ECOLOGICAL STUDY ON CONGREGATING FIREFLIES (COLEOPTERA: LAMPYRIDAE) IN SULAMAN LAKE FOREST RESERVE, SABAH, EAST MALAYSIA

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ABSTRACT

The purpose of this study was to examine the correlation between firefly population and abiotic factors in Sulaman Lake Forest Reserve (SLFR), Sabah, East Malaysia. Sampling was conducted at four sampling stations of SLFR using a sweep net. Water sampling has also been conducted. The study was conducted in July, October, and December 2021. The SLFR is dominated by one mangrove species tree, *Rhizophora apiculata*. A total of 97 individual fireflies were collected, with *Pteropytx bearni* (67) being the most abundant firefly species compared to *P. gelasina* (30). The average water quality of the SLFR was found to be in an acceptable standard value as determined by the Interim National Water Quality Standard (INWQS) Malaysia. Apart from other abiotic influences, water temperature (WT) and wind speed (WS) were found to be significantly different between stations (P<0.05) and months of sampling (P<0.05) between stations. Pearson correlation and stepwise regression analysis showed that there was a positive correlation (P<0.001) between relative humidity (RH) and the firefly population. Because of their sensitivity to the environment, fireflies are considered strong indicators of the health of ecosystems. An unfavourable atmosphere would eventually reduce the number of fireflies.

Keywords: Congregating fireflies, *Pteropytx*, Sabah, population monitoring, conservation, abiotic factors

ABSTRAK

Tujuan kajian ini adalah untuk mengkaji korelasi antara populasi kelip-kelip dengan faktor abiotik di Hutan Simpan Tasik Sulaman (SLFR), Sabah, Malaysia Timur. Persampelan telah dijalankan di empat stesen persampelan di SLFR menggunakan jaring udara. Persampelan air juga telah dijalankan. Kajian telah dijalankan pada Julai, Oktober dan Disember 2021. SLFR didominasi oleh satu spesies bakau, *Rhizophora apiculata*. Sebanyak 97 kelip-kelip individu telah dikumpulkan dengan *Pteropytx bearni* (67) merupakan spesies kelip-kelip yang paling dominan berbanding *P. gelasina* (30). Purata kualiti air SLFR didapati berada dalam nilai piawai yang boleh diterima seperti yang ditentukan oleh Piawaian Kualiti Air Kebangsaan Interim (INWQS) Malaysia. Selain daripada pengaruh abiotik lain, suhu air (WT) dan kelajuan angin (WS) didapati berbeza dengan ketara antara stesen (P<0.05) dan bulan pensampelan (P<0.05). Korelasi Pearson dan analisis regresi berperingkat menunjukkan terdapat korelasi positif (P<0.05) antara kelembapan relatif (RH) dan populasi kelip-kelip. Kerana kepekaan mereka terhadap alam sekitar, kelip-kelip dianggap sebagai indikator kuat ke atas kesihatan ekosistem. Persekitaran yang tidak sesuai akan mengurangkan bilangan kelip-kelip.

Kata kunci: Kelip-kelip berhimpun, *Pteropytx*, Sabah, pemantauan populasi, pemuliharaan, faktor abiotik

INTRODUCTION

Fireflies (Coleoptera: Lampyridae) are known for their flashing adults, and there are approximately 2,200 species identified worldwide that exhibit morphological and ecological diversity, including diurnal and dusky species that are less well known (Branham 2010; Martin et al. 2019). *Pteroptyx* spp. (Coleoptera: Lampyridae) have a habit of congregating and flashing in large numbers. In Thailand and other countries, the number of firefly tourists has increased, attracted by the synchronization of the communication flashes that the insects produce on the mangrove trees (Khoo et al. 2009; Thancharoen 2012). *Pteroptyx* spp. are valuable insects because they provide revenue to local communities through firefly boat trips.

Pteroptyx spp. can be found in saline or brackish water habitats and is considered an expert on the mangrove and intertidal zone (Jusoh et al. 2018; Ohba & Sim 1994). On the underside of their abdomen, these tiny insects are equipped with special luminescent organs that can flash in luminous flashes primarily for sexual communication (McDermott 1917; Lloyd 1983). A total of five species of *Pteropytx.* are currently known in Sabah, namely, *P. bearni* (Olivier 1909); *P. tener* (Olivier 1907); *P. malaccae* (Gorham 1880); *P. gelasina* (Ballantyne 2001) and *P. valida* (Olivier 1909).

Conservation of the *Pteropytx* firefly is important not only because of its economic importance. The firefly serves as a flagship species by encouraging people to protect their economic and aesthetic values by protecting the environment. Since its introduction as an economic and ecological value, it has shown the ability to get large numbers of people to participate in its conservation efforts. Studies have shown that getting the public interested in nature by conserving conspicuous species is critical to effective conservation (Suh & Samways 2001). A second reason is that fireflies are extremely sensitive to the environment. Both their larvae and adults are intolerant to pollution and chemicals. Therefore, fireflies are an excellent biomarker for an unpolluted and healthy environment. In Japan, for example, firefly larvae of *Luciola* spp. are used to test the quality of treated wastewater before it is discharged into the sea (Chan 2012). In this respect, they are relatively sensitive to changes in the environment (Yuma 2000).

This species has already received considerable conservation attention because of its widespread attractiveness. Effective conservation of firefly populations requires a thorough understanding of their range, abundance, and habitat requirements (Takeda et al. 2006). Surprisingly, there are only a few scientific data on the habitat requirements of the *Pteropytx* firefly that could lead to meaningful conservation measures. For instance, previous authors noted that despite the discovery of synchronous blinking fireflies of the genus *Pteroptyx* throughout Southeast Asia, little is known about their biodiversity (Jusoh et al. 2020; Jaikla et al. 2020; Mahadimenakbar & Fiffy 2016). Moreover, the population of the *Pteropytx* firefly has been declining rapidly, and human activities such as urbanisation, agriculture, and industrialization threaten its survival (Lewis et al. 2020; Nallakumar 2002; Ohba & Wong 2004; Wong 2008). Therefore, the objectives of this study were to determine: (i) the abundance of firefly population at the selected sampling stations, and sampling months (ii) the water quality level at selected sampling stations and sampling months, and (iii) the relationship between the abundance of firefly population and the water quality level measured at selected sampling stations of SLFR. This study provides significant information for habitat protection and species management in the SLFR.

MATERIAL AND METHODS

Study Area

Sulaman Lake Forest Reserve (SLFR) is a forest reserve in Sabah located southeast of Sulaman Harbour and north of Tanjong Serusup (Figure 1). The Forest Enactment of 1968 designated this area as a Class V Forest Reserve with a total size of approximately 2,635 hectares. This classification was made as part of Sabah's efforts to conserve mangrove forests. Several land titles belonging to the inhabitants of the surrounding villages surround this region (Kg. India, Temunong, Kg. Sambah, Kg. Serusop, and Simpangan). The SLFR serves as a loading point for the surrounding towns seeking access to the sea. Some villages rely on the sea for their subsistence. The field sampling was carried out within the floodplain approximately 5.53 kilometres southwest of Pekan Tenghilan. Along the 3 km of SLFR, the *Rhizophora* trees cover most of the 0.985 square kilometres of the river. The coordinates are N 60 15' 15.48" latitude and E 1160 16' 55.19" longitude, and the elevation is 18 meters above sea level. The surveys were conducted on July 17^{th}, October 30^{th}, and December 10^{th} 2021.

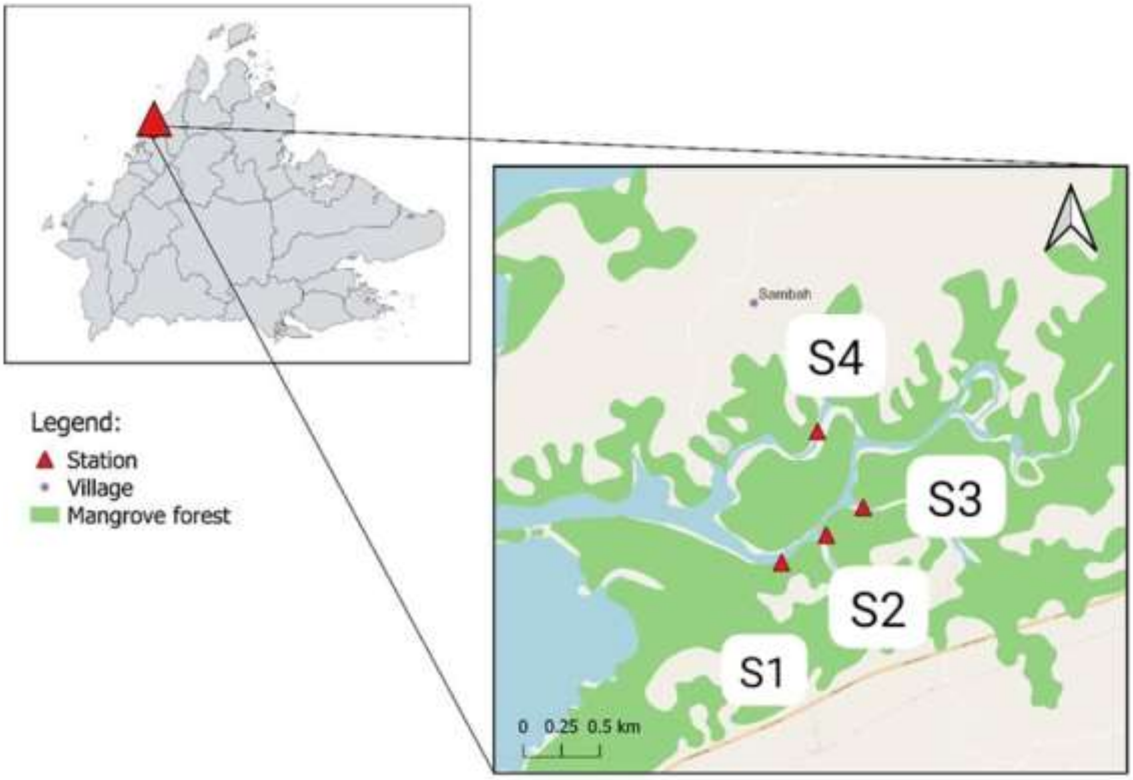


Figure 1. Locations of the four stations for the firefly population samplings along the Sulaman Lake Forest Reserve (SLFR)

Selection of Sampling Stations and Sample Collection

The studied area was divided into four stations, approximately 100 m apart. In each station, three display trees (sampling stations) with the highest congregation of fireflies were sampled. A total of 12 firefly-flashing *Rhizophora* trees were sampled at approximately 10 m intervals. The main display trees were identified to species level by collecting leaf and flower/fruit specimens. Firefly specimens were collected at each station for 4 minutes using an aerial net. All captured fireflies were collected and placed in plastic bags. The number of fireflies and their sex ratio were also recorded for each sample. Sampling at SLFR requires a boat because the firefly habitat is difficult to access on foot. Sampling began between 7:00 pm and 10:00 pm. Collected samples were returned to Universiti Malaysia Sabah (UMS) for species identification using published identification keys and later transferred to separate vials containing 75% ethanol solution. Species identification of fireflies was performed, with male specimens identified by morphological characteristics using the key from Ballantyne et al. (2019). Female specimens were determined to species level when a description was available from the key or when found mating with a known male (Mobilim & Mahadimenakbar 2020).

The measurement of abiotic parameters was also carried out in SLFR. Four stations (namely S1 – S4) were chosen based on accessibility. Eutech Instruments PCD 650 Multiparameter Meter was used to record aquatic variables such as pH, water temperature (WT, °C), dissolved oxygen (DO, mg/L), electric conductivity (EC, %), salinity (Sa, ppt) and total dissolved solid (TDS, mg/L), while other terrestrial variables such as wind speed (WS, m/s), relative humidity (RH, %), ambient temperature (AT, °C), and light intensity (LI, LUX) were measured with Kestrel 5500 Portable Weather Meter.

Statistical Analysis

A two-way ANOVA test (Khalik et al. 2013) was utilized to determine if there is a significant difference between stations, abiotic influences, and months in affecting the water quality. Meanwhile, Pearson's correlation analysis (Kamsia et al. 2007) and stepwise regression analysis were used in this work to further interpret the relationship between abiotic influences and firefly population. Pearson correlation coefficients at a 5% significance level and coefficient of value (r) were used to examine the relationship between firefly population and fluctuations in the abiotic parameters were analyzed.

In stepwise regression analysis, the independent variable with the greatest correlation with the dependent variable is selected first, followed by the independent factors that contribute most to the observed variability, in this order, as assessed by multiple R^2 values (Nie 1975). In this study, stepwise regression analyses were used for both species, with population assessment as the dependent variable and environmental variables as the independent variables. Stepwise regression analysis disclosed the most significant factors affecting the distribution of both species. Therefore, the results of stepwise regression studies are published here only when they provide further insight into the variables affecting the population of species beyond what a simple correlation analysis can provide. SPSS® software version 27.0 from International Business Machines Corporation was used to perform the statistical tests.

RESULTS AND DISCUSSION

Total Population of Fireflies at Sulaman Lake Forest Reserve (SLFR)

Two species of *Pteroptx* fireflies were sampled throughout four stations (Table 1). They were confirmed to be *Pteroptyx bearni* and *Pteroptyx gelasina*. A total of 97 individuals of fireflies were collected from four stations in three surveys. *Pteroptyx bearni* was dominant with 67 individuals while *P. gelasina* was 30 individuals. The display trees found in SLFR were all from the same species, *Rhizophora apiculata* (Rhizophoracea).

Table 1. The number of samples collected on each display tree with coordinates

Station	Coordinate Latitude	Coordinate Longitude	Tree	*P. gelasina*	*P. bearni*	Total Per Station
S1	06 14'39.8"	116 17'43.5"	A	4	0	34
	06 14'40.1"	116 17'43.6"	B	0	16	
	06 14'43.6"	116 17'44.7"	C	6	8	
S2	06 14'28.6"	116 17'52.0"	D	0	7	14
	06 14'27.5"	116 17'54.4"	E	0	6	
	06 14'27.3"	116 17'54.8"	F	0	1	
S3	06 14'22.8"	116 17'47.5"	G	3	9	30
	06 14'21.6"	116 17'46.6"	H	3	1	
	06 14'21.3"	116 17'46.4"	I	0	14	
S4	06 14'18.2"	116 17'37.8"	J	6	1	19
	06 14'15.8"	116 17'37.1"	K	6	3	
	06 14'15.6"	116 17'36.4"	L	2	1	
		Total		**30**	**67**	**97**

Table 2 shows the distribution of fireflies among stations, with the highest number of 34 individuals at S1, which was about 35.05% and the lowest with 14 individuals at S2 (14.89%). The distribution of fireflies at sampling showed that the highest number was in October 2021 with 56 individuals (57.73%), followed by 23 individuals in December (23.71%) and the lowest number was in July 2021 with 18 individuals (18.56%). The highest mean per station was at S1 (11.33±16.29) and the highest mean per month was in October (14.00±16.24).

Table 2. Total number, mean value, and standard error of fireflies in SLFR

Station	July	Oct	Dec	Total Per Station	Mean Per Station±SE
S1	4	30	0	34	11.33±16.29
S2	7	0	7	14	4.67±4.04
S3	0	26	4	30	10.00±14.00
S4	7	0	12	19	6.33±6.03
Total Per Month	18	56	23	97	-
Mean Per Month±SE	4.50±3.32	14.00±16.24	5.75±5.06	-	-

Abiotic Qualities of SLFR

From Figure 2, the highest pH at S4 was 7.3 and the lowest at S1 was 6.99. The highest average pH value was 7.25±0.97 (December). The highest water temperature (WT) was recorded at S4 (29.17^{o}C) in October and the lowest at S1 (27.03^{o}C). The highest mean water temperature (WT) was in October (29.10±0.74^{o}C). Meanwhile, the lowest value of DO was 2.58 mg/L in S2, while the highest value was 3.38 mg/L in S4. The highest mean value of DO was in December with 3.06±0.58 mg/L. EC's highest value was in S2 (152.93 µS /cm) and the lowest in S1 (143.67 µS /cm). EC's highest mean value was in October (148.83±5.69 µS /cm). The next value for the highest amount of Sa was 38.94 ppt in S3 and the lowest was 38.50 ppt in S2. The highest average value for Sa was in July (39.12±1.00 ppt). The highest TDS value was in S3 (159.5 mg/L) and the lowest was in S2 (138.32 mg/L). The highest mean TDS value was 147.14±8.44 mg/L in December. Subsequently, the highest value of wind speed (WS) was 0.3 m/s in S4 and the lowest was 0.0 m/s in S3. The highest mean value of wind speed (WS) was in July with a value of 0.40±0.37 m/s. This was followed by the lowest and highest values of relative humidity (RH) with 94.23% and 84.33%, respectively. The highest mean value of relative humidity (RH) was 86.95±8.13 % in December. The result in Table 3. showed that the values for pH, DO, EC and TDS were in Class I with the average mean of pH (7.20±0.12), DO (2.88±0.51 mg/L), EC (147.53±4.65 %), and 145.73±8.80 mg/L for TDS. In contrast, Sa (3.87±0.10 ppt) does not fall into Class I of NWQS Malaysia.

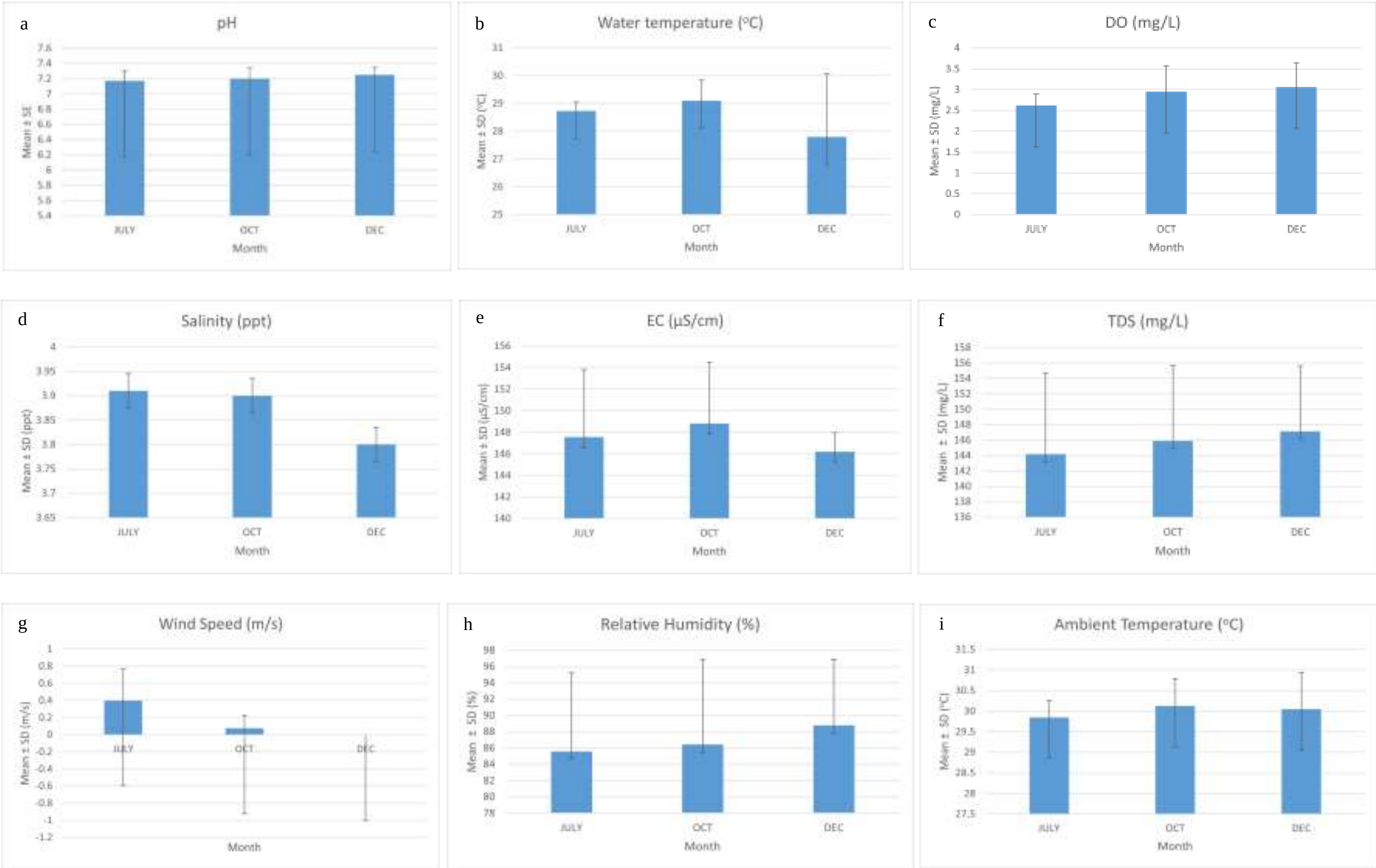


Figure 2. Mean value and standard deviation of (a) pH, (b) WT, (c) DO, (d) Sa, (e) EC, (f) TDS, (g) WS, (h) RH, and (i) AT

Table 3. Mean Values with Standard Errors, and Interim National Water Quality Standard (INWQS) Malaysia (Department of Environment 2008) classification for each water parameter

Parameters	Unit	July	Oct	Dec	Aver	NWQS Malaysia (Class I)
pH	-	7.17±0.13	7.20±0.14	7.25±0.10	7.20±0.12	6.5–8.5
WT	°C	28.73±0.32	29.10±0.74	27.80±2.27	28.54±1.38	-
DO	mg/L	2.62±0.27	2.95±0.63	3.06±0.58	2.88±0.51	7
EC	µS/cm	147.55±6.27	148.83±5.69	146.20±1.76	147.53±4.65	1000
Sa	ppt	3.91±1.00	3.90±1.06	3.80±0.82	3.87±0.10	0.5
TDS	mg/L	144.18±10.50	145.88±9.83	147.14±8.44	145.73±8.80	500

Table 4. Results of Two-way ANOVA on abiotic factors between stations and months

Parameters	Between Station		Between Month	
	***F* value**	***P* value**	***F* value**	***P* value**
pH	1.693	0.267	1.131	0.383
WT	29.710	<0.001	48.410	<0.001
DO	1.793	0.249	1.289	0.342
EC	0.287	0.834	0.493	0.633
Sa	0.961	0.470	1.518	0.293
TDS	0.904	0.492	0.445	0.660
WS	5.405	0.038	8.544	0.018
RH	0.218	0.881	0.134	0.877
AT	0.775	0.549	0.883	0.461
LI	0.0	0.0	0.0	0.0

A two-way ANOVA (Table 4) revealed a significant difference between the sampling stations and the parameters of WT (P=<0.001). Other parameters did not show significant differences between sampling stations. This indicates that only water temperature (WT) could be affected by sampling stations between S1 and S4. Similarly, ANOVA analysis showed no significant differences among the monthly factors of pH (P=0.383), DO (P=0.342), EC (P=0.633), Sa (P=0.293), and TDS (P=0.660) but only WT showed a positively significant difference (P<0.001) from the respective monthly factors, indicating that only WT could be affected by the sampling monthly factors.

It is also shown that wind speed (WS) also has a significant difference between the four sampling stations (P=0.038) and the three different months (P=0.018). However, relative humidity (RH) and ambient temperature (AT) did not show significant differences between the sampling stations and the months of samplings. This proves that only wind speed (WS) can be affected by the differences between sampling stations and sampling months.

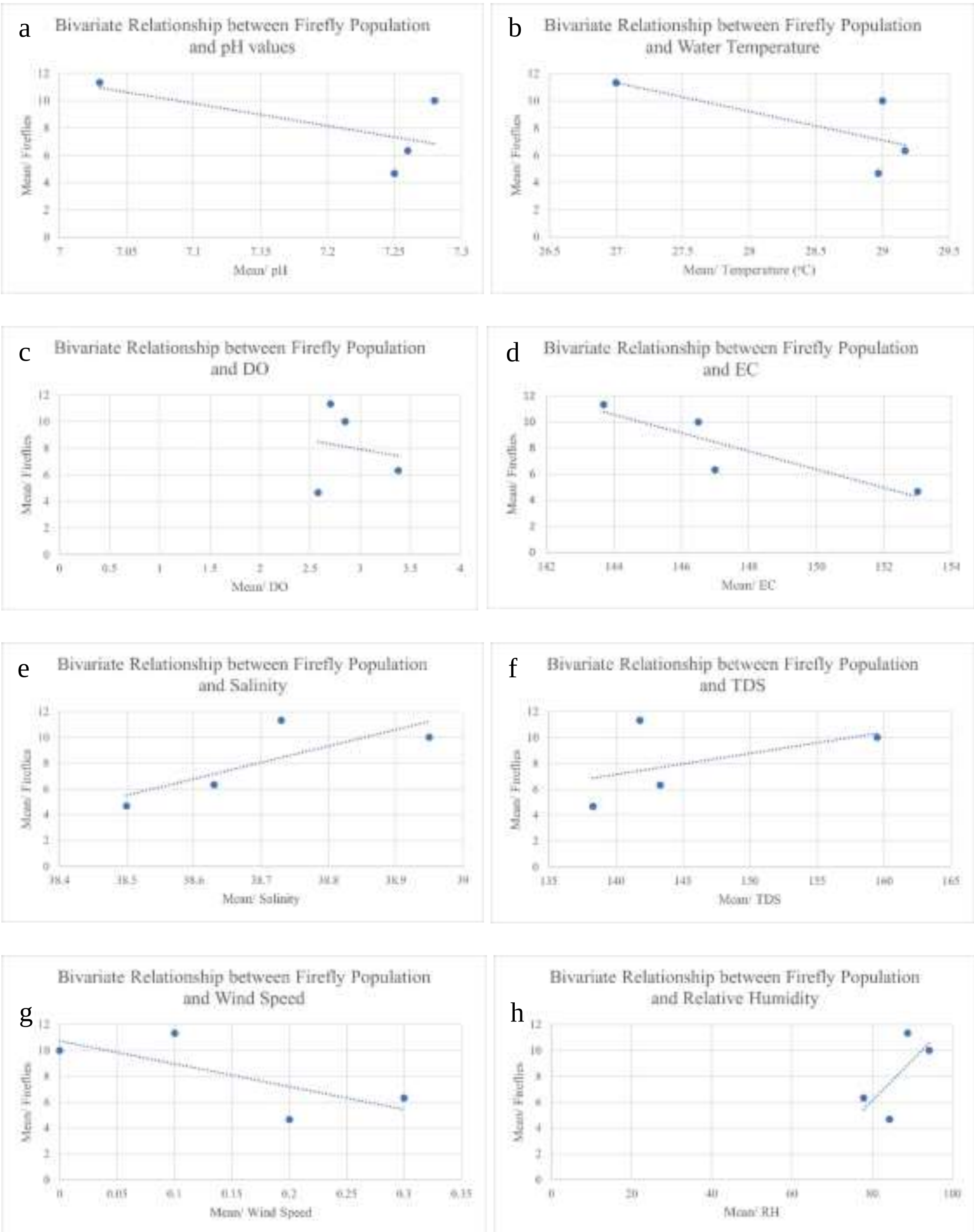
Relationship of abiotic factors on firefly population in the study area

A Pearson correlation matrix of the variables in the firefly population study is shown in Table 5. It is shown that only relative humidity (RH) apart from other abiotic influences was detected in all stations with different sampling months indicating significant differences (P<0.05). Pearson product correlation between firefly population and relative humidity (RH) was found to be highly positive and statistically significant (r = 0.724, P<0.001). This indicates that an increase in relative humidity (RH) would result in a higher firefly population. To support the relationship between the abundance of firefly population and abiotic influences, bivariate data analysis (Figure 3) was also included for reference.

Table 5. Pearson Correlation matrix between firefly population and abiotic factors

	pH	WT	DO	EC	Sa	TDS	WS	RH	AT
Firefly population	-.259	-.474	-.053	-.477	-.113	.287	-.357	.724*	-.439
P-value	.417	.119	.870	.117	.726	.365	.254	.008	.153

*Correlation is significant at the 0.05 level (2-tailed)



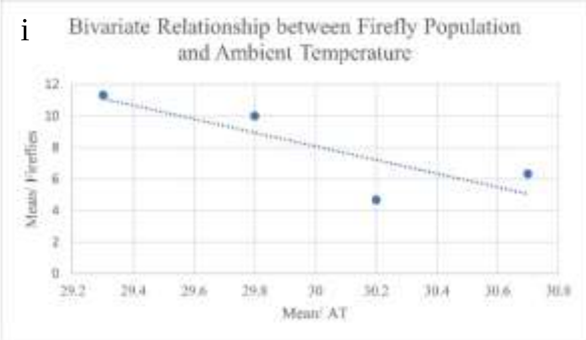


Figure 3. Bivariate relationship between firefly population and (a) pH (b) WT (c) DO (d) EC (e) Sa (f) TDS (g) WS (h) RH and, (i) AT

Stepwise regression analysis was conducted to evaluate whether various dimensions of abiotic factors (pH, WT, DO, Sa, TDS, WS, RH, AT and LI) predict the firefly population in SLFR. It was found that the stepwise regression model was able to reduce them to one factor. In Tables 6 and 7, relative humidity (RH) appears as a significant predictor of the firefly population. The model summary is based on Table 6. The R^2 value is 0.524, which explains 52.4% of the variance in firefly population values. The predicted firefly population is equal to 0.413 - 27.6 x RH, and (β=.72, *t*=3.31, *P*=0.008), where the relative humidity (RH) is coded or measured as a percentage. This means that every 1% increase in relative humidity (RH) leads to an increase in the firefly population of r=.72. This explains that relative humidity (RH) is an important factor in the firefly population.

Table 6. Model Summary: Showing the variable (relative humidity) of abiotic factor as a predictor of the firefly population

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.724[a]	.524	.476	3.552	.524	10.995	1	10	.008

Predictors: (Constant), RH
Dependent Variable: Firefly Population

Table 7. Coefficients[a] for The Final Model

Model		Unstandardized Coefficients		Standardized Coefficients	*t*	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-27.606	10.812		-2.553	.029	-51.696	-3.516					
	RH	.413	.124	.724	3.316	.008	.136	.691	.724	.724	.724	1.000	1.000

Dependent Variable: Firefly Population

Total Population of Firefly at Sulaman Lake Forest Reserve (SLFR)

A total of 97 individuals of fireflies were recorded from 4 stations in Sulaman Lake Forest Reserve (SLFR). The firefly species were *P. bearni* and *P. gelasina*. The highest number of fireflies individuals was obtained at S1 with a total of 34 individuals (35.05%) due to the minimum disturbance from human activity such as shrimp farming. This was also probably due to the condition of the mangrove plants along the riparian zone which are seen to be in good condition without any disturbance and physical changes as per observed during the sampling sessions.

Meanwhile, S2 having the smallest firefly population with only 14 individuals was due to the presence of shrimp aquaculture attributed. Shrimp farms lead to water quality degradation, resulting in a shift in firefly populations along the river (Hazmi & Sagaff 2017). During their larval stage, fireflies that are aquatic or semiaquatic are at risk from shrimp farms (Lewis et al. 2020). Pesticides can also indirectly affect firefly populations by reducing the availability or toxicity of their larval food (Lewis et al. 2020). Leong et al. (2007) detected levels of many pesticides that occasionally exceeded permissible limits for freshwater organisms during a two-year study in the Selangor River in Malaysia. In Japan, the decline in populations of *Luciola cruciata* and *Aquatica lateralis* in the second half of the twentieth century was due to the pollution of rivers by industry and contamination with pesticides (Ohba 2004; Yuma 1993). In addition, the use of spotlights by locals to monitor their shrimp farms became a disruptor of firefly communication (Chalkias et al. 2006; Mahadimenakbar & Foo 2016; Veronica 2018).

Abiotic Qualities of SLFR

Water temperature, pH, DO, salinity, EC, and TDS, were relatively stable and appear to be below the maximum default value required by the INWQS. However, the waters of SLFR have an average salinity of 3.87±0.10 ppt, which is above the maximum standard value mandated by the INWQS. The major dissolved constituents of the river water are the cations: calcium, magnesium, and sodium and the anions: sulphate, chloride, and bicarbonate. These and small amounts of other dissolved constituents are commonly referred to as salinity. The high concentration of dissolved mineral salts threatens to become a major ecological problem for the SLFR. The battle against private development along SLFR, such as housing developments, retail stores, restaurants, and shrimp ponds, has become one of the catalysts for water pollution. In addition, salinity tends to decrease as the value of salinity decreases from July, October, and December. Changes in salinity can affect firefly populations (Idris et al. 2021). Salinity is particularly important for the growth of aquatic and semi-aquatic insects, including firefly populations. Most larval growth occurs in water, so river salinity should be tolerable. As the direct effects of salt on fireflies have been studied, salt may also affect the soil in which fireflies lay their eggs and hatch as larvae (Abdullah et al. 2019).

Results from the two-way ANOVA analysis showed that the water temperature (WT) indicated a positively significant difference between stations (r = 29.71, P<0.001) and months of samplings (r = 48.41, P<0.001). Other water quality measurements did not appear to show any significant differences between stations and month factors. The highest water temperature (WT) was recorded at S4 (29.17±0.83) and the lowest at S1 (27.0±2.29). The high temperature at S4 was due to the location of the station, which is closer to the sea than S1, which is closer to the villages. Water temperatures may be higher in the estuary (Kiffney et al. 2006). Actual coastal temperatures can vary by several degrees, and this can also be strongly influenced by weather conditions. Strong winds can cause cold, deep water to displace surface water heated by the sun, and heavy rains can also lower sea surface temperatures (Sea Temperatures 2022). Fish and other aquatic organisms have not evolved the ability to adapt to rapid temperature changes. Therefore, it is evident that temperature is an important parameter for water quality. Dissolved oxygen content is also related to water temperature. Warm water naturally contains less dissolved oxygen and prolonged warm conditions can deplete dissolved oxygen from the water body (Delaware River Basin Commission 2022). As water temperatures rise, more dissolved oxygen is needed to support aquatic life. Temperature fluctuations can lead to algal blooms, which in turn change the taste, odour, and colour of the river.

A significant variation in wind speed (WS) between measurement stations (P=0.038) and measurement month (P=0.018) is also evident. There were no significant differences in relative humidity (RH), ambient temperature (AT), or light intensity (LI) between sampling stations and sampling months. The type of vegetation and its lushness have a significant effect on wind speed (Abdullah et al. 2019). This vegetation also acts as a buffer zone (Okin 2008), reducing the force of the air on the ground and the small-bodied insect species living in the region (Pasek 1988). While air movement aids in the movement of flying insects, a strong wind can cause small insects to be blown in less desirable directions as they are quickly carried along by the fast-moving air (Gatehouse 1997). Based on the size of fireflies identified in this study, which ranged from 0.1 mm to 5.0 mm, it is likely that they are affected by wind speed. The low total firefly numbers recorded at S4 and in July might be affected by wind speed. Therefore, we must emphasise the importance of maintaining the riparian zone, even though this has proven difficult in the face of various land use changes. This is particularly evident in the SLFR, where mangrove habitats are gradually being converted to agricultural land and residential areas. Research on land use changes should be expanded to protect the insect groups that live there.

Relationship of abiotic factors on firefly population in the study area

There was a strong positive relationship between the firefly population and relative humidity (RH, %) with a coefficient of r = 0.724 as well as a significant relationship between the two variables of *p*-value 0.008. This describes that every 1% increase in relative humidity leads to an increase in the firefly population of r = .72. Higher relative humidity benefits firefly populations, which is not surprising since firefly larvae must live and grow in a wide range of relative humidity. Levi-Mourao et al. (2021) previously examined the combined influence of relative humidity and temperature on the embryonic stage and discovered that low relative humidity resulted in significantly increased egg mortality. Although few *Hypera postica* (Coleoptera: Curculionidae) eggs hatched at temperatures below 95% humidity, nearly half of the eggs survived at low relative humidity (Koehler & Gyrisco 1961). When hot and dry conditions combine, only a tiny percentage of embryos grow normally. Levi-Mourao et al. (2021) discovered that in general, the adult larvae strived to hatch for numerous days and died before hatching from the egg. It is well known that low RH levels impair egg development (Guarneri et al. 2003). In other cases, egg metabolism appeared to be reduced because of water loss during periods of low relative humidity, resulting in prolonged development (Zrubek & Woods 2006).

In addition, humidity plays an important role in egg development (Wiggleswort 1972). While eggs of some species can absorb sufficient water from the air, others require contact with water to grow (Gillott 2005). Eggs stored in conditions that are too dry may not hatch: in some cases, the embryo inside dries out; in others, the chorion becomes too heavy for the young insect to escape (Wiggleswort 1972). In many Coleoptera insects, low humidity in the environment, most likely due to a lack of water, delays egg-laying (Ofuya & Reichmuth 2001). Fireflies prefer warm, moist areas such as temperate and tropical climates and most often live in moist areas such as swamps, wooded areas, or near ponds and streams as these types of areas provide the best food sources for firefly larvae (Miller 2014).

Lower humidity also plays a role in affecting firefly abundance and diversity (Gardner et al. 2018; Lebrija-Trejos et al. 2011) and ultimately reduces their suitability for fireflies (Kaufmann 1965; Koji et al. 2012). The high humidity in marshy areas also contributes to the congregation of sexually mature animals in mating (Lloyd 1966). Consequently, this is due to a possible mechanism whereby firefly populations select suitable humidity through habitat selection that increases aggregation efficiency for sexual attraction (Lloyd 1966). Several species of fireflies live on lakeshores and uplands where the humidity is ideal for their habitat (Nada 2013).

CONCLUSION

A total of 97 individuals of *Pteroptyx* sp. were successfully captured with river water less than the maximum standard value according to the INWQS established by INWQS. It was found that only water temperature (WT) and wind speed (WS) were affected by the different sampling stations and the months of samplings. On the other hand, relative humidity (RH) was found to be the only abiotic factor that could influence the number of firefly populations at each of the SLFR sampling stations. Firefly numbers may be affected by habitat modification due to human activities and land development. It is important to understand how land use affects firefly populations. To improve our understanding of the ecosystem, this topic needs to be addressed in future research.

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AUTHORS DECLARATIONS

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The authors declare that they have no conflict of interest.

Ethics Declaration
No ethical issue is required for this research.

Data Availability Statement
All data have not been published yet. All raw data are kept by CLB.

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

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