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Effect of Water Quality on the Abundance of Firefly Populations at Cherating River, Pahang, Malaysia

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Abstract

The decreasing of firefly population is due to the alteration of habitats such as pollution, physical changes, and human activities that are voraciously destroying the environment. This study aims to determine the abundance of the firefly population, to measure the river water quality level and to analyse the relationship between the firefly population and the river water quality. Six sampling stations were set up along Cherating River. The photo visual method was used for the firefly sampling and was conducted on three different nights. The water sampling was conducted at two different times of day and night. A total of 243 individual fireflies were counted from each sampling station, with *Pteroptyx bearni* was the dominant species in the area. Based on Water Quality Index (WQI) and Interim National Water Quality Standards (INWQS), the water quality of Cherating River was in Class III (medium contaminated). The Pearson correlation result showed that there was a strong positive correlation between dissolved oxygen (DO) and the firefly population, but strongly negatively correlated with temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and ammonia nitrogen. The parameters of pH, total suspended solid (TSS) and *Escherichia coli* did not show any correlation with firefly populations. Therefore, only temperature, DO, BOD, COD and ammonia nitrogen seem to influence the population abundance of fireflies in Cherating River. To agitate the abundance of firefly populations, organic pollutants should be removed from the water body to prevent DO from decreasing while increasing BOD, COD, and Ammonia-nitrogen.

Keywords: Fireflies; Aquatic ecosystem; Biomonitoring; Ecosystem services; Tropical river ecosystem; Environmental management

1. Introduction

Cherating River is one of the main sites that is known to hold the high abundance of firefly population distribution (Mohd *et al.,* 2019). However, the physical environment changes, due to massive human activities are slowly destroying the natural habitat. For example, fireflies diversity at Sepetang River has declined due to tourism activity (Hazmi and Sagaff, 2018) and according to Jusoh (2012), fireflies were nearly extinct from Rembau-Linggi River due to urban expansion and resettlement. These problems that gradually worsen on each day can be seen through several eco-tourism sites where the impact has dampened the eco-tourism and local socioeconomic activities while also

led to the destruction of the firefly habitat (Mokhtar *et al.,* 2010).

Fireflies (Lampyridae) or also known as *Kelip-kelip* or *kunang-kunang* are part of the largest Order of Coleoptera, from the family of Lampyridae beetle, and the most commonly found species in Malaysia are the *Pteroptyx tener* and *Pteroptyx bearni* (Jamaluddin, 2014; Jusoh *et al.,* 2018). The fascinating feature of *Pteroptyx bearni* is its ability to produce non-synchronise bioluminescent light between individuals but congregates in high enough numbers to produce a spectacular display of light unlike *Pteroptyx tener* that synchronise its light display.

Firefly commonly can produce bioluminescent light at the ends of the abdomen that are used to communicate, avoiding predators and as a signal to copulate (Lewis and Cratsley, 2008; Velcoff, 2013; Tooker 2017). On top of their incandescent beauty, fireflies are considered important in the ecosystem, preying upon creatures such as slugs and snails (Shahara *et al.,* 2017). Additional, firefly also is an important natural pollinator in the ecosystem (Norela *et al.,* 2020). In Malaysia, fireflies can be found mostly in mangrove ecosystem where trees like *Berembang* (*Sonneratia caseolaris*) act as the shelter during the day and the firefly will display their bioluminescent light at night, as an addition to the variety of other mangrove plants that grow on the riparian zone (Chan Su Hooi, 2012). However, some species of firefly can be found living on the lakesides and highland areas which provide temperatures and humidity that are more suitable for their habitat. (Nada and Salleh, 2013).

Studies in eco-tourism sites have demonstrated that deforestation activities along the river banks of Kampung Kuantan, Selangor have left only a small number of *Berembang* trees that line the Selangor River (Nada and Kirton 2009). Similar situations were reported in the eco-tourism area of Sepetang River, Kampung Dew, Taiping, Perak where the inaugural aquacultural development of shrimp pond in the area led to a concentration of heavy metal content in the river which leads to the declining of water quality thus disrupting the life cycle of the fireflies (Nada and Kirton 2004; Izfa *et al.,* 2018).

While in Teratak River and Kuwang River, Sabah, anthropogenic activities at night time contributes to light pollution that was seen as a setback to mating and reproduction process of the invertebrate that depends on the light produced by it as a signal of communication between males and females (Dawood and Foo, 2016). In addition, a study made by Jusoh *et al.,* (2012) discovered that the population of firefly in Rembau-Linggi estuary, Negeri Sembilan were decreasing by 30% from the original total population by the factor of land use activities where mangrove area in the estuary had been intensively modified for agriculture, oil palm plantation, urbanization, and aqua-cultural purposes.

The problems and issues arise not only in Malaysia, in fact be fall other countries as well. Studies on the firefly population that were conducted by Picchi *et al.,* (2013), in Turin, Northern Italy, found that the changes on certain geographical level from increased modernization led to the decreasing of trees density and excessive production of artificial light in that area. *Luciola italica* and *Luciola lusitanica* found in the area showed a negative tolerance and a high degree of sensitivity towards light pollutions. Similar issues also arise in the Piedmont district of Maryland, United States. Costin and Boulton (2016) had found that the desecration of land use had led to a widespread use of artificial light around the area, massive use of vehicle, and the ever-presence of industrial development that were causing a decline in numbers of firefly population (45% from the original total population) from *Photinus marginellus, Photinus pyralis* and *Ellychnia corrusca* species in the area.

The population of firefly usually associated with the water quality in their respective ecosystem. This is due to firefly lay their eggs in crevices or loose soil on the ground in the tidal flood plains of the river. Therefore, our objectives are to: (i) measure the abundance of firefly population at the sampling stations; (ii) measure the water quality level at selected sampling stations and; (iii) analyse the relationship between the abundance of firefly population and the water quality level measured at selected sampling stations of Cherating River.

2. Materials and Methods

2.1 Research Area

Cherating River is located at the territorial division of Karang River, Kuantan District, in the state of Pahang, Malaysia. A total of six sampling stations were selected along Cherating River (Figure 1) and (Table 1). The selection of sampling station was based on the distance between the six stations with approximately 700 meters between each station (distance between upstream and downstream of Cherating river is 4.3km) and the risk of pollution, physical changes and human activity that occur at these locations as per observed along the riverside on March 7 of 2019, one day before sampling was conducted.

The trees for the firefly sampling were selected randomly without any specific criteria but with the same trees on each station for each night (Nada and Kirton, 2004). The condition of trees along the riparian zone was also observed. The sampling stations were marked as SS (Sampling Station) from SS1 to SS6 at each selected sampling stations (Figure 1) and (Table 1). The sampling for the abundance of firefly population was conducted on March 8, 9, and 10 of 2019, during the dark moon phase and from 8.00 to 11.00 pm. While the water sampling was conducted within the same days but during day and night time from 8.00 to 11.00 am and 8.00 till 11.00 pm.

2.2 Samplings and Data Collection

The photo visual method was used to collect the data of the firefly population by using a high-resolution camera (720 pixels HD) to produce an accurate and high-quality image (Nada, 2011). Overlapping images from each station and an editing method were used to analyse the population data (Norela *et al.,* 2020). The light produced by the fireflies was used as an index of the population. A flash of light was counted as a single individual.

A total of six key parameters of the Water Quality Index (WQI) including pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), and total suspended solid (TSS) of Cherating River were measured. In addition, factors such as water temperature and *Escherichia coli* were present. Water temperature, pH and DO parameters were measured in-situ, while other parameters were analysed in the laboratory (ex-situ). The specification of river water quality standards was based on the National Water Quality Index (WQI) and the Interim National Water Quality Standards (INWQS) set by the Department of Environment (DOE) (Izfa *et al.,* 2018).

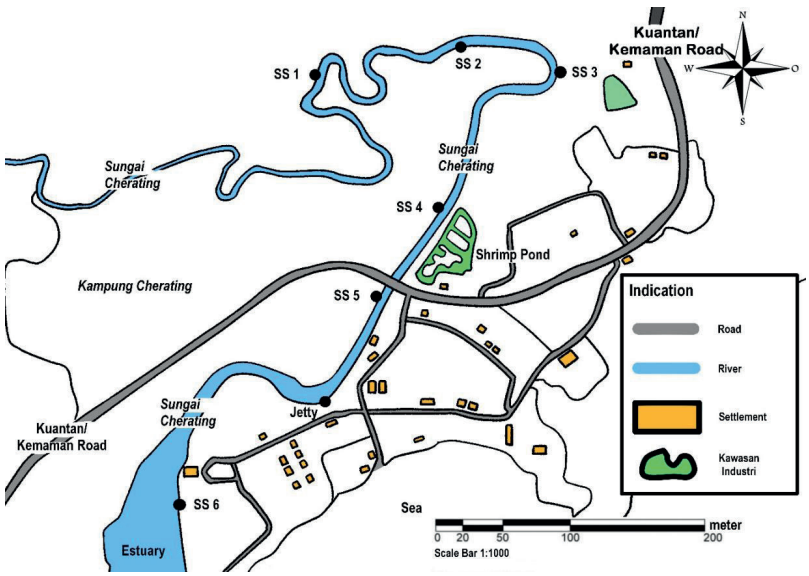

Figure 1. Map area of Cherating River

A two-way ANOVA test (Khalik *et al.,* 2013) was used by using Statistical Package for Social Science (SPSS) to determine if there is a significant difference between stations, time difference and water parameters in affecting the water quality. Meanwhile, Pearson's correlation test (Kamsia *et al.,* 2007) was used to determine whether there is a relationship between firefly population and water quality level of Cherating River with a significance value $p < 0.05$ as a reference and a coefficient of value (r).

3. Results

3.1 Total Population of Firefly at Cherating River

A total of 243 light spots representing individuals of fireflies were counted across six stations along Cherating river within three days of sampling period (Table 2). The highest and lowest number of the individual recorded was at SS6 (28) and SS4 (4), respectively. The firefly distribution per stations showed that the highest was 77 individuals at SS6 which was around 31.68%. The distribution of firefly by the day of sampling showed the highest count was on the first day of March 8 with 85 individuals (34.97%), followed by 84 individuals (34.56%) on the third day and the lowest number was on the second day with 74 individuals (30.45%). The highest mean value per station was at SS6 (25.67 ± 1.45) while the highest mean per station was on the 8th March 2019 (14.17 ± 3.08).

3.2 Water Quality of Cherating River

From Figure 2, it can be seen that the maximum day temperature was 30.6°C at SS5 while at night, the highest temperature was 29.3°C recorded at SS4 and SS5. The highest mean value for temperature was 29.95 ± 0.65 °C. The maximum pH value during day and night time was 7.5 at SS3 and 7.3 at SS5 respectively and with the highest mean value of 7.25 ± 0.25. Meanwhile, the minimum DO value during day and night time was 2.79 mg/L and 2.6 mg/L recorded at SS4 and SS5, respectively. The DO highest mean reading was 4.26 ± 0.25 mg/L. BOD highest value for each day and night time was 3.18 mg/L at SS4 and 4.59 mg/L at SS5 with the highest mean value of 3.84 ± 0.66 mg/L. Value for the highest amount of COD during day and night time was 3.71 mg/L at SS5 and 3.21 mg/L at SS5 with the highest mean reading of 346.00 ± 25.00 mg/L. The maximum NH_3-N reading during day time was 0.05 mg/L at SS3, SS4 and SS5 while during night time was 0.07 mg/L at SS2. The highest mean reading for NH_3-N was 0.06 ± 0.02 mg/L. TSS highest value was 32 mg/L at SS3 and 10 mg/L at SS2 during day and night time with highest mean value of 17.00 ± 15.00 mg/L. Finally, the maximum reading of *E. coli* during day and night time was 960.6 MPN/100 ml at SS5 and 1011.1 MPN/100 ml at SS4 with the highest mean reading of 960.60 ± 0.00 MPN/100 ml.

A two-way ANOVA analysis (Table 3) revealed a significant difference between sampling stations and the parameters of DO ($p = 0.05$), NH_3-N ($p = 0.02$)

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

Sampling Station	8th March	9th March	10th March	Total Per Station	Mean ± SE
SS1	20	15	16	51	17.00 ± 1.52
SS2	10	8	14	32	10.67 ± 1.76
SS3	14	14	16	44	14.67 ± 0.66
SS4	6	4	6	16	5.33 ± 0.66
SS5	9	10	4	23	7.67 ± 1.85
SS6	26	23	28	77	25.67 ± 1.45
Total Per Time	85	74	84	243	-
Mean Per Time ± SE	14.17 ± 3.08	2.33 ± 2.69	14 ± 3.50	-	-

and *E. coli* (p = 0.00). Other parameters showed no significant differences between sampling stations. This indicated that only DO, NH_3-N and *E. coli* were able to be influenced by the sampling stations between SS1 to SS6. Meanwhile, the ANOVA analysis showed no significant differences between time factor and the parameters of pH (p = 0.16), DO (p = 0.13), COD (p = 0.17), NH_3-N (p = 0.61), TSS (p = 0.28) and *E. coli* (p = 0.16). Only temperature and BOD showed a significant difference with respective time factors thus indicates that only temperature and BOD were able to be influenced by time sampling factors between day and night.

The result in Table 4 showed that the values for the pH, NH_3-N and TSS were in Class I with mean of 7.17 ± 0.03 mg/L for pH, 0.04 ± 0.01 mg/L for NH_3-N, and 7.66 ± 1.95 mg/L for TSS. In contrast BOD and DO with mean of 3.53 ± 0.09 mg/L and 3.21 ± 0.22 mg/L, respectively fell into Class III. Meanwhile, COD was in Class V with mean 270.42 ± 19.93 mg/L. When referred to WQI and INWQS standards, it was clear that the overall water quality of Cherating River is in Class III with WQI of 64 which was moderately polluted.

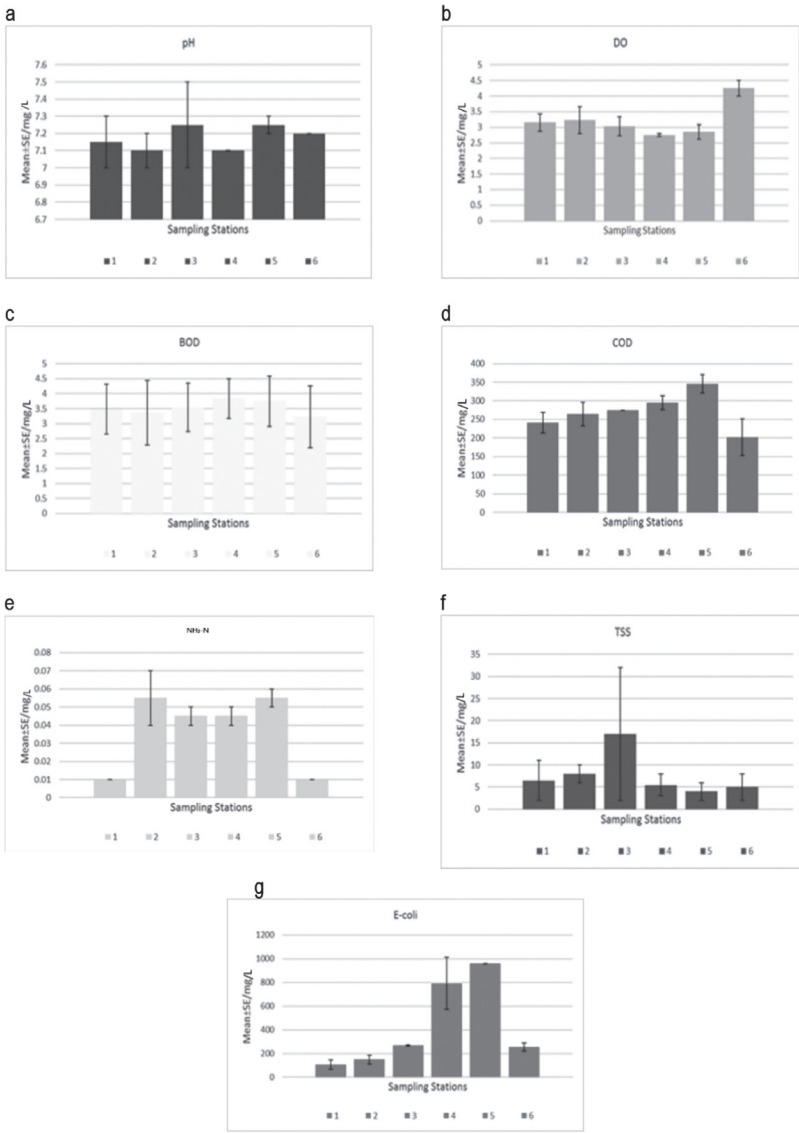

Figure 2. Mean value and standard error of (a) pH, (b) DO, (c) BOD, (d) COD, (e) NH_3-N, (f) TSS, and (g) *E. coli.*

Table 3. Values of Two-Way ANOVA analysis between water parameters, stations and time sampling

Parameters	Between Station		Between Time	
	F Value	*P* Value	*F* Value	*P* Value
Temperature	2.86	0.14	27.14	0.00
pH	0.37	0.85	2.65	0.16
DO	5.10	0.05	3.18	0.13
BOD	2.23	0.20	191.72	0.00
COD	3.46	0.10	2.59	0.17
NH_3-N	7.88	0.02	0.29	0.61
TSS	0.55	0.74	1.44	0.28
E. coli	19.34	0.00	2.78	0.16

Table 4. Mean Values, WQI Levels and INWQS classification for each water parameter

Parameters	pH	DO (mg/L)	BOD (mg/L)	COD (mg/L)	NH_3-N (mg/L)	TSS (mg/L)
Mean	7.17	3.21	3.35	270.4	0.04	7.66
WQI	6.5 – 8.5	3 – 5	3 – 6	>100	<0.1	<25
INWQS	I	III	III	V	I	I

Table 5. Correlation between Firefly Population and Water Parameters

Variables/Parameters	Relation	*r* Value	*p* Value
Fireflies and Temperature	Negative	-0.96	0.00
Fireflies and pH	None	0.27	0.60
Fireflies and DO	Positive	0.91	0.01
Fireflies and BOD	Negative	-0.84	0.04
Fireflies and COD	Negative	-0.87	0.03
Fireflies and NH_3-N	Negative	-0.82	0.05
Fireflies and TSS	None	0.07	0.89
Fireflies and *E. coli*	None	-0.65	0.16

3.3 Relationship between Firefly Population Abundance and Water Quality Parameters

Apart from pH, TSS, and *E. coli*, all variables showed a correlated relationship between the abundance of fireflies and water parameters. Table 5 showed the distribution of fireflies and temperature were significant and strongly negatively correlated (r = -0.96). There was also a positive significant relationship (p = 0.01) between firefly abundance and temperature. The correlation between firefly distribution and pH was positively low (r = 0.27) but there was no significant relationship between them (p = 0.60). Meanwhile, DO show strongly positively correlations (r = 0.91) with the distribution of fireflies, and a significant relationship at (p = 0.01).

The distribution of fireflies and BOD were strongly negatively correlated (r = -0.84). This was a significant relationship with (p = 0.04). COD and firefly distribution showed a strong negative (r = -0.87) and significant relationship between it (p = 0.03). NH_3-N had a high negative correlation (r = -0.82) with the abundance of fireflies with a significant relationship (p = 0.05). On the other hand, the result for TSS and firefly distribution had a negligible correlation (r = 0.07) but with no significance (p = 0.89). The results for *E. coli* and the distribution of fireflies were highly correlated (r = -0.65) but with no significant relationship (p = 0.16). To support the relationship between the abundance of fireflies and water parameters bivariate data analysis (Figure 3) was also inserted for reference.

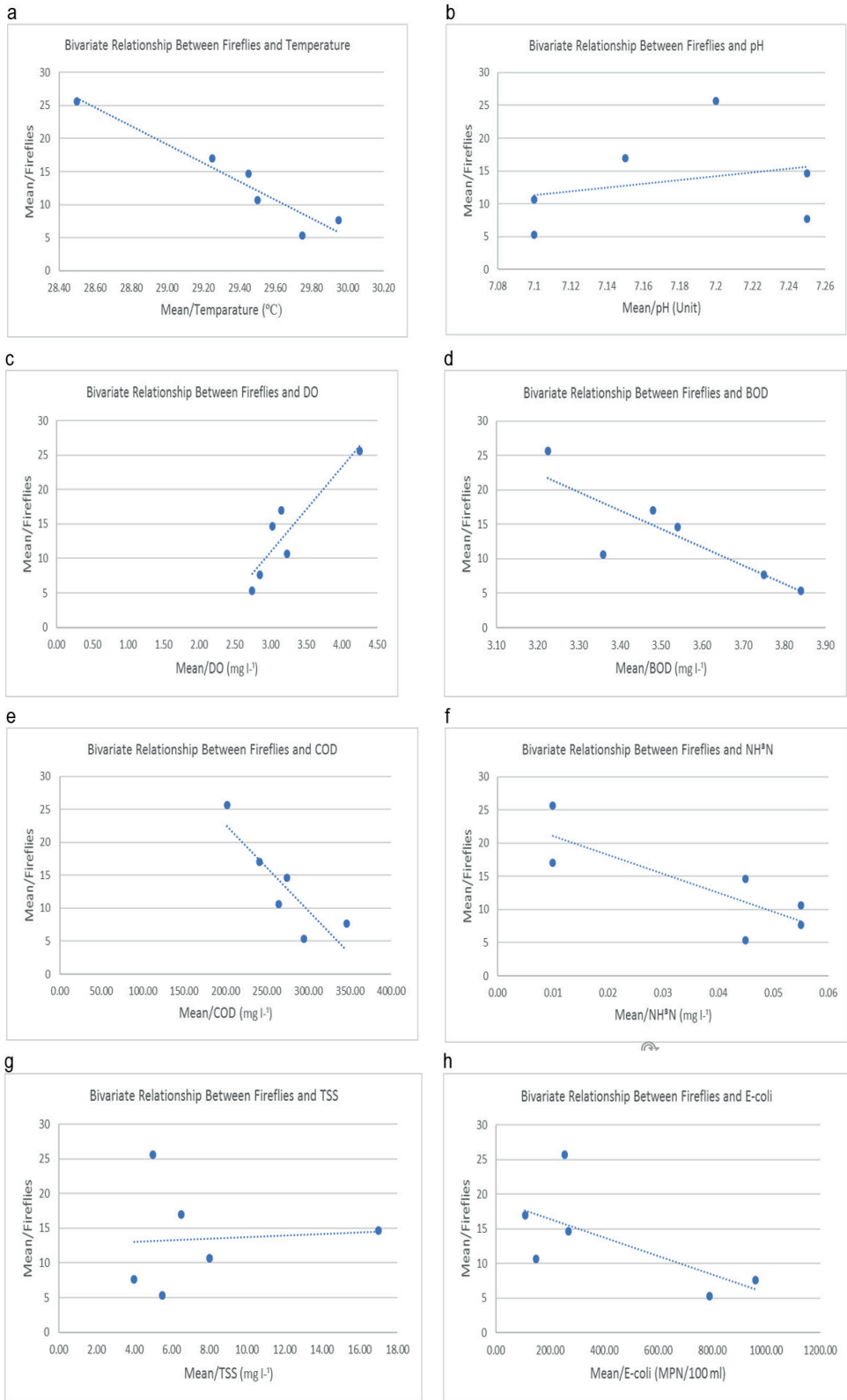

Figure 3. Bivariate Relationship Between Fireflies and (a) Temperature, (b) pH, (c) DO, (d) BOD, (e) COD (f) NH3-N, (g) TSS, and (h) *E. coli.*

4. Discussion

4.1 Firefly's Population at Cherating River

A total of 243 light spots representing individuals of fireflies was counted from six sampling station in Cherating River. The species of fireflies was *Pteroptyx bearni* as identified from recorded firefly species in Universiti Kebangsaan Malaysia (UKM) Insect Museum. The highest number of fireflies was obtained at SS6 with a total of 77 (31.68%) individuals due to the area being far from human activity and minimum disturbance such as artificial light from street lamps, settlements and shop-houses. 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 sampling session.

Meanwhile, the lowest number of fireflies recorded was at SS4 sampling station with a total of 16 individuals (6.58%) and it most probably was due to the presence of shrimp breeding pond which opened on the river bank of the area. The organic and inorganic residues produced from the shrimp's livestock continue to flow into the main river and lead to the river pollution. According to Izfa *et al.* (2016) the presence of shrimp ponds can lead to a declining in the water quality, thus changing the firefly population along the river. In addition, there was also light pollution interference caused by the usage of spotlight installed in the shrimp pond by directing it towards the river bank. Frequent strong light is seen to interfere with the communication between fireflies (Veronica, 2018; Dawood and Foo 2016; Chalkias *et al.,* 2006).

4.2 Water Quality of Cherating River

Private developments such as settlement, shop-houses, restaurants, resorts, and shrimp ponds established near and along Cherating River were the cause of water pollution. The discharge of chemical and organic matter into the river had triggered some parameters to increase and some to decrease. A large amount of DO is needed for decomposition and oxidation of organic matter in the water (Kadaruddin 1998). This leads to a reduction in the amount of DO in the water due to BOD and COD decomposing and oxidizing chemical and organic matter released into the river (Metcalf and Eddy, 1991).

However, NH_3-N and *E. coli* showed a low mean reading with 0.04 mg/L and 421.47 MPN/100 ml respectively, due to the minimum domestic sewage, excrement and organic wastes although there were domestic channels from these areas that were seen to flow directly into the river plus the uncontrolled waste of animals that help the growth of bacteria that can lead to disease and water pollution (Mohd Noor, 2003). Private land use activities undertaken for river bank agriculture purposes and the used of strong engine fan from boats for aquatic activities caused the sedimentation at the base of the river to rise thus led to an amount of TSS reading (Ang, 2015; Sulaiman *et al.,* 2017). Therefore, due to these conditions, it helps to attracts firefly to lay eggs at the nearby loose soil alongside of Cherating River.

Cherating River was in Class III with WQI of 64 which was moderately polluted. Water in Cherating River is seen as a source of water that requires full treatment if it is to be used as a source of water supply to humans. However, the water source still has an economic value where it can be used for an aquatic breeding activity as well as beverages source for livestock.

4.3 Relationship between Firefly Population Abundance and Water Quality Parameters

There was a strong negative relationship between the firefly population and the temperature, with a coefficient of $r = -0.96$ as well as a significant relationship between the two variables with a value of $p = 0.05$. Low temperature leads to a large distribution of the fireflies. This was due to the highest number of fireflies obtained at SS6 sampling station with 27.3°C and SS1 with 28.8°C. A negative value of $r = -0.96$ indicated that the higher the temperature in a water, the lower the number of the fireflies in a given area. According to Iguchi (2002) and Abdullah *et al.* (2020), based on the data of the study, the estimated value of the appropriate temperature

parameter to obtain a large number of distributions of the firefly populations are at 27.3 - 28.8°C.

DO indicated a strongly positively correlation with the firefly population by the value of r = 0.91 and was supported by the p = 0.01 value. This indicated that there was a significant relationship between the two variables. Thus, the higher the DO in the water, the higher the oxygen content which aids in the decomposition process and for respiration of aquatic life (Mazlin *et al.,* 2008). This can be seen at the SS6 sampling station with the DO value of 4.50 mg/l which had the highest number of the firefly distribution with a total of 77 individual fireflies. The estimated value of the DO parameter to obtain a large number of firefly populations was at the DO value of 2.87 - 4.50 mg/L.

A strong negative correlation was shown between firefly population and BOD, COD and NH_3-N with a coefficient r = -0.84 for BOD, r = −0.87 for COD, and r = −0.82 for NH_3-N. Whereas the p values indicated that there was a strong significant relationship between the two variables with values of p = 0.04 for BOD, p = 0.03 for COD and p = 0.05 for NH_3-N. Based on the data, the estimated BOD value for obtaining a large number of firefly distribution was (4.26 - 4.32 mg/L), COD (251 – 269 mg/L), and NH_3-N (0.01 mg/L). The highest BOD, COD and NH_3-N reception rates were at SS4 and SS5, which had the lowest population density among all stations with 16 individuals at SS4 and 23 individuals at SS5. It can be concluded that the increasing values of BOD, COD and NH_3-N parameters will lead to water pollution as well as reducing the firefly population in the area (Takeda *et al.,* 2006; Shahara *et al.,* 2017)

However, the correlation test conducted between firefly population and pH, TSS and *E-coli* parameters showed that there was no significant correlation between them. It can be concluded that the pH, TSS and *E. coli* parameters did not affect the amount of firefly population distribution at the sampling stations in Cherating River.

Overall, this study agree that water quality parameters such as DO, BOD, COD and Ammonia Nitrogen play important roles in the determination of the abundance of firefly at the aquatic ecosystem. This is also agreed by previous studies such as Shahara *et al.* (2017), Norela *et al.* (2020), Nada and Kirton (2004) and Nada and Salleh (2013).

5. Conclusion

A total of 243 individuals of the *Pteroptyx bearni* were successfully recorded with moderately polluted river water that placed in Class III according to the WQI and INWQS standards set by the DOE. Only a few of the water parameters like temperature, DO, BOD, COD and Ammonia Nitrogen (NH_3-N) were found to be able to influence the number of firefly population distributed at each sampling stations of Cherating River. On the whole, this study conclude that the increase of river pollution can lead to disruptions of aquatic life especially firefly habitat. Future study should include longer sampling time for the fireflies and water quality to optimize the data collection. Other than that, future study can focus on other abiotic factors such as air and soil quality, the fertility of the riparian zone and light pollution at Cherating River.

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References

Abdullah N, Asr, L, Radzi S, Musbah M, Hazmi I, Sulaiman N. Abiotic factors influencing diversity and abundance of congregating fireflies (Coleoptera: Lampyridae) in Miri, Sarawak, Malaysia. Oriental Insects 2020: 1-16. https://doi.org/10.1080/00305316.2020.1757529

Ang KH, Kualiti Sumber. Air di Malaysia: Satu Analisis. Malaysian Journal of Society and Space 2015; 11(6): 98 – 108.

Chan SH. Special Ecology Feature: Habitat Enhancement for Fireflies. A Centre for Urban Greenery and Ecology Publication 2012.

Chalkias C, Petrakis M, Psiloglou B, Lianou M. Modelling of light pollution in suburban areas using remotely sensed imagery and GIS. Journal of Environmental Management 2006; 79:57–63.

Costin K, Boulton A. A Field Experiment on the Effect of Introduced Light Pollution on Fireflies (Coleoptera: Lampyridae) in the Piedmont Region of Maryland. The Coleopterists Bulletin 2016; 70(1): 84-86. https://doi.org/10.1649/072.070.0110

Dawood M, Foo K. Short Notes on Fireflies of Sungai Kawang, Sabah. Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah. Journal of Tropical Biology and Conservation 2016; 13: 125–128.

Hazmi IR, Sagaff SAS. Fireflies Population and The Aquaculture Industry (Coleoptera: Lampyridae) of the Sungai Sepetang, Kampung Dew, Perak, Malaysia. Serangga 2018; 22(2): 217-237

Iguchi Y. The Influence of Temperature on Flash Interval in the Genji Firefly Luciola cruciata (Coleoptera: Lampyridae). Entomological Review of Japan 2002; 57 (1): 199-122.

Jamaluddin Abdullah Habitat Kelip-kelip di Tasik Chini. Universiti Malaysia Sabah. 2014.

Jabatan Alam Sekitar. Indeks Kualiti Air. Portal Rasmi Jabatan Alam Sekitar. Kementerian Tenaga, Sains, Teknologi, Alam Sekitar dan Perubahan Iklim. http://doe.gov.my [29 September 2018].

John FT. Silent sparks: The wondrous world of fireflies *Sara lewis*, American Entomologist 2017; 63(2):133–134.

Jusoh WFA. The effect of habitat modification on firefly populations at the Rembau-Linggi estuary, Peninsular Malaysia. Universiti Putra Malaysia 2012.

Jusoh W, Ballantyne L, Lambkin CL, Hashim NR, Wahlberg N. The firefly genus *Pteroptyx olivier* revisited (Coleoptera: Lampyridae: Luciolinae). Zootaxa 2018; 4456(1): 1-71. doi: 10.11646/zootaxa.4456.1.1

Kamsia B, Amran A, Noraini A. Maryam D. Correlation analysis on water quality parameter with aquatic insects' abundance in Telipok River, Sabah, Malaysia. 12th WSEAS International Conference on Applied Mathematics 2007; 12: 29-31.

Kadaruddin A. Impak Perubahan Gunatanah Terhadap Kualiti Sumber Air dan Pengurusannya Oleh Pihak Berkuasa Tempatan. Kertas Kerja Seminar Kebangsaan Kerajaan Tempatan dan Pembangunan Sosial. Universiti Utara Malaysia 1998.

Khalik WMA, Abdullah WM, Amerudin NA, Padli N. Physicochemical analysis on water quality status of Bertam River in Cameron Highlands, Malaysia. Journal of Materials and Environmental Science Environ Sci 2013; 4: 488–495.

Lewis SM, Cratsley CK. Flash signal evolution, mate choice, and predation in fireflies. Annual Review of Entomology 2008; 53: 293–321, doi: 10.1146/annurev.ento.53.103106.093346.

Mazlin M, Othman K, Irene LPN. Penentuan Kualiti Air Tasik Kejuruteraan UKM Kampus Bangi: Ke Arah Sistem Pengurusan Sumber Air Bersepadu. The Malaysian Journal of Analytical Science 2008; 12(1): 123-134

Malayka SP, Giuseppe C, Laura A. Fireflies and land use in an urban landscape: The case of *Luciola italica* L. (Coleoptera: Lampyridae) in the city of Turin. Journal of Insect Conservation 2013; 43(2): 122-131.

Metcalf, Eddy, Inc. Wastewater engineering: Treatment, disposal, and reuse. 3rd Edition, McGraw-Hill, Inc. Singapore 1991.

Mohd F, Abdul Maulud K, Karim O, Begum R, Awang N, Ahmad A. Comprehensive coastal vulnerability assessment and adaptation for Cherating-Pekan coast, Pahang, Malaysia. Ocean and Coastal Management 2019; 182: 104948. https://doi.org/10.1016/j.ocecoaman.2019.104948

Mohd Noor. Status Pengurusan Kualiti Air Sungai Langat: Kajian Kes dari Pangsun hingga ke West Country. Master Thesis, Universiti Kebangsaan Malaysia, Malaysia. 2003.

Mokhtar J, Asmah A, Zaini S. Kemandirian industri eko pelancongan: Kes tarikan pelancong kelip-kelip Kg. Kuantan. Geografia: Malaysian Journal of Society and Space 2010; 6 (3): 89-97.

Nada, Kirton. The Fireflies of Kuala Selangor - Conservation of Berembang Alone Won't Save Them. Forest Research Institute Malaysia (FRIM). 2009.

Nada, Salleh. A survey of fireflies (Coleoptera: Lampyridae) in Fraser's Hill, Pahang. Forest Research Institute Malaysia (FRIM) 2013.

Nada B. Ecology and Behaviour of Fireflies (Coleoptera: Lampyridae) Along the Selangor River, Kuala Selangor, Semenanjung Malaysia. Universiti Malaya. 2011.

Nada, Kirton. The secret life of fireflies. IRBM Updates. Integrated River Basin Management, Issue NBo 2004; 3: 2−4.

Norela S, Amirul-Aiman A J, Noraini T, Ismail BS. Leaf ultrastructure of firefly display trees. Malayan Nature Journal 2020; 72: 93-102.

Sulaiman N, Loo MC, Abdullah M. Association between the firefly population and some biotic and abiotic factors along the Sungai Sepetang river banks at Kampung Dew, Taiping, Perak, Malaysia. Malayan Nature Journal 2017; 69(3): 110-118.

Shahara A, Nura A, Abdullah M, Sulaiman N. Assessment of firefly abundance at a new ecotourism site of Sungai Bernam, Selangor, Malaysia. Malayan Nature Journal 2017; 69(2): 67-74.

Takeda M, Amano T, Katoh K, Higuchi H. The Habitat Requirement of the Genji- Firefly *Luciola cruciata* (Coleoptera: Lampyridae), a Representative Endemic Species of Japanese Rural Landscape. Biodiversity and Conservation 2006; 15: 191-203.

Velcoff Z. All About Fireflies. Naturalist Outreach. Cornell University 2013.

Veronica KS. The Effect of Artificial Illumination on The Display Behaviour of The Firefly *Pteroptyx tener* Olivier (Coleoptera: Lampyridae). University Sains Malaysia 2018.