THE SEASONAL MONSOON VARIATIONS AND THE CLIMATIC EFFECTS ON THE ABUNDANCE OF FIREFLIES (COLEOPTERA: LAMPYRIDAE) AT KLIAS RIVER, BEAUFORT, SABAH, EAST MALAYSIA

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ABSTRACT

Understanding the pattern of firefly abundance in an area is useful in minimizing visitors' impact on firefly populations and enhancing the quality of the firefly experience for all visitors. Implementing strategic protection guidelines greatly helps conserve species population and the chances of bioluminescent courtship behaviour in the firefly population. Klias River in Sabah, Malaysia has been listed among the top sites featuring congregating fireflies in Southeast Asia. In this study, the abundance of congregating fireflies was studied from 2006 to 2007, during the transitional monsoon (phase 1) and the northeast monsoon (phase 2) at Klias River. A total of 155 display tree stations were sampled by using a two-minute sweep netting technique, resulting in a total of 5,368 individual fireflies collected from both phases. Five species of fireflies from two genera i.e *Pteroptyx* and *Luciola* were recorded namely *Pteroptyx tener* (91.30%), *Pteroptyx malaccae* (8.53%), *Pteroptyx valida*, *Luciola* sp. 1 and *Luciola* sp. 2. The number of males was higher than the females in a ratio of ±7:3 on each sampling occasion. Mann-Whitney analysis [$U_{(n=12)}$=34, P<0.05] indicated that the abundance of male fireflies during phase 2 was significantly higher, while the abundance of females was not significantly different in both phases [$U_{(n=12)}$=24, P>0.05]. The abundance of the firefly community was significantly different from the two sampling phases [$U_{(n1=6,\ n2=6)}$=34, P<0.05)], with the northeast monsoon season (phase 2) presenting a higher abundance of congregating fireflies. Spearman's correlation analysis showed that the mean of climate parameters i.e relative humidity (±82.52%; P=0.779; r= -0.091), rainfall (±3.84 mm; P=0.210; r=0.390), and temperature (±27.34°C; P=0.557; r=0.189) were significantly but weakly correlated with the mean of firefly abundance from the whole sampling sessions. Twelve display tree species were recorded, namely, *Excoecaria indica*, *Heriteria littoralis*, *Cerbera odolam*, *Hibiscus tiliaceus*, *Ficus benjamina*, *Sonneratia alba*, *Rhizophora apiculata*, *Nypa fruticans*, *Hernandia nymphacifolia*, *Barringtonia racemosa*, *Acrostichum* sp. and *Acacia magnum. Heriteria*

littoralis (n=83) was the highest in frequency used as the display trees, but the firefly abundance was higher on *Excoecaria indica* (n=32) with 42% of abundance tendencies. The survival of congregating firefly species population is interconnected with the existence of certain species of mangrove trees. Identifying these display trees is important to support the protection of the natural mangrove ecosystem and the conservation of mangrove swamp tree species.

Keywords: Congregating fireflies, Klias, Sabah, *Pteroptyx*, *Luciola*, display trees, mangrove, eco-tourism, monsoon

ABSTRAK

Memahami corak kelimpahan kelip-kelip di sesuatu kawasan adalah penting untuk meminimumkan kesan pelancong terhadap populasi kelip-kelip dan meningkatkan kualiti pengalaman melihat kelip-kelip untuk semua pelancong. Pelaksanaan garis panduan perlindungan strategik mampu membantu melindungi populasi spesies dan meningkatkan peluang mengawan secara biopendarcahaya pada populasi kelip-kelip ini. Sungai Klias di Sabah, Malaysia telah disenarai antara lokasi terbaik untuk melihat kerlipan kelip-kelip berkumpul di Asia Tengara. Dalam kajian ini, kelimpahan kelip-kelip berkumpul telah dikaji pada tahun 2006 hingga 2007, iaitu semasa fasa monsun peralihan (fasa 1) dan monsun timur laut (fasa 2) di Sungai Klias. Sebanyak 155 stesen pokok peragaan telah diambil sampel dengan menggunakan teknik sapuan selama dua minit, menghasilkan sejumlah 5,368 individu kelip-kelip telah dikumpulkan dari kedua-dua fasa. Lima spesies kelip-kelip dari dua genus iaitu *Pteroptyx* dan *Luciola* berjaya direkodkan iaitu *Pteroptyx tener* (91.30%), *Pteroptyx malaccae* (8.53%), *Pteroptyx valida*, *Luciola* sp. 1 dan *Luciola* sp. 2. Bilangan kelip-kelip jantan sentiasa lebih tinggi daripada betina dalam nisbah ±7:3 dalam setiap sesi persampelan. Analisis Mann-Whitney [$U_{(n=12)}$=34, P<0.05] menunjukkan bahawa kelimpahan kelip-kelip jantan semasa fasa 2 adalah lebih tinggi, sementara kelimpahan kelip-kelip betina adalah sama di seluruh fasa [$U_{(n=12)}$=24, P>0.05]. Kelimpahan komuniti kelip-kelip adalah berbeza di kedua-dua musim persampelan [$U_{(n1=6,\ n2=6)}$=34, P<0.05)], dengan musim monsun timur laut menunjukkan kelimpahan kelip-kelip berkumpul yang lebih tinggi. Analisis korelasi Spearman menunjukkan bahawa min parameter iklim iaitu kelembapan relatif (±82.52%; P=0.779; r=-0.091), limpahan hujan (±3.84 mm; P=0.210; r=0.390) dan suhu (±27.34°C; P=0.557; r=0.189) berkorelasi lemah secara signifikan dengan min kelimpahan kelip-kelip dari keseluruhan sesi pensampelan. Dua belas spesies pokok peragaan telah disenaraikan iaitu *Excoecaria indica*, *Heriteria littoralis*, *Cerbera odolam*, *Hibiscus tiliaceus*, *Ficus benjamina*, *Sonneratia alba*, *Rhizophora apiculata*, *Nypa fruticans*, *Hernandia nymphacifolia*, *Barringtonia racemosa*, *Acrostichum* sp. dan *Acacia magnum*. *Heriteria littoralis* (n=83) adalah yang tertinggi dari segi kekerapan yang digunakan sebagai pokok peragaan, tetapi kelimpahan kelip-kelip lebih tinggi pada *Excoecaria indica* (n=32) dengan 42% kecenderungan. Kemandirian spesies kelip-kelip berkelip secara berkumpul adalah saling berhubung-kait dengan kewujudan spesies pokok tertentu. Mengenal pasti spesies pokok-pokok peragaan ini penting untuk menyokong perlindungan ekosistem bakau semulajadi dan pemuliharaan spesies pokok paya bakau.

Kata kunci: Kelip-kelip berkumpul, Klias, Sabah, *Pteroptyx*, *Luciola*, pokok peragaan, paya bakau, ekopelancongan, monsun

INTRODUCTION

Fireflies are beetles (order Coleoptera) under the family of Lampyridae with nearly 2,200 species that have been described worldwide (Lewis et al. 2021). Fireflies are holometabolous insects that undergo complete metamorphosis, dramatically altering their morphology and ecological niche during the four stages of their life cycle (Lloyd 2004; Menayah 2000), and usually semelparous, i.e., they spend most of their lives as larvae (Riley et al. 2021). The adult stage only lasts up to a couple of weeks, during which they reproduce and disperse (Faust 2017; Riley et al. 2021). All firefly larvae produce bioluminescence; the adults of many, though not all, species also generate light as a courtship signal (Lewis et al. 2021; Lewis & Cratsley 2008). The light of the firefly is the outcome of a very efficient reaction, called a chemiluminescent reaction (Rabha et al. 2021). It is known that oxygen is the biochemical trigger that excites the substrate luciferin and produces the photo-emitter molecule oxyluciferin in the presence of ATP and Mg^{+2}, the reaction being catalyzed by the enzyme luciferase (Gajendra & Kannan 2002; Rabha et al. 2021). Bioluminescence emissions from a few species of fireflies have been studied at different temperatures, and based on a study of variations in the flash duration had been concluded that temperature tolerance is a major role in the selection of the habitat for the firefly (Rabha et al. 2021).

Eighteen species of *Pteroptyx* firefly are currently recognized, and this group of species is the best-known icon to flash emission light in a group, and they are found distributed in Southeast Asia, in the Western Pacific, from East India to Thailand, Malaysia, and Indonesia to the Philippines and Papua New Guinea, with one species found in Hong Kong (Ballantyne et al. 2019; Ballantyne et al. 2011; Jaikla et al. 2020b; Jusoh et al. 2018). The habitat of this species reported along the riverbank with moister soil and a tree for flash display, inhabit wetlands, estuaries, and brackish water ecosystems (Ballantyne & McLean 1970; Mahadimenakbar et al. 2004; Maryati et al. 2004). *Pteroptyx* spp. is considered semiaquatic fireflies because they live on muddy riverbanks during their larval stage and can survive underwater for a short period (Jaikla et al. 2020a). Adult male *Petroptyx* spp. show lekking behaviour in which males congregate and emit synchronous courtship flashes while perched in mainly mangrove trees; females are attracted to this display and fly to display trees to find mates. Different *Pteroptyx* species can coexist on the same display tree, however, male flash patterns are unique to each species (Buck & Buck 1968; Jaikla et al. 2020b; Lloyd et al.1989).

The General Effect of Season and Climates on Insect Population

Karthik et al. (2022), stated that the most dynamic and global environmental issue to date is climate change already evident i.e increased temperatures and CO_2 higher levels of solar radiation, the greenhouse effect, rapid changes in rainfall patterns, and changes in rainfall patterns over the seasons, can dramatically alter the biochemistry of plants as for defence responses. These effects can have important implications for insects in general and also firefly in fertility, feeding rates, survival, population size, dispersal, shelter, copulation, and oviposition sites (Karthik et al. 2022; Wattanachaiyingcharoen et al. 2016). The relationships between plants and insects are thus changed with significant consequences for food security and natural ecosystems (Karthik et al. 2022).

Wattanachaiyingcharoen et al. (2016), revealed that firefly species preferences in ambient conditions; adult fireflies were observed all year round but varied in seasons. Some species had a seasonal specificity or a wider range of adult seasonal appearance, which may only appear only in winter, summer through to rainy, or only in the rainy season. The study also indicated the influences of climate on firefly diversity as the majority of firefly species occurred

in late summer through to the rainy seasons which resulted from the availability of vegetation in their preferred habitats. The congregating flashing fireflies phenomenon is one of the best nocturnal nature tourism products and had its economic benefits for the local community (Elora 2022; Nadirah et al. 2021). The seasonality of firefly tourism depends both on geographic location and on species ecology; for example in Southeast Asia where adults of various *Pteroptyx* spp. actively display and attract visitors year-round (Lewis et al. 2021).

Klias communities of Bisaya named fireflies *dolepot*, or *dadipot*, and the indigenous community of Kadazan-Dusun in Sabah generally named it *ninipot*. The Malay community called it as *kunang-kunang* or *kelip-kelip*. To enhance the quality of the firefly experience for all visitors it is useful to know the appropriate season and environment of the firefly present abundance in the relevant habitat locations. This facilitates tour operators as well as related agencies in the management of tourist attendance schedules and implementing protection guidelines for surrounding habitat management. The aims of this study were; (1) to investigate the abundances of fireflies between two monsoon seasons, (2) to study the correlation of firefly abundances with the climatic parameters i.e. rainfall, relative humidity, and temperature; and (3) to identify display trees preferences of synchronous congregating fireflies.

MATERIALS AND METHODS

Location Overview

Klias peninsular faces the South China Sea (SCS) and is influenced by its seasonality effect. According to Wang et al. (2007), SCS is the largest semienclosed marginal sea in the Northwest Pacific with an area of about 3.5×106 km^2 and is under the influence of the East Asia Monsoon. The onset of the mild southwesterly summer winds over the SCS usually occurs suddenly around mid-May in its southern and central part and soon expands to the entire SCS in June. In contrast, the strong northeast winter monsoon is established progressively over the SCS, first appearing over its northern part in September, reaching its central in October and covering the entire SCS in November. The winter monsoon gradually diminishes in April and most of the oceanic characteristics of the SCS are influenced by the monsoon.

The vegetation of Klias consists of wetland plants, swamps, and mangroves along the coast, as well as mixed plants in the upper part of the river (Eric 2003; Payne & Vaz 1998). Fireflies-based-watching tourism activity is very synonymous with this area (Rozziana et al. 2020), and the congregation of flashing fireflies has attracted in annually more than 100,400 tourists (Lewis et al. 2021). There are four nature tourism tour operators actively running the firefly watching activity in Klias River during the study i.e. Klias Wetland Adventures, Borneo Proboscis River Lodge, Borneo Authentic Adventure and Klias River Cruise. This river is also easy to navigate by boat and rarely experiences low tide (Payne & Vaz 1998).

Sampling Design

The sampling occasions were conducted in two phases, which were during the transitional monsoon from September to November of 2006 (phase 1), and during the northeast monsoon from January to March of 2007 (phase 2). Each phase took a term of three months, with twice sampling occasions in each of the months. Each sampling occasion consisted of two nights, each was started at opposite starting points, i.e. the first night was started from upstream to downstream, while the second night started from the opposite direction. Thus, every phase had an equal 12 nights of sampling. However, for the analysis, abundance data from those two-night samplings were combined and the mean was calculated, making the sampling data for analysis in every phase six samplings on each occasion. Thus, overall there were 12 sampling occasions.

The study recorded climate parameter data i.e. rainfall, temperature and humidity, from the nearest Klias Baru Meteorological station. The data parameters were the average mean of general environmental data recorded by this station every day.

Based on the preliminary observations, fireflies were seen to start flashing at 18:30, slowly developing the synchronous flashing at around 19:00 and intensifying until 20:00. The flashing slowly faded in the next hours and ended at around 5:00 in the morning. During the study, the presence of fireflies flashing was seen in most sections along the Klias riverbank. Their flashing can be seen on certain species of display trees, shrubs, and wild plants along the river. Sampling started at 19:00 to 21:00 by motorized boat along the river. The sampling distance is fixed at 4,090 meters along the Klias River (Figure 1a). The sampling method is designed based on how the firefly pattern forms congregating flashes. The grouping of flashes lights gradually increases with time to reach the peak abundance time. While sampling using a boat took time from the beginning to the end sampling. By selection from different directions, all tree stations can be ensured sampled at the beginning and also at the end to reduce data biased, and to get an accurate average min of abundance on the selected day.

A total of 155 good display trees of congregating synchronous fireflies along the sampling site were recorded. A ‘good display tree’ refers to a tree that is easy to access (less than five meters) from a boat sweeper and displays an abundance of congregating firefly flashes. These good display trees were subsequently designated as the sampling stations. However, this station position varies in each sampling occasion, as it depends on the preferences of congregating fireflies in the display tree (Figure 1b). Fireflies were sampled using a two-minute sweep technique at each sampling station using an aerial net, marked using Geographical Positioning System (GPS) coordinate, and mapped using ArcGIS9.3 software in the GIS laboratory (Figure 1b). Collected samples of fireflies and leaves of display trees were transferred to plastic bags by station and brought up to the laboratory for further arrangement.

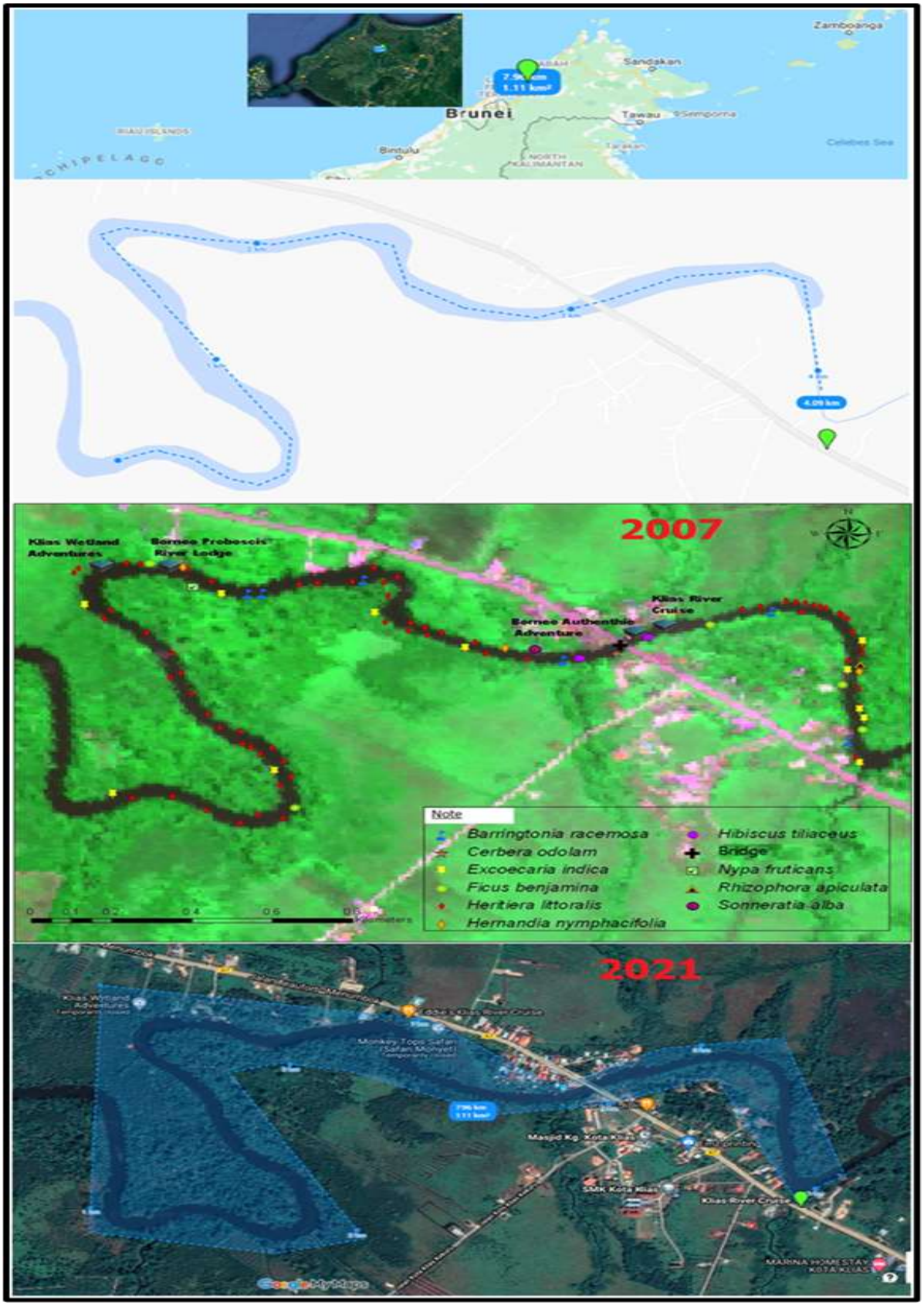


Figure 1a. Klias River with the study site views using the Global Positioning System (GPS) in 2007, and updated views from Google MyMaps in 2021

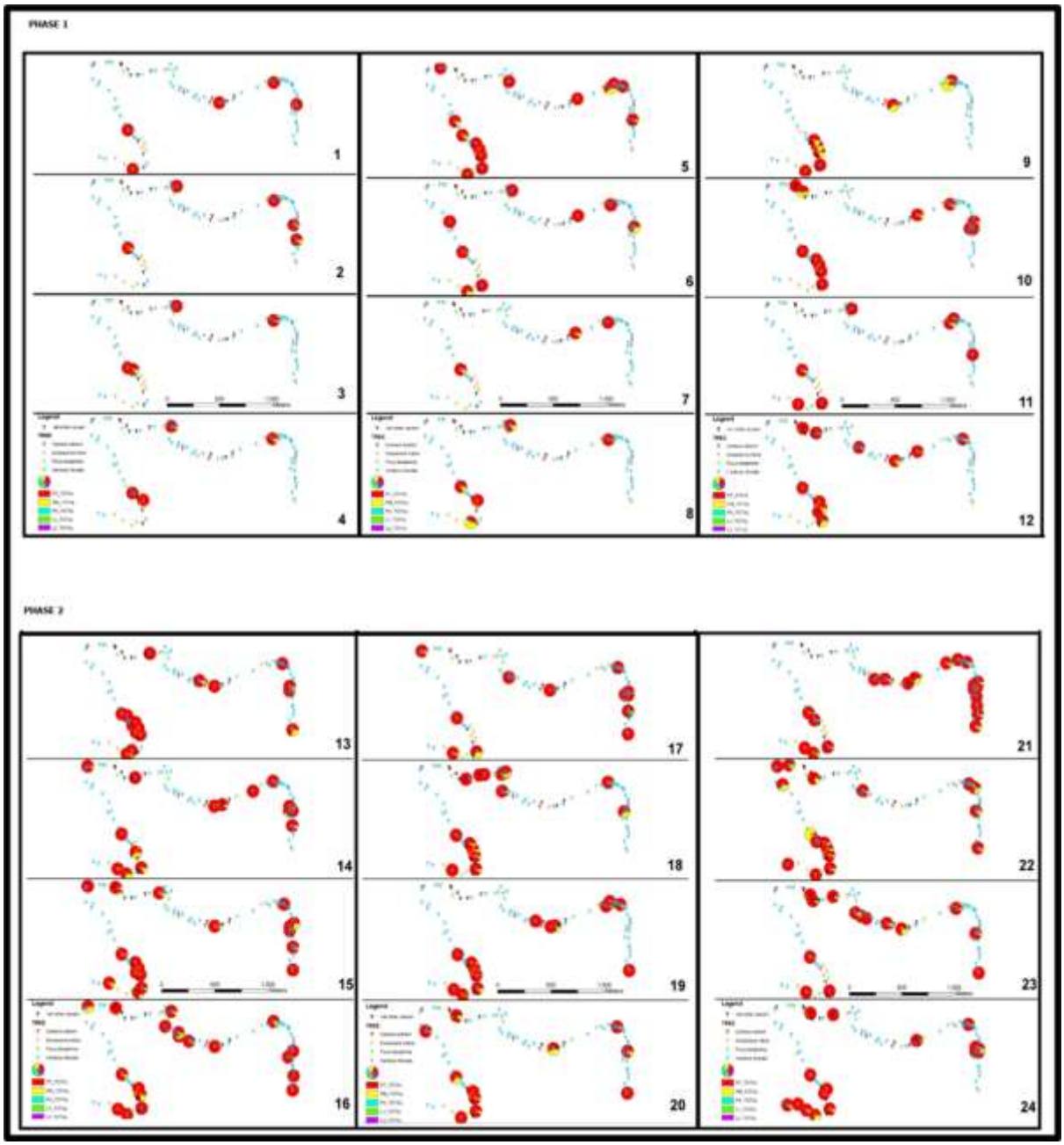


Figure 1b. Sampling stations marked by Geographical Positioning System (GPS) coordinate and mapped by ArcGIS 9.3 software in the GIS laboratory

Sample Arrangement and Species Identification

Fireflies specimens were placed in a refrigerator with a constant temperature of ±15ºC, for 12 to 24 hours until all the fireflies die. This is to ensure the firefly specimen is in a stable moisture condition and reduce the fragility of the specimen. Samples were then transferred to specimen bottles, tagged by station, and preserved with 95% of ethanol. Leaves of the display tree were also preserved with 95% of ethanol and proceeded for species identification by a specialist. Collected firefly specimens were arranged to be deposited at the BORNEENSIS reference collections of the Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah. Male firefly specimens collected were examined on external morphology depending on the taxonomic characters following Ballantyne (2001), Ballantyne and Lambkin (2000), and Ballantyne and McLean (1970). Significant morphological features used to genera were; males

of three *Pterotyx* spp. examined had a bipartite light organ (LO) present in ventrite 7 (V7), LO entirely in V6, metafemoral comb (MFC), and median posterior projection (MPP) is present. Added noticeable characteristics observed were; the ocular is larger and slightly concave at the vertex and the posterior apex of the elytra is deflexed. Abbreviation morphology to examine the genus of *Luciola* in conjunction with the structural characteristic described by Sanga et al (1996) i.e., a male of *Luciola* spp. had two segments of LO entirely through the end of the ventral abdominal segments, the pronotum extends forward over the head making the head largely or entirely concealed from above, and the wings (elytra) are soft, flexible and rather flat. Female *Pterotyx* specimens were examined to have a pale light organ in V6 only, and V7 to V8 is yellow (Ballantyne 2001; Ballantyne & McLean 1970). Differentiation to species is based on the external morphology with male specimens, i.e. coloured as for male specimens and were caught together during sampling (Ballantyne 2001; Ballantyne & McLean 1970). Added noticeable characteristics observed were; (1) the ocular is smaller than the male and convex at the vertex, (2) the posterior elytra apex does not deflexed, (3) MFC and MPP do not present.

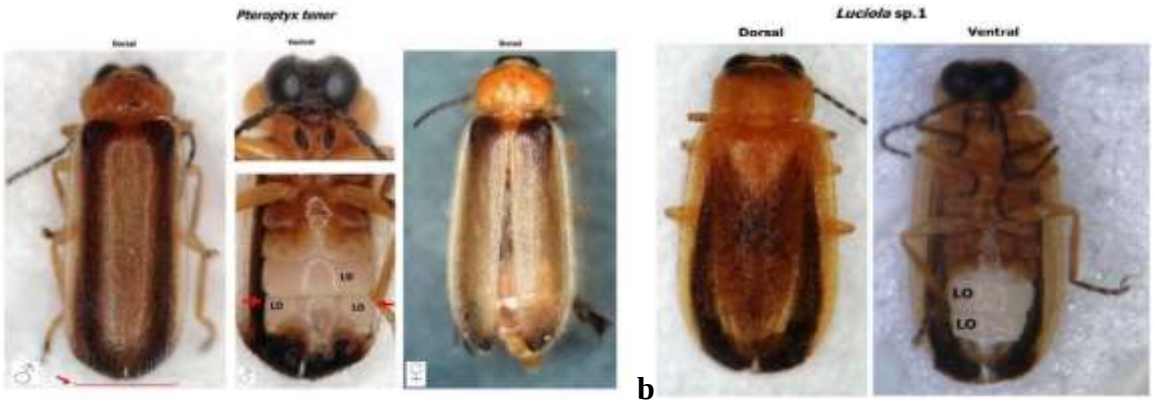
Statistical Data Analysis

A non-parametric U-test analysis was used since the collected data were ordinal and not fit for normal distribution. Mann-Whitney analysis was used to indicate; (1) the difference in abundance of male to female fireflies between two phases of monsoon; (2) the difference in firefly community abundance between two phases of monsoon. Spearman's correlation analysis was used to investigate the significant correlation of climate parameters i.e. relative humidity, rainfall and temperature with the mean of firefly abundance from the whole session sampling.

RESULTS

Species Occurrence, Abundances and Climate Effect

Two genera of fireflies were found in this study; *Pteroptyx* and *Luciola* (Figure 2). From these genera, five species were identified i.e. *Pteroptyx tener* (±91.30%; n=4,901), *Pteroptyx malaccae* (±8.53%; n=458), *Pteroptyx valida* (n=2), *Luciola* sp. 1 (n=6), and *Luciola* sp. 2 (n=1). Species for the *Luciola* specimens were unknown and only dorsal and ventral view features of external morphology were recorded (Figure 2 b, d).



a **b**

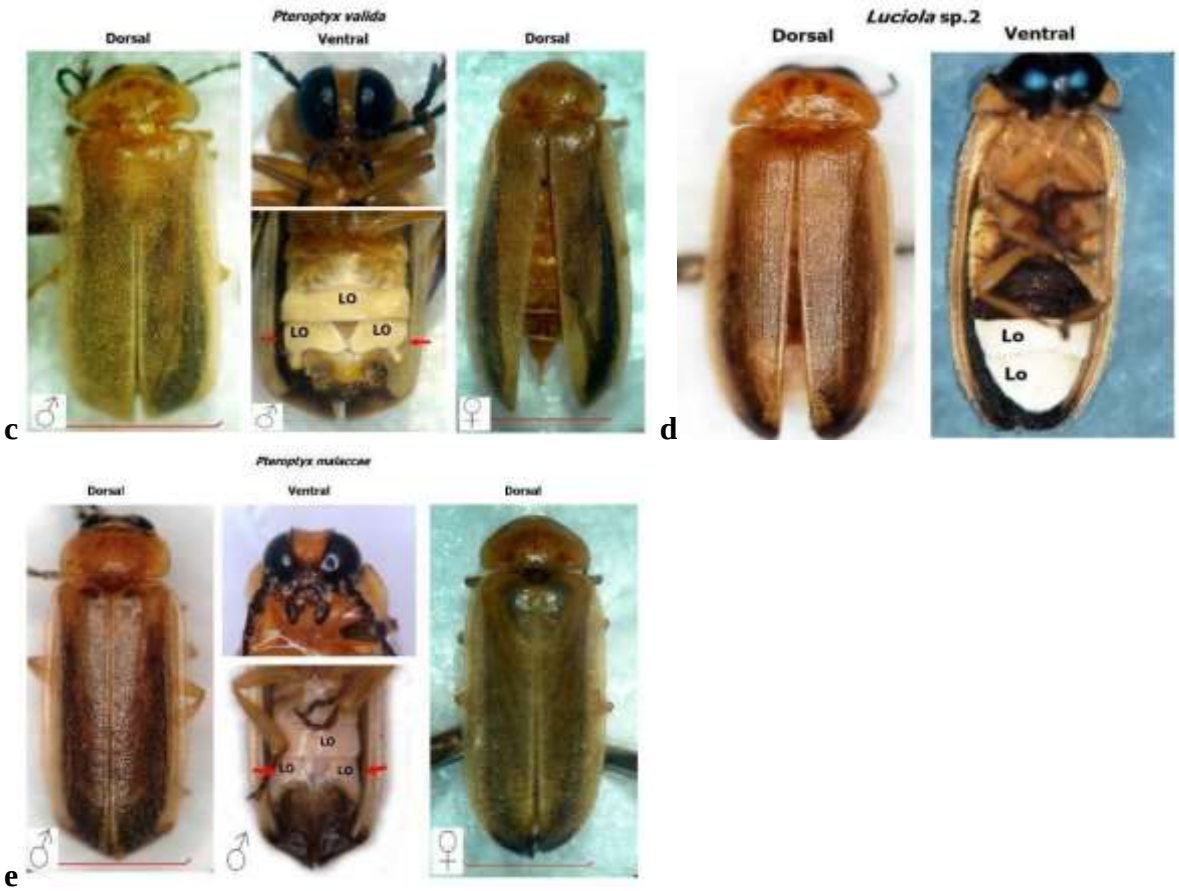


Figure 2. Firefly species at Klias River of Sabah Malaysia; a, *Pteroptyx tener* Olivier, 1907; b, *Luciola* sp.1; c, *Pteroptyx valida* Olivier. Riley, 1996; d, *Luciola* sp.2; e, *Pteroptyx malaccae* Gorham, 1903

A total of 5,368 firefly individuals of both sexes were collected from both sampling phases, with phase 1 (n=1,320) being much lower in terms of individual numbers than phase 2 (n=4,048). Mann-Whitney-U test analysis showed that there was a difference between the average abundance of fireflies in the two phases [$U_{(n1=6,\ n2=6)}$=34, P<0.05)] (Figure 3). This indicated that the abundance of fireflies during the northeast monsoon season (phase 2) was significantly higher than in the transitional monsoon season (phase 1). Firefly-watching activities with strict implementation of firefly-watching etiquette suggested can be implemented during the northeast monsoon season (phase 2), which is expected to take place from November to March each year.

Session	1	2	3	4	5	6
Phase 1	13.50	21.10	20.86	12.55	19.58	15.94
Phase 2	22.32	22.41	22.59	27.63	19.62	26.00

Independent-Samples Mann-Whitney U Test Summary

Total N	12
Mann-Whitney U	34.000
Wilcoxon W	55.000
Test Statistic	34.000
Standard Error	6.245
Standardized Test Statistic	2.562
Asymptotic Sig.(2-sided test)	.010
Exact Sig.(2-sided test)	.009

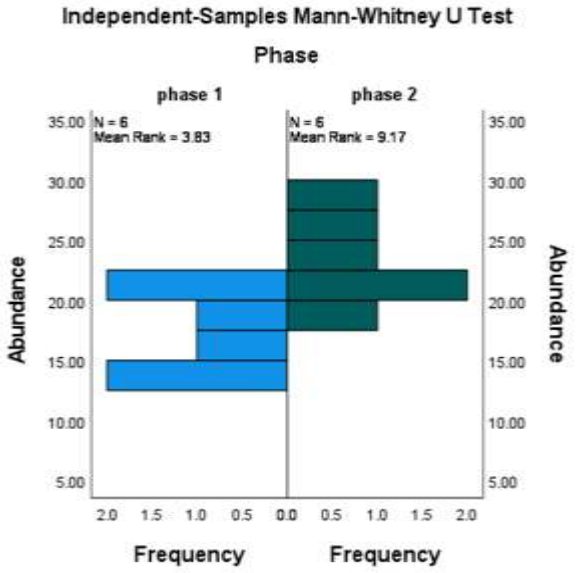


Figure 3. Comparison of mean firefly abundance between transitional monsoon (phase 1) in September to March 2006 and northeast monsoon (phase 2) in February to March 2007 at Klias River of Sabah, Malaysia

A total of 928 males and 392 females were in phase 1, while 2,825 males and 1,223 females were sampled in phase 2. Total calculations make male individuals always higher than female individuals in a 7:3 ratio in each sampling season. Mann-Whitney-U test analysis showed that there is a different abundance of male fireflies across phases [$U_{(n=12)}$=34, P<0.05]. While, the same analysis indicated no difference in the average abundance of female fireflies in both phases [$U_{(n=12)c}$=24, P>0.05.].

There were differences in the average climate parameters data collected in each sampling occasion. Spearman's correlation analysis showed a significantly weak correlation between the firefly abundances and the climate parameters during the study. The mean relative humidity from the whole sampling was ±81.5% [n=12, P=0.779, r=-0.091], relative temperature was ±27.34^{o}C [n=12, P=0.557, r=0.189], and rainfall was ±3.84 mm [n=12, P=0.210, r=0.390]. Accurate interpretation and thorough analysis are merely available if the variable data of temperature and abundance of fireflies are variates.

Display Tree

Twelve species of display trees from the mangrove swamp forest of Klias River were identified in this study, with a total of 155 stations. *Heriteria littoralis* was the dominant species located in 83 stations (n) with a 22% of abundance tendency (t). This is followed by *Excoecaria indica* (n=32, *t*=42%). *Ficus benjamina* (n=15, *t*=5%), *Barringtonia racemose* (n=6, *t*=1%), *Hernandia nymphacifolia* (n=5, *t*=1%), *Cerbera odolam* (n=4, *t*=13%), *Hibiscus tiliaceus* (n=4, *t*=12%), *Nypa fruticans* (n=4, *t*=1%), *Sonneratia alba* (n=1, *t*= 2%), and *Rhizophora apiculata* (n=1, *t*=1%)(Table 1). These findings found that *Excoecaria indica* species was the preferable display tree for firefly selection to flash in the congregation group.

Table 1. Firefly display trees or plants at Klias River and the abundance of firefly species

No	Display Tree	Number Of Stations	(%) Abundance	*P.tener*	*P. malaccae*	*P. valida*	*Luciola* sp. 1	*Luciola* sp. 2
1.	*Excoecaria indica*	32	42	2058	201	0	4	1
2.	*Heriteria littoralis*	83	22	1078	101	2	2	0
3.	*Cerbera odolam*	4	13	637	59	0	0	0
4.	*Hibiscus tiliaceus*	4	12	588	55	0	0	0
5.	*Ficus benjamina*	15	5	245	23	0	0	0
6.	*Sonneratia alba*	1	2	98	9	0	0	0
7.	*Rhizophora apiculata*	1	1	50	0	0	0	0
8.	*Nypa fruticans*	4	1	49	5	0	0	0
9.	*Hernandia nymphacifolia*	5	1	49	0	0	0	0
10.	*Barringtonia racemosa*	6	1	49	5	0	0	0
11.	*Acrostichum sp.*	-	-	-	-	-	-	-
12.	*Acacia magnum*	-	-	-	-	-	-	-
	Total	**155**	**100**	**4901**	**458**	**2**	**6**	**1**

DISCUSSION

Conservation and Sustainability of Firefly Eco-tourism at Klias River

Klias River has been listed as one of the top and major sites that features congregating fireflies in the genus *Pteroptyx* in Southeast Asia and the world geographical region chart (Lewis et al. 2021; page 7, Table 2, figure 2b). Other listed locations in Southeast Asia are Kg Kuantan in Selangor, Sungai Cherating in Pahang, Sungai Sepetang in Perak, together with Amphawa (Mae Klong River), Bang Bai Mai (Tapi River), and Phrom Yothi Military Camp in Thailand, and also Purushwadi in India. It has been estimated that each year over 1 million tourist travel to destinations in at least 12 countries to enjoy this unique wildlife experience. This phenomenon embarks firefly tourism activities that can bring economic benefits in the form of employment and revenue across multiple levels, including local communities, states, nations, and regions. Firefly offers an unforgettable experience, viewed as romantic, evokes happy childhood memories, reporting transformative experiences of delight and even spiritual awe (Faust 2017) and that such firefly experiences may have long-lasting and widespread beneficial impacts, including not only improved mental health and well-being but also promoting more positive attitudes towards biodiversity conservation (Lewis et al. 2021). Fireflies have the potential to serve as flagship species for establishing key biodiversity areas (Lewis et al. 2020). In particular, *Pteroptyx* sp. can be used as an umbrella species to protect mangrove ecosystems through firefly-watching activity, which can be done all year round (Mahadimenakbar & Fiffy 2016). Sabah, Malaysia is blessed to have this highly charismatic and iconic insect on land. However, there is some concern and urgency onward to sustain the ecotourism activity and the stability of the congregating firefly present in Klias River. A global perspective on firefly extinction threats had been summarized that habitat loss, artificial light, and pesticide use were identified as the three most serious threats to the firefly population. The remaining threats with lower average scores were water pollution, climate change, invasive species, tourism, and overharvest (Lewis et al. 2020; Table 2). Klias is located with the surrounding gazette Forrest by local authorities with about six gazetted forests i.e. *Hutan Simpan Binsuluk, Hutan Simpan Padas Damit, Hutan Simpan Menumbuk, Hutan Simpan Klias, Hutan Simpan Nabahan and Hutan Simpan Sipitang* (Payne & Vaz 1998). This might provide suitable habitat and produce clean water flow for establishing sanctuaries to protect the key fireflies population.

Suggesting tourists to come to see fireflies during higher abundance on northeast monsoon is merely appropriate in moving towards sustainable firefly ecotourism in Klias, and enhancing the visitor experience. A high concentration of visitors and unpractical services management in an area could negatively impact the firefly bioluminescent courtship behaviour, habitat, and population. Fireflies world experts have identified practical solutions and offer guidelines intended to support this practitioner (Cheng et al. 2021; Lewis et al. 2021). Implementing these guidelines is highly recommended by Lewis et al. (2021) in public and private tour operators and these guidelines are summarized as; (1) conserve the habitats required for all life stages to thrive, (2) involve local communities as key stakeholders, (3) provide training programs for guides and interpretive materials for visitors and, (4) implementing firefly-watching etiquette to help minimize visitors' impact on firefly population. Highlighted firefly-watching guidelines during activities include the followings (1) no artificial lights such as flashlights, lanterns, phones, or light-up shoes, (b) no flash photography, (c) stay on the marked trail at all times, (d) speak quietly, (e) do not capture fireflies or disturb their display sites, (f) no smoking or heavy perfume, (g) cover up for mosquito protection (if you need insect repellent, apply it before arriving at the site).

Pteroptyx spp., Display Trees and Mangrove Swamp Forest

A higher concentration in the abundance of *Pteroptyx* spp. especially *P. tener* in Klias River is an issue that needs to be concern by the community, state and federal authorities to either develop or refine guidelines and policies on tourism development in an area and our region. Other studies at the same and nearby locations indicated that *P. tener* is present and congregating in Klias Peninsular (Chey 2004; Foo & Mahadimenakbar 2017). Study reports also showed that *P. tener* is dominant species in several localities i.e. Rembau-Linggi Estuary (Jusoh et al. 2010a), Sepetang Estuary (Jusoh et al. 2010b), Kampung Kuantan (Ballantyne & Menayah 2000), Sungai Johor (Norela et al. 2015), Garama River (71.6 %) and Weston River (52.4 %) located also in Klias Peninsular of Sabah (Foo et al. 2017). *Pteroptyx* Olivier fireflies is a major tourist attraction because they congregate nightly in large numbers on particular mangrove tree along tidal rivers (Jusoh et al. 2010a; Lewis et al. 2020; Wong & Yeap 2012). *Pteroptyx* spp. in Malaysia and Thailand only breed in pristine mangrove forests which makes this species vulnerable to tourism-associated threats (Lewis et al. 2021; Reed et al. 2020).

Pteroptyx spp. is a common firefly species that is reportedly moving in groups and flashing synchronously in Southeast Asia (Moiseff & Copeland 2000; Ohba & Wong 2004). *P. malaccae* is a species often found flashing along or together with *P. tener* species and has a combination of strong synchronous flashing when in groups (Buck & Buck 1968; Copeland & Moiseff 1995). *P. valida* is usually less reported to flash in groups or synchronously (Ballantyne 2001). *P. cribellatta* and *P. malaccae* species flashed on the same display tree in Bangkok (Ballantyne & Mclean 1970; Buck & Buck 1966), with the presence of *P.valida* (Lloyd et al. 1989; Nallakumar 2003). Only the male individuals of the *P.malaccae* species flash in rhythmic synchronously, while *P.valida* does not act in such flashing (Lloyd et al. 1989). *P. malaccae* is more likely to be grouped with *P. tener* than *P. valida* (Ballantyne & Mclean 1970).

A field study by Foo & Mahadimenakbar (2017) at the Klias Peninsular of Sabah revealed that the composition of the sex ratio in the field sample was, males always higher than females with a ratio of 7:3. The higher ratio of males in every sample of fireflies is related to the synchronous flashing of fireflies because it is knowns that male fireflies are more actively flashing to find a mate (Buck & Buck 1978).

Smith (1935) discovered that the synchronously flashing fireflies are males, and Haneda (1941) found that females are also present in the trees, though they take no part in the synchrony (Buck & Buck 1978). Rhythmically flashing males fly individual patrols over low vegetation where females are perched. If the female answers the signal of the male, the two fireflies may begin a courtship involving a series of altering, timed flashes (Buck & Buck 1978). Laboratory data plus observation by Buck & Buck (1968; 1978) found that *Pteroptyx* males synchronize when brought together in groups and that flashing synchronously with neighbours seems to be practically their only luminescent activity during life (Smith 1935), leading to the important conclusion that flash synchronization is reflex and obligatory whenever males are sufficiently close to one another.

Six display tree species from mangroves in this study are the species listed in the IUCN Red List for mangrove flora diversity (Aldrie 2022; He et al. 2022), i.e. *Excoecaria indica, Heriteria littoralis*, *Cerbera odolam*, *Sonneratia alba*, *Rhizophora apiculata* and *Nypa fruticans*. As stated above, *Excoecaria indica* with a 42% of abundance tendency (t) was the preferable display tree for firefly selection to flash in the congregation group. A similar pattern was also observed in Lower Kinabatangan (Mahadimenakbar et al. 2003, 2004). A previous report by Chey (2004) at Klias River indicated that *Heriteria littoralis* known as Dunggun was

the dominant tree, while *Excoecaria indica*, also known as Ligura was the preferred display tree, and others were *Rhizophora apiculata*. A more recent study by Foo & Mahadimenakbar (2017) at nearby locations i.e. Garama River, Teratak River and Weston River, reported the same species of display trees to be preferred by congregating fireflies such as *Avicennia alba*, *Excoecaria agallocha, Excoecaria indica, Hibiscus tiliaceus, Nypa fruticans, Sonneratia alba* and *Rhizophora apiculata*.

The relationship between mangrove tree species along the coast of the river with congregating *Pteroptyx* spp. is very synonym in Southeast Asia. In terms of conservation issues, congregating fireflies population and the mangrove ecosystem are interconnected. If we lose a healthy mangrove ecosystem, then we will lose the beauty of assembling firefly flashing lights (Elora 2022). Therefore, it is suggested that the protection of the fireflies population is in tandem or aligned with the protection of display tree species in the mangrove swamp ecosystem. The Global Mangrove Alliance (GMA) is rallying the world around a target of increasing mangrove coverage by 20% over the current extent by 2030, and this ambitious goal required collaboration among partners from all sectors in every corner of the world (Dixon 2022). *Pteroptyx* fireflies can be the flagship species to educate people about the need to protect mangrove habitats used by other invertebrate and vertebrate species (Jaikla et al. 2020a; Jaikla et al. 2020b).

CONCLUSION

The functioning of the mangrove ecosystem is explained by specialist around the world and conservation issues is a concern globally. Mangroves naturally can solve climate change, provide a natural coastal buffer from erosion, tsunami, storm-driven wind and wave, run-off retention, habitat for flora and fauna, nutrient cycle, silt deposit, carbon accumulation, food and resource for community livelihood. Intergovernmental Panel on Climate Change (IPCC) defined 'Climate change' as "any change in climate over time, whether due to natural variability or as a result of human activity". Increasing temperatures is a significant climate change that causes detrimental global warming in much of the world region, and may affect insect variability, structure, and function in ecosystems. Thus, the future of this firefly population depends on the healthy of the habitat. Not only do the habitats of the display trees matter, but the vegetations behind the display trees are also important as the breeding ground for the fireflies as the larvae can be found 15-20 m away behind the display trees.

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AUTHORS DECLARATIONS

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Conflict of Interest
The authors declare that they have no conflict of interest.

Ethics Declarations
No ethical issue is required for this research

Data Availability Statement
This is a Master of Science Project and the data are currently in MSc thesis entitled “Kajian Taburan dan Kelimpahan Kelip-Kelip (Coleoptera; Lampyridae) di Sungai Klias, Beaufort, Sabah, Malaysia” (2012).

Authors' Contributions
EP and MM conceptualized this research and designed experiments; MMD participated in the design and interpretation of the data; EP, MM and MMD wrote the paper and participated in the revisions of it. All authors read and approved the manuscript.

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