As the firefly is dominant in the riparian zone of our study area, it easily outnumbered the other co-existing

insects including the soldier beetle. However, as the Cantharids are predatory, the more likely situation would be of Mertensian mimicry. Mertensian mimicry occurs when the deadly species mimics the harmless species as a lesson-teaching model (Emsley 1966). It is hypothesised through this finding that Cantharid beetle mimics the firefly in order for it to look innocuous to other prey insects residing on the same vegetation in the daytime. There is also an additional advantage in the lesson-teaching model as a higher predator to the cantharid beetle could learn to avoid them from the unpalatable firefly. The likelihood of mimicry between the soldier beetle and the congregating firefly is a new finding that needs to be explored through further ethological and ecological study.

Environmental influences over insect community

The average value of wind speed (m/s), salinity (% of NaCl), temperature (°C), relative humidity (RH%) are shown in Table 3. The Spearman’s correlation values are summarised in Table 4.

Table 3.
Summary of ANOVA results for Sungai Sepetang, Sungai Rembau and Sungai Chukai. Mean values of each environmental parameter are given.

	F	df	p	Sg. Sepetang	Sg. Rembau	Sg. Chukai
Wind speed (m/s)	17.39	2	P < 0.05	0.39 ± 0.30	0.56 ± 0.24	0.38 ± 0.16
Salinity (NaCl %)	35.77	2	P < 0.05	2.94 ± 1.50	1.04 ± 1.02	0.21 ± 0.04
Temperature (°C)	144.55	2	P < 0.05	27.68 ± 1.88	29.89 ± 0.73	26.17 ± 0.41
Relative Humidity (%)	69.87	2	P < 0.05	75.74 ± 13.14	70.58 ± 3.81	79.82 ± 1.19
Light intensity (lux)	34.75	2	P < 0.05	64.33 ± 6.60	34.59 ± 15.72	35.58 ± 7.66

Table 4.
Spearman’s correlation value between abundance, richness and diversity of insect to selected abiotic factors. Numbers in bold indicate correlation significant at 0.05 level.

Abiotic factors	Sungai Sepetang		Sungai Rembau		Sungai Chukai	
	Abundance (Number of individuals)	Diversity (H')	Abundance (Number of individuals)	Diversity (H')	Abundance (Number of individuals)	Diversity (H')
Temperature	0.112	-0.671	0.112	-0.447	-0.359	-0.616
Humidity	-0.447	0.447	0.112	-0.783	0.667	-0.103
Wind Speed	-0.447	-0.266	-0.200	-0.100	0.359	-0.410
Salinity	-0.089	-0.454	0.298	0.146	-0.465	-0.422

The salinity at each sampling point in all locations decreased with an increase in distance from the outfall. There is a significant negative correlation between abundance of insects in Sungai Chukai with salinity. The diversity of insects in Sungai Sepetang also negatively correlated with the salinity of the river. The total abundance of insects in Sungai Sepetang,

Sungai Rembau and Sungai Chukai comparatively showed an increasing trend as salinity decreased from S1 to S20 (Fig. 6). The salinity of the water is especially critical for the growth of aquatic and semi-aquatic insects including the firefly population. Results from this study showed a relative pattern at which the abundance of insects is increasing with the decreasing value of salinity. As most of the larval growth occurred in water, salinity of the river needs to be within a tolerated range. An increase in salinity of the river is an issue faced by several insects, such as the mayflies and non-biting midges, *Chironomus* sp. (Hassell et al. 2006). The salinity increase caused the growth rate of the insect to be slower and reduced the number of emerging adult (Castillo et al. 2018; Kefford et al. 2006). Salinity may also affect the soil where fireflies laid their eggs and hatch as larvae though the direct effect of salinity on the firefly has never been studied. Nonetheless, Khoo et al. 2012 reported that the sudden increase in salinity in Sungai Selangor does not affect the firefly population residing on *S. caseolaris* at the riverbanks. In spite of that, it is still essential to monitor the river water salinity in our study area in order to oversee the health of these rivers as a water supply to the whole riparian ecosystem.

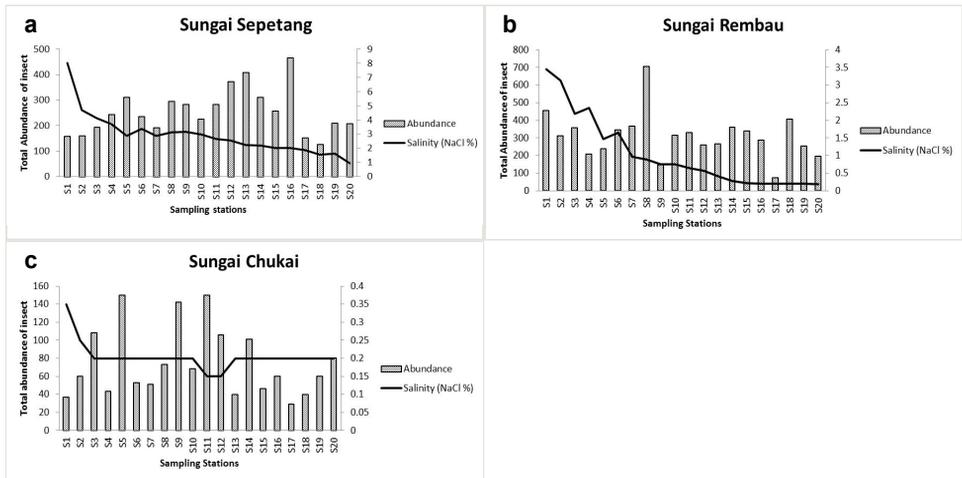


Figure 6.

The abundance of insects in each study site against river salinity across S1-S20.

- a: Sungai Sepetang, Taiping, Perak [doi](#)
- b: Sungai Rembau, Linggi, Negeri Sembilan [doi](#)
- c: Sungai Chukai, Kemaman, Terenggan [doi](#)

There is also a significant negative correlation between abundance and diversity of insects in Sungai Sepetang with wind speed. Although temperature and humidity show no significant correlation to the insect community, a hotter and less humid condition can cause death to the insects. Riparian vegetation acts as a key role in determining riparian microclimatic conditions (Briers and Gee 2004). Temperature, humidity, light intensity and wind speed are very much affected by vegetation type and lushness. The canopy of the tree provide shades from light which will also then regulate river water temperature (Garner et al. 2017). This vegetation also acts as a windbreak and reduces the force of air towards

the soil (Okin 2008), as well as to the small-bodied insect species living in the area (Pasek 1988). While the movement of air helps in flying insect movement, a high speed of wind may affect small-sized insects in directing them to less optimal directions as they are easily carried away by the fast moving air (Gatehouse 1997). Based on the size of insect individuals ranging from 0.1 mm to 5.0 mm collected from this study, it is very much expected for them to be affected by wind speed. For that reason, it is important for us to highlight the importance of conserving the riparian zones as a whole, though it proved to be difficult when facing many land use changes. This can be significantly seen in Sungai Rembau and Sungai Sepetang where the riparian areas are rapidly converted into agricultural, industrial and residential areas. The study of land use changes in our study sites is currently ongoing to further verify this issue. For the time being, this study sees the need for tighter regulations in maintaining riparian zones that will help to conserve the insect communities living within it.

Conclusion

We have successfully made a list of insect taxa in riparian zones of Peninsular Malaysia. The list may serve as a solid baseline to compare with future data. In the light of firefly conservation as a unique inhabitant of the study areas, it is also important to understand how this insect community interacts with the firefly population. This question needs to be answered with future studies for the whole ecosystem knowledge to be expanded. Nonetheless, at the present moment, we insist upon and anticipate a more dynamic effort in the conservation of the riparian area. A conservation effort, especially for the vegetation community, is much needed as it holds the key to the maintenance of the riparian ecosystem as a whole, including the insect community that dwells within it.

Acknowledgements

We are grateful to Mohammad Zabidi Yaacob, Engku Mohd Faris, Mohd Faizul Mohamad, Mohammad Syukor Ishak, Shamsul Anuar Mohd Yusof, Mohd Syazwan Hussin, Nadia Shohaimay and staff of Mini Zoo Kemaman and TNB Research Sdn. Bhd. for assistance given in completing the project. This research is funded through research grant ST-2017-013 awarded by TNB Research Sdn. Bhd.

Author contributions

This study was designed, directed and coordinated by Izfa Riza Hazmi, Azman Sulaiman and Norela Sulaiman. Nur-Athirah Abdullah, Lailatul-Nadhirah Asri and Siti Nur Fatehah Radzi planned and conducted the sampling. Nur-Athirah Abdullah performed all data analysis and wrote the manuscript. Nor Shafikah Idris generated the map used in the manuscript. Siti Nur Fatehah Radzi and Shamsul Khamis assisted in identification of the

plants and wrote the results for vegetation composition. The manuscript was commented by all authors.

References

- Ayub S, Rosli NAM, Maimon Abdullah NS (2017) Assessment of firefly abundance at a new ecotourism site of the Bernam River. Peninsular Malaysia. Serangga 22 (2): 33-46.
- Barber NA, Marquis RJ (2011) Leaf quality, predators, and stochastic processes in the assembly of a diverse herbivore community. Ecology 92 (3): 699-708. <https://doi.org/10.1890/10-0125.1>
- Briers RA, Gee JH (2004) Riparian forestry management and adult stream insects. Hydrology and Earth System Sciences 8 (3): 545-549. <https://doi.org/10.5194/hess-8-545-2004>
- Castillo AM, Sharpe DM, Ghalambor CK, De León LF (2018) Exploring the effects of salinization on trophic diversity in freshwater ecosystems: a quantitative review. Hydrobiologia 807: 1. <https://doi.org/10.1007/s10750-017-3403-0>
- Chey VK (2004) Fireflies of Sungai Klias and their display trees. Sepilok Bulletin 1: 67-69.
- Daly HV, Doyen JT, Purcel AH (1998) Introduction to Insect Biology and Diversity. Oxford University Press, New York.
- Dawood MM, Saikim FH (2016) Studies on congregating fireflies (Coleoptera; Lampyridae; *Pteroptyx* sp.) in Sabat: a review. Journal of Tropical Biology and Conservation 13: 13-25.
- Emsley MG (1966) The Mimetic Significance of *Erythrolamprus aesculapii ocellatus* Peters from Tobago. Evolution 20 (4). <https://doi.org/10.2307/2406599>
- Foo K, Dawood MM (2017) Diversity of *Pteroptyx* fireflies (Coleoptera: Lampyridae) and their display trees at Klias Peninsula, Sabah, Malaysia. Journal of Tropical Biology & Conservation 14: 95-103.
- Garner G, Malcolm I, Sadler J, Hannah D (2017) The role of riparian vegetation density, channel orientation and water velocity in determining river temperature dynamics. Journal of Hydrology 553: 471-485. <https://doi.org/10.1016/j.jhydrol.2017.03.024>
- Gatehouse AG (1997) Behavior and ecological genetics of wind-borne migration by insects. Annual Review of Entomology 42 (1): 475-502. <https://doi.org/10.1146/annurev.ento.42.1.475>
- Grootaert P, Shamshev I (2012) The fast-running flies (Diptera, Hybotidae, Tachydromiinae) of Singapore and adjacent regions. European Journal of Taxonomy 5: 1-162. <https://doi.org/10.5852/ejt.2012.5>
- Halim M, Muhaimin AMD, Syarifah Zulaikha SA, Nor Atikah AR, Masri MMM, Yaakop S (2018) Evaluation of infestation in parasitoids on *Metisa plana* Walker (Lepidoptera: Psychidae) in three oil palm plantations in Peninsular Malaysia. Serangga 22 (2): 135-14.
- Hassell KL, Kefford BJ, Nugegoda D (2006) Sub-lethal and chronic salinity tolerances of three freshwater insects: *Cloeon* sp. and *Centroptilum* sp. (Ephemeroptera: Baetidae) and *Chironomus* sp. (Diptera: Chironomidae). The Journal of Experimental Biology 209 (Pt 20): 4024-32. <https://doi.org/10.1242/jeb.02457>
- Hazmi IR, Sagaff SAS (2017) Fireflies population and the aquaculture industry (Coleoptera: Lampyridae) of the Sungai Sepetang, Kampung Dew. Serangga 22 (2): 217-237.

- Herrera AM, Dudley TL (2003) Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (*Arundo donax*) invasion. *Biological Invasions* 5 (3): 167-177. <https://doi.org/10.1023/A:1026190115521>
- Hunter MD, Price PW (1992) Playing chutes and ladders heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. *Ecology* 73 (3): 724-732. <https://doi.org/10.2307/1940152>
- Izzati Osman N, Jaafar Sidik N, Awal A (2017) Ethnobotanical profiles and phytochemical constituents of *Barringtonia racemosa* L. for potential scrutiny of bioactive compounds through plant biotechnology. *Journal of Natural Remedies* 17 (2): 57-68. <https://doi.org/10.18311/jnr/2017/15945>
- Joern A, Laws A (2013) Ecological mechanisms underlying arthropod species diversity in grasslands. *Annual Review of Entomology* 58 (1): 19-36. <https://doi.org/10.1146/annurev-ento-120811-153540>
- Jusoh WFAW, Hashim NR, Ibrahim Z (2010) Firefly distribution and abundance on mangrove vegetation assemblages in Sepetang estuary, Peninsular Malaysia. *Wetlands Ecology and Management* 18 (3): 367-373. <https://doi.org/10.1007/s11273-009-9172-4>
- Kefford B, Nugegoda D, Zalizniak L, Fields E, Hassell K (2006) The salinity tolerance of freshwater macroinvertebrate eggs and hatchlings in comparison to their older life-stages: a diversity of responses. *Aquatic Ecology* 41 (2): 335-348. <https://doi.org/10.1007/s10452-006-9066-y>
- Khoo V, Nada B, Kirton LG, Phon C- (2012) Monitoring the population of firefly *Pteroptyx tener* along the Selangor River, Malaysia for conservation and sustainable ecotourism. *Lampyrid* 2: 162-173.
- Kremen C, Colwell RK, Erwin TL, Murphy DD, Noss RF, Sanjayan MA (1993) Terrestrial arthropod assemblages: Their use in conservation planning. *Conservation Biology* 7: 796-808. <https://doi.org/10.1046/j.1523-1739.1993.740796.x>
- Lewis SM, Faust L, De Cock R (2012) The dark side of the light show: Predators of fireflies in the great smoky mountains. *Psyche*
- Li F, Liu J, Liu C, Liu Q, Niu R (2012) Shrubs and species identity effects on the distribution and diversity of ground-dwelling arthropods in a Gobi desert. *Journal of Insect Conservation* 17 (2): 319-331. <https://doi.org/10.1007/s10841-012-9512-1>
- Lloyd JE (1973) Firefly parasites and predators. *The Coleopterists Bulletin* 2: 91-10.
- Lokman T (2016) Rivers may get bigger buffer zones. *New Straits Times* 24 URL: <https://www.nst.com.my/news/2016/05/147492/rivers-may-get-bigger-buffer-zones>
- Maia MF, Moore SJ (2011) Plant-based insect repellents: a review of their efficacy, development and testing. *Malaria Journal* 10 (1): 467-476. <https://doi.org/10.1186/1475-2875-10-S1-S11>
- Morante-Filho JC, Arroyo-Rodríguez V, Lohbeck M, Tschamtké T, Faria D (2016) Tropical forest loss and its multitrophic effects on insect herbivory. *Ecology* 97 (12): 3315-3325. <https://doi.org/10.1002/ecy.1592>
- Murphy D (1990) The natural history of insect herbivory on mangrove trees in and near Singapore. *Raffles Bulletin of Zoology* 38: 119-203.
- Nur Khairunnisa S, Nurul Wahida O, Norela S (2016) The localization of luciferase in *Pteroptyx tener* (Coleoptera: Lampyridae) light organ. *Serangga* 21 (1): 55-62.
- Obermaier E, Heisswolf A, Poethke HJ, Randlkolfer B, Meiners T (2008) Plant architecture and vegetation structure: Two ways for insect herbivores to escape parasitism. *European Journal of Entomology* 105 (2): 233-240. <https://doi.org/10.14411/eje.2008.033>

- Ohba N, Meyer-Rochow VB (2012) Insect species co-existing with the Papua New Guinea firefly *Pteroptyx effulgens* share aspects of appearance and behaviour. *Lampyrid* 2: 2012-127.
- Okin G (2008) A new model of wind erosion in the presence of vegetation. *Journal of Geophysical Research* 113 <https://doi.org/10.1029/2007jf000758>
- Pasek JE (1988) Influence of wind and windbreaks on local dispersal of insects. *Agriculture, Ecosystems & Environment* 22: 539-554. <https://doi.org/10.1016/b978-0-444-43019-9.50045-6>
- Prasertkul T (2018) Characteristics of *Pteroptyx* firefly congregations in human dominated habitat. *Journal of Insect Behavior* 31 (4): 436-457. <https://doi.org/10.1007/s10905-018-9687-8>
- Randlkofer B, Obermaier E, Hilker M, Meiners T (2010) Vegetation complexity—The influence of plant species diversity and plant structures on plant chemical complexity and arthropods. *Basic and Applied Ecology* 11 (5): 383-395. <https://doi.org/10.1016/j.baae.2010.03.003>
- Schaffers A, Raemakers I, Sýkora K, ter Braak CF (2008) Arthropod assemblages are best predicted by by plant species composition. *Ecology* 89 (3): 782-794. <https://doi.org/10.1890/07-0361.1>
- Schowalter TD (2016) *Insect ecology: An ecosystem approach*. 4th Edition. Academic Press, 753 pp.
- Stapp P (1997) Microhabitat use and community structure of darkling beetles (Coleoptera: Tenebrionidae) in shortgrass prairie: Effects of season shrub and soil type. *American Midland Naturalist* 137 (2). <https://doi.org/10.2307/2426849>
- Stewart AJA, Bantock TM, Beckmann BC, Botham MS, Hubble D, Roy DB (2015) The role of ecological interactions in determining species ranges and range changes. *Biological Journal of the Linnean Society* 115 (3): 647-663. <https://doi.org/10.1111/bij.12543>
- Stork N (2018) How many species of insects and other terrestrial arthropods are there on Earth? *Annual Review of Entomology* 63 (1): 31-45. <https://doi.org/10.1146/annurev-ento-020117-043348>
- Sulaiman N, Loo MC, Abdullah M (2017) Association between the firefly population and some biotic and abiotic factors along the Sungai Sepetang river banks at Kampung Dew. *Malayan Nature Journal* 69 (3).
- Triplehorn CA, Johnson N (2005) *Borror and DeLong's introduction to the study of Insects*. Brooks/Cole
- Veenakumari K, Mohanraj P, Bandyopadhyay (1997) Insect herbivores and their natural enemies in the mangals of the Andaman and Nicobar Islands. *Journal of Natural History* 31: 1105-1126. <https://doi.org/10.1023/a:1018424302583>
- Veenakumari K, Prashanth M (2009) A note on the entomofauna of mangrove associates in the Andaman Islands (Indian Ocean: India). *Journal of Natural History* 43: 807-823. <https://doi.org/10.1080/00222930802610550>
- Wan Juliana WA, Shahril MH, Nik Abdul Rahman NA, Nurhanim MN, Abdullah M, Sulaiman N (2012) Vegetation profile of the firefly habitat along the riparian zones of Sungai Selangor at Kampung Kuantan. Kuala Selangor. *Malaysian Applied Biology* 41 (1): 55-58.
- Wan Jusoh WFA, Hashim NR, Ibrahim ZZ (2010) Distribution and abundance of *Pteroptyx* fireflies in Rembau-Linggi Estuary, Peninsular Malaysia. *Environment Asia* 3: 56-60. <https://doi.org/10.14456/EA.2010.40>

- Yu H, Zhang Y, Wu K, Gao XW, Guo YY (2008) Field-testing of synthetic herbivore-induced plant volatiles as attractants for beneficial insects. *Environmental Entomology* 37 (6): 1410-1415. <https://doi.org/10.1603/0046-225X-37.6.1410>