Tropical Life Sciences Research, 25(2), 61–79, 2014

The Influence of Heavy Metals and Water Parameters on the Composition and Abundance of Water Bugs (Insecta: Hemiptera) in the Kerian River Basin, Perak, Malaysia

Nur Adibah Mohd Ishadi, Che Salmah Md Rawi*, Abu Hassan Ahmad and Nurul Huda Abdul

School of Biological Sciences, Universiti Sains Malaysia, 11800 USM, Pulau Pinang, Malaysia

Abstrak: Kepelbagaian hemipteran (Insekta) di bahagian atas lembangan Sungai Kerian adalah rendah dengan hanya 8 famili dan 16 genus direkod dari 4 kawasan penelitian pada 3 sungai. Komposisi mereka berbeza secara signifikan antara kawasan penelitian (Kruskal-Wallis $\chi^2 = 0.00$, $p<0.05$) tetapi tidak dipengaruhi oleh musim hujan dan kering ($Z = 0.00$, $p>0.05$). Semua parameter air yang direkod berkait lemah dengan kelimpahan genus tetapi permintaan oksigen biokimia (BOD), permintaan oksigen kimia (COD), indeks kualiti air (WQI) dan logam berat (zink dan mangan) menunjukkan hubungan negatif atau positif yang hampir kuat terhadap kepelbagaian dan kekayaan hemipteran (H' and R_2). Rangkuman julat parameter air yang diukur, WQI adalah berkait secara negatif dengan kepelbagaian dan kelimpahan hemipteran yang menunjukkan toleransi mereka terhadap tahap pencemaran yang terdapat di lembangan sungai ini. Berdasarkan kepada kelimpahan dan kekerapannya yang tinggi (ISI) *Rhagovelia* adalah genus yang paling penting dan bersama dengan *Rheumatogonus* dan *Paraplea,* mereka sangat banyak ditemui di kawasan penelitian. Sebagai kesimpulan, keterdapatan dan kesesuaian habitat serta beberapa parameter persekitaran mempengaruhi kepelbagaian dan kelimpahan hemipteran di lembangan sungai ini.

Kata kunci: Hemiptera Akuatik, Kepelbagaian, Kekayaan, Parameter Air, Kesesuaian Habitat, Habitat Sungai

Abstract: The hemipteran (Insecta) diversity in the upper part of the Kerian River Basin was low with only 8 families and 16 genera recorded at 4 study sites from 3 rivers. Water bug composition varied among sampling sites (Kruskal-Wallis $\chi^2 = 0.00$, $p<0.05$) but was not affected by wet-dry seasons ($Z = 0.00$, $p>0.05$). All recorded water parameters were weakly associated with generic abundance but the biochemical oxygen demand (BOD), chemical oxygen demand (COD), Water Quality Index (WQI) and heavy metals (zinc and manganese) showed relatively strong positive or negative relations with hemipteran diversity and richness (H' and R_2). Within the ranges of measured water parameters, the WQI was negatively associated with hemipteran diversity and richness, implying the tolerance of the water bugs to the level of pollution encountered in the river basin. Based on its highest abundance and occurrence (ISI), *Rhagovelia* was the most important genus and along with *Rheumatogonus* and *Paraplea,* these genera were common at all study sites. In conclusion, habitat availability and suitability together with some environmental parameters influenced the abundance and composition of hemipterans in this river basin.

Keywords: Aquatic Hemiptera, Diversity, Richness, Water Parameters, Habitat Suitability, Riverine Habitat

---

*Corresponding author: csalmah@usm.my

INTRODUCTION

Investigations of aquatic macroinvertebrates in Malaysia began as early as 1966 when Furtado studied Malayan Odonata and slightly later when Bishop (1973) extensively examined the riverine invertebrate fauna of the Gombak River in Selangor state. In the 1990s, several documented observations of aquatic insect assemblages were published by many researchers who focused on inventory types of investigations (Shabdin *et al*. 2002; Yap *et al*. 2003; Morse *et al.* 2007; Wahizatul *et al.* 2011; Aweng *et al*. 2012) about specific groups of aquatic insects within some habitats or water quality ranges, for dragonflies and chironomids in rice fields or rivers (Yap *et al*. 2003; Che Salmah *et al.* 2004, 2005; Che Salmah & Wahizatul 2004; Che Salmah *et al*. 2006; Al-Shami *et al*. 2010), stoneflies (Plecoptera) in a river system (Wan Nurasiah *et al*. 2009) and Ephemeroptera, Plecoptera and Trichoptera (EPT) in forest streams (Che Salmah *et al*. 2001, 2007; Suhaila & Che Salmah 2011a, b; Suhaila *et al*. 2011, 2013). More recent investigations have addressed the effects of various water parameters and habitat qualities that have shaped the pattern of macroinvertebrate distribution in specific habitats at a local scale (Che Salmah *et al*. 2014) and a landscape scale (Che Salmah *et al.* 2013) to justify their roles and potential in the biological biomonitoring of water quality or as indicator species. Several researchers who were involved in assessing various land use effects, particularly oil palm plantations (Mercer *et al*. 2014), forest logging and fragmentation (Aweng *et al*. 2011; Che Salmah *et al*. 2013), industrial (Al-Shami *et al*. 2011a) and anthropogenic activities (Azrina *et al*. 2006; Al-Shami *et al*. 2011b) on aquatic macroinvertebrates, have made important contributions to the understanding of their function in the aquatic ecosystem.

Among the aquatic insect groups, hemipterans (water bugs) receive little attention from researchers primarily because of their infrequent occurrence in many aquatic habitats. Nevertheless, many hemipterans are tolerant and able to survive in a wide range of aquatic environments (Foltz & Dodson 2009). Semi-aquatic gerromorphan hemipterans move actively on the water surface and are less affected by disturbances or polluted habitats. Because of their habits, the calculations for some biological indices for assessing anthropogenically polluted water bodies such as the Family Biotic Index (FBI) (Hilsenhoff 1988) do exclude water bugs. Two other indices, namely the Biological Monitoring Working Party (BMWP) and Average Score Per Taxon (ASPT), include the presence of hemipterans in their estimations (Armitage *et al.* 1983) because these insects are common in moderately polluted aquatic habitats.

Although many aquatic hemipterans are less effective bioindicators, they play important roles in the aquatic food-chain (Ahmed & Gadalla 2005; Ohba & Nakasuji 2006). Large-sized Belostomatidae, Nepidae and Notonectidae are often placed at the top of the aquatic food web (Bay 1974; Spence & Andersen 1994; Toledo 2003; Ohba 2011). They prey on a variety of aquatic organisms (Motta & Uieda 2004) such as other insects, cladocerans, amphipods, fish, tadpoles (Spence & Andersen 1994; Tobler *et al*. 2007) and adult frogs (Hirai & Hidaka 2002; Batista *et al*. 2013). Larger aquatic bugs are a concern to fisheries sometimes (Spence & Andersen 1994; Tobler *et al*. 2007). In relation to their effective predation, Spence and Andersen (1994) associate hemipteran diets with the distribution of available prey within the habitat. Smith and Horton (1998) found that, despite being a good predator, Belostomatidae also contributed to the higher trophic level when they became an important dietary component for brown trout (*Salmo truta*) in Little Colorado River, Arizona.

In paddy fields, gerromorphans (veliids and gerrids) become important natural enemies by feeding upon several plant and leaf hopper pests and moths that fall from rice plants (Spence & Andersen 1994). These insects are effective predators of freshwater vector snails and mosquitoes in India (Aditya *et al*. 2004). At least 12 hemipteran genera (17 species) including *Sphaeroderma, Anisops* and *Laccotrephes* feed on various species of mosquito larvae (Saalan & Canyon 2009) and other dipteran vectors of some diseases, and hence they are useful as biological control agents (Yang *et al.* 2004).

The Kerian River Basin (5°9'–5°21'N and 100°36.5'–100°46.8'E) is one of the largest river basins in peninsular Malaysia with a catchment area of 1418 km^2 that provides the water required for a population of approximately 196,500 (Yap & Ong 1990). The primary Kerian River stretches approximately 90 km along the border of Kedah and Perak states and is accompanied by several tributaries. With a good road network, this river basin has become the focus of many ecological investigations such as fish population and biology (Zakaria *et al*. 1999; Mansor *et al*. 2010; Mohd-Shafiq *et al*. 2012), fish genetics (Jamsari *et al*. 2011), hydrology, water quality and macroinvertebrates (Yap & Ong 1990; Haque *et al*. 2010; Al-Shami *et al*. 2013) and avian diversity (Nur Munira *et al*. 2011). In this study, we examined the water quality and habitat suitability of a hemipteran community in the Kerian River and its tributaries to elucidate their adaptation to these environments. These findings would provide greater insight into the ecological requirements that led to their successful colonisation.

MATERIALS AND METHODS

Sampling Sites

Four Kerian River tributaries were selected as sampling sites (Fig. 1): the Mahang River (MR) (5°20'43.70"N and 100°46'17.70"E), the Kerian River (KR) (5°18'47.50"N and 100° 46'53.61"E), and the Selama River (SR), which were divided into the Upper Selama (US) (5°15'33.33"N and 100°50'37.18"E) and Lower Selama (LS) (5°15'34.60"N and 100°50'42.10"E). These first to second order rivers of different substrate types and compositions are subject to various anthropogenic disturbances, and their water surfaces are shaded by a varying amount of canopy cover. In the US, the river substrate consists primarily of boulders and cobbles and the water surface is partially shaded. Several shrubs (*Bambusa* sp.) and woody tree species (*Koompassia malaccensis*, *Chassalia chartacea* and *Nenga pumila)* grow on the river banks. It is a popular upstream recreational area for the locals although part of the nearby area has been planted with oil palm and pineapples. The LS passes through a sparsely populated village. At the sampling site, the river is rather wide with a relatively flattened river bed made of course sandy substrate and with an open canopy. All sampling points are located in a running area of fast flowing water. The MR is characterised by sandy substrate with gravel. Scattered vegetation along the river banks covers part of the water surface. Active sand mining and other human activities in the nearby area affect the river's condition. The KR is a large river of fast-flowing open water. Its substrates are primarily cobble and gravel, and some vegetation grows along the river banks. This river passes through the margin of a secondary forest and presumably receives minimal perturbations compared with other rivers.

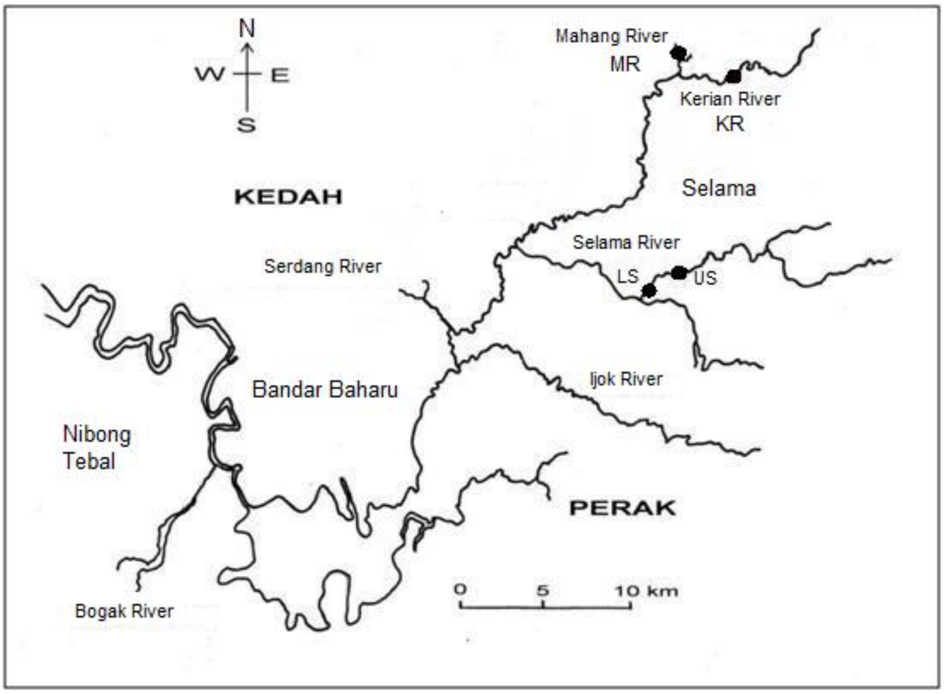

Figure 1: A map of the study areas; the MR, KR, US and LS in the Kerian River Basin. *Note:* Black dots are study sites

Monthly weather data for all sampling sites from January 2008 until December 2009 were obtained from the Malaysian Meteorological Department in Kuala Lumpur. The data were recorded at meteorological stations located approximately 50 km from the respective sampling areas.

Sampling Aquatic Hemiptera

Bimonthly aquatic hemipteran collections were taken at all sampling sites from July 2008 until July 2009 following the methods of Hellawell (1986) and Meritt and Cummins (1996). Ten samples were collected within approximately 100 m of river from available substrates, marginal vegetation, leaf pack in running water and pool areas from each sampling site by using a kick-net method (D-pond aquatic net, 30 cm width, 300 µm mesh size fitted with a 1.2 m-long handle). The net was dragged on approximately 1 m² of substrate or marginal vegetation, or approximately 1 m² of the substrates in front of the net was disturbed for approximately 2 minutes. In the laboratory, each sample was washed through a 300 µm sieve, and leaves, stems and other debris were removed. The aquatic bugs were sorted and preserved in 75% ethanol. Individual hemipterans were identified to the lowest possible taxa following keys by Yang *et al.* (2004) and Morse *et al.* (1994).

River Attributes and Measurements of Physicochemical Water Parameters

On every sampling occasion, the amount of canopy covering the water surface, the components of the substrate, and the activities on adjacent land were recorded. The water parameters, pH, dissolved oxygen (DO) and temperature (T) were measured in-situ at each sampling site. The pH value was obtained by using a sensION1 pH meter (HACH, Colorado, USA) and the DO and T were measured with a DO meter (YSI 550A, YSI Environment, Ohio, USA). Three replicates of each water sample were collected randomly from each site in 500 ml polyethylene bottles and transported to the Laboratory of Aquatic Entomology, School of Biological Sciences, Universiti Sains Malaysia (USM) in an ice chest. The biochemical oxygen demand (BOD) content was recorded with a DO meter (YSI 550A) and other chemical water parameters, nitrate (NO_3-N), ammonia-nitrogen (NH_3-N), total suspended solids (TSS) and chemical oxygen demand (COD) were analysed with a DR/890 colorimeter (HACH, Colorado, USA). The water quality status of each river was determined according to the Water Quality Index (WQI) classification of the Department of Environment (DOE), Malaysia (DOE, 1988) (Table 1). A subindex (SI) calculation for all parameters was used to generate the WQI as displayed in Appendix 1. The WQI is calculated as follows:

$$\mathrm{WQI} = (0.22 \times \mathrm{SIDO}) + (0.19 \times \mathrm{SIBOD}) + (0.16 \times \mathrm{SITSS}) + (0.16 \times \mathrm{SICOD}) + (0.15 \times \mathrm{SINH_3N}) + (0.12 \times \mathrm{SIpH}).$$

Table 1: River classification according to the WQI (DOE 1988).

River class	Score	Description
I	>92.7	Very good water quality. Suitable for livestock drinking without treatment.
II	76.5–92.7	Good water quality. Suitable for livestock drinking with treatment.
III	51.9–76.6	Can be used as drinking water but needs very intensive treatment.
IV	31.0–51.9	Water quality suitable for plantation drainage but not suitable to apply to sensitive vegetation.
V	<31.0	Water unsuitable for any of the above uses.

Analysing Sediment Heavy Metals

Sediment samples were collected on every sampling occasion from each site and air-dried in the laboratory to analyse their heavy metal contents [zinc (Zn), nickel (Ni), copper (Cu) and manganese (Mn)] following the method of Chester and Voutsinou (1981). In the laboratory, the sediment was separated from large debris by using a 500 µm mesh sieve. Five grams of dried sediment was weighed accurately and placed in a 100 ml-wide neck glass flask. Subsequently, 75 ml of 0.5 M HCl was added. The flask was shaken for approximately 16 hours. The mixture was filtered through 0.45 µm filter paper to separate the non-residual solution. The solution was sprayed directly into an Atomic AAnalyst 100 Absorption Spectrophotometer (Flame AAS) (PerkinElmer, Massachusetts, USA) with appropriate lamps and wavelength settings for specific metals.

Statistical Analysis

Variations among the bimonthly mean distributions for the aquatic bugs were analysed by using the Kruskal-Wallis test for non-normally distributed data. At all sites, the hemipteran community features of diversity (Shannon Wiener H'), evenness (Pielou J), similarity of distribution (Bray Curtis) and richness (Menhinick Richness Index) were analysed with Species, Diversity and Richness Software (PISCES Conservation Ltd. 2007, Hampshire, UK) using generic abundances and diversities that were assumed to represent their morpho-species. The similarities of hemipteran abundances between pairs of sites were calculated as Whittaker's beta diversity Index (Whittaker 1972; Magurran 2004). The Important Species Index (ISI) was used to rank various genera based on their abundance and their frequency of occurrence at each site (Magurran 2004). The species richness in the upper Kerian River basin was expressed as Gamma diversity (Whittaker 1972). Associations among various physicochemical water parameters including the WQI with hemipteran abundance, diversity and richness were indicated by Spearman's rho correlation coefficients.

RESULTS

The Composition and Abundance of Hemiptera in Rivers Within the Kerian River Basin

The hemipterans were represented by 8 families, 16 genera and 849 individuals. *Rhagovelia* was the most common genus contributing 36.98% of the total hemipterans followed by *Paraplea* (22.03%) and *Laccocoris* (11.54%) (Table 2). The abundance of hemipterans was significantly different among sampling sites (Kruskal-Wallis $\chi^2 = 0.00$, $p<0.05$) but no temporal abundance (Kruskal-Wallis $\chi^2 = 0.144$, $p>0.05$) or wet-dry seasonal variation ($Z = 0.00$, $p>0.05$) was detected.

Among the sampling sites, the MR had the highest hemipteran abundance followed by the KR, and the LS and US had the lowest (Fig. 2). Out of the 16 genera collected, 6 genera occurred in high abundance at the MR, reflecting its habitat suitability to the hemipterans. *Rhagovelia*, *Pseudovelia*, *Pleciobates*, *Rheumatogonus*, *Cylindrostethus* and *Paraplea* were well distributed at all sites and some genera such as *Angilovelia*, *Amemboa*, *Micronecta* and *Limnogonus* were only collected at one of the sites (Table 2). Coinciding with the highest abundance, *Rhagovelia* was the most important genus (highest ISI score) in the upper basin of the Kerian River followed by *Rheumatogonus* and *Cylindrostethus* (Table 3). The hemipteran community diversity, richness and evenness were higher in the US (Table 4), which was complemented by its difference from other sites as reflected by the score for the Whittaker's β diversity index (Table 5). The hemipteran community in the KR was more similar to that of the MR and LS but the US separated itself from other sites (Fig. 3). Considering the low number of sampling sites from limited habitats that were sampled, the total richness of Hemiptera in this part of the river basin as represented by gamma diversity (16) was fair.

Table 2: The hemipteran generic abundance at each sampling site during the study.

Family/genus	US	LS	MR	KR
VELIIDAE				
Angilovelia	0	0	1	0
Rhagovelia	6	11	181	116
Pseudovelia	1	5	47	4
GERRIDAE				
Pleciobates	10	5	1	4
Rheumatogonus	32	20	24	21
Amemboa	0	0	3	0
Ptilomera	2	0	0	1
Cylindrostethus	4	3	7	2
Limnogonus	0	0	0	2
NEPIDAE				
Cercotmetus	0	0	12	3
MICRONECTIDAE				
Micronecta	0	3	0	0
NAUCORIDAE				
Laccocoris	11	62	0	25
APHELOCHEIRIDAE				
Aphelocheirus	6	12	0	4
PLEIDAE				
Paraplea	12	92	40	43
HELOTREPHIDAE				
Hydrotrephes	0	0	1	7
Helotrephes	0	0	0	3
Total abundance (genus)	84(9)	213(9)	317(10)	235(13)

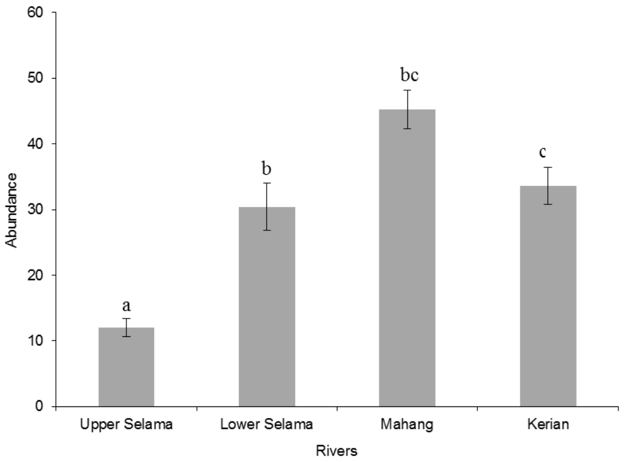

Figure 2: The abundance (mean±SE) of Hemiptera at four study sites in the Kerian River Basin as collected from July 2008 until July 2009.

Notes: Bars indicate standard errors. Histograms sharing the same letter are not significantly different (at *p* = 0.05) based on the Mann-Whitney test.

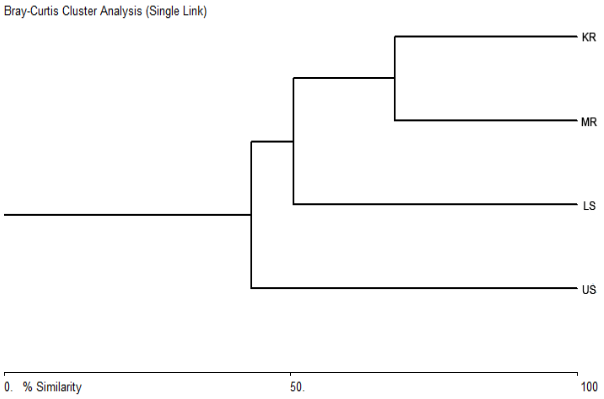

Figure 3: A similarity analysis of hemipteran abundance among sampling sites.

Table 3: The Important Species Index of Hemiptera in selected rivers in the Kerian River Basin.

Genus	US	LS	MR	KR
Rhagovelia	1.87	4.22	57.60	33.84
Angilovelia	0	0	0.07	0
Pseudovelia	0.07	1.71	5.64	0.99
Cylindrostethus	15.53	1.34	0.54	0.22
Ptilomera	0.19	0	0	0.08
Rheumatogonus	36.45	10.53	4.50	7.11

(*continued on next page*)

Table 3: (*continued*)

Genus	US	LS	MR	KR
Pleciobates	0.93	1.48	0.07	0.9
Amemboa	0	0	0.13	0
Limnogonus	0	0	0	0.3
Cercotmetus	0	0	3.42	0.56
Micronecta	0	0.81	0	0
Laccocoris	10.44	28.87	0	12.43
Aphelocheirus	3.47	4.16	0	0.43
Helotrephes	0	0	0	0.32
Hydrotrephes	0	0	0.002	0.39
Paraplea	5.69	12.57	14.83	15.77

Table 4: Ecological Index scores of hemipteran communities from rivers in the Kerian River Basin.

Ecological index	US	LS	MR	KR
Shannon (H')	1.69	1.41	1.35	1.58
Menhinick (R2)	0.91	0.56	0.51	0.79
Pielou J	0.81	0.68	0.61	0.64

Table 5: Scores for the Whittaker's beta diversity index from the sampling sites in the upper catchment of the Kerian River Basin (KRB).

Rivers	Whittaker's beta diversity index
US–LS	0.11
US–MR	0.37
US–KR	0.18
LS–MR	0.37
LS–KR	0.27
MR–KR	0.30

The Influence of Physico-chemical Parameters and Heavy Metals in the Sediments

Environmental parameters in all rivers fell within similar ranges (Tables 6 and 7). The TSS and water turbidity varied among rivers; it was very low in the US but steadily increased from the LS to the MR with its highest in the KR. Although sand was actively mined in MR, the water quality (WQI scores) was very good (Class I) at all sites suggesting very clean water suitable for human consumption with only minimal treatment required for the LS. The LS passes through a sparsely populated village, and its WQI fell into Class II. There were very weak associations between some water parameters (Table 8) and individual generic abundance, but stronger relations for DO, COD, and temperature were observed with the diversity (H') and richness (R_2) of the water bug community in the river basin. Out of four heavy metals analysed in the sediments from all sites, only zinc and manganese were detected, and they showed weak to fair associations with generic abundance, hemipteran diversity and richness (Table 8 and Table 9). Other parameters had no relation to the abundance of the water bugs.

Table 6: The environmental characteristics of the study sites.

River attribute	US	LS	MR	KR
Canopy cover	Partially shaded	Fully open	Partially shaded	Fully open
Substrate type	Boulder, cobble	Cobble, gravel	Gravel, sand	Cobble, gravel
Land use	Recreational	Residential	Residential; sand mining	None observed disturbance

Table 7: Physicochemical water parameters [Mean ± standard error (SE)] and river classifications based on the WQI.

Water parameter	US	LS	MR	KR
pH	6.49±0.046	6.20±0.063	6.73±0.051	6.20±0.071
DO (mg/L)	8.65±0.082	8.70±0.140	8.40±0.116	8.42±0.088
Temperature (°C)	21.99±0.127	22.46±0.134	21.9±0.178	23.02±0.102
Velocity (ms^{-1})	0.46±0.008	0.87±0.025	0.51±0.007	0.85±0.010
TSS (mg/L)	2.43±0.212	3.71±0.211	4.14±0.337	12.57±0.992
Turbidity (NTU)	1.36±0.055	1.45±0.076	2.37±0.217	5.71±0.556
Nitrate (mg/L)	0.04±0.003	0.05±0.003	0.06±0.003	0.08±0.006
Amm. N (mg/L)	0.04±0.002	0.05±0.001	0.05±0.001	0.06±0.001
COD (mg/L)	27.57±0.440	34.14±0.512	37.43±0.321	35.71±0.374
BOD (mg/L)	0.60±0.044	0.63±0.050	0.68±0.007	0.44±0.025
WQI	102.77	90.89	112.30	100.64
Mn (ppm)	37.57±1.28	40.59±2.14	31.19±0.99	24.75±1.76
Zn (ppm)	6.01±0.22	6.18±0.53	4.31±0.19	6.33±0.42
River class	I	II	I	I

Notes: Amm. N = Ammonical nitrogen (NH_3N) at study sites. Ni and Cu were not detected in the sediments at all sites.

Table 8: Relation [Spearman's rho Correlation Coefficient (ρ)] between water parameters and the abundance of selected Hemiptera genera.

Genus	pH	DO	NH_3N	TSS	COD	BOD	Turbidity	T
Rhagovelia	0.09	–0.07	0.04	0.25**	0.28**	0.08	0.18**	0.05
Cercotmetus	0.08	–0.01	0.03	0.04	0.12*	0.13*	–0.01	–0.02
Pleciobates	0.11	–0.16**	–0.01	0.01	–0.14**	–0.01	0.11	0.11
Cylindrostethus	0.13*	–0.04	–0.05	0.01	–0.05	0.06	0.02	–0.05
Hydrotrephes	–0.06	0.10	0.01	0.12	0.11	0.04	0.13*	0.04
Helotrephes	–0.08	0.09	0.06	0.14*	0.11	–0.06	0.14*	0.06

(*continued on next page*)

Table 8: (*continued*)

Genus	pH	DO	NH_3N	TSS	COD	BOD	Turbidity	T
Laccocoris	–0.26**	0.08	0.13*	0.07	0.00	–0.15*	0.00	0.04
Paraplea	–0.05	0.13*	0.05	–0.03	0.07	0.07	–0.16**	–0.04
Micronecta	0.08	–0.11	–0.06	–0.11	–0.06	0.07	0.05	0.13*

Note: *significant at $p = 0.05$ level (2-tailed), **significant at $p = 0.01$ level (2-tailed)

Table 9: Relations [Spearman's rho Correlation Coefficient (ρ)] between Hemiptera abundance and ecological indices with water and sediment parameters.

Parameter	Shannon (H')	Menhinick (R1)	Abundance
DO	–0.37**	–0.38**	0.01
Ammonia	-0.06	–0.14*	0.13*
TSS	0.25**	0.09	0.19**
COD	–0.43**	–0.34**	0.18**
BOD	0.10	0.30**	–0.01
Turbidity	0.26**	0.32**	0.09
Temperature	0.39**	0.37**	0.08
WQI	–0.26**	–0.29**	–0.05
Zn	0.08	–0.21*	–0.27**
Mn	–0.41**	–0.48*	–0.13

Note: *significant at $p = 0.05$ level (2-tailed), **significant at $p = 0.01$ level (2-tailed)

DISCUSSION

Out of 18 families and 64 genera recorded in peninsular Malaysia and Singapore (Yang *et al.* 2004), only 8 families and 16 genera were collected from the 3 rivers in the Kerian River Basin. As a group, aquatic hemipterans inhabit various freshwater habitats, moist soil, ponds, streams, rivers, rock pools, phytotelmata, water-splashed rocks, hot springs, brackish water, intertidal coral reef flats and the ocean (Yang *et al*. 2004). The study sites covered here provided limited habitats for the bugs and thus was reflected in their low diversity. The composition of the hemipterans differed among the four sites but with only slightly lower diversity (H' = 1.35) at the MR where sand mining was still in operation. There were very weak associations of hemipteran abundance with water quality because of the small variations in water parameters recorded at all sites. Although the water quality is important in determining the abundance and distribution of many aquatic insect groups (Dance & Hynes 1980; Ahmad *et al*. 2002; Azrina *et al*. 2006), the different composition and abundance of Hemiptera at each site was likely more related to habitat availability and suitability where they lived (Stout 1982).

Environmental characteristics are important in shaping the structure of aquatic macroinvertebrate communities (Buss *et al*. 2002; Murphy & Davy-Bowker 2005; Subramanian & Sivaramakrishnan 2005; Beauger *et al*. 2006;

Hughes 2006) including the hemipterans observed in this study. More hemipteran genera of higher abundance were recorded in KR and MR and a lower hemipteran assemblage inhabited the US in which the substrates consisted primarily of boulders and large cobbles. Nonetheless, the US habitat was preferred by some prey (Subramanian & Sivaramakrishnan 2005; Hoang & Bae 2006) of the predatory hemipterans (Yang *et al*. 2004). The gerrid *Rheumatogonus* was relatively common in the US, and it skated on the water surface with the aid of densely haired, long middle legs, which enabled it to live on fast running water (Yang *et al*. 2004). A very low abundance of other fast running water gerrids (*Pleciobates, Ptilomera* and *Cylindrostethus*) was recorded. Most of these gerrids occurred in higher abundance in the US, which has the slowest water flow among the four sites and possibly within a more suitable range for the insects or their prey. Six genera, *Cercotmetus, Hydrotrephes, Amemboa, Helotrephes, Micronecta* and *Limnogonus,* commonly inhabited stagnant, slow-moving water or vegetated areas, and they were completely absent from the US and LS and in general were poorly represented in this part of the basin. The scores for Whittaker's beta diversity index supported the close similarity of the hemipteran community in the US and LS but were different from that of the MR.

Rhagovelia was highly abundant in the MR and KR but very few were collected from the US and LS. This aquatic insect was commonly found near the roots of aquatic vegetation where the water was stagnant or moving very slowly. McPherson and Taylor (2006) also reported that *Steinovelia stagnalis* (Veliidae) was collected in enormous numbers from emergent vegetation among the roots of weeds and along the banks of stagnant pools in small streams. The importance of rooted weeds was supported by Wood and Sites (2002) when they found that the structural and habitat complexity offered by the root mats increased the abundance of these insects. Small and hard-bodied veliids exploit surface tension and particular body postures to escape from predators by climbing out of the water and onto aquatic plants (Ahmed & Gadalla 2005). The LS lacked aquatic vegetation and the water flow in the US was fast, and hence these two sites were less suitable for this genus.

The abundance of hemipteran genera in the Kerian River basin was weakly associated with measured water parameters as indicated by Spearman ρ scores that ranged from 0.12 (*Cercotmetus* and COD) to 0.28 (*Rhagovelia* and COD). However, there were relatively strong negative influences especially by DO, COD and manganese on the collective hemipteran diversity (H') and richness (R_2). Interestingly, there were weak negative associations for hemipteran diversity and richness with the water quality (WQI), which nevertheless translated into their tolerance to the ranges of water parameters within the river basin.

The effects of various heavy metals on macroinvertebrates [such as cadmium (Cd), Cu, Zn, lead (Pb), iron (Fe), Mn and chromium (Cr)] were previously documented by several authors (Marques *et al*. 2003; Smolders *et al*. 2003; Iwasaki *et al*. 2009; Al-Shami *et al*. 2011b; Warrin *et al*. 2012). Individual macroinvertebrates that were exposed to heavy metal contamination experienced decreased survival in addition to shorter and lower body length and weights, respectively (Wentsel *et al*. 1977). The diversity and richness of the benthic macroinvertebrate community are much reduced in heavy metal-contaminated water bodies (Marques *et al*. 2003; Smolders *et al*. 2003). In this part of the river basin, fertiliser leachates from agricultural land, domestic and industrial effluents or naturally occurring geological weathering may have introduced heavy metals into rivers (Forstner & Wittmann 1983). Although most hemipteran genera are surface dwellers, some genera, such as *Laccocoris* and *Aphelocheirus,* live in close contact with the contaminated sediments and are thus more exposed to heavy metals either in the sediment or to the amount that is occasionally released into the water (Beasley & Kneale 2002). Zinc and manganese were negatively associated with both the diversity and richness of the hemipteran community although the concentration of both metals for all study sites were way below those reported to cause deleterious effects on aquatic insects (Wentsel *et al*. 1977).

In the LS, *Laccocoris* (Naucoridae) was markedly abundant but it was not found in the MR, and very few were found in the US. The result of this study also implied that *Laccocoris* was relatively tolerant to the increasing water acidity and ammonia content in the water. Among all the sites, the LS received continuous anthropogenic discharge from human dwellings along the stream banks, which apparently did not adversely affect the *Laccocoris* population at the site. *Paraplea, Rheumatogonus* and *Rhagovelia* were well distributed at all sites. These hemipterans were able to tolerate a wide range of environmental parameters and inhabited the many types of microhabitats available in the river basin.

CONCLUSION

The findings of this study showed that some water parameters and heavy metals in the sediments had fairly negative or positive associations with hemipteran diversity and richness in the upper Kerian River Basin. The Hemiptera diversity was low and its generic abundance at all sampling sites was more related to habitat availability and suitability. *Rhagovelia, Rheumatogonus* and *Paraplea* were common at all study sites.

ACKNOWLEDGEMENT

This study was jointly funded by the USM Research Grant (815068) and the Fundamental Research Grant Scheme of the Ministry of Higher Education Malaysia (6711224). Transportation and laboratory facilities were furnished by the School of Biological Sciences, USM. The first and last authors were partially supported by a Graduate Fellowship Scheme from the Institute for Graduate Studies, USM.

APPENDIX

The Best Fit for the estimation of Sub-index values.

Subindex for DO (in % saturation)
$SIDO = 0$ for $x \leq 8$
$= 100$ or $x \geq 92$
$SIDO = -0.395 + 0.030x^2 + -0.00020x^3$ for $8 < x < 92$

Subindex for BOD
$SIBOD = 100.4 - 4.23x$ for $x \leq 5$
$SIBOD = 108 * \exp(-0.0157x - 0.04x)$ for $x > 5$

Subindex for COD
$SICOD = -1.33x + 99.1$ for $x \leq 20$
$SICOD = 103 * \exp(-0.0157x - 0.04x)$ for $x > 20$

Subindex for AN
$SIAN = 100.5 - 105x$ for $x \leq 0.3$
$SIAN = 94 * \exp(-0.573x - 5 * |x - 2|)$ for $0.3 < x < 4$
$SIAN = 0$ for $x \geq 4$

Subindex for SS
$SISS = 97.5 * \exp(-0.0067x + 0.05x)$ for $x \leq 100$
$SISS = 71 * \exp(-0.001x - 0.015x)$ for $100 < x < 1000$
$SISS = 0$ for $x \geq 1000$

Subindex for pH
$SIPH = 17.2 - 17.2x + 5.02x^2$ for $x < 5.5$
$SIPH = -242 + 95.5x - 6.67x^2$ for $5.5 \leq x < 7$
$SIPH = -181 + 82.4x - 6.05x^2$ for $7 \leq x < 8.75$
$SIPH = 536 - 77.0x + 2.76x^2$ for $x \geq 8.75$

(x = concentration in mg/L for all parameters except pH and DO)

The calculation for the WQI is performed according to the following equation:
$WQI = (0.22 \times SIDO) + (0.19 \times SIBOD) + (0.16 \times SICOD) + (0.15 \times SIAN) + (0.16 \times SISS) + (0.12 \times SIPH)$

Notes: The SI is the subindex for each parameter. The water quality for the rivers is categorised based on the WQI values. AN = ammonia nitrogen, SS = suspended solid.

REFERENCES

Aditya G, Bhattacharyya S, Kundu N, Saha G K and Raut S K. (2004). Predatory efficiency of the water bug *Sphaerodema annulatum* on mosquito larvae (*Culex quinquefasciatus*) and its effect on the adult emergence. *Bioresource Technology* 95(2): 169–172.

Ahmad A, Maimon A, Othman M S and Mohd Pauzi A. (2002). The potential of local benthic macroinvertebrates as a biological monitoring tool for river water quality assessment. *Proceedings of the Regional Symposium on Environment and Natural Resources* 1: 464–471.

Ahmed R S and Gadalla S M. (2005). Contribution to the study of Heteroptera, Gerromorpha (semiaquatic bugs) v. water crickets (Family Veliidae) from Egypt. *Journal Asia-Pacific Entomology* 8(3): 219–226.

Al-Shami S, Che Salmah M R, Abu Hassan A and Madziatul Rosemahanie M. (2013). Biodiversity of stream insects in the Malaysian Peninsula: Spatial patterns and environmental constraints. *Ecological Entomology* 38(4): 238–249.

Al-Shami S A, Che Salmah M R, Abu Hassan A, Suhaila A H and Siti Azizah M N. (2011a). Influence of agriculture, industrial and anthropogenic stresses on the distribution and diversity of macroinvertebrates in Juru River Basin, Penang, Malaysia. *Ecotoxicology and Environmental Safety* 74(5): 1195–1202.

Al-Shami S A, Che Salmah M R, Siti Azizah M N and Abu Hassan A. (2011b). Evaluation of mentum deformities of *Chironomus* spp. (Chironomidae: Diptera) larvae using Modified Toxic Score Index (MTSI) to assess the environmental stress in Juru River Basin, Penang, Malaysia. *Environmental Monitoring and Assessment* 177(1–4): 233–244.

Al-Shami S A, Che Salmah M R, Abu Hassan A and Siti Azizah M N. (2010). Temporal distribution of larval Chironomidae (Diptera) in experimental rice fields in Penang, Malaysia. *Journal of Asia-Pacific Entomology* 13(1): 17–22.

Armitage P D, Moss D, Wright J F and Furse M T. (1983). The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research* 17(3): 333–347.

Aweng E R, Ismid-Said M., Maketab-Mohamed and Ahmad-Abas K. (2011). Effect of logging activities on water quality and benthic macroinvertebrate assemblages of Madek River Basin, Kluang, Johor, Malaysia. *Journal Applied Science and Environmental Management* 15(2): 337–340.

Aweng E R, Suhaimi O and Nur Izzati S. (2012). Benthic macroinvertebrate community structure and distribution in Sungai Pichong, Gunung Chamah, Kelantan, Malaysia. *American International Journal of Contemporary Research* 2(1): 163–167.

Azrina M Z, Yap C K, Ismail A R, Ismail A and Tan S G. (2006). Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. *Ecotoxicology and Environmental Safety* 64(3): 337–347.

Batista V G, Affonso I D P, Hanisch R G and Oda F H. (2013). Predation on *Eupemphix nattereri* Steindachner, 1863 (Anura, Leiuperidae) by giant water bugs, *Lethocerus delpontei* De Carlo, 1930 and *L. annulipes* (Herrich-Schäffer, 1845) (Hemiptera, Belostomatidae). *Pan-American Journal of Aquatic Sciences* 8(4): 364–368.

Bay E C. (1974). Predator – prey relationships among aquatic insects. *Annual Review of Entomology* 19: 441–453.

Beasley G and Kneale P. (2002). Reviewing the impact of metals and PAHs on macroinvertebrates in urban watercourses. *Progress in Physical Geography* 26(2): 236–270.

Beauger A, Lair N, Reyes-Marchant P and Peiry J L. (2006). The distribution of macroinvertebrate assemblages in a reach of the River Allier (France), in relation to riverbed characteristics. *Hydrobiologia* 571(1): 63–76.

Bishop J E. (1973). *Limnology of a small Malayan River Sungai Gombak*. The Hague: Dr. W Junk B V. Publishing.

Buss D F, Baptista D F, Silveira M P, Nessimian J L and Dorvill´e L F M. (2002). Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in south-east Brazil. *Hydrobiologia* 481(1–3): 125–136.

Che Salmah M R, Abu Hassan A and Ameilia Z S. (2004). Odonate communities (Odonata: Insecta) in a tropical river basin, Malaysia. *Wetland Science* 2(1): 1–9.

Che Salmah M R, Abu Hassan A and Jongkar G. (2007). Diversity of Ephemeroptera, Plecoptera and Trichoptera in various tributaries of Temenggor catchment, Perak, Malaysia. *Wetland Science* 5(1): 20–31.

Che Salmah M R, Abu Hassan A and Wahizatul A A. (2005). Preliminary study on composition and distribution of Odonata in Perlis State Park. *Journal Malayan Nature Society* 57(3): 317–326.

Che Salmah M R, Al-Shami S A, Madziatul Rosemahanie M and Abu Hassan A. (2014). Biological and ecological diversity of aquatic macroinvertebrates in response to hydrological and physicochemical parameters in tropical forest streams of Gunung Tebu, Malaysia: implications for ecohydrological assessment. *Ecohydrology* 7(2): 496–507.

____. (2013). Local effects of forest fragmentation on diversity of aquatic insects in tropical forest streams: Implications for biological conservation. *Aquatic Ecology* 47(1): 75–85.

Che Salmah M R, Amelia Z S and Abu Hassan A. (2001). Preliminary distribution of Ephemeroptera, Plecoptera and Trichoptera (EPT) in Kerian River Basin, Perak, Malaysia. *Pertanika Journal of Agricultural Science* 24(2): 101–107.

Che Salmah M R, Surya Wardhani T and Abu Hassan A. (2006). The population of Odonata (dragonflies) in small tropical rivers with reference to asynchronous growth patterns. *Aquatic Insects* 28(3): 195–209.

Che Salmah M R and Wahizatul A A. (2004). Distribution of Odonata (Insecta) in various ecosystems in northern peninsular Malaysia. *Wetland Science* 2(3): 184–191.

Chester R and Voutsinou F G. (1981). The initial assessment of trace metal pollution in coastal sediment. *Marine Pollution Bulletin* 12(3): 84–91.

Dance K W and Hynes H B N. (1980). Some effects of agricultural land use on stream insect communities. *Environmental Pollution Series A, Ecological and Biological* 22(1): 19–28.

Department of Environment Malaysia (DOE). (1988). *Malaysia Environmental Quality Report*. Putrajaya, Malaysia: Department of Environment, Ministry of Science, Technology and Environment.

Foltz S J and Dodson S I. (2009). Aquatic Hemiptera community structure in storm water retention ponds: A watershed land cover approach. *Hydrobiologia* 621(1): 49–62.

Forstner U and Wittmann G T W. (1983). *Metal pollution in the aquatic environment.* Berlin: Springer-Verlag.

Furtado J I. (1966). *Studies on Malayan Odonata*. PhD diss., University of Malaya.

Haque M A, Huang Y F and Lee T S. (2010). Seberang Perai rice sheme irrigation water quality assessment. *Journal of the Institution of Engineers Malaysia* 71(4): 42–48.

Hellawell J M. (1986). *Biological indicators of freshwater pollution and environmental management.* London: Elsevier.

Hilsenhoff W L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. *Journal of North America Benthological Society* 7(1): 65–68.

Hirai T and Hidaka K. (2002). Anuran-dependent predation by the giant water bug, *Lethocerus deyrollei* (Hemiptera: Belostomatidae), in rice fields of Japan. *Ecological Research* 17(6): 655–661.

Hoang D H and Bae Y J. (2006). Aquatic insect diversity in a tropical Viatnamese stream in comparison with that in a Korean stream. *Limnology* 7(1): 45–55.

Hughes S J. (2006). Temporal and spatial distribution patterns of larval Trichoptera in Madeiran streams. *Hydrobiologia* 553(1): 27–41.

Iwasaki Y, Kagaya T, Miyamoto K and Matsuda H. (2009). Effects of heavy metals on riverine benthic macroinvertebrate assemblages with reference to potential food availability for drift-feeding fishes. *Environmental Toxicology and Chemistry* 28(2): 354–63.

Jamsari A F J, Tan M P and Siti-Azizah M N. (2011). Genetic structure of the snakehead murrel, *Channa striata* (Channidae) based on the cytochrome c oxidase subunit I gene: Influence of historical and geomorphological factors. *Genetics and Molecular Biology* 34(1): 152–160.

Magurran A E. (2004). *Measuring biological diversity*. Massachusetts, USA: Blackwell Publishing.

Mansor M I, Che Salmah M R, Rosalina R, Shahrul Anuar M S and Amir Shah Ruddin M S. (2010). Length-weight relationships of freshwater fish species in Kerian River Basin and Pedu Lake. *Research Journal of Fisheries and Hydrobiology* 5(1): 1–8.

Marqués M J, Martínez-Conde E and Rovira J V. (2003). Effects of zinc and lead mining on the benthic macroinvertebrates of a fluvial ecosystem. *Water, Air and Soil Pollution* 148(4): 363–388.

McPherson J E and Taylor S J. (2006). Observations on the field life history of *Steinovelia stagnalis* (Hemiptera: Veliidae) in Southern Illinois, USA, with a survey of the biological literature. *Entomological News* 117(4): 399–405.

Mercer E V, Mercer T G and Sayok A K. (2014). Effects of forest conversions to oil palm plantations on freshwater macroinvertebrates: A case study from Sarawak, Malaysia. *Journal of Land Use Science* 9(3): 260–277.

Meritt R W and Cummins K W. (1996). *An introduction to the aquatic insects of North America*, 3rd ed. Dubuque, Iowa: Kendall/Hunt Publishing Company,12–28.

Mohd Shafiq Z, Mansor M I, Che Salmah M R, Amir-Shahruddin M S and Abu Hassan A. (2012). Assessment of suitability of Kerian River tributaries using length-weight relationship and relative condition factor of six freshwater fish species. *Journal of Environment and Earth Science* 2(3): 52–60.

Morse J C, Liangfang Y and Tian L (eds.). (1994). *Aquatic insects of China useful for monitoring water quality*. Nanjing, China: Hohai University Press, 117–540.

Morse J C, Bae Y J, Munkhjargal G, Sangpradub N, Tanida K, Vshivkova T S, Wang B, Yang L and Yule C M. (2007). Freshwater biomonitoring with macroinvertebrates in East Asia. *Frontiers in Ecology and the Environment* 5(1): 33–42.

Motta R L and Uieda V S. (2004). Diet and trophic groups of an aquatic insect community in a tropical stream. *Brazilian Journal of Biology* 64(4): 809–817.

Murphy J F and Davy-Bowker J. (2005). Spatial structure in lotic macroinvertebrate communities in England and Wales: Relationship with physical, chemical and anthropogenic stress variables. *Hydrobiologia* 534(1–3): 151–164.

Nur Munira A, Nurul Salmi A L, Shahrul Anuar M S, Mohd Abdul Muin M A, Nur Juliani S and Nurul Liyana K. (2011). Avian diversity and feeding guilds in a secondary forest; an oil palm plantation and a paddy field in riparian areas of the Kerian River Basin, Perak, Malaysia. *Tropical Life Sciences Research* 22(2): 45–64.

Ohba S. (2011). Density-dependent effects of amphibian prey on the growth and survival of an endangered giant water bug. *Insects* 2(4): 435–446.

Ohba S and Nakasuji F. (2006). Dietary items of predacious aquatic bugs (Nepoidea: Heteroptera) in Japanese wetlands. *Limnology* 7(1): 41–43.

Saalan E A S and Canyon D V. (2009). Aquatic insect predators and mosquito control. *Tropical Biomedicine* 26(3): 223–261.

Shabdin M L, Fatimah A and Khairul Adha A R. (2002). *The macroinvertebrate community of the fast flowing rivers in the Crocker Range National Park, Sabah, Malaysia. ASEAN Review of Biodiversity and Environmental Conservation (ARBEC).* http://www.arbec.com.my/pdf/art12julysep02.pdf (accessed on 1 April 2014).

Smith R L and Horton C. (1998). Fish predation on giant water bug (Heteroptera: Belostomatidae) eggs in an Arizona stream. *Great Basin Naturalist* 58(3): 292–293.

Smolders A J P, Lock R A C, Van der Velde G, Hoyos R M and Roelofs J G M. (2003). Effects of mining activities on heavy metal concentrations in water, sediment, and macroinvertebrates in different reaches of the Pilcomayo River, South America. *Archives of Environmental Contamination and Toxicology* 44(3): 314–323.

Spence J R and Andersen N M. (1994). Biology of water striders: Interactions between systematics and ecology. *Annual Review of Entomology* 39(1): 101–28.

Stout R J. (1982). Effects of a harsh environment on the life history patterns of two species of tropical aquatic Hemiptera (Family: Naucoridae). *Ecology* 63(1): 75–83.

Subramanian K A and Sivaramakrishnan K G. (2005). Habitat and microhabitat distribution of stream insect communities of the Western Ghats. *Current Science* 89(6): 976–987.

Suhaila A H and Che Salmah M R. (2011a). Influence of substrate embeddedness and canopy cover on the distribution of Ephemeroptera, Plecoptera and Trichoptera (EPT) in tropical rivers. *Aquatic Insects* 33(4): 281–292.

____. (2011b). Stoneflies in Malaysian tropical rivers: Diversity and seasonality. *Journal of Entomology and Nematology* 3(2): 30–36.

Suhaila A H, Che Salmah M R and Al-Shami S A. (2013). Temporal distribution of Ephemeroptera, Plecoptera and Trichoptera (EPT) adults at a tropical forest stream: Response to seasonal variations. *Environmentalist* 32(1): 28–34.

Suhaila A H, Che Salmah M R, Hamady D, Abu Hassan A, Tomomitsu S and Fumio M. (2011). Seasonal changes in mayfly communities and abundance in relation to water physicochemistry in two rivers at different elevations in northern peninsular Malaysia. *Wetland Science* 9(3): 240–250.

Tobler M, Schlupp I and Plath M. (2007). Predation of a cave fish (*Poecilia mexicana*: Poeciliidae) by a giant water-bug (*Belostoma*: Belostomatidae) in a Mexican sulphur cave. *Ecological Entomology* 32(5): 492–495.

Toledo L F. (2003). Predation of seven South Amerian anuran species by water bugs (Belostomatidae). *Phyllomedusa* 2(2): 105–108.

Wahizatul A A, Long S H and Ahmad A. (2011). Composition and distribution of aquatic insect communities in relation to water quality in two freshwater streams of Hulu Terengganu, Terengganu. *Journal of Sustainability Science and Management* 6(1): 148–155.

Wan Nur Asiah W M A, Che Salmah M R and Sivec I. (2009). Description of *Etrocorema belumensis* sp.n. from Royal Belum State Park, Perak, Malaysia. *Illiesia* 5(17): 182–187.

Warrin E, Che Salmah M R, Zubir D and Al-Shami S A. (2012). Toxicity of cadmium and lead on tropical midge larvae, *Chironomus kiiensis* Tokunaga and *Chironomus javanus* Kieffer (Diptera: Chironomidae). *Asian Pacific Journal of Tropical Biomedicine* 2(8): 631–634.

Wentsel R, Mcintosh A and Atchiso G. (1977). Sublethal effects of heavy metal contaminated sediment on midge larvae (Chironomus tentans). *Hydrobiologia* 56(2): 153–156.

Whittaker R H. (1972). Evolution and measurement of species diversity. *Taxon* 21(2/3): 213–251.

Wood D L and Sites R W. (2002). Submerged rootmats: A mesohabitat harbouring a distinct insect community in Ozark Streams. *Journal of Freshwater Ecology* 17(3): 431–440.

Yang C M, Kovac D and Cheng L. (2004) Insecta: Hemiptera, Heteroptera. In C M Yule and H S Yong (eds.). *Freshwater invertebrates of the Malaysian region.* Kuala Lumpur: Academy of Sciences Malaysia, 457–459.

Yap S Y and Ong H T. (1990). The effects of agrochemicals on an aquatic ecosystem: A case study from the Krian River Basin, Malaysia. *The Environmentalist* 10(3): 189–202.

Yap C K, Rahim I A and Tan S G. (2003). Species diversity of macrobenthic invertebrates in the Semenyih River, Peninsular Malaysia. *Pertanika Journal of Agriculture Science* 26(2): 139–146.

Zakaria M, Mansor M and Ali A B. (1999). Swamp-riverine tropical fish population: A comparative study of two spatially isolated freshwater ecosystems in Peninsular Malaysia. *Wetlands Ecology and Management* 6(4): 261–268.