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Review Article

The Compilation Records of Fireflies (Coleoptera: Lampyridae) Diversity and Distribution and Display Trees Throughout Malaysia

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ABSTRACT

The populations of fireflies (Coleoptera: Lampyridae) are increasingly being threatened, and it is, thus, a significant problem in Southeast Asia, particularly Malaysia. Fireflies and their habitat must immediately be protected before they go extinct. Simpson's Diversity Index used in this paper review to measure the diversity of firefly species across Malaysia. The Simpson's Diversity Index showed that the richness and evenness of firefly species in Malaysia is infinite diversity with D = 0.2255. The authors compiled and reviewed the studies on the firefly species to incorporate available information/data and emphasised their preferred habitat/display trees in response to the issue. Therefore, this paper was also able to track down records of fireflies' species' distribution through the previous studies in eight states in West Malaysia (Peninsula), namely Johor, Kelantan, Kuala Lumpur, Pahang, Perak, Negeri Sembilan, Selangor, and Terengganu, as well as two states in East Malaysia (Borneo), namely Sabah and Sarawak. It indicates that firefly species, especially from the genera *Pteroptyx* (*Pteroptyx tener* species), are widely distributed in Peninsular Malaysia and East Malaysia. Based on the records from the study conducted by previous researchers, it was found that the population of fireflies is declining in some areas in Malaysia, and so are their habitats and host/display trees that have suffered the same decline. Perhaps, this paper will help broaden human beings' geographical understanding/knowledge and create awareness which eventually leads to conservation actions of firefly species and their host/display trees.

Keywords: Coleoptera, distribution, fireflies, Lampyridae, population

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INTRODUCTION

Fireflies are categorised in the beetle family Lampyridae. They are made up of ten subfamilies, with around 2200 species described worldwide (Martin et al., 2019). Fireflies are from the Lampyridae family and are not classified as "flies" since flies have only one pair of wings while all other winged insects have two or four wings (Mahadimenakbar & Saikim, 2016). Fireflies have four growth stages: eggs, larvae, pupae, and adults. Within 24 to 48 hours post-mating, adult female fireflies will lay 80 to 150 eggs. Adult female fireflies will die two to three hours after oviposition. After that, the eggs will be incubated for two to four weeks. The newly emerged larvae will feed on the mangrove snail (*Cyclotropis carinata*) (Nallakumar, 2003). If these snails are not found in the area, the larvae will eat any species of snail that is available. Lastly, the larvae prepare for pupation by making a soiled space in the soil, where they will dwell for six to ten days until they emerge as adult fireflies (Nallakumar, 2003).

Luciola pupilla, Pteroptyx malaccae, and *Pteroptyx tener* are three species found predominantly in Southeast Asian countries, including Malaysia (Razak & Sulaiman, 2016), and this region is home to a wide range of *Pteroptyx* fireflies (Ballantyne et al., 2019; Jusoh et al., 2018). The most common species of fireflies in Malaysia are *Pteroptyx tener* and *Pteroptyx bearni* (Jusoh et al., 2018). The fireflies from the genus *Pteroptyx* are mainly linked with the aquatic-terrestrial ecotone near the edge of mangrove forests, where they congregate (Foo & Mahadimenakbar, 2017). *Pteroptyx tener* congregates in large colonies every night in certain mangrove trees along tidal rivers, providing a stunning bioluminescent flash (Jusoh et al., 2010b), ranking them among the fascinating insects due to their spectacular bioluminescent flash (Oba et al., 2011). Male and female fireflies have distinct flashes of light to help them find mates (Buck & Buck, 1968).

In certain regions, it is reported that habitat loss and degradation have led to the reduction of firefly populations (Khoo et al., 2012; Wong & Yeap, 2012). For example, in Malaysia, the mangrove *Pteroptyx tener* have already experienced a significant decline (Jusoh & Hashim, 2012). A recent global survey has identified three major threats to firefly species in Australia, Central America, East Asia, North America, South America, South Asia, Southeast Asia and the United Kingdom and Europe that include habitat loss and fragmentation, adult dating disorders due to the artificial light at night (ALAN) and excessive use of pesticides (Lewis et al., 2020). It is critical to address this issue since there is a possibility that fireflies are a vital natural pollinator in ecosystems (Sulaiman et al., 2020). As well known, insects are vital pollinators, and many plants rely exclusively on insects for reproduction (Ollerton, 2017; Paudel et al., 2015). Furthermore, fireflies feed primarily on nectar (Nallakumar, 2003).

For the effective conservation of firefly populations, a thorough understanding of their range, abundance, and habitat requirements is needed (Takeda et al., 2006). Cheng

et al. (2020) mentioned that fireflies in the genus *Pteroptyx* are designated as a potential flagship group, umbrella species or indicator species for biodiversity conservation and environmental health in Southeast Asia. It is based on several characteristics, such as adult fireflies in estuarine ecosystems in areas of the region are easier to spot and quantify because of their synchronised flashing behaviour. The *Pteroptyx tener* larvae reside in the topsoil horizon/organic layer, daily inundated by the tidal river. They spend most of their time in this area hunting for their host (*Cyclotropis carinata*; Assimineidae); Finally, their eggs and pupae that also live in the topsoil horizon can be used as effective gauges/indicators of environmental health. Settling on the topsoil horizon makes them extremely sensitive to water and soil quality changes.

Looking at the problems faced by this insect species (fireflies) as well as the lack of studies conducted in some areas, for example, Jusoh et al. (2020) mentioned that although synchronous flashing fireflies of the genus *Pteroptyx* are found across Southeast Asia, very little is known about their biodiversity. Abdullah et al. (2021) also stated that in Malaysia, the records of firefly populations in Sarawak are still lacking compared to Malaysia Peninsula and Sabah. Then according to Chung (2007), a body of research on the diversity of beetles has been conducted in Malaysia; however, due to the high diversity of beetles, the understanding of taxonomy, diversity, species groupings, and ecology is still insufficient. Therefore, the primary purpose of this paper is to compile the records of congregating firefly distribution throughout Malaysia. By knowing the areas that have not yet been covered in the study related to the biodiversity of this species, the researchers and those responsible for wildlife management and forestry can do better planning. Meanwhile, the second objective of this paper is to identify the display tree species favoured by fireflies in Malaysia. Listing the types of tree species chosen by fireflies as host/display trees will help preserve and conserve the tree species.

FIREFLY LIST AND SPECIES DIVERSITY IN MALAYSIA

Bassot and Polunin (1967) were the first to study congregating fireflies in Peninsular Malaysia (Benut River mangrove on the west coast of Johore). *Colophotia, Luciola, Lychnuris,* and *Pteroptyx* are the four groups of fireflies found in Peninsular Malaysia (Nada & Kirton, 2004; Nallakumar, 2003). The *Pteroptyx* population size changed over time is very concerning (Jusoh et al., 2010a) because one of these species, *Pteroptyx tener,* was a widespread species in Malaysia (Foo & Mahadimenakbar, 2017). If there is a reduction in the number of these species, then it will affect the number of fireflies species found throughout Malaysia. The *Pteroptyx tener* is found at various locations in Peninsular Malaysia, such as in Sungai Sepetang, Perak (Hazmi & Sagaff, 2018; Norela et al., 2017), Sungai Bernam, Selangor (Shahara et al., 2017), Sungai Johor, Johor (Norela et al., 2016) and Chukai River, Kemaman (Mahmod et al., 2018). The Malaysian Nature Society (MNS)

performed a nationwide survey on Congregating Firefly Zones (CFZs) in Malaysia between 2009 and 2010. The goal of the survey was to determine the status of land use, hazards, ecotourism potential, and other features in 28 main CFZs. The majority of CFZs have one to four congregating firefly species, with the east coast having a larger concentration of CFZs. Figure 1 below shows the 58 Congregating Firefly Zones (CFZs) in Peninsular Malaysia (Wong & Yeap, 2012), while Figure 2 shows the location of firefly species that have been found throughout Peninsular Malaysia and Borneo (Sabah and Sarawak).

In Rembau River, a total of 87 colonies of *Pteroptyx* were detected, while in Linggi (two colonies), Ramuan China Besar (13 colonies), and Ramuan China Kechil (20 colonies) (Jusoh et al., 2010a). Hazmi and Sagaff (2018) carried out a study in March, May, and June 2014, successfully collecting 3044 individuals of adult *Pteroptyx tener* fireflies along the Sungai Sepetang in Kampung Dew Perak. The study found that the abundance of the firefly population in Sungai Sepetang dropped as the concentration of heavy metals in the river water increased where the Water Quality Index (WQI) was acquired with polluted status (59%). Meanwhile, firefly eggs and larvae have been discovered to survive on soil with a high percentage of silt (Hazmi & Sagaff, 2018). Mahmod et al. (2018) collected 505 fireflies in Chukai River Kemaman, Terengganu, between November 2017 and April 2018, representing three species: *Pteroptyx tener* Olivier (503 individuals, 99.6%), *Pteroptyx malaccae* Gorham, and *Pteroptyx valida* Olivier (1 individual, 0.2% respectively). In addition, *Pteroptyx valida* is very uncommon in the Klias Peninsula, Sabah (Mahadimenakbar et al., 2007).

In the meantime, a study conducted by Foo and Mahadimenakbar (2017) in the eastern part of Malaysia in three locations in Sabah (Garama River, Teratak River and Weston River) recorded about 1,750 individuals representing four species (namely *Pteroptyx bearni* Ballantyne, *Pteroptyx malaccae* Gorham, *Pteroptyx tener* Olivier, and *Pteroptyx valid*a Olivier). *Pteroptyx tener* (344 individuals) and *Pteroptyx malaccae* (306 individuals) were the most common species in Weston River. In contrast, *Pteroptyx tener* (187 individuals) was the most common in Garama River and *Pteroptyx bearni* (255 individuals) was most common in Teratak River. In addition, Foo and Mahadimenakbar (2016) reported that the *Pteroptyx bearni* was also a dominant firefly species found in the mangrove forest of Kawang in Sabah, Malaysia.

Pteroptyx bearni was documented in Miri, Sarawak (Niah River, Sibuti River and Raan River), Terengganu (Kerteh River) on the East Coast of Peninsular Malaysia (Jusoh et al., 2011; Abdullah et al., 2021). In Sarawak, *Pteroptyx bearni* has also been recorded in various locations, including Balingian, Bintulu, Kadulit, and Raan, indicating that both species are widespread in Sarawak (Jusoh et al., 2018). Two hundred ninety-six individual fireflies were reported in Miri, Sarawak, Malaysia, notably *Pteroptyx bearni* Olivier 1909 and *Pteroptyx malaccae* Gorham 1880. Both species were found in the Niah River (146 individuals), the

Sibuti River (97 individuals), and the Raan River (53 individuals) (Abdullah et al., 2021). The population of *Pteroptyx bearni* in Likas, Sabah, recorded a very alarming decline triggered by the loss of mangroves. Most worrying is when *Pteroptyx bearni* is found to no longer exist in Likas, and it can be concluded that it is likely that the species is going to extinct (Mahadimenakbar & Saikim, 2016). At the same time, *Pteroptyx gelasina* also suffered the same fate as *Pteroptyx bearni* when the species was no longer found in Likas, Sabah (Mahadimenakbar & Saikim, 2016). Therefore, a study needs to be done in the Likas area, Sabah, to determine the actual situation of these two species, whether they are entirely extinct, and the cause of the loss of the species there.

In the work of Jusoh et al. (2018), there was only one record of *Pteroptyx malaccae* in Sarawak, which is in Limbang. Meanwhile, Abdullah et al. (2021) have successfully recorded the first presence of this species in Niah River, Miri, Sarawak. In 2014 this species was also found in Teratak River, Sabah (Foo & Mahadimenakbar, 2015). Apart from Sabah and Sarawak, this species has also been recorded in Rembau, Negeri Sembilan (Jusoh et al., 2010a), then in Muar, Johor, Chukai, Terengganu and Sungai Pahang Tua, Pahang (Jusoh et al., 2018). However, due to urbanisation and resettlement, fireflies in the Rembau-Linggi River are almost gone (Jusoh & Hashim, 2012). At the same time, *Pteroptyx asymmetria* has only been found in the western region of Peninsular Malaysia (Jusoh et al., 2018). *Pteroptyx* fireflies are known to flash synchronously but not the *Pteroptyx asymmetria* males. Instead of perching on the display trees, *Pteroptyx asymmetria* males are likely to fly about the tops of their trees (Jusoh et al., 2018).

In October 2018, a new record of three species, *Pygoluciola wittmeri*, *Luciola* sp., and eleven out of 17 larvae, was discovered in Kangkawat Research Station, Imbak Canyon, Sabah (genus *Pyrocoelia* sp.). There were 33 solitary fireflies (3 adult males; 13 adult females), and 17 larvae were collected (Mobilim & Mahadimenakbar, 2020). Ballantyne and Lambkin (2006) and Nada and Ballantyne (2018) also stated that the species of *Pygoluciola* fireflies was found in Malaysia, which proves that other species of fireflies other than *Pteroptyx* also exist in Malaysia. It suggests that there is a possibility that there are not many studies done concerning the species that are still not widely covered. Perhaps *Pteroptyx* is somewhat synonymous with its habitat in mangrove areas, but other species inhabit the non-mangrove areas. These species are not as well known as *Pteroptyx* because they can only be found in a few places. For example, *Luciola* sp. in the Maliau Basin (Muslim et al., 2010); *Lychnuris* opaca in Tabin Wildlife Reserve (Chung & Binti, 2008); *Pygoluciola dunguna* Nada sp. nov in Dungun, Jengai Forest Reserve (Nada & Ballantyne, 2018); *Pygoluciola guigliae* and *Pygoluciola wittmeri* in Mahua, Sabah (Ballantyne & Lambkin, 2006); *Pygoluciola kinabalua* found in Mesilau, Sabah (Ballantyne & Lambkin, 2001) and *Pygoluciola wittmeri* in Kionsom, Sabah (Chey, 2008). Three non-synchronised firefly genera were found from December 2011 until January 2013 in UNESCO Chini Lake

Biosphere Reserve, namely *Colophotia* sp., *Pygoluciola* sp. and *Pyrocoelia* sp. (Roslan & Sulaiman, 2015). However, no further studies have been done to prove the existence of fireflies except *Pteroptyx* in non-mangrove areas.

To conclude the findings of this paper review, the authors have utilised Simpson's Diversity Index to highlight the diversity of firefly species found throughout Malaysia. Simpson's Diversity Index showed that the richness and evenness of firefly species in Malaysia is infinite diversity with D = 0.2255 (Table 2).

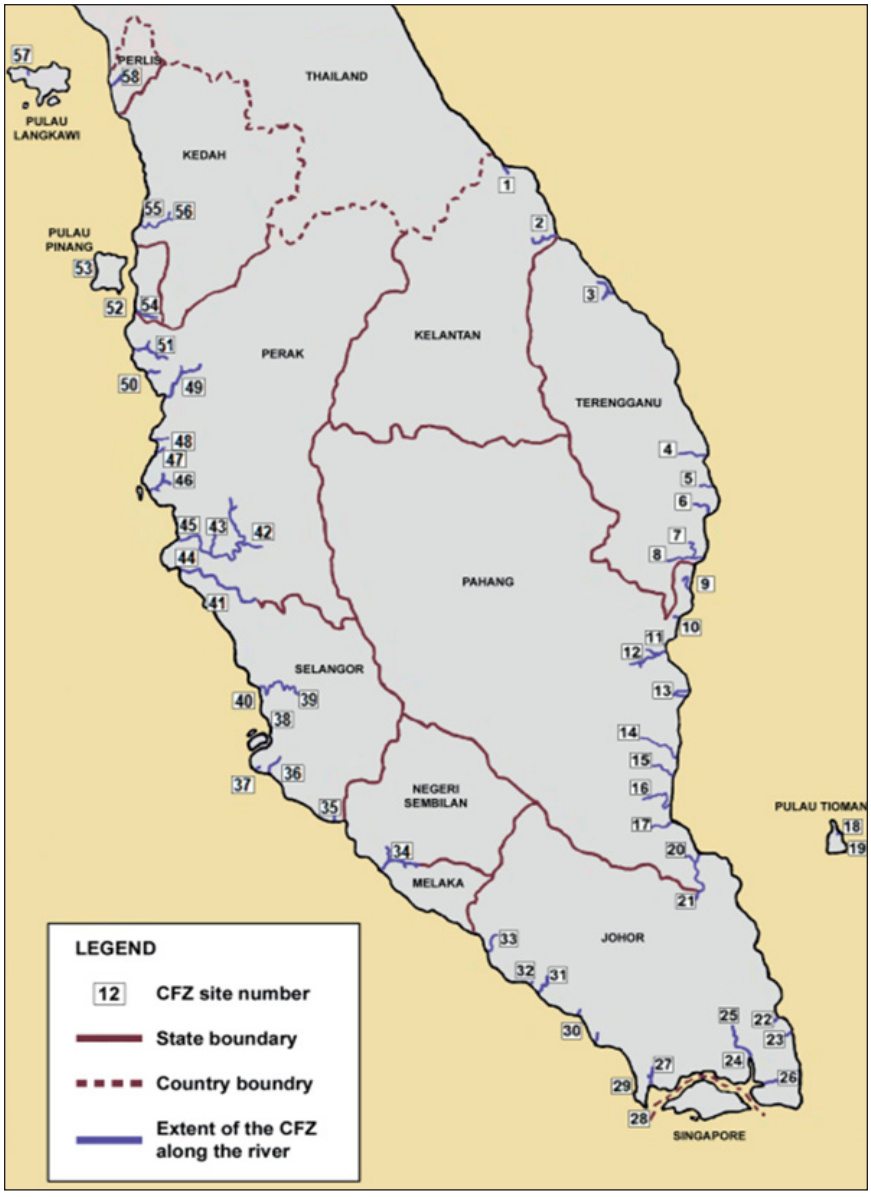


Figure 1. The 58 congregating firefly zones (CFZs) in Peninsular Malaysia (Wong and Yeap, 2012)

Table 1
The compilation of firefly species recorded in Malaysia

No.	Species	Location	References
1	*Abscondita berembun* Nada sp. nov.	• Negeri Sembilan (Mount Berembun) • Pahang (Fraser's Hill) • Perak (Mount Liang)	Ballantyne et al. (2019)
2	*Abscondita jerangau Nada* sp. nov.	• Terengganu (Jerangau Forest Reserve; Pasir Raja Selatan Forest Reserve)	Ballantyne et al. (2019)
3	*Abscondita pallescens* (Gorham 1880) comb. nov.	• Kelantan (Banjaran Titi Wangsa Kampong Lawa) • Kuala Lumpur • Negeri Sembilan (Mount Berembun; Mount Besar Hantu) • Pahang (Cameron Highlands Tanah Rata; Fraser's Hill; Mager Trail; Kuala Tahan National Park) • Penang (Penang Hills) • Perak (Mount Kledang; Mount Liang; Larut Hills) • Sarawak (Mount Mulu National Park; Matang; Mount Dempo; Mount Dulit; Mount Merinjak; Quop) • Selangor (Canopy Walkway Trail; Forest Research Institute Malaysia; Gombak Valley; Mount Nuang; Mersawa Trail; Selangor Museum near L gardens) • Terengganu (Besul Forest Reserve; Hulu Terengganu Tambahan Forest Reserve; Jengai Forest Reserve; Jerangau Forest Reserve; Pasir Raja Barat Forest Reserve; Pasir Raja Selatan Forest Reserve)	Ballantyne et al. (2019)
4	*Atripennis* Pic 1934	Malaysia Peninsula (Specific location not stated)	Ballantyne et al. (2019)
5	*Baolacus lajoyei* Pic, 1915	Malaysia (Specific location not stated)	Janisova and Bocakova (2013)
6	*Colophotia brevis*	Malaysia Peninsula (Specific location not stated)	Jusoh et al. (2018)
7	*Colophotia brevis* Olivier	• Pahang (Chini Lake) • Negeri Sembilan (Mount Besar Hantu) • Selangor (Mount Nuang) • Terengganu (Besul Forest Reserve; Jengai Forest Reserve; Jerangau Forest Reserve)	Ballantyne et al. (2019)

Table 1 *(continue)*

No.	Species	Location	References
8	*Colophotia miranda* Olivier 1886	Sarawak (Specific location not stated)	Ballantyne et al. (2019)
9	*Colophotia praeusta*	East Malaysia (Specific location not stated)	Jusoh et al. (2018)
10	*Colophotia* sp.	Pahang (Chini Lake)	Roslan and Sulaiman (2015)
11	*Drilaster axillaris* Kiesenwetter, 1879	Malaysia (Specific location not stated)	Janisova and Bocakova (2013)
12	*Emasia* gen. nov.	Borneo (Specific location not stated)	Bocakova and Janisova (2010)
13	*Emasia dentata* sp. n.	Borneo (Specific location not stated)	Bocakova and Janisova (2010)
14	*Kuantana menayah* Ballantyne sp. nov.	Selangor (Selangor River)	Ballantyne et al. (2019)
15	*Luciola chapaensis* Pic 1923	• Kelantan (Banjaran Titiwangsa Kampong Lawa) • Pahang (Cameron Highlands)	Ballantyne et al. (2019)
16	*Luciola jengai* Nada sp. nov.	• Pahang (Fraser's Hill) • Perak (Mount Liang) • Negeri Sembilan (Mount Besar Hantu) • Terengganu (Jengai Forest Reserve; Pasir Raja Barat Forest Reserve)	Ballantyne et al. (2019)
17	*Luciola lata* Olivier 1883	• Sabah (Danum Valley) • Sarawak (4th division Gn. Mulu NP; Quop)	Ballantyne et al. (2019)
18	*Luciola niah* Jusoh sp. nov.	Sarawak (Kapit; Lambir Hill; Long Aton; Ulu Baram; Niah National Park Forest track)	Ballantyne et al. (2019)
19	*Luciola pallidipes* Pic 1928	• Pahang (Fraser's Hill; Bishop Trail; Taman Negara: Kuala Tahan) • Perak (Banjaran Bintang Bukit Berapit)	Ballantyne et al. (2019)
20	*Luciola Pygoluciola* kinabalua	Sabah (Kundasang; Mesilau; Mount Kinabalu)	Ballantyne and Lambkin (2001)
21	*Luciola* sp.	Sabah (Kangkawat Research Station)	Mobilim and Mahadimenakbar (2020)
22	*Luciola tiomana* Ballantyne sp. nov.	• Johor (Tioman Island Jungle track) • Terengganu (Pasir Raja Selatan Forest Reserve)	Ballantyne et al. (2019)
23	*Luciola* WFA	East Malaysia (Specific location not stated)	Jusoh et al. (2018)

Table 1 *(continue)*

No.	Species	Location	References
24	*Luciolinae maculipennis* Olivier	Malaysia (Borneo) (Specific location not stated)	Ballantyne et al. (2016)
25	*Medeopteryx fraseri* Nada sp. nov.	Pahang (Fraser's Hill Bishop Trail)	Ballantyne et al. (2019)
26	*Ototreta subvittata* Pic, 1943	Malaysia (Specific location not stated)	Janisova and Bocakova (2013)
27	*Ototreta weyersi* E. Olivier, 1900	Malaysia (Specific location not stated)	Janisova and Bocakova (2013)
28	*Poluninius selangoriensis (Pteroptyx testacea)*	East Malaysia (Specific location not stated)	Jusoh et al. (2018)
29	*Pteroptyx asymmetria*	Perak (Sungai Sepetang)	Abdullah et al. (2019); Jusoh et al. (2018)
30	*Pteroptyx asymmetria* Ballantyne	Negeri Sembilan (Rembau River)	Asri et al. (2020)
31	*Pteroptyx balingiana*	East Malaysia (Specific location not stated)	Jusoh et al. (2018)
32	*Pteroptyx bearni* Ballantyne	Sabah (Garama River; Teratak River; Weston River)	Foo and Mahadimenakbar (2017)
33	*Pteroptyx bearni* or *Pteroptyx similis*	• Pahang (Cherating River) • Sabah (Binsulok River; Kawang River; Kudat Bay; Likas; Paitan River; Sakar Island, Garama River; Kawang River; Klias River; Sungai Sepilok Besar; Sungai Sepilok Kecil; Teratak River; Trayong)	Ballantyne (2001); Chey (2006); Chey (2008); Chey (2009); Chey (2010); Chey (2011); Faudzi et al. (2021); Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2016); Foo et al. (2017); Jusoh et al. (2018); Mahadimenakbar et al. (2007); Mahadimenakbar et al. (2018)
34	*Pteroptyx bearni* (Olivier, 1909)	Sarawak (Niah River; Sibuti River; Raan River)	Abdullah et al. (2021)
35	*Pteroptyx galbina* Jusoh sp. nov.	Sarawak (Niah; Suria Timon; Ulu Baram)	Ballantyne et al. (2015); Jusoh et al. (2018)
36	*Pteroptyx gelasina*	Sabah (Binsulok River; Likas; Paitan River; Sakar Island; Sipitang River; Sungai Sepilok Kecil)	Ballantyne (2001); Chey (2006); Chey (2008); Chey (2011); Mahadimenakbar et al. (2018)

Table 1 *(continue)*

No.	Species	Location	References
37	*Pteroptyx gombakia* sp. nov.	Selangor (Kuala Lumpur Gombak Valley)	Ballantyne et al. (2015)
38	*Pteroptyx malaccae*	• Perak (Sungai Sepetang) • Negeri Sembilan (Rembau River) • Sabah (Binsulok River; Garama River; Sipitang; Kawang River; Klias River; Teratak River; Trayong)	Abdullah et al. (2019); Ballantyne (2001); Chey (2009); Chey (2010); Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2016); Mahadimenakbar et al. (2018)
39	*Pteroptyx malaccae* Gorham	• Sabah (Garama River; Weston River) • Negeri Sembilan (Rembau River) • Terengganu (Chukai River)	Asri et al. (2020); Foo and Mahadimenakbar (2017); Mahadimenakbar et al. (2007); Mahmod et al. (2018)
40	*Pteroptyx malaccae* (Gorham, 1880)	• Sarawak (Niah River)	Abdullah et al. (2021)
41	*Pteroptyx malaccae* Group 2	Peninsular Malaysia (Specific location not stated)	Jusoh et al. (2018)
42	*Pteroptyx malaccae* Group 3	Peninsular Malaysia (Specific location not stated)	Jusoh et al. (2018)
43	*Pteroptyx malaccae* Group 4	Peninsular Malaysia (Specific location not stated)	Jusoh et al. (2018)
44	*Pteroptyx sayangia* sp. nov.	Malaysia (Specific location not stated)	Ballantyne et al. (2015)
45	*Pteroptyx tener*	• Perak (Sepetang estuary; Sepetang River) • Negeri Sembilan (Linggi River; Rembau River) • Sabah (Abai; Binsulok River; Garama River; Klias River; Teratak River) • Selangor (Bernam River; Kg. Kuantan; Selangor River) • Terengganu (Chukai River)	Abdullah et al. (2019); Ballantyne (2001); Cheng et al. (2017); Cheng et al. (2020); Chey (2010); Foo and Mahadimenakbar (2015); Hazmi and Sagaff (2018); Jusoh et al. (2010b); Jusoh et al. (2018); Khoo et al. (2012); Mahadimenakbar et al. (2018); Othman et al. (2018); Shahara et al. (2017)
46	*Pteroptyx tener* Olivier	• Sabah (Garama River; Teratak River; Weston River) • Selangor (Selangor River) • Negeri Sembilan (Rembau River) • Terengganu (Chukai River)	Asri et al. (2020); Foo and Mahadimenakbar (2017); Mahadimenakbar et al. (2007); Mahmod et al. (2018); Salleh et al. (2019)

Table 1 *(continue)*

No.	Species	Location	References
47	*Pteroptyx valida*	• Sabah (Binsulok River; Teratak River) • Terengganu (Chukai River)	Foo and Mahadimenakbar (2015); Mahadimenakbar et al. (2018)
48	*Pteroptyx valida* Group 2	Malaysia (Specific location not stated)	Jusoh et al. (2018)
49	*Pteroptyx valida* Olivier	• Sabah (Garama River; Teratak River; Weston River) • Terengganu (Chukai River)	Foo and Mahadimenakbar (2017); Mahadimenakbar et al. (2007); Mahmod et al. (2018)
50	*Pyrocoelia analis*	Peninsular Malaysia (Specific location not stated)	Jusoh et al. (2018)
51	*Pygoluciola dunguna* Nada sp. nov.	• Banjaran Titiwangsa • Negeri Sembilan (Mount Besar Hantu; Mount Berembun) • Perak (Mount Liang) • Selangor (Bukit Kutu; Mount Nuang) • Terengganu (Besul; Besul Tambahan; Dungun Timber Complex; Hulu Terengganu Tambahan; Jengai; Jerangau; Pasir Raja Barat; Pasir Raja Selatan)	Ballantyne et al. (2019); Nada and Ballantyne (2018)
52	*Pygoluciola nitescens* (Olivier 1903b) comb. nov.	Sabah (Ranau)	Ballantyne et al. (2019)
53	*Pygoluciola* sp.	Pahang (Chini Lake)	Roslan and Sulaiman (2015)
54	*Pygoluciola wittmeri*	Sabah (Kangkawat Research Station)	Mobilim and Mahadimenakbar (2020)
55	*Pyrophanes semilimbata* (Olivier)	Sabah (Likas; Sandakan)	Ballantyne et al. (2015)
56	*Pyrocoelia* sp.	• Pahang (Chini Lake) • Sabah (Kangkawat Research Station)	Mobilim and Mahadimenakbar (2020); Roslan and Sulaiman (2015)
Simpson's Diversity Index			
$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right)$		D = Diversity index N = The total number of organisms of a particular species N = The total number of organisms of all species	

Table 2
Simpson's Diversity Index of firefly species in Malaysia

Species	Number of Adult Fireflies (n)	n(n-1)	References
***Luciola* sp.**	2	2	Mobilim and Mahadimenakbar (2020)
***Pteroptyx asymmetria* Ballantyne**	2	2	Asri et al. (2020)
***Pteroptyx bearni* Ballantyne**	1750	3,060,750	Foo and Mahadimenakbar (2017)
Pteroptyx bearni* or *Pteroptyx similis	2655	7,046,370	Faudzi et al. (2021); Foo et al. (2017); Foo and Mahadimenakbar (2016); Mahadimenakbar et al. (2007); Mahadimenakbar et al. (2018)
***Pteroptyx bearni* (Olivier, 1909)**	277	76,452	Abdullah et al. (2021)
Pteroptyx gelasina	2	2	Mahadimenakbar et al. (2018)
Pteroptyx malaccae	9	72	Mahadimenakbar (2015); Mahadimenakbar et al. (2018)
***Pteroptyx malaccae* Gorham**	375	140,250	Asri et al. (2020); Foo and Mahadimenakbar (2017); Mahadimenakbar et al. (2007); Mahmod et al. (2018)
***Pteroptyx malaccae* (Gorham, 1880)**	19	342	Abdullah et al. (2021)
Pteroptyx tener	3051	9,305,550	Foo and Mahadimenakbar (2015); Hazmi and Sagaff (2018); Mahadimenakbar et al. (2018)
***Pteroptyx tener* Olivier**	2594	6,726,242	Asri et al. (2020); Mahadimenakbar et al. (2007); Foo and Mahadimenakbar (2017); Mahmod et al. (2018)
Pteroptyx valida	10	90	Foo and Mahadimenakbar (2015); Mahadimenakbar et al. (2018)
***Pteroptyx valida* Olivier**	28	756	Foo and Mahadimenakbar (2017); Mahadimenakbar et al. (2007); Mahmod et al. (2018)
***Pygoluciola dunguna* Nada sp. nov.**	37	1,332	Nada and Ballantyne (2018)
Pygoluciola wittmeri	1	0	Mobilim and Mahadimenakbar (2020)
Total	N = 10812	$\sum n(n-1) = 26{,}358{,}212$	
		Simpson's Diversity Index = 0.2255	

**Notes*. D = 0 represents infinite diversity and 1, no diversity

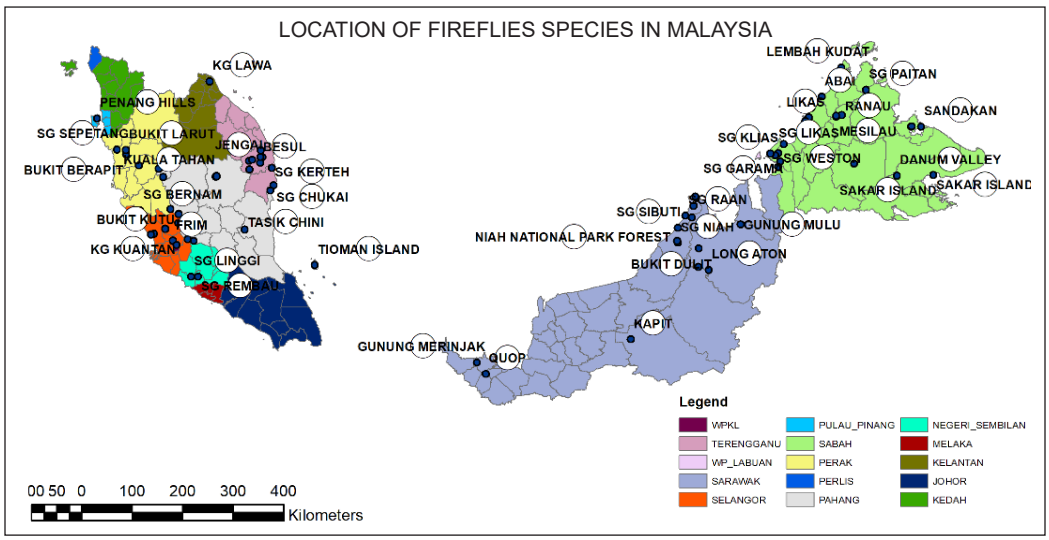


Figure 2. Location of firefly species throughout Malaysia

FIREFLY HABITAT AND HOST/DISPLAY TREES IN MALAYSIA

Firefly habitat is typically situated near the water areas, particularly in mangroves. They lay their eggs near the Nypa tree on the riverbanks, and their larvae eat tiny river snails and insects (Hazmi & Sagaff, 2018). According to Ballantyne and McLean (1970), fireflies of the species *Pteroptyx* live in wetlands, estuaries, and brackish water environments. *Pteroptyx* fireflies have been recorded in various mangrove species as display trees (Chey, 2004); however, they are most seen congregating in *Sonneratia caseolaris* (L.) Engl. Trees (Cheng et al., 2017; Jusoh et al., 2010b; Ohba & Wong, 2004) (see figure 3). In conformity with Mahmod et al. (2018), most synchronous fireflies in Chukai River, Terengganu, inhabit *Sonneratia caseolaris* (L.) Engl, which are 432 individuals (85%). Forty-four individuals (9%) inhabit *Hibiscus tiliaceus* L., and 29 individuals (6%) inhabit *Nypa fruticans* Wurmb. They also detected fireflies in different vegetation types, such as *Guilandina bonduc* L. and *Barringtonia* sp. However, it does not demonstrate the best synchronisation.

According to Nallakumar (2003), adult fireflies only occupy the young berembang tree (*Sonneratia caseolaris*) associated with *nectaries*. This nectar is a vital nutrient for adult fireflies and a catalyst for the chemical processes that result in synchronised photon flashes. It was also found that this tree is a food source for *Pteroptyx tener* because it contains some amount of sucrose in the sap (Jaafar et al., 2010; Juliana et al., 2012; Nada et al., 2009). The density of firefly larvae was significantly higher in Sago palm groves than in oil palm stands (Kirton et al., 2006). Streambank palms (*Nypa fruticans* and *Metroxylon* sago) are essential food sources for the snail predators the firefly larvae feed (Nada & Kirton, 2004). It is in line with the work of Juliana et al. (2012), who found that the fireflies in Selangor

River are found in Sago's palms (*Metroxylon* sago) and Rengas air (*Gluta velutina*). Kirton et al. (2006) have made a preliminary study to determine firefly larval habitat requirements that show that *Pteroptyx tener* larval densities were high in sago patches (*Metroxylon* spp.), They are low in orchards (mixed fruit tree species) and low in all but one of five oil palm plantation locations (*Elaeis guineensis*).

Pteroptyx tener and *Pteroptyx bearni* adults in Kerteh River, Terengganu, in 2009 were found to select 170 trees from 27 different species located 2–15 km from the estuary as display trees. For instance, most of these fireflies congregated on *Sonneratia caseolaris* (L.) Engl. (22%) of total display sections. Then, this is followed by *Gluta velutina* Blume (15%), *Hibiscus tiliaceus* L. (13%), *Xylocarpus granatum* J. König (9%), *Avicennia alba* Blume (8%), *Rhizophora apiculata* Blume (6%) whilst the remaining individuals were found on other display tree species such as *Brownlowia argentata* Kurtz, *Barringtonia racemosa* (L.) Spreng., *Bruguiera gymnorrhiza* (L.) Lam., *Ceriops decandra* (Griff.) Ding Hou*, Derris trifoliata* Lour*, Excoecaria agallocha* L., and *Nypa fruticans* Wurmb (Jusoh et al., 2011).

In contrast to *Sonneratia caseolaris*, fireflies are also reported to be mainly congregating on *Heritiera littoralis* (the dominant trees found in Klias River, Sabah) (Chey, 2004) durian and bachang trees (Nada & Kirton, 2004). In a study conducted by Abdullah et al. (2021), it was found that fireflies were detected to be present in *Pandanus* sp. as a display tree in Sibuti River Sarawak for the first time it was recorded. Meanwhile, fireflies in Bako National Park Sarawak (Sibuti River and Raan River) prefer *Avicennia marina* trees as their display tree (Buck & Buck, 1966). The study conducted by Abdullah et al. (2021) found that *Rhizophora apiculata* was the most preferred display tree for the firefly population in Miri, Sarawak. Aside from that, *Derris* sp., in Raan River, was previously identified as a good display tree for the firefly population in Kerteh River, Terengganu (Jusoh et al., 2011). *Pteroptyx* and its display trees in the Rembau-Linggi Estuary have been studied and found to have the highest abundance percentage (6%) in November and December, while the lowest abundance percentage was observed in January and March (2%). It was also discovered that firefly colonies for two display trees (no. 7 and 10; species unspecified) had disappeared for two months, namely January and March.

Furthermore, one of the display trees died, and the colony that occupied it was relocated to another tree nearby. A tree 50 metres away from the dead tree has around 3% firefly cover (Jusoh et al., 2010a). It concludes that fireflies can inhabit different display trees, and they will need to adapt to the tree species if their original display tree dies or is destroyed. It also proves that fireflies can live or choose display trees other than their common display trees.

Pteroptyx tener is found in estuary ecosystems in Peninsular Malaysia's coastal areas, and it is particularly well-known in Selangor (Selangor River), Rembau, Negeri Sembilan (Sungai Linggi), Kuala Sepetang, Perak (Sungai Sepetang), Johore (Sungai Muar), and Chukai, Terengganu (Chukai River) (Jusoh et al., 2013). In Peninsular Malaysia's

mangrove forests, *Pteroptyx tener* Olivier congregated on several mangrove species, notably *Sonneratia* sp. (Ohba & Wong, 2004). They also suggested that several factors influence firefly species' selection of display trees, including a) the display tree should be at the water's edge, as this allows fireflies to communicate more easily; b) each display tree's leaf arrangement must be ideal for mating (see Figure 3); c) the display tree must be in a healthy condition; d) display trees must have nectar or rubber for adult fireflies if they eat; and e) the larval prey food plant must be closer to the display tree (Ohba & Wong, 2004). Meanwhile, Jusoh et al. (2010b) proposed that favourable display trees for *Pteroptyx* include those that are: a) near the water's edge; b) strong trees; c) near larval food sources; d) supply nectar or rubber for the adults' diet; and e) have an easy-to-communicate leaf arrangement.

According to Cheng et al. (2017), adult *Pteroptyx tener* dietary requirements were unknown, except the suggestion that these insects feed on the nectar and rubber of mangrove trees. In the same investigation, they found only plant DNA and fireflies DNA in extracts of *Pteroptyx tener* gut content DNA fragments which used adult samples of *Pteroptyx tener* fireflies collected from the wild from Selangor, Sepetang (Perak) and Rembau Rivers (Negeri Sembilan) along the west coast of Peninsular Malaysia. The study analysis did not detect *Sonneratia caseolaris* and *Hibiscus tiliaceus* in their gut DNA extracts, although these species relied on the plant for most of their adult lives. In contrast, the analysis discovered a single plant DNA sequence from *Pteroptyx tener* that was similar to the rbcL sequences of *Heritiera littoralis* (Malvaceae), *Lawsonia inermis* (Lythraceae), *Aquilaria* sp. and *Gonystylus bancanus* (Thyme laeaceae). All these plants are cultivated and natural, and they may have originated either in hamlets or isolated freshwater swamps located further inland. Thus, with the identification of these four plant DNA sequences in *Pteroptyx tener* gut DNA extracts, possible that the insect species went deep inland to find this host (Cheng et al., 2017).

Pteroptyx mangrove forest habitats are currently jeopardised by urbanisation, industrialisation, and firefly tourism activities (Wong & Yeap, 2012). The destruction of firefly habitats is due to ecotourism activities and local socioeconomic activities (Jaafar et al., 2010). One of the most famous areas for firefly population distribution was around Cherating River in Pahang, Malaysia (Mohd et al., 2019). According to Jusoh and Hashim (2012), 14 of 122 tree species utilised as firefly display trees in 2008 were destroyed in 2010. Based on their mapping, the number of trees inhabited by fireflies has reduced by more than half, from 122 to 57, and no new trees have been used for displays (Figure 4). The decrease and destruction of these trees occurred over a two-decade period due to the Rembau River's mangrove forest being altered. This mangrove forest has also been extensively converted to various land uses like agriculture, aquaculture, and urban areas (Jusoh & Hashim, 2012). According to Kirton et al. (2006), there are three contributors

to the reduction in the total population of fireflies in Kuala Selangor, namely: a) the loss of riverbank vegetation near firefly habitat for development and agricultural activities; b) pesticide usage in oil palm plantations that can affect firefly larvae survival; and c) changes in river water quality caused by pollution or the development of dams and barrages further upstream will also affect the survival of snails and riverside plants on which the fireflies depend. The map in Figure 5 illustrates the distribution of fireflies' display trees in Peninsular Malaysia and Malaysia Borneo (Sabah and Sarawak).

Table 3
Display trees of fireflies in Malaysia

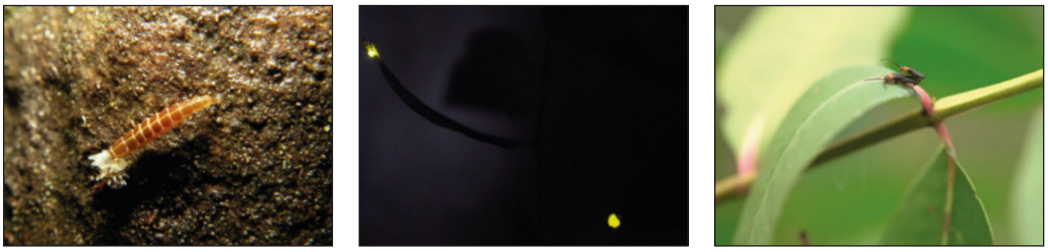
No.	Scientific Name	Location	References
1	*Acrostichum aureum*	• Teratak River, Sabah • Sepetang Estuary • Selangor River, Kampung Kuantan	Foo and Mahadimenakbar (2015); Jusoh et al. (2010b); Juliana et al. (2012)
2	*Aegiceras floridum*	• Kawang River, Sabah	Foo and Mahadimenakbar (2016)
3	*Avicennia alba*	• Teratak River, Sabah • Paitan River, Sabah • Klias Peninsula, Sabah	Chey (2006); Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2017)
4	*Avicennia alba* Blume	• Kerteh River, Terengganu	Jusoh et al. (2011)
5	*Avicennia marina*	• Sibuti River, Miri, Sarawak • Raan River, Miri, Sarawak	Abdullah et al. (2021)
6	*Avicennia rumphiana*	• Niah River, Miri, Sarawak	Abdullah et al. (2021)
7	*Barringtonia* sp.	• Chukai River Kemaman, Terengganu	Mahmod et al. (2018)
8	*Barringtonia racemosa* (L.) Spreng.	• Kerteh River, Terengganu	Jusoh et al. (2011)
9	*Brownlowia argentata* Kurtz	• Kerteh River, Terengganu	Jusoh et al. (2011)
10	*Bruguiera gymnorrhiza* (L.) Lam.	• Kerteh River, Terengganu	Jusoh et al. (2011)
11	*Bruguiera parvifolia*	• Raan River, Miri, Sarawak • Niah River, Miri, Sarawak • Garama River, Sabah	Abdullah et al. (2021); Mahadimenakbar et al. (2007)
12	*Ceriops decandra* (Griff.) Ding Hou	• Kerteh River, Terengganu	Jusoh et al. (2011)
13	*Clerodendrum inerme* (Verbenaceae)	• Garama River, Klias	Chey (2010)
14	*Derris* sp.	• Raan River, Miri, Sarawak	Abdullah et al. (2021)
15	*Derris trifoliata* Lour	• Kerteh River, Terengganu	Jusoh et al. (2011)
16	*Excoecaria agallocha* L.	• Teratak River • Kerteh River, Terengganu	Foo and Mahadimenakbar (2017); Jusoh et al. (2011)
17	*Excoecaria indica* L.	• Garama River, Sabah	Foo and Mahadimenakbar (2017)

Table 3 *(continue)*

No.	Scientific Name	Location	References
18	*Excoecaria indica* (Willd.) Muell. Arg. (Euphorbiaceae)	• Garama River, Sabah • Klias River, Sabah	Chey (2004); Mahadimenakbar et al. (2007)
19	*Ficus binjamina*	• Garama River, Sabah	Mahadimenakbar et al. (2007)
20	*Ficus microcarpa* (Moraceae)	• Garama River, Sabah • Klias River, Sabah	Chey (2010)
21	*Ficus* sp.	• Selangor River, Kampung Kuantan • Sungai Bernam, Selangor	Juliana et al. (2012); Shahara et al. (2017)
22	*Glochidion littorale* (Euphorbiaceae)	• Klias River, Sabah	Chey (2010)
23	*Gluta velutina Blume*	• Kerteh River, Terengganu	Jusoh et al. (2011)
24	*Guilandina bonduc* L.	• Chukai River Kemaman, Terengganu	Mahmod et al. (2018)
25	*Heritiera littoralis* Dry. ex W. Ait. (Sterculiaceae)	• Klias River, Sabah	Chey (2004)
26	*Hibiscus tiliaceous*	• Raan River, Miri, Sarawak • Garama River, Sabah	Abdullah et al. (2021); Cheng et al. (2017); Foo and Mahadimenakbar (2017); Juliana et al. (2012); Mahadimenakbar et al. (2007)
27	*Hibiscus tiliaceus* L.	• Kerteh River, Terengganu • Chukai River Kemaman, Terengganu	Jusoh et al. (2011); Mahmod *et al.* (2018)
28	*Lumnitzera littorea* (Combretaceae)	• Kawang River, Sabah	Chey (2008); Chey (2009); Foo and Mahadimenakbar (2016)
29	*Nypa fruticans*	• Garama River, Sabah • Sungai Selangor, Kampung Kuantan	Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2017); Jusoh et al. (2010b); Juliana et al. (2012); Mahadimenakbar et al. (2007)
30	*Nypa fruticans* Wurmb	• Kerteh River, Terengganu • Chukai River Kemaman, Terengganu	Jusoh et al. (2011); Mahmod et al. (2018)
31	*Pandanus* sp.	• Sibuti River, Miri, Sarawak	Abdullah et al. (2021)
32	*Rhizophora apiculata* (Rhizophoraceae)	• Raan River, Miri, Sarawak • Sibuti River, Miri, Sarawak • Niah River, Miri, Sarawak • Garama River, Sabah • Klias, River • Teratak River, Sabah • Paitan River, Sabah • Mangrove of Sepilok Forest Reserve, Sandakan • Sakar Island off coast of Lahad Datu Sabah	Abdullah et al. (2021); Chey (2004); Chey (2006); Chey (2008); Chey (2010); Chey (2011); Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2017); Mahadimenakbar et al. (2007)

Table 3 *(continue)*

No.	Scientific Name	Location	References
33	*Rhizophora apiculata* Blume	• Kerteh River, Terengganu	Jusoh et al. (2011)
34	*Rhizophora mucronata* (Rhizophoraceae)	• Mangrove of Sepilok Forest Reserve, Sandakan • Sakar Island off coast of Lahad Datu Sabah • Kawang River, Sabah	Chey (2008); Chey (2011); Foo and Mahadimenakbar (2016)
35	*Rhizophora* sp.	• Sepetang Estuary	Jusoh et al. (2010b)
36	*Rhizophora stylosa*	• Sakar Island off coast of Lahad Datu Sabah	Chey (2011)
37	*Scyphiphora hydrophyllacea* (Rubiaceae)	• Sakar Island off coast of Lahad Datu Sabah • Paitan River, Sabah • Mangrove of Sepilok Forest Reserve, Sandakan • Trayong, Tuaran	Chey (2006); Chey (2008); Chey (2009); Chey (2011)
38	*Sonneratia alba* J. Smith	• Weston River, Sabah	Foo and Mahadimenakbar (2017)
39	*Sonneratia caseolaris*	• Sepetang River, Kampung Dew • Sungai Selangor, Kampung Kuantan • Sepetang Estuary • Bernam River, Selangor	Cheng *et al.* (2017); Hazmi and Sagaff (2018); Juliana et al. (2012); Jusoh et al. (2010b); Shahara et al. (2017)
40	*Sonneratia caseolaris* (L.) Engl.	• Kerteh River, Terengganu • Chukai River Kemaman, Terengganu	Cheng *et al.* (2017); Jusoh et al. (2011); Mahmod et al. (2018)
41	*Thespesia populnea*	• Raan River, Miri, Sarawak	Abdullah et al. (2021)
42	*Xylocarpus granatum*	• Sibuti River, Miri, Sarawak	Abdullah et al. (2021); Chey (2006)
43	*Xylocarpus granatum* J. König	• Kerteh River, Terengganu	Jusoh et al. (2011)



(a) (b) (c)

Figure 3. (a) *Pteroptyx tener* larvae feed on *Plectostoma fraternum* in Sukau, Kinabatangan, Sabah; (b) A pair of *Pteroptyx tener* flashes synchronously on a mangrove tree (Malaysia); (c) Pteroptyx *tener* mating in *Sonneratia caseolaris* (Berembang tree) during the day (Malaysia) (Cheng et al., 2021)

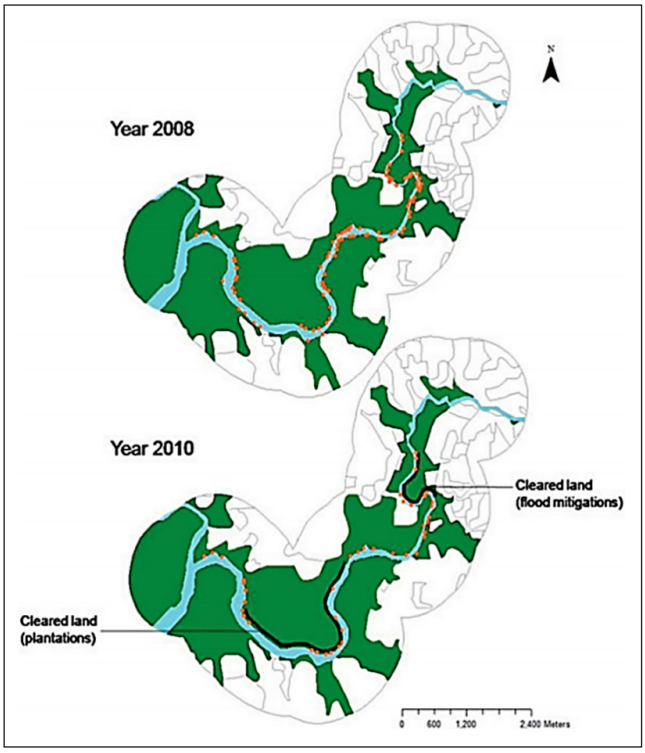


Figure 4. Changes in the number of firefly display trees (orange dots) along the banks of the Rembau-Linggi estuary (2008-2010) (Jusoh and Hashim, 2012)

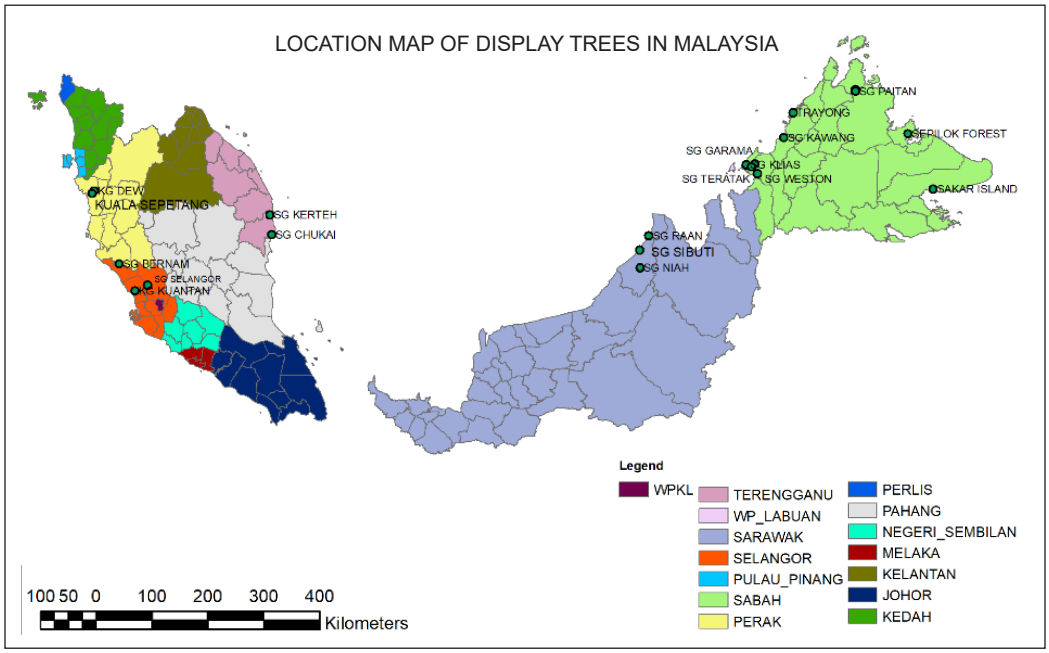


Figure 5. Distribution of firefly's display trees throughout Malaysia

CONCLUSION

Fireflies undergo a complete metamorphosis with four phases in their life cycle: egg, larva, pupa, and adult, all highly dependent on mangrove plants. Although they have been shown to rely on mangrove plants, particularly *Sonneratia caseolaris*, there are trees of other species that also host or display trees for fireflies. Therefore, there is a need to conserve all plant species near their habitat, including the host/display trees utilised by fireflies at different phases of their lifespan. The host/display trees are essential as they depend on different plant species for protection and feed (mangrove snails are a source for their diet). At the same time, the conservation of these plant species would aid in the protection of the diminishing firefly species, particularly in ecotourism hotspots such as Sabah (Likas), Rembau River (Negeri Sembilan), and Kuala Selangor (Selangor). Lastly, the richness and evenness of firefly species in Malaysia are infinite diverse with D = 0.2255 according to the Simpson's Diversity Index.

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