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Review Article

The Importance of Vegetation Landscape in Firefly Habitats

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ABSTRACT

This study explores the importance of vegetation (display trees) in shaping the habitat preferences, mating behaviours, and survival strategies of *Pteroptyx* fireflies in Southeast Asia, especially Malaysia. The research highlights the crucial role of diverse plant species, tree characteristics, and specific plant components in influencing firefly behaviour, emphasising the impact of vegetation composition, structure, and function. The findings underscore the essential role of vegetation in providing resources such as food, shelter, and suitable breeding sites, thereby shaping the distribution and abundance of firefly populations in their natural habitats. Moreover, the study elucidates the significant influence of plant-related chemical compounds and emissions on firefly behaviour and ecosystem dynamics, underscoring the intricate interplay between plant life and insect populations. This comprehensive understanding of the intricate dynamics between fireflies and their vegetation landscape has substantial implications for conservation efforts and the sustainable management of their habitats.

Keywords: Chemical compounds, display trees, fireflies, Malaysia, *Pteroptyx*, sustainable management, vegetation

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INTRODUCTION

Fireflies (Coleoptera: Lampyridae), also known as lightning bugs, are charismatic insects that attract many people worldwide because of their bioluminescence (Faust, 2004), which enables them to light up the night sky. Yet, these insects experience threats to their ecosystem, and the vegetation landscape is a vital determinant in their

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survival. Vegetations are vital in firefly ecosystems because they offer these insects food, shelter, and breeding grounds (Jusoh et al., 2010a; Kaiser et al., 2017; Sriboonlert et al., 2015; Wattanachaiyingcharoen et al., 2011).

Firefly habitats range from mangroves to rivers, inland to highlands (Ballantyne et al., 2011). The abundance of vegetation not only provides them with a suitable habitat but also allows them to hide during the day and increases their chances of finding a mate when females respond to male signals from perches in vegetation (Lewis & Cratsley, 2008; Wang et al., 2007). Unfortunately, the population of fireflies has been declining recently (Lauff, 2017). One of the main causes is the destruction of their environment brought on by urbanisation and deforestation (Nadirah et al., 2020; Thancharoen, 2007).

On a variety of temporal scales, the vegetation landscape influences biogeochemical functions (such as production and nutrient cycling, controlling soil condition), ecological functions (such as habitats for organisms at various tropical levels), and anthropogenic functions (such as sediment management) (Bouillon et al., 2008; Field et al., 1998; McKee & Faulkner, 2000). However, little is known about the specific vegetation characteristics that support firefly populations in different habitats. Understanding the vegetation landscape of firefly habitats can provide insights into the ecology and conservation of these insects.

Several key research gaps warrant attention in the pursuit of understanding fireflies' display tree preferences in Malaysia. Firstly, there remains a need for a comprehensive and systematic assessment of the underlying ecological and environmental factors influencing the selection of specific display trees by fireflies. Investigating the precise role of vegetation composition, structure, and function in shaping the display tree preferences of fireflies could provide valuable insights into the intricacies of their habitat selection.

Furthermore, a deeper exploration of the chemical and physical attributes of favoured display trees and their potential influence on firefly behaviour is essential. Understanding the specific plant-related compounds or emissions that attract fireflies to certain tree species could illuminate the interplay between plant chemistry and firefly ecological dynamics.

Lastly, Lampyridae's genetic foundation and evolutionary traits lead to a lack of comprehensive information in public databases regarding firefly species. Despite their ecological significance and potential as umbrella species for conservation efforts, the paucity of genetic data and comprehensive knowledge limits effective strategies for their preservation.

THE ROLE OF VEGETATION LANDSCAPE (COMPOSITION, STRUCTURE, AND FUNCTION)

Vegetation Landscape (Composition)

The overall physical appearance of an area primarily defined by its vegetation is referred to as a vegetation landscape. The plant community's composition, structure, and function can be used to describe a vegetation landscape. Vegetation landscape refers to an area's physical and visible features determined by the types of plants that grow in that area. It encompasses the natural distribution and patterns of different plant species and the ecosystems and habitats they create. Fireflies inhabit many habitats, including mangrove forests, rivers, inland, and the highlands (Ballantyne et al., 2011), particularly along elevational ranges, and are most prevalent in locations with high humidity and extensive vegetation (Branham, 2010; Branham, 2015). Figure 1 highlights the interconnectedness of composition, structure, and function in vegetation landscape, emphasising the importance of balanced, diverse landscapes for supporting firefly populations and holistic habitat management for conservation.

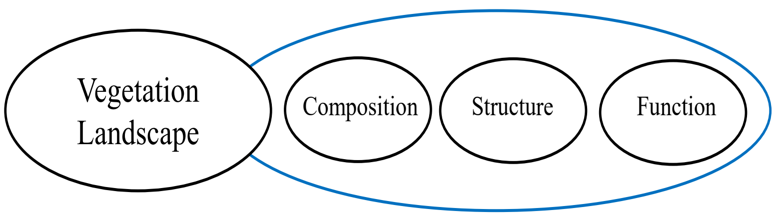

Figure 1. Three elements of vegetation landscape in firefly habitat

The vegetation landscape may include a variety of plants native to the region, such as trees, shrubs, grasses, and other types of vegetation. It is known as composition in the vegetation landscape, which refers to the various types of plants available in a certain ecosystem or geographical area. The composition of the vegetation landscape within firefly habitats refers to the diverse array of plant species that play a crucial role in providing the necessary resources for the survival and thriving of firefly populations. Understanding the intricate composition of vegetation is essential for comprehending the complex ecological dynamics that govern firefly habitats. In the context of firefly ecosystems, the composition of the vegetation landscape encompasses various aspects, including the types of plants present, their distribution patterns, and their ecological significance for fireflies. For example, in the firefly's habitat area, they are found on certain species of riparian vegetation, including *Sonneratia caseolaris*, *Hibiscus tiliaceus*, *Nypa fruticans*, *Acrotichum aureum*, *Areca cathechu*, *Oncosperma tigillarium*, and *Ficus* sp., especially in Peninsular Malaysia and Thailand (Juliana et al., 2012; Khoo et al., 2012; Prasertkul, 2018). Figure 2 illustrates five vegetation assemblages related to *Pteroptyx tener* abundance. Vegetation Group A (*Sonneratia caseolaris*-*Rhizophora*); Vegetation Group B (*Sonneratia caseolaris*-*Nypa fruticans*); Vegetation Group C (*Sonneratia caseolaris*-*Rhizophora*-*Nypa fruticans*); Vegetation Group D (*Sonneratia caseolaris*-*Rhizophora*-*Acrostichum Aureum*); Vegetation

Group E (*Sonneratia caseolaris*-*Rhizophora*-*Nypa fruticans*-*Acrostichum Aureum*) (Jusoh et al., 2010b).

In addition, fireflies were found appearing in other vegetation species in riparian areas, including *Rhizophora apiculata*, *Clerodendrum inerme*, *Glochidion littorale*, *Bruguiera parviflora*, and *Excoecaria indica* (Chey, 2004; Mahadimenakbar & Saikim, 2016) proving that tree selection the display of these species is not necessarily from the same vegetation species (Chey, 2004; Ohba & Wong, 2004).

Table 1
Classification of vegetation assemblies in firefly areas (Jusoh et al., 2010b)

Vegetation Assemblage	Vegetation Species	Diagram of Vegetation Assemblage	Vegetation Profile
A	• *Sonneratia caseolaris* • *Rhizophoria* sp.		
B	• *Sonneratia caseolaris* • *Nypa fruticans*		
C	• *Sonneratia caseolaris* • *Rhizophoria* sp. • *Nypa fruticans*		
D	• *Sonneratia caseolaris* • *Rhizophoria* sp. • *Acrotischum aureum*		
E	• *Sonneratia caseolaris* • *Rhizophoria* sp. • *Nypa fruticans* • *Acrotischum aureum*		

Note:

 *Sonneratia caseolaris*

 *Acrotischum aureum*

 *Nypa fruticans*

 *Rhizophoria* sp.

Within firefly habitats, various plant species contribute to creating a suitable environment for fireflies, offering essential resources such as food, shelter, and breeding sites. Certain vegetation types are more favourable for firefly populations, indicating a specific preference for plant species. Previous research (Chey, 2010; Jusoh et al., 2010b; Norela et al., 2017) have identified several key plant species that serve as favoured habitats for fireflies, such as *Sonneratia caseolaris*, *Rhizophora apiculata*, *Nypa fruticans*, and many others, emphasising the importance of specific plant compositions for firefly survival.

Furthermore, the diversity of vegetation composition within firefly habitats is critical in supporting the broader ecosystem, fostering a rich and balanced environment for various flora and fauna. The presence of specific plant species, especially those with high ecological significance, contributes to the habitat's overall biodiversity and ecological stability. For instance, as one of the initial trees to emerge on tidal mudflats, *Sonneratia caseolaris* helps to stabilise the riverbanks and coastal areas, creating a more conducive environment for the growth of other varieties of trees and plants. Studies have indicated that the spontaneous regrowth of *Sonneratia caseolaris* is highly effective, often eliminating the necessity for deliberate planting efforts (Aziz et al., 2012).

Vegetation Landscape (Structure)

The structure of the vegetation landscape refers to the physical arrangement and spatial distribution of plant communities within a particular landscape or ecosystem. It encompasses various characteristics such as the type and abundance of vegetation, the height and size of plants, the arrangement and spacing of plant communities, and the distribution of plant species and their associated habitats. *Sonneratia caseolaris*, a firefly's favourite display tree, has a distinct structural architecture that distinguishes it from other trees. It has a more complex structure and larger plants, providing more resources for insects to thrive, particularly food sources, such as leaves and litter (Abdullah et al., 2019).

Due to unique tree characteristics/structures such as height, crown size, leaf density, and stem diameter, Jusoh et al. (2010a) assumed that fireflies only occupied young *Sonneratia caseolaris* trees. This research suggests that the specific characteristics and structure of *Sonneratia caseolaris* trees, including their height, crown size, leaf density, and stem diameter, play a significant role in the habitat preferences of fireflies. The study implies that fireflies tend to occupy or prefer young *Sonneratia caseolaris* trees, likely due to certain advantageous features offered by these trees. Young trees may provide an ideal environment for mating and breeding fireflies, offering suitable conditions such as manageable heights for light signalling, appropriate crown sizes for shelter, optimal leaf density for protection and food sources, and stem diameters that may facilitate various life cycle activities.

An optimal foliage density within these landscapes fosters a rich insect population, ensuring an essential food supply for firefly larvae and adults. Moreover, maintaining a balanced foliage density creates a favourable microclimate that sustains firefly populations' healthy development and activity. The unique combination of these three characteristics is thought to create an environment conducive to the specific requirements of fireflies, which may explain their preference for young *Sonneratia caseolaris* trees over other tree types or age groups. Further exploration of these tree characteristics and their relationship with firefly behaviour and habitat selection can provide valuable insights into the intricate dynamics of their ecological interactions, contributing to a deeper understanding of the factors influencing the distribution and abundance of firefly populations within their natural habitats.

Moreover, *Pteroptyx olivier* was also found in numerous mangrove swamp shrub trees (Jusoh et al., 2018). There was a reason why this species of firefly preferred mangrove trees, such as the fact that *Pteroptyx* fireflies preferred trees with a greater proportion of apertures or open spaces in the canopy. In contrast, trees surrounded by 0 to 25% open space are seldom chosen as display trees. *Pteroptyx* fireflies never inhabit trees with a dense canopy (Jaikla et al., 2020). Unfortunately, the conversion of mangrove swamp forests to other land use land cover (LULC) led to a reduction of more than half of the number of display trees inhabited by fireflies in the Rembau-Linggi estuary. This development will certainly jeopardise the firefly population in the area (Jusoh & Hashim, 2012).

Fireflies are bioluminescent insects that survive and reproduce by relying on vegetation cover and structure. Thus, their abundance, distribution, and behaviour can be influenced by the type and distribution of vegetation in their habitats. *Pteroptyx* larvae that feed on snails and reside in moist, frequently flooded soils are vulnerable to events such as rain, and many prey are likely to harm both larval and adult populations (Loomboot, 2007). It results from adult females depositing eggs in wetlands in river intertidal zones. Mangrove snails and other soft-bodied animals are firefly larvae prey (Barrows et al., 2008; Lewis et al., 2020). Prasertkul (2018) hypothesises that the trees that have attracted large numbers of *Pteroptyx* may be adjacent to the oviposition or eclosion site of the female pupa, which may be related to the larval feeding site. Yet, there is currently insufficient evidence to support any hypothesis.

Vegetation landscape structure becomes more important to fireflies because daytime resting sites for terrestrial larvae have been postulated in the soil, leaf litter, and rock crevices (Vaz et al., 2020; Vaz, Manes et al., 2021). These larvae are visible at night on the surface, creeping through the weeds and grass and occasionally climbing a few inches up the stem, especially under humid conditions (Faust, 2017). The larvae prepare for pupation by creating a dirty chamber in the soil, where they will reside for six to ten days until emerging as adult fireflies (Nallakumar, 2003).

Vegetation Landscape (Function)

Plants' ecological roles in the ecosystem are referred to as functions in the vegetation landscape, such as providing food and habitat for wildlife. According to Jusoh et al. (2010b), firefly populations are ecologically linked to ground cover with display trees and/or specific plant assemblages. For instance, the vegetation landscape in the forest area, especially mangrove forests, plays a critical role in maintaining a healthy ecosystem for fireflies. A healthy ecosystem for fireflies includes food for them to consume. Although the nutritional requirements of adult *Pteroptyx tener* are unknown, it is assumed that this insect feeds on the nectar and sap of mangrove trees (Cheng et al., 2017). Some congregating firefly species, notably *Photinus pallens*, may have resource-related leks (mating swarms), such as nectar or plant sap (Lloyd, 1998).

However, research shows that this vegetation provides important food sources for fireflies, such as sugar in the nectar/sap from trees for adults to feed (Jusoh et al., 2010a, 2010b; Othman et al., 2018). It is uncertain how much Southeast Asian *Pteroptyx* lekking behaviour is related to food because the main display tree plant, *Sonneratia caseolaris*, does not flower and fruit year-round, unlike *Hibiscus tiliaceus*. While *Terminalia catappa*, another non-primary display tree, blossoms and bears fruit twice a year (Prasertkul, 2018). Hence, it may be inferred that the appearance of flowers or fruits on trees is not a prerequisite for forming a firefly's colonies. Prasertkul (2018) reveals that *Pteroptyx malaccae* and *Pteroptyx valida* may select plants based on seasonal suitability and broad-leaved species such as *Terminalia catappa* or *Acacia mangium*. These plant species may be protected from wind and rain.

In addition to providing food and shelter, the vegetation landscape is also essential for fireflies' mating and breeding behaviour (Kaiser et al., 2017). Fireflies use their light signals to communicate with potential mates (Fallon et al., 2019), and the vegetation landscape provides a suitable platform for them to do so. The light signals are also used to attract prey (Bechara & Stevani, 2018), so the presence of vegetation helps to ensure enough food for the fireflies to survive and reproduce.

Jusoh et al. (2010b) proposed that suitable display trees for *Pteroptyx* include those that are (1) near the water's edge, (2) sturdy trees, (3) near larval food sources, (4) provide nectar or rubber for the adults' diet, and (5) have a leaf arrangement that is easy for flash communication. Meanwhile, Ohba and Wong (2004) proposed that several factors influence firefly species' selection of display trees, including (1) the display tree should be near the water's edge, as this facilitates firefly communication, (2) each display tree's leaf arrangement must be ideal for mating, (3) the display tree must be in good health, (4) must contain nectar or rubber for an adult if they eat, and (5) the larval prey food.

Furthermore, the vegetation landscape is important for maintaining the quality of the habitat because vegetation helps to prevent soil erosion, filter pollutants, and maintain water quality in streams and rivers. It is important for firefly habitats, as water sources are essential for the survival of firefly larvae. Adult fireflies and their larvae may also be affected by saltwater intrusion resulting from water pollution caused by pesticides from agricultural landfills and illegal emissions (Lewis et al., 2020). It is evident when the number of fireflies is decreasing due to changes in river water quality caused by river pollution, diesel use, and development around firefly habitat areas (Jusoh et al., 2010b).

Vegetation provides shelter and hiding places for fireflies during the day. Fireflies are found in the butterfly larvae nests left out during the day (Ohba & Wong, 2004). It is due to the high light intensity during the day, forcing the fireflies to seek a dark environment. Therefore, it can be concluded that a suitable vegetation landscape to be used as a habitat for fireflies must have these characteristics. It is recommended that future research be done to observe the behaviour of these fireflies during the day, especially in areas exposed to sunlight.

The vegetation also helps to maintain humidity levels in the habitat, which is important for the survival of firefly eggs and larvae. Without the proper vegetation landscape, firefly habitats become dry and inhospitable, leading to a decline in firefly populations. Jusoh et al. (2010a) stated that firefly eggs needed wet soil and a shaded location to survive heat and dryness. Fireflies preferred plants from *Rhizophora* species (*Rhizophora Mucronata* and *Rhizophora Apiculata*) to deposit their eggs (Norela et al., 2017).

FIREFLY DISPLAY TREES IN MALAYSIA

Table 1 shows the tabulation of firefly display trees in Malaysia. This table displays the firefly display trees plants, highlighting the diverse range of plant species that serve as habitats for different firefly species. In Malaysia, firefly display trees are those specifically favoured by fireflies for their light signalling behaviours and reproduction. These trees, typically found in mangrove areas and other suitable habitats, play a crucial role in supporting the life cycle of fireflies. Some common firefly display trees in Malaysia include *Sonneratia caseolaris* and other mangrove species like *Rhizophora apiculata* and *Nypa fruticans*. These trees provide an essential environment for fireflies to thrive, offering suitable surfaces for light signalling, shelter, and food sources. Understanding the significance of these specific trees in the context of firefly habitats is essential for conserving and managing firefly populations in Malaysia, contributing to preserving this natural wonder for future generations.

Since Malaysia has a vast area of mangrove forest, a favoured habitat for fireflies, this may be one of the reasons why many species of fireflies have been identified in Malaysia, and there may be even more undocumented species. The total mangrove forest cover worldwide is 15.62 million hectares, with 577,940 hectares (3.7%) in Malaysia. Although this percentage is small, mangrove swamp forests are among Malaysia's most important forest types. In Peninsular Malaysia, the area of mangrove swamp forest is 98,249.8 hectares (17%), Sabah has the largest mangrove swamp forest area in Malaysia at 338,672.8 hectares (58.6%), and Sarawak covers 141,017.4 hectares (24.4%) of the total (Ahmad et al., 2018). The comprehensive presence of mangrove swamp forests across the country underscores their critical role in supporting diverse flora and fauna, including firefly populations. Understanding the distribution and extent of these forests aids in implementing effective conservation strategies. It underscores the significance of preserving these crucial habitats for the sustained well-being of various species, including fireflies. Further research and documentation of firefly species within these mangrove habitats is essential for developing comprehensive conservation efforts and ensuring the long-term survival of these unique and fascinating insects in Malaysia.

Meanwhile, *Nypa fruticans* and *Metroxylon sago* are important for firefly larvae because their food sources, which are snail prey, live in that area (Nada & Kirton, 2004). The density of firefly larvae is higher in sago plantations than in oil palm trees (Kirton et al., 2006), which may be related to more snails in sago plantations. Tiny snails (*Cyclotropis carinata*) are prey of firefly larvae that inhabit the riverbanks (Nada & Kirton, 2004) and are becoming increasingly endangered because of human activities or natural disasters (Foo & Mahadimenakbar, 2015).

It also serves as a habitat for their prey, such as snails, an essential food source for firefly larvae. The survival of fireflies in their larval stage depends on the tiny snails that live in the damp areas of mangrove swamps. Fireflies spend a substantial amount of time in this stage, which lasts 97.83 days, depending on the river water (Loomboot et al., 2007). The larvae, which feed on river snails, are frequently found 5 to 30 metres from Nipah and Sago palm trees (Loomboot et al., 2007).

Table 1
Firefly display trees in Malaysia

Scientific Name	Vernacular name	Sources
Acrostichum aureum	Coarse Swamp Fern	Jusoh et al. (2010b); Juliana et al. (2012); Foo and Mahadimenakbar (2015)
Aegiceras floridum	Black Mangrove	Foo and Mahadimenakbar (2016)
Areca catechu	Pinang	Nada et al. (2009)
Avicennia alba Blume	Api-api Hitam	Chey (2006); Jusoh et al. (2011); Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2017);
Avicennia marina	Api-api Jambu	Abdullah et al. (2020)
Avicennia rumphiana	Api-api Bulu	Abdullah et al. (2020)
Barringtonia sp.	-	Ohba and Wong (2004); Mahmod et al. (2018)

Table 1 *(Continue)*

Scientific Name	Vernacular name	Sources
Barringtonia racemosa (L.) Spreng.	Putal Kedul	Jusoh et al. (2011)
Brownlowia argentata	-	Jusoh et al. (2011)
Bruguiera gymnorrhiza	Tumu Merah	Ohba and Wong (2004); Jusoh et al. (2011)
Bruguiera parvifloraa	-	Mahadimenakbar et al. (2007); Abdullah et al. (2020)
Ceriops decandra	Tengar	Jusoh et al. (2011)
Clerodendrum inerme (Verbenaceae)	-	Chey (2010)
Derris sp.	-	Abdullah et al. (2020)
Derris trifoliata Lour	Common Derris	Jusoh et al. (2011)
Excoecaria agallocha L.	Bebuta	Jusoh et al. (2011); Foo and Mahadimenakbar (2017)
Excoecaria indica L.	-	Foo and Mahadimenakbar (2017)
Excoecaria indica (Willd.) Muell. Arg. (Euphorbiaceae)	-	Chey (2004); Mahadimenakbar et al. (2007)
Ficus binjamina	-	Mahadimenakbar et al. (2007)
Ficus microcarpa (Moraceae)	Jejawi	Chey (2010)
Ficus sp.	-	Ohba and Wong (2004); Juliana et al. (2012); Shahara et al. (2017)
Glochidion littorale (Euphorbiaceae)	Selunsur	Chey (2010)
Gluta velutina Blume	Rengas Air	Ohba and Wong (2004); Jusoh et al. (2011)
Guilandina bonduc L.	Grey Nicker	Mahmod et al. (2018)
Heritiera littoralis Dry. ex W. Ait. (Sterculiaceae)	Dungun	Chey (2004)
Hibiscus tiliaceus/ *Talipariti tiliaceum*	Bebaru Tree	Ohba and Wong (2004); Mahadimenakbar et al. (2007); Jusoh et al. (2011); Juliana et al. (2012); Abdullah et al. (2020); Cheng et al. (2017); Foo and Mahadimenakbar (2017); Jusoh et al. (2018); Mahmod et al. (2018)

Table 1 *(Continue)*

Scientific Name	Vernacular name	Sources
Lumnitzera littorea (Combretaceae)	Teruntum Merah	Chey (2008); Chey (2009); Foo and Mahadimenakbar (2016); Jusoh et al. (2018)
Metroxylon sagu	Pokok Sagu	Nada et al. (2009)
Nypa fruticans Wurmb		Ohba and Wong (2004); Mahadimenakbar et al. (2007); Jusoh et al. (2010b); Jusoh et al. (2011); Juliana et al. (2012); Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2017); Mahmod et al. (2018)
Oncosperma tigillarium	Nibung Palm	Nada et al. (2009); Juliana et al. (2012)
Pandanus sp.	-	Abdullah et al. (2020)
Rhizophora apiculata Blume	Bakau Minyak	Chey (2004); Chey (2006); Mahadimenakbar et al. (2007); Chey (2008); Chey (2010); Chey (2011); Jusoh et al. (2011); Foo and Mahadimenakbar (2015); Foo and Mahadimenakbar (2017); Jusoh et al. (2018); Abdullah et al. (2020)
Rhizophora mucronata	Bakau Kurap	Chey (2008); Chey (2011); Foo and Mahadimenakbar (2016)
Rhizophora sp.	Bakau	Jusoh et al. (2010b)
Rhizophora stylosa	Bakau Kurap	Chey (2011)
Scyphiphora hydrophyllacea	Chengam	Chey (2006); Chey (2008); Chey (2009); Chey (2011)
Sonneratia alba	Perepat	Jusoh et al. (2011); Foo and Mahadimenakbar (2017); Jusoh et al. (2018)
Sonneratia caseolaris (L.) Engl.	Berembang	Jusoh et al. (2010b); Jusoh et al. (2011); Juliana et al. (2012); Cheng et al. (2017); Hazmi and Sagaff (2017); Shahara et al. (2017); Jusoh et al. (2018); Mahmod et al. (2018)
Thespesia populnea	Bebaru	Abdullah et al. (2020)
Xylocarpus granatum J. König	Nyireh Bunga	Chey (2006); Jusoh et al. (2011); Jusoh et al. (2018); Abdullah et al. (2020)

FIREFLY DISPLAY TREES CHEMICAL COMPOUND

Three varieties of cuticular wax (crustose, granules, and flake cuticular wax) were detected on the leaf epidermal surfaces of four tree species, namely *Sonneratia caseolaris*, *Barringtonia racemosa*, *Gluta renghas*, and *Hibiscus tiliaceus*, potentially contribute to the influencing factors in the selection of display trees by fireflies. All four tree species exhibited flake cuticular wax except for *Sonneratia caseolaris*, which displayed granular and crustose cuticular wax on its epidermal surface (Norela et al., 2020). Cuticular wax constitutes a lipid-based covering that envelops the external surface of leaves and other plant structures. It comprises a blend of lipids, encompassing fatty acids, alcohols, and hydrocarbons. This shielding layer serves to safeguard the plant from diverse threats, including loss of moisture (Sevanto, 2020), ultraviolet (UV) radiation (Krauss et al., 1997), damage caused by herbivores (Eigenbrode & Espelie, 1995), elevated temperatures (Salem-Fnayou et al., 2011), and physical strain (Dominguez et al., 2011; Khanal & Knoche, 2017).

The presence and composition of cuticular wax on plant surfaces are vital in influencing the abundance of insects, including fireflies, in their selected habitats. This protective wax layer serves as a physical barrier against pathogens (Wang et al., 2020), creating a safer environment for these insects by minimising the risk of pathogen invasion. Additionally, as a reservoir of signals triggering plant defence responses, cuticular wax indicates a healthier and more resilient ecosystem, potentially attracting insects like fireflies to habitats with robust defence mechanisms. Moreover, the cues provided by the cuticular wax layer, which pathogens could exploit, have implications for the overall health of the plant population. Well-maintained cuticular wax layers in habitats effectively regulating these cues can foster a more balanced and sustainable ecosystem, consequently drawing a higher abundance of insects, such as fireflies, reliant on a thriving plant environment for their survival and reproduction. Hence, the integrity and functionality of the cuticular wax layer in plant-pathogen interactions indirectly influence the presence and population density of insects, including fireflies, as they tend to favour habitats with effective protective mechanisms, contributing to a sustained presence in these environments.

Trichomes were observed exclusively on *Gluta renghas* and *Hibiscus tiliaceus* leaf epidermal surfaces. However, no trichomes were detected on the epidermal surface of *Sonneratia caseolaris* and *Barringtonia racemosa*. Consequently, *Sonneratia caseolaris* and *Barringtonia racemosa* may possess diminished leaf resistance (Norela et al., 2020). The absence of trichomes on the epidermal surface of *Sonneratia caseolaris* and *Barringtonia racemosa* may suggest lower resistance to environmental stressors and herbivores. Consequently, these plants could be more attractive to fireflies for laying their eggs, as the lack of trichomes might provide easier access to suitable locations for their reproductive activities. However, when considering the findings by Norela et al. (2020) that plants without trichomes might be more attractive to fireflies for egg-laying, it is essential to reconcile this with the observation that female fireflies typically deposit their eggs on the soil behind display trees, not directly on the trees themselves. This nuance raises questions about the direct association between plant trichome absence and firefly egg-laying preferences.

Furthermore, there appears to be a potential contradiction within their study's findings. While it suggests that fireflies may prefer plants with lower resistance due to the absence of trichomes, it contradicts earlier research (e.g., Jusoh et al., 2010a, 2010b; Norela et al., 2017; Ohba & Wong, 2004) indicating that fireflies tend to favour habitats with effective protective mechanisms. This article raises a question regarding the consistency of firefly habitat preferences. As stated earlier, do fireflies indeed prefer habitats with effective protective mechanisms, or are they more attracted to plants with lower resistance, as suggested by the absence of trichomes? It may be necessary to consider a more comprehensive understanding of firefly habitat selection, acknowledging that multiple factors beyond trichome presence or absence can influence their preferences to resolve this apparent contradiction. Further research and a nuanced exploration of the interplay between firefly behaviour, plant characteristics, and habitat dynamics may clarify this.

Excoecaria agallocha, commonly called the blind-your-eye mangrove, is a unique mangrove plant belonging to the Euphorbiaceae family. Notably, the milky latex produced by this plant contains various phytotoxins, particularly the excoecariatoxins, which possess potent irritant properties affecting the skin, eyes, and mucous membranes. These phytotoxins are attributed to three distinct groups of diterpene esters of the daphnane and tigliane types, which are responsible for the toxic effects exhibited by *Excoecaria agallocha* (Chan et al., 2018). The presence of phytotoxins in the *Excoecaria agallocha* plant's latex significantly impacts the behaviour and interactions of various insects, including fireflies, within the surrounding ecosystem. The irritant properties of the latex serve as a natural defence mechanism, deterring potential predators and herbivores from feeding on the plant, indirectly creating a safer environment for fireflies to thrive and reproduce. Additionally, the existence of these toxic compounds in the environment, particularly in regions abundant with *Excoecaria agallocha*, can alter the foraging behaviour of fireflies, potentially leading them to favour other plant species or habitats, thus influencing their distribution and population dynamics. Moreover, the toxic nature of the plant's latex may impact the selection of suitable breeding and mating sites for fireflies, as they may actively avoid areas with high concentrations of *Excoecaria agallocha* to safeguard themselves from potential harm.

According to the National Parks Board of Singapore (2022), *Sonneratia caseolaris* is recognised for its ability to attract fireflies through its aromatic flowers and emission of volatile organic compounds (VOCs). The tree exhibits striking red flowers that bloom at dusk, emitting a fragrance resembling sour milk that persists for a single night. While the precise mechanism by which the VOCs of *Sonneratia caseolaris* entice fireflies is not yet entirely comprehended, it is suggested that these organic compounds function as a signal for the fireflies, potentially aiding them in locating and recognising potential mates. This fascinating correlation between the plant's emissions and the behavioural patterns of fireflies illuminates the intricate workings of the natural world, underscoring the diverse ways in which different organisms communicate and interact within their shared ecosystems. Further investigation into this dynamic relationship has the potential to yield valuable insights into the broader ecological significance of such interactions and their impact on the overall biodiversity and sustainability of the surrounding environment.

Fireflies have also been found in *Guilandina bonduc* L. and *Barringtonia* sp. vegetation, though not with the best synchronisation (Mahmod et al., 2018). The presence of the plant *Barringtonia racemosa* in a habitat or ecosystem can repel the presence of insects because this plant species is known to contain the insecticide Saponin (Osman et al., 2017), potentially leading to a reduced presence of insects, including fireflies, within its vicinity. This repellent effect is linked to the plant's ability to release Saponin, a natural defence mechanism against insect infestations and herbivory. The implications of *Barringtonia racemosa's* presence on insect populations underscore the intricate relationships between plant chemistry and the ecological balance of a habitat. While the protective characteristics of Saponin contribute to the plant's resilience and survival, they can also inadvertently impact the broader ecosystem by influencing the abundance and distribution of insects, including those crucial to the ecosystem's biodiversity.

SIGNIFICANCE OF FIREFLY CONSERVATION IN TROPICAL ENVIRONMENTS

There are numerous Lampyridae species, and efforts to conserve them from extinction, such as making fireflies into enigmatic umbrella species, have been made. Still, the endeavour has come to a halt. Lampyridae's genetic foundation and evolutionary traits are still unknown, and public databases have relatively little information regarding fireflies (Fu et al., 2017). Several international treaties protect mangrove trees, which are crucial to reaching the Paris Climate Agreement's targets (Taillardat et al., 2018). Insects must be protected by being viewed as distinct species with specific survival mechanisms focusing on tropical insects and their environments (Basset & Lamarre, 2019). The species of fireflies must be conserved since they belong to the insect kingdom. Insects are the most varied group of multicellular animals on Earth, as purveyors of ecological services including pollination, pest control (biocontrol), decomposition, and energy transfer through the food chain, and many more (Chowdhury et al., 2017).

In this firefly conservation initiative, species distribution models (SDMs) are one of the modelling approaches that might be considered and utilised. Modelling SDMs can establish conservation guidelines by forest remnant and firefly protection rules. The outcomes of this modelling can combine taxonomic and ecological knowledge and contribute to filling in significant gaps in firefly biology (Vaz, Guerrazzi et al., 2021). This modelling also entails mapping the possible distribution of fireflies in their habitat areas to evaluate pressure changes over time. Then, the categorisation of potential distribution ranging from 0% to 100% suitable into three increasing suitability criteria, which corresponds to the projected fitness with the event location to determine the lowest fitness value at which any firefly is detected in the field (Vaz, Guerrazzi et al., 2021). This model can forecast biodiversity's spatial and temporal distribution in response to environmental stressors.

Malaysia is rich in natural resources, but if they are not managed and do not have solid and efficient protection or conservation strategy, it is no surprise that the country's biodiversity cannot last for a very long time. Thus, for the efficient protection of firefly populations, a thorough comprehension of their distribution, abundance, and habitat requirements is needed (Takeda et al., 2006). The conservation of these fireflies strongly relies on preserving their natural habitats, which are vital to their life cycle. Therefore, it is extremely important to conserve the habitat of fireflies, the mangrove forest, because this will indirectly protect the firefly species that inhabit the area. Among the successful and necessary conservation efforts to be followed by state and national forestry agencies are, as Goessens et al. (2014) proposed, mangroves replanting at Matang Mangrove Forest Reserve (MMFR) handled precisely with best practices in the world since 1902. Since Malaysia's independence in 1957, the MMFR has been maintained sustainably based on five work programs (Ibharim et al., 2015).

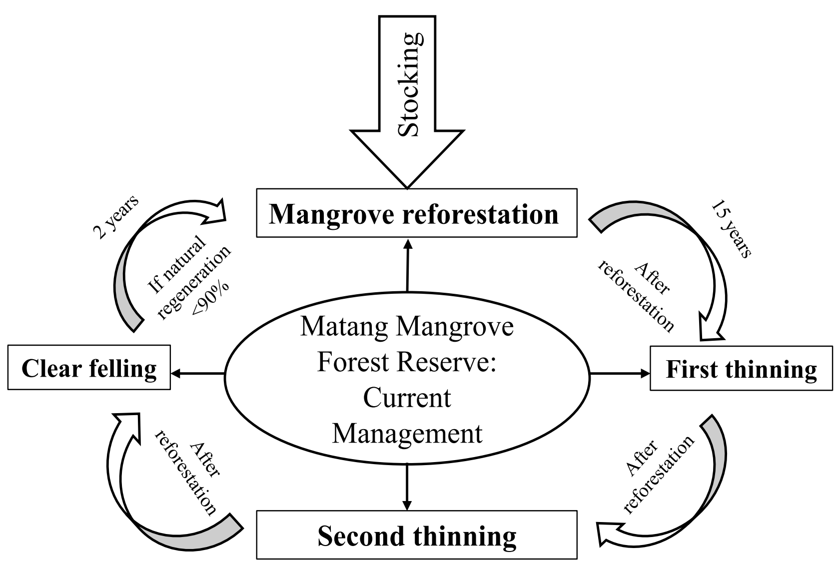

Figure 3. Matang Mangrove Forest Reserve (MMFR) management system (Goessens et al., 2014)

Figure 3 depicts the Matang Mangrove Forest Reserve in Perak-West Coast, Peninsular Malaysia. The yellow circle with red dots indicates the location of the Virgin Forest Reserve (VJR). At the same time, the block of Managed Mangrove Forest (marked with MF and including vegetation that is 15, 20, and 30 years old) is considered for silvimetric measures. Including silvicultural approaches in managing mangrove resources could result in more sustainable management (Roy, 2016; Santos & Lana, 2017).

CONCLUSION

In conclusion, fireflies, known as lightning bugs, hold a charismatic allure with their bioluminescent displays, capturing people's global fascination. However, their existence is threatened by various ecological pressures, predominantly stemming from human-induced changes in their natural habitats. The vegetation landscape plays a pivotal role in the survival and well-being of firefly populations, offering essential resources such as food, shelter, and breeding grounds. A thorough understanding of the vegetation landscape's composition, structure, and function is crucial for comprehending the complex ecological dynamics that govern firefly habitats.

The diversity of firefly habitats, ranging from mangroves to rivers and inland to highlands, underscores the significance of various vegetation types in supporting firefly populations. While the destruction of their habitats due to urbanisation and deforestation remains a primary concern, the specific characteristics of the vegetation landscape that support firefly populations are not yet fully understood. Research gaps persist, necessitating comprehensive assessments of the ecological and environmental factors influencing firefly preferences for specific display trees.

The chemical and physical attributes of favoured display trees, including the role of cuticular wax, trichomes, and plant emissions, are integral to firefly behaviour and habitat selection. Understanding the intricate interplay between vegetation characteristics and firefly ecology can illuminate the nuanced relationships between plants and insects, offering valuable insights into the underlying mechanisms shaping firefly habitats.

Furthermore, the conservation of fireflies is crucial for preserving the charismatic appeal of these insects and safeguarding the broader ecosystem. Given the limited genetic data and knowledge of firefly species, comprehensive conservation efforts are necessary to protect these insects from extinction. Species distribution models (SDMs) offer a promising approach to establishing effective conservation guidelines and mapping the potential distribution of fireflies in response to environmental changes. Implementing sustainable management practices, such as mangrove reforestation and silvicultural measures, can contribute to the long-term preservation of firefly habitats and the biodiversity they support.

By prioritising the conservation of fireflies and their habitats, especially within the rich tropical environments of countries like Malaysia, it is possible to ensure the sustained well-being of these captivating insects and the broader ecosystems they inhabit. Effective conservation strategies should aim to protect and restore the vegetation landscape, promoting the coexistence of fireflies and other vital organisms in these unique and diverse ecosystems.

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