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MONITORING OF WATER QUALITY USING AQUATIC INSECTS AS BIOLOGICAL INDICATORS IN THREE STREAMS OF TERENGGANU

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Abstract: Aquatic insects are amongst of the most frequently benthic macroinvertebrates used in freshwater monitoring and assessment worldwide. However, relatively less attention has been paid to include aquatic insects for purposes of health and water quality bioassessment particularly in Malaysia. Here, we investigated the abundance of aquatic insects as well as its relationship with physico-chemical parameters in three streams of Terengganu (i.e. Lata Changkah, Sungai Peres and Sungai Ular) which experienced different levels of human disturbance from September to November 2015. A total of 1,361 individuals from seven orders belonging to 35 families of aquatic insects were identified in the streams. The total abundance was significantly greater in Lata Changkah than in Sungai Ular and Sungai Peres (F=5.146, df=2, p=0.035). The most dominant family of aquatic insects in Lata Changkah and Sungai Peres was Heptageniidae (Order Ephemeroptera), followed by Perlidae (Order Plecoptera), Stenopsychidae and Hydropsychidae (Order Trichoptera). In contrast, Libellulidae (Order Odonata) was the most dominant family found in Sungai Ular. High abundance of intolerant taxa such as Ephemeroptera, Plecoptera and Trichoptera were observed in the least disturbed streams; Lata Changkah and Sungai Peres. Decreasing abundance of intolerant taxa and a high number of the most tolerant taxa (Chironomidae, Diptera) were collected from the most highly disturbed stream, Sungai Ular. Based on physico-chemical parameters and biological indices, Lata Changkah and Sungai Peres were categorized as of "Excellent" to "Good" water quality, while Sungai Ular was classified as "Moderately Good". Findings from this study provide a useful baseline for appropriate water management using aquatic insects as bioindicators for assessing anthropogenic impacts on streams of Malaysia.

Keywords: aquatic insects, diversity, abundance, bioindicator, human disturbance

Introduction

Aquatic insects have been used as bioindicators and are amongst the most frequently used groups in biological assessment of water quality worldwide (Davy-Bowker *et al.,* 2005; Bunn *et al.,* 2010; Chon *et al.,* 2013). They offer a spectrum of responses to different degrees of environmental stress and change over time (Hawkes, 1997). The number and type of species of aquatic insects present in certain water bodies reflect the quality of the site from which they are collected (Metcalfe, 1989; Boonsoong *et al.,* 2009).

Some studies reported that aquatic insects are very good in detecting anthropogenic disturbance and habitat quality (Clarke *et al.,* 2002; Verandas & Cortes, 2010). This is due to their sensitivity towards various factors responsible for water quality changes (Pontash & Cairns, 1991). Generally, aquatic insects from Orders Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) are bioindicators for good water quality, while Diptera (midges) are excellent in detecting bad water quality conditions (Metcalfe, 1989).

The use of aquatic insects for biomonitoring the health of aquatic ecosystems has many advantages. One of these is the possibility of detecting changes in water quality that occur at the time of sampling as well as changes that have occurred prior to sampling due to the relatively sedentary life style and long life spans of these organisms (Rosenberg & Resh, 1996). In contrast, physico-chemical analysis might be more accurate, but only reflect the actual conditions in the water body at the time of sampling. Furthermore, aquatic insects show sensitivity towards various factors that are responsible for changes to water quality, and they are cheaper to work with than physico-chemical analysis (Pontash & Cairns, 1991; Pardo *et al.,* 2014).

Several studies on distribution and diversity of aquatic insects have been reported in Malaysia. For example, Sahana *et al.* (2010) at Meliau stream, Sabah, Ahmad *et al.* (2002) at Sungai Linggi, Negeri Sembilan and Che Salmah and Abu Hassan (2005) at Sungai Bebar, Pahang. However, to date, very few studies have been carried out to investigate the impact of human disturbances on the community of aquatic insects in Peninsula Malaysia. Azrina *et al.* (2005) compared the distribution of benthic macroinvertebrates between clean and polluted sites at the Langat River. Another study was performed by Yap *et al.* (2003) where they investigated the species diversity of macrobenthic invertebrates in Semenyih River, Selangor, in relation to water quality. A study on aquatic insects in the East Coast of Peninsula Malaysia had been done by Wahizatul *et al.* (2011) which focused on the composition and distribution of aquatic insects in two freshwater streams of Sekayu, Hulu Terengganu.

In the current study, our research aim was to monitor water quality in three streams of Terengganu which experienced different levels of human disturbance by using aquatic insects as biological indicators. Physico-chemical analysis and several biological indices such as Biological Monitoring Working Party (BMWP), Family Biotic Index (FBI), Average Score Per Taxon (ASPT), and Interim National Water Quality Standard for Malaysia (INWQS) were also measured in order to obtain reliable data on the health status of the water environment. Outcomes of this study could give an insight for baseline data needed for water management in Malaysia especially in Terengganu state.

Materials and Methods

Study sites

In this study, three streams experiencing different levels of human disturbance were selected. The first stream, Sungai Ular, Setiu (N05º40.116´ E102º42.625´) is considered to be highly disturbed as it is surrounded by oil palm plantations and other agricultural activities. The major components of substrates are silt, muddy sediment and sand, with floating macrophytes, litter riparian and debris. The second stream, Sungai Peres (N04º57´.742 Eº102´57.115) is located in Sekayu Recreational Forest, Hulu Terengganu, represents a moderately disturbed stream due to recreational and agricultural activities. The stream bed is debris-free, mainly comprising sand, pebbles, cobbles and small boulders. The stream reaches are mostly covered by forest canopy, with grasses and shrubs. The third stream, Lata Changkah, Setiu (N05º28.602´ E102º39.194´) was the least disturbed stream (a control site), is an isolated area with little impact of human activity observed at this site. The substrata mainly consisted of gravels, cobbles, pebbles and boulders, with crystal clear fast-flowing water.

Sampling of aquatic insects

Aquatic insects were sampled nine times from September to November 2015 using a stratified random sampling design. The streams were divided into three parts: which were upper, middle and lower stream. Several methods were used to collect the aquatic insects which include i) kicking bottom technique, ii) hand picking technique and iii) stone rubbing technique. Kick sampling was done with a D-shaped aquatic net or commonly known as a kick-net (20cm radius, 40 cm wide and 300 μm mesh size). Invertebrates and content of each sample were transferred into labeled plastic containers, preserved in 80% ethanol and taken back to the laboratory for further analysis. In the laboratory, samples were viewed under a dissecting microscope and identification was made until the family level using the identification keys of Yule and Yong (2004) and Che Salmah *et al.* (2014).

Physico-chemical analysis

Physico-chemical parameters such as water temperature (°C), conductivity (ms/cm^3), pH and dissolved oxygen (mg/l) were measured in situ at each sampling site using the Multiparameter Digital (model MPS YSI 556) before the collection of the aquatic insects was conducted. Turbidity (NTU) was measured by a Turbidity Meter and water velocity (m/s) was recorded using the hydropropeller. Width and depth (m) of the streams were measured using a measuring tape. Water samples were incubated for 5 days at 20ºC and the initial DO was measured using calibrated Biological Oxygen Demand (BOD) and total suspended solid (TSS) was determined using standard method and procedure developed by APHA (1995).

Data analysis

Three biological indices used to monitor the effect of human disturbance and pollution condition on the streams were used. They were Biological Work Party (BMWP), Family Biotic Index (FBI) and Average Score Per Taxon (ASPT) (Hilsenhoff, 1988). These indices were used to assess water health based on the diversity of the taxa with known environmental pollution tolerances (Blijswijk *et al.,* 2004). The health of water quality of each stream was then determined and compared with the Interim National Water Quality Standards (INWQS) (DOE, 2008). INWQS is the Malaysian standard values to determine the water quality status by classifying the health of water quality into several classes whether clean, slightly polluted or polluted. Pearson Correlation Analysis was also used to investigate the influences of physico-chemical parameters on the abundance of aquatic insects at each site. One-way ANOVA was used to evaluate differences in aquatic insect distribution at different sites. Data were log(x+1) transformed first to ensure normality in calculations of means and ANOVAs (PRISM, 2007).

Results and Discussion

Assemblages of Aquatic Insect Communities among Three Streams

A total of 1,361 individuals from seven orders across 35 families of aquatic insects were identified from Lata Changkah, Sungai Peres and Sungai Ular (Table 1). Significantly more aquatic insects were collected in Lata Changkah (689 individuals) compared with Sungai Peres (318 individuals) and Sungai Ular (353 individuals) (ANOVA, $F=5.146$, $df=2$, $p=0.035$). A higher number of families was recorded in Lata Changkah (29), followed by Sungai Peres (24) and Sungai Ular (18). Orders Hemiptera, Trichoptera, Plecoptera, Coleoptera, Ephemeroptera, Odonata and Diptera were the main taxonomic groups collected from Lata Changkah and Sungai Peres. However, no Plecoptera was found in Sungai Ular.

Table 1: The composition and total abundance of aquatic insect communities in Lata Changkah, Sungai Peres and Sungai Ular

Order	Family	Lata Changkah	Sungai Peres	Sungai Ular
Ephemeroptera	Baetidae	6	9	-
	Caenidae	-	1	44
	Ephemerellidae	5	3	-
	Heptageniidae	168	76	-
	Isonychidae	7	10	13
	Potamanthidae	1	-	1
Plecoptera	Perlidae	99	54	-
Trichoptera	Glossosomatidae	-	1	-
	Hydropsychidae	57	28	5
	Leptoceridae	-	2	-
	Polycentropodidae	47	32	7
	Stenopsychidae	73	16	-
Odonata	Chlorocyphidae	2	1	5
	Coenagrionidae	8	-	29
	Calopterygnidae	3	1	-
	Corduliidae	1	-	26
	Euphaeidae	5	7	-
	Gomphidae	29	9	32
	Libellulidae	24	4	98
	Platycididae	3	3	27
Hemiptera	Belostomatidae	-	-	5
	Gerridae	34	32	10
	Naucoridae	21	-	-
	Nepidae	3	-	25
	Notonectidae	8	-	2
	Vellidae	12	5	-
Coleoptera	Dytiscidae	22	-	-
	Elmidae	9	7	-
	Eulichadidae	3	4	-
	Gyrinidae	2	1	8
	Psephenidae	33	10	-
Diptera	Chironomidae	-	2	15
	Deuterophlebiidae	-	-	1
	Dixidae	0	0	1
	Tipulidae	3	-	-
Total		**689**	**318**	**353**

Note: - indicates absence (-) of individuals

In Lata Changkah, the highest percentage of individuals collected was from order Ephemeroptera (27%), followed by Trichoptera (26%), Plecoptera (14%), Coleoptera (10%), Hemiptera and Odonata, each contributing 11% of total abundance collected. Diptera showed the lowest abundance; only 1% was collected from this stream. Similarly, in Sungai Peres, the most dominant order was Ephemeroptera (31%). Trichoptera was the second most abundant aquatic insects in Sungai Peres (26%), followed by Plecoptera (14%), Hemiptera

(11%), Odonata (11%), Coleoptera (10%) and Diptera 1% was the lowest in the stream. In contrast, different trends in total abundance were observed in Sungai Ular. Order Odonata was the highest percentage of aquatic insects at Sungai Ular, comprising more than half of the total abundance at the site (61%). It was followed by Ephemeroptera (11%), Hemiptera (12%), Diptera (5%), Trichoptera (3%) and Coleoptera (2%).

The most abundant families found in this study were Heptageniidae (Order Ephemeroptera), followed by Perlidae (Order Plecoptera), Stenopsychidae and Hydropsychidae (Order Trichoptera) (Table 1). Interestingly, Libellulidae (Order Odonata) was the most dominant family found in Sungai Ular. Other commonly occurring families' evident at all sampling sites were Polycentropodidae, Gerridae, Hydropsychidae, Platycididae, Chlorocyphidae, Gyrinidae, Isonychidae and Gomphidae. In Lata Changkah, families of Naucoridae, Dytiscidae and Tipullidae were uniquely found at this site. Belostomatidae and Dixidae families were only found at Sungai Ular.

Aquatic insects in Lata Changkah were more diverse and rich compared to Sungai Peres and Sungai Ular. However, composition and distribution of aquatic insects in Lata Changkah were slightly similar to Sungai Peres. From observation, the microhabitats and substrate components that can be found in Lata Changkah and Sungai Peres were quite similar. Mohd Rasdi *et al.,* (2012) previously reported that heterogeneity of microhabitats is one of the factors influencing the assemblages of aquatic insects. Galuppo *et al.,* (2007) suggested that desirable habitat quality is generally characterized by a heterogeneous habitat with both slow and fast moving water, woody debris, substrate variety, and well-vegetated and stable banks. All of these microhabitats could be observed in both Lata Changkah and Sungai Peres. In contrast, very few of these microhabitats could be found in Sungai Ular and the substrata of the stream mostly consisted of muddy sediment, with little pebbles and contained a lot of suspended sediment. Thus, it seems that the assemblages of aquatic insects frequently change in response to anthropogenic stress in predictable ways (Azrina *et al.,* 2005).

Order Ephemeroptera was found to be the most abundant in Lata Changkah and Sungai Peres and Heptageniidae was the most dominant family collected for both streams. These mayflies show a strong preference for a rocky substratum and marginal vegetation, and both streams contain fast-flowing running water. Filter-feeders or scrappers like these mayflies generally prefer a clean cobble substratum for attachment and high to turbulent flow to facilitate filtering (Sivaramakrishnan & Venkataraman, 1987).

The members of Trichoptera are always found in less disturbed areas and they are very good as bioindicators of water quality monitoring for the health of streams (Yule & Yong, 2004). In this study, Trichoptera were abundantly found in Sungai Peres (25%) and Lata Changkah (26%) compared to Sungai Ular (3%). Stenopsychidae was the most dominant family collected in Lata Changkah followed by Hydropsychidae and Polycentropodidae. In Sungai Peres, the most abundant family collected was Polycentropodidae followed by Hydropsychidae and Stenopsychidae. The microhabitats for both streams are similar including pebbles and rocks sheltered with debris and silk that is highly preferred by these families (Morse, 2004). Moreover, this is supported by Wiggins (1996) who reported that the immature stages of Trichoptera live in freshwater and flourish in running waters greater than in any other freshwater body. Trichopterans are especially sensitive to decrease in water quality (Guilpart *et al.,* 2012). Therefore, this indicates that this order is very selective to their habitats to survive.

According to Che Salmah and Abu Hassan (2005), the diversity of Plecoptera families is generally low in tropical Asian streams. But, in Sungai Peres and Lata Changkah, the abundance of Plecoptera (Perlidae) was found to be high and no Plecoptera was found in Sungai Ular. This might be due to the preferred habitats for Plecopterans especially at streams that have variation of substrate components such as pebble, cobble, rocks and gravel with high vegetative substrate. The fast running water is also more preferred by Plecoptera. The water in Sungai Ular was slow-flowing to almost stagnant, which may be the reason why no Plecopteran could be found there. Based on Arman Hadi *et al.* (2015), Plecoptera are good water quality bioindicators with intolerance to anthropogenic pollution. Perlidae nymphs need high concentrations of dissolved oxygen, normal pH, relatively clean water and are restricted to lotic water to survive. This was supported by Sivec and Yule (2004) who reported that the presence of Plecopterans with high diversity indicates clean water quality.

The number of Chironomidae, the most tolerant taxa was higher at Sungai Ular than in Lata Changkah and Sungai Peres. This could be due to slow-flowing streams and muddy or sandy areas, with high fine-sediment particles known to support higher abundance of Chironomidae (Wahizatul *et al.,* 2011). The presence of Chironomidae larvae in Sungai Ular indicated that the area is highly influenced by the oil palm plantation and agriculture activities which might cause slight pollution to the stream. Chironomidae is a pollution-tolerant invertebrate and considered as a bioindicator for polluted aquatic systems (Azrina *et al.,* 2005).

Classification of Water Quality based on Physico-Chemical Analysis and Biological Indices

The water physico-chemical measurements of Lata Changkah, Sungai Peres and Sungai Ular are shown in Table 2. For the water temperature, Sungai Ular showed the highest reading which was 28.84°C±0.21, while Lata Changkah and Sungai Peres had lower readings, 24.46°C±0.006 and 24.15°C±0.021, respectively. DO and BOD in Lata Changkah and Sungai Peres were relatively higher compared to Sungai Ular. For the pH level, Sungai Ular showed that the water was slightly acidic (pH= 5.47±0.015), while Lata Changkah and Sungai Peres had neutral pH. However, based on Pearson Correlation Analysis, no significant correlation was detected between the abundance of aquatic insects and physico-chemical parameters.

Table 2: The average readings and standard deviation of water quality parameters at Lata Changkah, Sungai Peres and Sungai Ular

Water Parameters	Lata Changkah	Sungai Peres	Sungai Ular
Temperature (°C)	24.46±0.006	24.15±0.021	28.84±0.212
pH	6.46±0.040	6.38±0.035	5.47±0.015
Dissolved oxygen (mg/L)	8.16±0.030	7.98±0.006	5.62±0.015
Turbidity (NTU)	2.18±0.017	3.35±0.249	2.15±0.285
Biological oxygen demand (mg/L)	2.37±0.200	1.01±0.012	1.63±0.015
Conductivity (ms/cm)	0.030±0.000	0.022±0.000	0.036±0.000
Total dissolved oxygen (mg/L)	0.020±0.000	0.019±0.000	0.026±0.000
Total suspended solid (mg/L)	0.006±0.005	2.31±1.995	0.005±0.005
Velocity (s)	45.33±9.386	25.90±2.128	17.16±0.763
Depth (m)	0.691±0.102	0.472±0.033	0.314±0.036
Width (m)	0.638±0.024	0.390±0.015	0.161±0.005

Table 3 shows the classification of water quality of Lata Changkah, Sungai Peres and Sungai Ular based on biological indices, BMWP, FBI and ASPT. The BMWP values of all streams were 'Very Good'. The FBI values in Lata Changkah and Sungai Peres were 'Excellent', whereas Sungai Ular scored 'Good'. The ASPT index indicates that both LataChangkah and Sungai Peres were 'Good' but Sungai Ular scored only as 'Moderately Good'. Based on INWQS, the water quality for Lata Changkah was classified as Class I, Sungai Peres as Class IIA and Class III for Sungai Ular (Table 4). The range of water temperature was considered as normal for all streams. For the TSS, all streams were classified as Class I. In LataChangkah, the DO was more than 7 mg/L and also with Sungai Peres the water quality was classified in Class I. DO of Sungai Ular was less than 7 mg/L, thus it was classified as Class IIA. Furthermore, turbidity for all sites was classified in Class I. BOD readings showed that Sungai Peres and Sungai Ular were classified as Class I, while Lata Changkah was classified in Class IIA. Overall, our results indicate that a better water quality was recorded in Lata Changkah and Sungai Peres compared to Sungai Ular where the impact of human disturbance on the distribution of aquatic insects and water quality seem clearly associated.

Table 3: The classification of water quality in Lata Changkah, Sungai Peres and Sungai Ular based on biological indices

Biological Indices / Study Sites	Lata Changkah	Sungai Peres	Sungai Ular
Biological Work Party (BMWP)	3796	1422	1484
Class	Very Good	Very Good	Very Good
Family Biotic Index (FBI)	2.65	2.42	5.00
Class	Excellent	Excellent	Good
Average Score Per Taxon (ASPT)	7.25	7.25	4.46
Class	Good	Good	Moderately Good

Table 4: Classification of water quality based on Interim National Water Quality Standards (INWQS) in LataChangkah, Sungai Peres and Sungai Ular

Water Parameter	Study Sites	Readings	INWQS unit	Class
Water temperature (°C)	Lata Changkah	24.45	-	Normal
	Sungai Peres	24.15	-	Normal
	Sungai Ular	28.84	-	Normal
pH level	Lata Changkah	6.46	6.5-8.5	I
	Sungai Peres	6.38	6.0-9.0	IIA
	Sungai Ular	5.47	5.0-9.0	III
Dissolved oxygen (mg/L)	Lata Changkah	8.16	7.0	I
	Sungai Peres	7.98	7.0	I
	Sungai Ular	5.62	5.0-7.0	IIA
Turbidity (NTU)	Lata Changkah	2.18	5.0	I
	Sungai Peres	3.35	5.0	I
	Sungai Ular	2.15	5.0	I
Total Suspended Solid (g)	Lata Changkah	0.006	25.0	I
	Sungai Peres	2.313	25.0	I
	Sungai Ular	0.005	25.0	I
Biological oxygen demand (mg/L)	Lata Changkah	2.37	3.0	IIA
	Sungai Peres	1.01	1.0	I
	Sungai Ular	1.63	1.0	I

Conclusion

In this study, Lata Changkah and Sungai Peres were considered as having good water quality due to greater diversity and abundance of aquatic insects. Both streams were considered as of "Good" to "Excellent" water quality with reference to biological indices such as ASPT, BMWP and FBI and Malaysian water quality standards, INWQS which is developed by the Department of Environment Malaysia. A higher distribution and abundance of intolerant taxa such as Ephemeroptera, Plecoptera and Trichoptera, which are sensitive to pollution in both streams indicate that both streams are clean and have good water quality. However, Sungai Ular was considered as only "Moderately Good" due to a higher abundance of tolerant taxa, Chironomidae (Order Diptera) and lower abundance of intolerant taxa, Ephemeroptera, Plecoptera and Trichoptera. Human disturbance like oil palm plantations and agricultural activities around Sungai Ular might lead to a greater abundance of Chironomidae. This present study has provided information on changes in aquatic insect communities that seem to occur due to human disturbance of freshwater ecosystems.

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