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Relationships of Distribution of Macrobenthic Invertebrates and the Physico-chemical Parameters from Semenyih River by Using Correlation and Multiple Linear Stepwise Regression Analyses

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ABSTRACT

The distribution of macrobenthic invertebrates at Semenyih River has been described by Yap *et al.* (2003a), but their relationships with physico-chemical characteristics of the river have yet to be established. By using correlation and multiple linear stepwise regression, it was found that BOD_3, orthophosphate, total suspended solids and turbidity were important in structuring the stream macrobenthic invertebrate communities because they determined whether organisms could colonize and persist in the stream habitats. Thus, the invertebrates are useful as bioindicators to the health of the river ecosystem, complementing water quality analysis. Impacts of anthropogenic inputs can therefore be assessed based on the macrobenthic invertebrates' different species distribution.

Keywords: Semenyih River, macrobenthic invertebrates, correlation analysis, multiple stepwise regression analysis

INTRODUCTION

A previous study reported by Yap *et al.* (2003a) at Semenyih River on a list of the macrobenthic invertebrates poses, among the non-biologists, a question on 'How valid is the bioindication concept be employed in the river pollution study?' In order to answer this question, the relationships between the distribution of macrobenthic invertebrates and the physico-chemical parameters of the river need to be conducted. Meanwhile, the analyses of the water quality and macrobenthic invertebrates has their respective advantages. For instance, water quality could give a rapid assessment on the water quality status of the river, while bioindication concept could reveal the health of the river ecosystem in response to pollution (Mason & Parr, 2003; Yap *et al.*, 2003a; Azrina *et al.*, 2006).

Regardless of which methodology (water quality or bioindicators) is employed, the relationships between water quality of the sampling sites and the distribution of macrobenthic invertebrates should be informative of the environmental quality of the river ecosystem, since in fact, both the physical-chemicals and biotic information/methodologies are giving the actual picture of the quality of the river being studied (Azrina *et al.*, 2006). Since ecological studies on the macrobenthic invertebrates involving their abundance and distribution are interrelated with their surrounding, such as physico-chemical components in which they are found at the

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bottom of the rivers, the relationships between the abundance/distribution of the macrobenthic invertebrates and the physico-chemical parameters of the habitat river waters should be conducted. Among the multivariate statistical analyses, correlation and regression analyses are among the most common methods used to show the relationships between the organisms and their surrounding since they have been widely used as reported in the literature (Yap *et al.*, 2010). In addition, Yap *et al.* (2003b) also used multiple linear stepwise regression (MLSR) in the study conducted on heavy metal accumulation by the green-lipped mussel, *Perna viridis*.

According to Norris *et al*. (1982), contaminants that may have impacts on aquatic system should be assessed by an interpretative study of the physico-chemical characteristics in relation to the biota. A biodiversity of the benthic communities, being dependent on the conditions and resources of its locations, may change if environmental factors change. Meanwhile, due to the complex interrelationships and the many environmental factors of the natural river ecosystem, only certain influential factors could potentially affect the distribution and abundance of macrobenthic invertebrates. An alteration in these conditions or resources that lead to one or more of these conditions to change may cause many of the populations to change, and be replaced by others (Warren, 1971). Therefore, the use of MLSRA is more logical to test and find out the most influential parameter that affects the density of macrobenthic invertebrate in Semenyir River. The objective of this study was to determine the relationships between the physico-chemical parameters and distribution of macrobenthic invertebrates found at Semenyih River using the correlation analysis and MLSRA.

MATERIALS AND METHODS

Study Area

This study covered the riverine system of Semenyih River, (2° 54'N to 3° N and 101° 48'E to 101° 53'E), a tributary of the Langat River. The sampling was conducted in June 1997. Seven stations were established along the river, with St-1 being the closest to Semenyih Dam (most upstream) and St-7 farthest to the downstream (*Fig. 1*). The sampling technique used for the macrobenthic invertebrates, their preservation and identification at the sampling sites and the list of macrobenthic invertebrates found in Semenyih River have already been reported by Yap *et al*. (2003a).

Water Quality Measurement

The physico-chemical characteristics of the stream, recorded directly at each sampling site, were water velocity, temperature, depth, river width, conductivity, pH and dissolved oxygen. Water velocity was measured by direct timing (Stopwatch, string and ping pong ball), whereas river depth and width were done using a meter ruler and measuring tape, respectively. The conductivity, temperature, and dissolved oxygen were measured using the YSI S-C-T meter, while pH was determined using a pH meter, i.e. Orion 410A+.

Samples of water were stored in polyethylene bottles (500 ml). Orthophosphate, nitrate, ammonia, turbidity and total suspended solids (TSS) were in accordance with the Standard Methods (APHA, 1985). Water in polyethylene bottles were preserved with 2 ml of concentrated hydrochloric acid (pH < 2.0) and brought back to the laboratory. These water samples were cleared by any suspended solids with paper filtration, except for the determination of turbidity. Meanwhile, the concentrations of nitrate, orthophosphate, ammonia and turbidity were determined using the spectrophotometer model HACH DR 2000 with specified wavelengths of 507 nm, 890 nm, 425 nm, and 450 nm, respectively. Blanks used to obtain the zero values were from 25.0 ml of deionised water that were put into the other sample cells.

For Biochemical Oxygen Demand (BOD_3), Wheaton bottles (300 ml) were filled until overflowed so that there were no bubbles inside the bottles before topping them with stoppers. These bottles were then put inside a cool box as

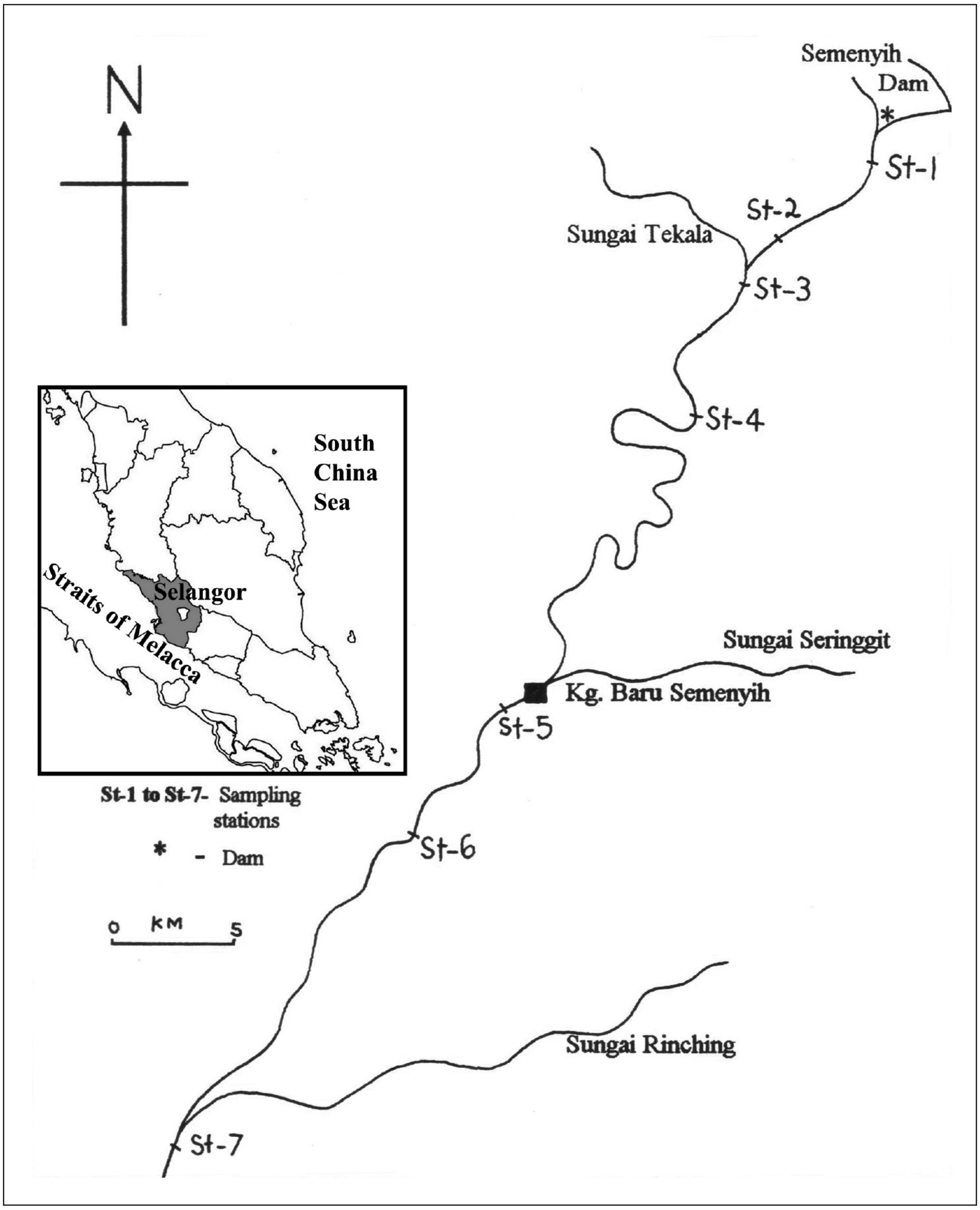

Fig. 1: The locations of the sampling stations in this study (The Directorate of National Mapping, Malaysia, 1982)

soon as they were collected in the field. At the laboratory, the initial DO was measured before 3-days incubation at room temperature (28ºC).

Statistical Analyses

The data transformation was carried out to normalize the data and reduce the errors. All the converted physico-chemical data were transformed by log10 while the macrobenthic invertebrates' density data by applying fourth root. Pearson's correlation analysis and MLSRA were carried out on the transformed data using the Statistical Analysis System Version 6.0 (SAS Institute, 1987).

RESULTS AND DISCUSSION

Physico-chemical Parameters of the River

The overall physical and chemical characteristics of Semenyih River are given in Table 1. In general, river width, total suspended solids, turbidity, BOD_3, orthophosphate, nitrate, and conductivity increased with the increasing distance from Semenyih Dam. The overall river widths of the region ranged from 5.58 (St-2) to 32.67 m (St-7). In regard to the total suspended solids and turbidity, both ranged from 5 to 147 mg/L and from 2.33 to 122.00 FTU, respectively. The highest TSS and turbidity recorded downstream (St-7) was due to the instability of the river bottoms (Coker, 1968) that was caused by land-based activities, including erosion and addition of human wastes. The significance of the suspended solids in natural water normally relates to their influence on light and sediments (Maitland, 1990). As for the BOD_3, it was found to have increased from 0.60 (St-1) to 3.37 mg/L (St-7). The concentrations of nitrate ranged from 0.10 (St-3) to 1.94 mg/L (St-6) at all the sampling stations. The mean organic orthophosphate concentrations ranged from 0.004 (St-1 and St-2) to 0.113 mg/L (St-6) at all the sampling stations. Overall, conductivity was observed to range from 31.33 to 70.00 μmhos. Conductivity was highest at the sampling St-7 (70.00 μmhos) which is close to the urban area. This was probably due to the dissociation of inorganic compounds and the releases of heavy metals ions into the river water from urban wastes and other human activities.

As expected, the parameters such as water velocity, DO, ammonia, and pH showed a reverse pattern at the polluted downstream stations of Semenyih River. In particular, the water velocity of St-1 at the upstream recorded the highest value (0.97 m/s), while St-7, at the downstream, recorded the lowest (0.17 m/s). The different altitudes or the inclination of the surface in the direction of flow (Coker, 1968) and the increased discharges of the Semenyih Dam were two possible reasons to account for the notable variations in water velocity. In the case of dissolved oxygen (DO), it must be noted that the contents of the water bodies were well above 6 mg/L, and these were possibly due to the photosynthetic activity at all the sampling stations. In addition, the higher water velocity at the upstream stations (St-1 and St-2) was associated with higher DO as the turbulence waters mixed air into the water bodies. The sampling St-2 had the highest average of the DO (7.97 mg/L), whilst the sampling St-6 was the lowest (6.40 mg/L). Interestingly, the concentration of ammonia was found in a reverse pattern when compared to the concentrations of nitrate and orthophosphate. The sampling stations at the upstream (St-1 and St-2), before merging with Tekala River, were found to have high ammonia concentrations (3.36 mg/L). This particular finding was possibly due to the bottom-released water of Semenyih Dam which contained high concentration of ammonia. After joining the Tekala River, dilution seemed to take place as the concentrations of ammonia recorded were low, ranging from 0.48 (St-4 and St-6) to 0.55 mg/L (St-7). On the contrary, the pH values could hardly show any differences, as they were found to range from 6.00 to 6.56.

River depth fluctuated along the sampling stations. The irregular pattern was due to depths where the macrobenthic invertebrates were sampled and were not the deepest parts of the sampling sites. The temperature showed a little fluctuation between the sampling stations, as it ranged from 26.0 to 29.5°C. The highest temperature (29.5°C) was recorded at the sampling St-4 as this site had no shades. On the other hand, the lower temperature at St-5 (26.0°C) was due to the site being located under a roadway bridge and had the lowest temperature amongst all the sampling stations. A slight decrease shown for sampling St-2 (29.0°C) to sampling St-3 (26.7°C) was due to the entry of a cooler and pristine water tributary (Tekala River) to Semenyih River.

TABLE 1
The physico-chemical parameters of the water quality for each station at Sg. Semenyih. All the values represent the means of three samples collected in June, 1997 (individuals/m^2 ± standard error; N= 3)

Station	Wd (m)	Dep (m)	Tem (°C)	Vel (m/s)	DO (m/s)	pH	Con (µmhos)	BOD_3 (mg/L)	Amm (mg/L)	Pho (mg/L)	Nrt (mg/L)	Tbt (FTU)	TSS (mg/L)
1.	11.19 ± 2.13	0.15 ± 0.02	28.0 ± 0.00	0.97 ± 0.12	7.93 ± 0.03	6.49 ± 0.03	35.00 ± 0.00	0.60 ± 0.07	3.36 ± 0.00	0.004 ± 0.001	0.67 ± 0.01	2.33 ± 0.67	4.67 ± 0.67
2.	5.58 ± 0.55	0.20 ± 0.07	29.0 ± 0.00	0.48 ± 0.12	7.97 ± 0.09	6.56 ± 0.04	35.00 ± 0.00	1.23 ± 0.09	3.36 ± 0.00	0.004 ± 0.001	0.70 ± 0.03	2.67 ± 0.33	25.33 ± 18.34
3.	6.50 ± 0.50	0.34 ± 0.02	26.7 ± 0.33	0.82 ± 0.05	7.80 ± 0.06	6.00 ± 0.10	35.00 ± 0.00	1.13 ± 0.18	0.62 ± 0.15	0.012 ± 0.003	0.10 ± 0.01	7.33 ± 0.33	14.00 ± 1.15
4.	11.20 ± 0.80	0.15 ± 0.03	29.5 ± 0.29	0.50 ± 0.11	7.70 ± 0.06	6.13 ± 0.03	31.33 ± 0.67	1.97 ± 0.09	0.48 ± 0.12	0.032 ± 0.003	0.23 ± 0.01	16.00 ± 0.00	25.33 ± 3.53
5.	20.33 ± 0.88	0.31 ± 0.03	26.0 ± 0.00	0.18 ± 0.04	7.43 ± 0.09	6.23 ± 0.01	39.00 ± 0.58	2.40 ± 0.15	0.50 ± 0.13	0.042 ± 0.007	0.60 ± 0.03	37.00 ± 9.54	77.33 ± 17.94
6.	15.67 ± 0.67	0.21 ± 0.04	27.8 ± 0.17	0.25 ± 0.08	6.40 ± 0.17	6.02 ± 0.02	39.00 ± 0.00	2.27 ± 0.12	0.48 ± 0.12	0.113 ± 0.004	1.94 ± 0.00	29.67 ± 0.88	34.00 ± 2.00
7.	32.67 ± 0.33	0.24 ± 0.02	27.8 ± 0.17	0.17 ± 0.01	6.60 ± 0.10	6.12 ± 0.01	70.00 ± 0.00	3.37 ± 0.19	0.55 ± 0.16	0.096 ± 0.005	1.44 ± 0.06	122.00 ± 14.47	146.67 ± 5.70

Wd: River width, Dep: Depth, Tem: Temperature, Vel: Water velocity, Con: Conductivity, Amm: Ammonia, Pho: Phosphate, Nrt: Nitrate, Tbt: Turbidity, TSS: Total suspended solids

Density and Distribution of Macrobenthic Invertebrates

The densities and distributions of macrobenthic invertebrates of Semenyih River are shown in *Fig. 2* through *5*. High diversities were observed at the upstream stations (St-1 to St-3), but at downstream stations (St-5 to St-7), the populations were restricted by sand-bottom substratum and anoxic conditions of silt or polluted mud (Thorne & William, 1997), and therefore, only two species were found at St-7. Meanwhile, only Oligochaeta (*L. hoffmeisteri*) could tolerate unfavourable conditions. In addition, a high density of oligochaetes is a good indication of organic pollution (Slepukhina, 1984). In particular, St-3 recorded the highest number of species. This might originate from the drift from Tekala River which is believed to have a very high species richness due to its pristine conditions and remoteness.

Out of all the taxa recorded, Hirudinea and Oligocheata were the organisms found predominately at the downstream stations (St-5 to St-7) with *L. hoffmeisteri* being the most abundant species. Conversely, the other taxa (Crustacea, Ephemeroptera, Odonata, Gastropoda, Trichoptera, Coleoptera and Diptera) were principally recorded at the upstream sampling stations (Stations 1-3), with Baetidae and *F. m. martensi* being the least abundant at St-1. These species, that seemed to be negligible, were still of paramount importance in contributing towards species richness. It is important to note that some taxa could only be found at St-3. These taxa were Leptophlebiidae, *Hydropsyche annulata*, *Polymorphanisus* sp. and Tipulidae. At St-4, however, only a semi-tolerant bivalve species was found at the sandy bottom site, i.e. *Corbicula javanica*. Details of these macrobenthos compositions can be found in Yap *et al.* (2003a).

Pearson's Correlation Coefficient and Multiple Linear Stepwise Regression Analyses

The Pearson's correlation coefficients between each species and each physico-chemical parameter are presented in Tables 2a, 2b, and 2c. The results indicated that the taxa abundance was significantly influenced by a combination of different physico-chemical parameters. Based on the MLSRA (Tables 3a and 3b), river width, temperature, conductivity, BOD_3 and turbidity were found as good physico-chemical parameters which influence *Pentaneura* spp. at the downstream stations. This finding is supported by the correlations (r values ranging from -0.89 to 0.08) between the abundance of macrobenthic invertebrates and the physico-chemical parameters. Nonetheless, temperature and conductivity were not significantly correlated with *Pentaneura* spp. This was due to the analysis of MLSRA which had generalized the most influential ones and excluded the less important parameters regardless of the significant correlated parameters found in the Pearson's correlation coefficient.

The somewhat non-correspondence between the Pearson's correlation coefficient and the MLSRA of their parameters found was attributed to the fact that the procedures of the MLSRA had enumerated all the physico-chemical parameters into determination for the most important variables and this statistical procedures are more logical in practice since the nature consists of complicated abiotic factors. Once again, only the good parameters were shown, whereas the less influential ones were eliminated. As for the Pearson's correlation coefficient, every single parameter was found to have correlated with a macrobenthic invertebrates, one at a time.

Macrostemum similior was found to be negatively correlated with the parameters such as river width, BOD_3, orthophosphate, turbidity, and total suspended solids. On the contrary, *Macrostemum* sp. was positively correlated with water velocity, DO, pH, and ammonia. As high DO was usually found at clean stations, it is therefore plausible to make a statement that *Macrostemum* sp. is a good bioindicator for that particular system. Based on the MLSRA, the most influential parameters for the density of *Macrostemum* sp. were river width, temperature, pH, conductivity, BOD_3, and ammonia.

At St-3, where the highest number of species was found at all the stations, river

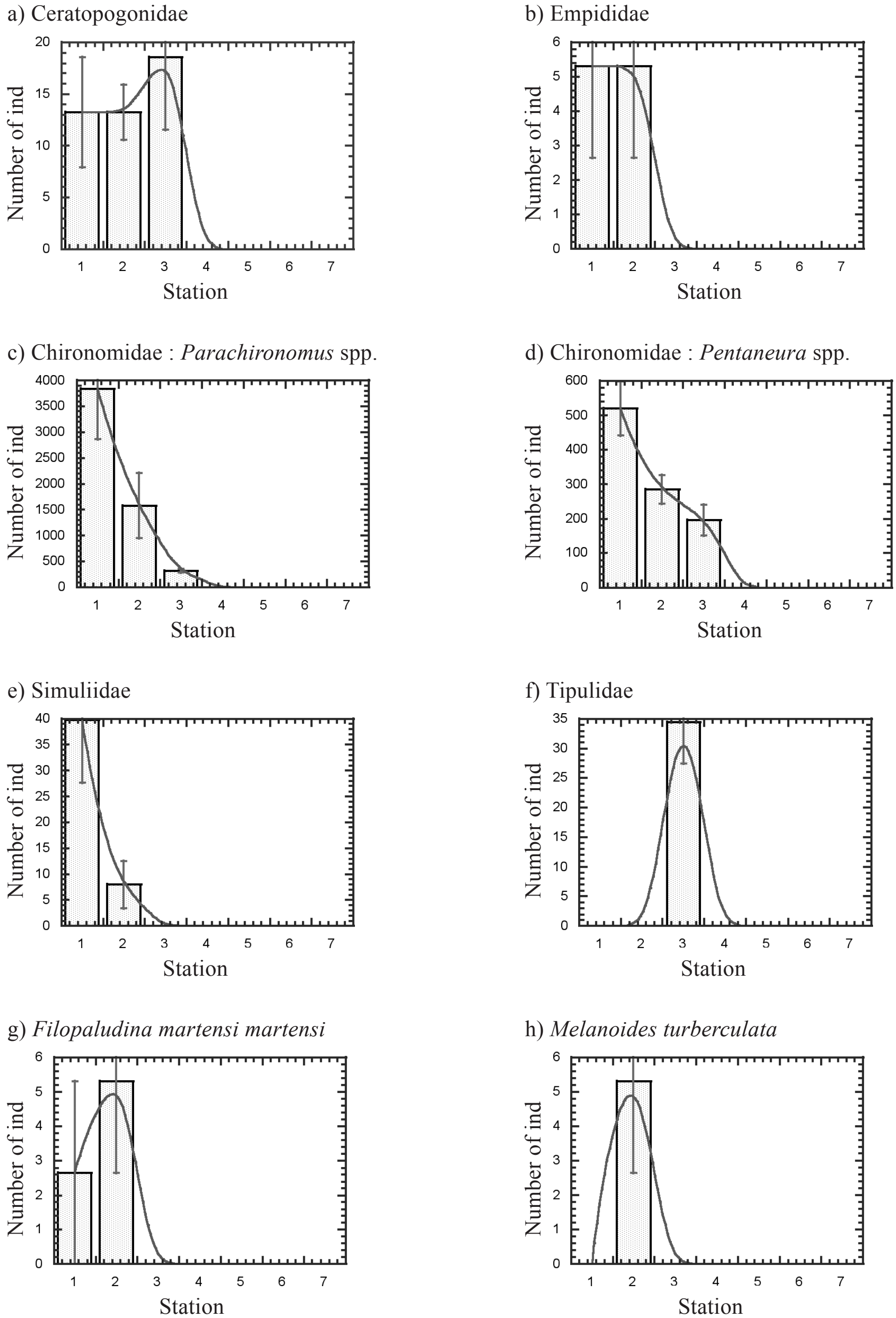

*Fig. 2: The mean number of individual (ind/m^2 ± SE; N= 3) Diptera (Ceratopogonidae, Simuliidae, Chironomidae, Empididae and Tipulidae) and Gastropoda (*F. m. martensi *and* M. turberculata*) at all the sampling stations at Sg. Semenyih in June, 1997*

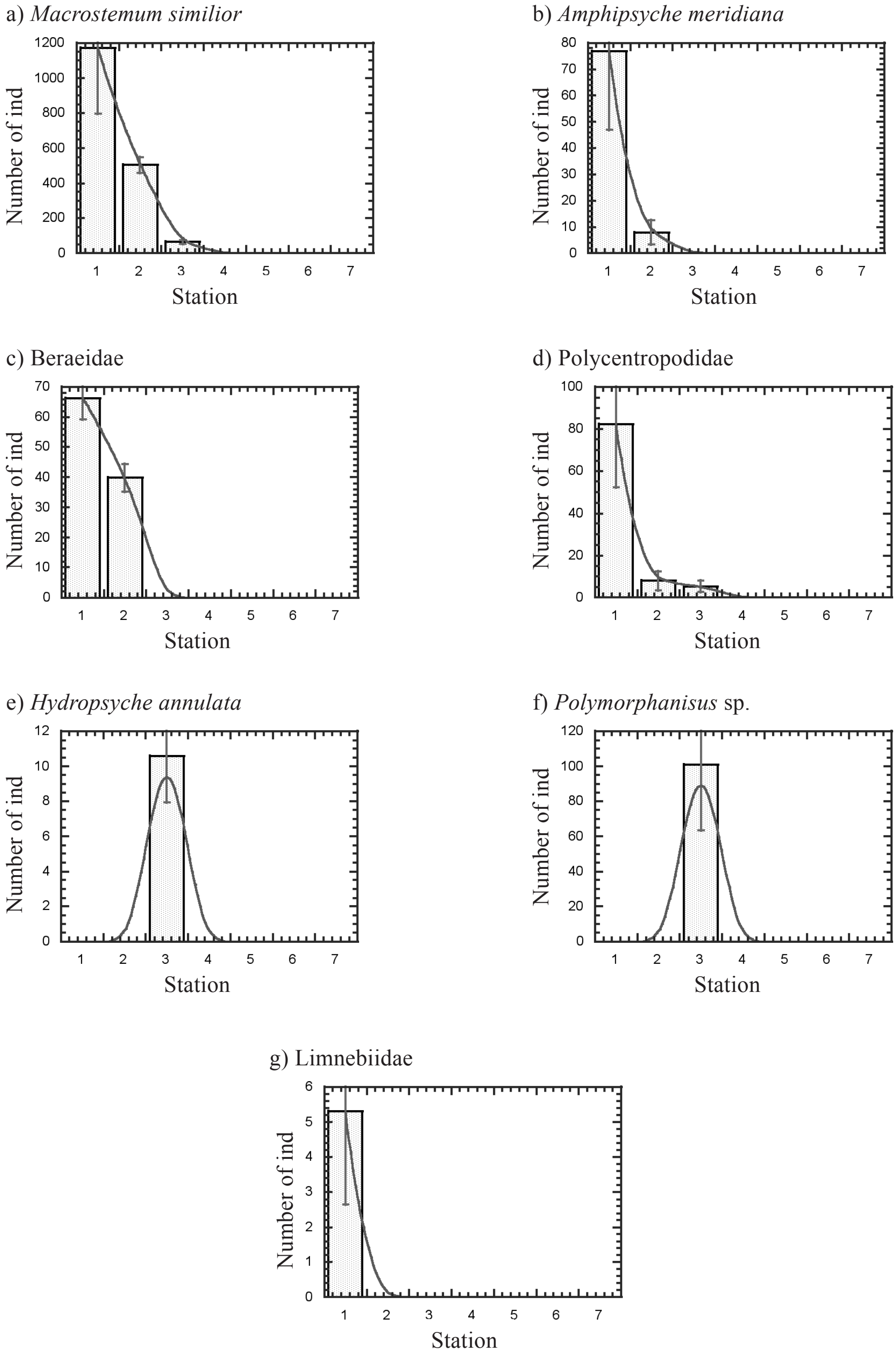

*Fig. 3: The mean number of individual (ind/m^2 ± SE; N= 3) Trichoptera (*M. similior*,* A. meridiana*, Beraeidae, Polycentropodidae,* H. annulata *and* Polymorphanisus *sp.) and Coleoptera (Limnebiidae) at all the sampling stations at Sg. Semenyih in June, 1997*

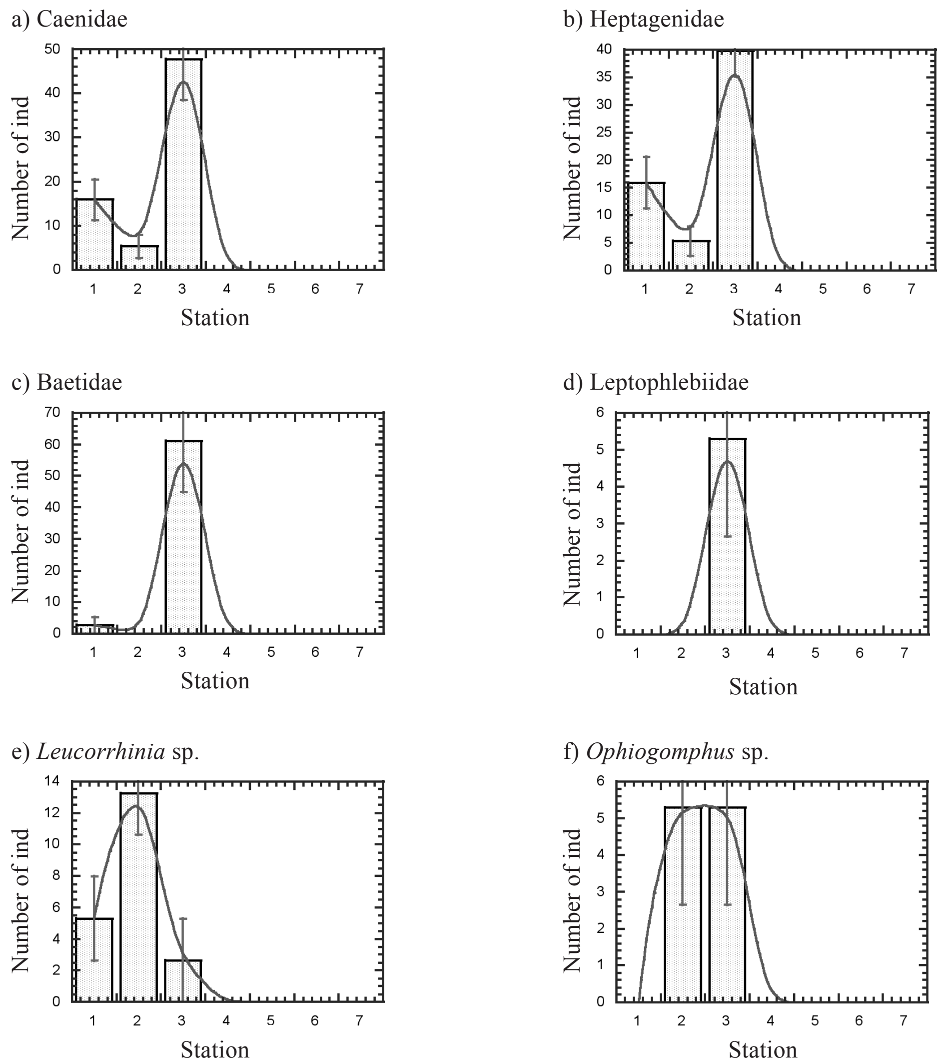

*Fig. 4: The mean number of individual (ind/m² ± SE; N= 3) Ephemeroptera (Caenidae, Heptagenidae, Baetidae and Leptophlebiidae) and Odonata (*Leucorrhinia *sp. and* Ophiogomphus *sp.) at all the sampling stations of Sg. Semenyih in June, 1997*

depth, pH, conductivity, nitrate, and total suspended solids were observed and found to be the most influential parameters by the MLSRA to Baetidae, although only river depth and nitrate were significantly correlated with the density and presence of Baetidae (Table 2a). Meanwhile, *Polymorphanisus* sp. was significantly influenced by river width, temperature, DO, conductivity, nitrate and turbidity, in which the only significantly correlated parameter was nitrate (Table 2b). *Heptageniidae* was significantly influenced by river depth, water velocity, DO, conductivity, BOD_3, nitrate and turbidity, in which the only significantly correlated parameters were water velocity, DO and BOD_3 (Table 2a).

Among the dominant species, *Parachironomus* spp. was positively correlated to water velocity, DO, pH, and ammonia (Table 2b). The species was negatively correlated to

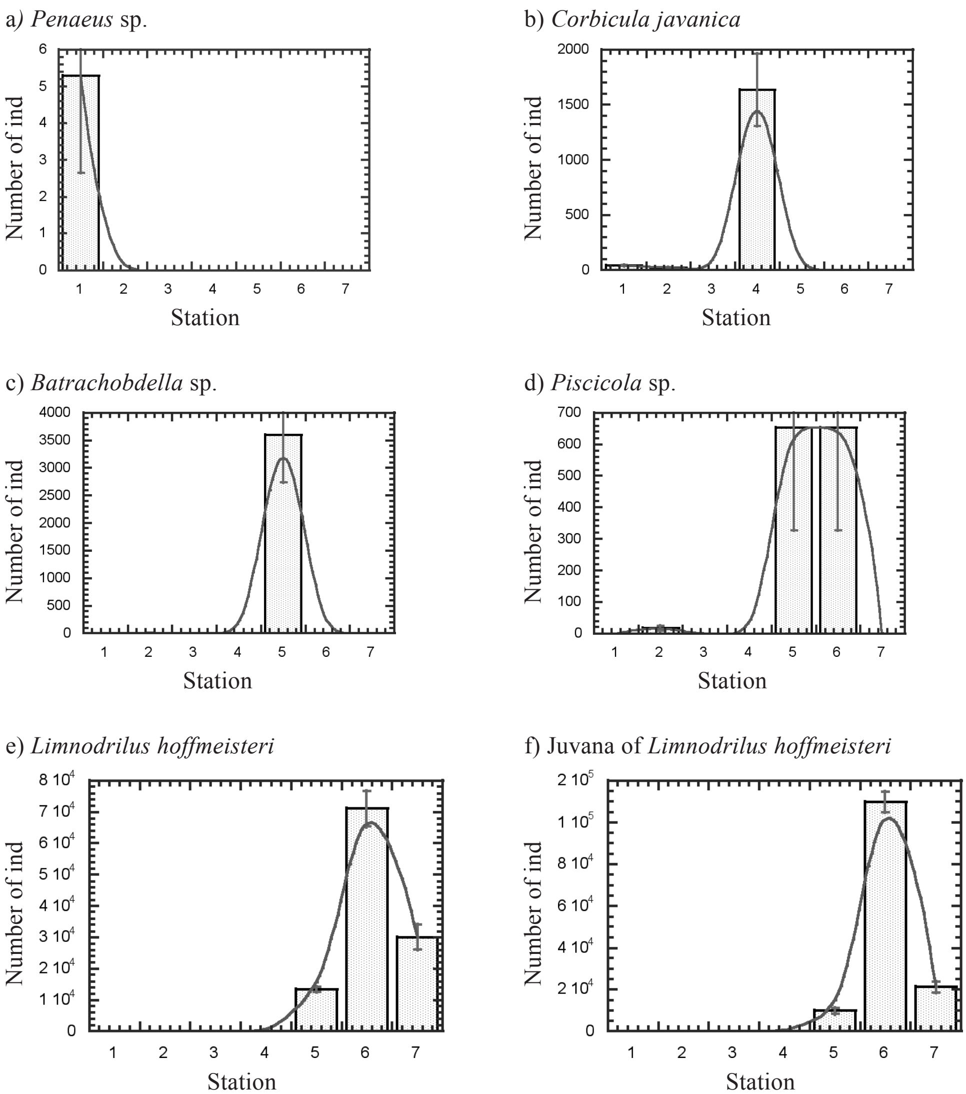

*Fig. 5: The mean number of individual (ind/m^2 ± SE; N= 3) Crustacea (*Penaeus *sp.), Bivalvia (*C. javanica*), Hirudinea (*Batrachobdella *sp. and* Piscicola *sp.) and Oligochaeta (*L. hoffmeisteri*) at all the sampling stations of Sg. Semenyih in June, 1997*

river width, BOD_3, orthophosphate, turbidity, and total suspended solids. Based on the MLSRA, the non-significant correlations (temperature and conductivity) were identified as the influential parameters, whilst water velocity and total suspended solids were eliminated.

As stated earlier, the only dominant species found at St-4 was *C. javanica*. The species was highly correlated with river depth, temperature, DO and conductivity, as shown in Table 2c. Izzatullayev (1992) studied the aquatic mollusks of Central Asia as water quality indicators. Amongst the frequencies of the occurrence of indicator mollusks in the waters of various types, genera *Corbicula* (*C. cor*, *C. fluminalis* and *C. purpurea*) appeared to be good indicators of oligosaprobic (very slightly polluted water). This raised the possibility for us to make a

TABLE 2a
The Pearson's correlation coefficients analysis between the physico-chemical factors (with log10 transformed) and the distributions of each macrobenthic invertebrate (with fourth-root transformed) at the 7 stations of Sg. Semenyih in June, 1997

	Wd (m)	Dep (m)	Tem (°c)	Vel (m/s)	DO (mg/L)	pH	Con (μmhos)	BOD_3 (mg/L)	Amm (mg/L)	Pho (mg/L)	Nrt (mg/L)	Tbt (FTU)	TSS (mg/L)
Piscicola sp.	0.16^{ns}	0.14^{ns}	-0.28^{ns}	0.60^{**}	-0.18^{ns}	-0.02^{ns}	-0.06^{ns}	0.21^{ns}	-0.23^{ns}	-0.28^{ns}	0.37^{ns}	0.19^{ns}	0.26^{ns}
Batrachobdella sp.	0.26^{ns}	0.39^{ns}	-0.60^{**}	-0.45^{*}	0.09^{ns}	0.13^{ns}	-0.04^{ns}	0.27^{ns}	-0.16^{ns}	0.11^{ns}	0.04^{ns}	0.20^{ns}	0.34^{ns}
Penaeus sp.	0.03^{ns}	0.40^{ns}	0.05^{ns}	0.47^{*}	0.26^{ns}	0.44^{*}	-0.15^{ns}	-0.53^{*}	0.47^{*}	-0.39^{ns}	0.05^{ns}	-0.48^{*}	-0.47^{*}
Caenidae	-0.66^{**}	-0.00^{ns}	-0.16^{ns}	0.76^{***}	0.58^{**}	0.21^{ns}	-0.35^{ns}	-0.77^{***}	0.47^{*}	-0.75^{***}	-0.56^{**}	-0.70^{***}	-0.76^{***}
Baetidae	-0.49^{*}	0.45^{*}	-0.40^{ns}	0.49^{*}	0.33^{ns}	-0.31^{ns}	-0.22^{ns}	-0.41^{ns}	-0.02^{ns}	-0.32^{ns}	-0.70^{***}	-0.26^{ns}	-0.34^{ns}
Heptageniidae	-0.65^{**}	0.16^{ns}	-0.15^{ns}	0.70^{***}	0.57^{**}	0.23^{ns}	-0.35^{ns}	-0.78^{***}	0.48^{*}	-0.72^{***}	-0.53^{*}	-0.69^{***}	-0.64^{**}
Leptoplebiidae	-0.38^{ns}	0.42^{***}	-0.23^{***}	0.37^{***}	0.21^{***}	-0.42^{***}	-0.15^{***}	-0.25^{ns}	-0.18^{ns}	-0.10^{ns}	-0.57^{***}	-0.14^{ns}	-0.20^{ns}
Leucorrhinia sp.	-0.60^{**}	-0.17^{ns}	0.30^{ns}	0.44^{*}	0.55^{**}	0.68^{***}	-0.29^{ns}	-0.55^{**}	0.77^{***}	-0.74^{***}	-0.08^{ns}	-0.72^{***}	-0.50^{*}
Ophiogomphus sp.	-0.55^{*}	0.22^{ns}	-0.04^{ns}	0.25^{ns}	0.36^{ns}	0.27^{ns}	-0.22^{ns}	-0.19^{ns}	0.33^{ns}	-0.43^{*}	-0.41^{ns}	-0.40^{ns}	-0.18^{ns}
Macrostemum similior	-0.68^{***}	-0.22^{ns}	0.17^{ns}	0.71^{***}	0.67^{***}	0.71^{***}	-0.37^{ns}	-0.89^{***}	0.86^{***}	-0.91^{***}	-0.19^{ns}	-0.87^{***}	-0.78^{***}

Note: Wd: River width, Dep: Depth, Tem: Temperature, Vel: Water velocity, Con: Conductivity, Amm: Ammonia, Pho: Phosphate, Nrt: Nitrate, Tbt: Turbidity, TSS: Total suspended solids. Values given are the correlation coefficients (r) and their levels of significance (ns $p > 0.05$, *$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

TABLE 2b
The Pearson's correlation coefficients analysis between the physico-chemical factors (with log10 transformed) and the distributions of each macrobenthic invertebrate (with fourth-root transformed) in the 7 stations of Sg. Semenyih in June, 1997

	Wd (m)	Dep (m)	Tem (°c)	Vel (m/s)	DO (mg/L)	pH	Con (μmhos)	BOD_3 (mg/L)	Amm (mg/L)	Pho (mg/L)	Nrt (mg/L)	Tbt (FTU)	TSS (mg/L)
A. meridiana	-0.36^{ns}	-0.52^{*}	0.22^{ns}	0.52^{*}	0.46^{*}	0.73^{***}	-0.25^{ns}	-0.76^{***}	0.78^{***}	-0.72^{***}	0.11^{ns}	-0.69^{***}	-0.77^{***}
H. annulata	-0.44^{*}	0.49^{*}	-0.42^{ns}	0.43^{ns}	0.26^{ns}	-0.42^{ns}	-0.19^{ns}	-0.27^{ns}	-0.16^{ns}	-0.22^{ns}	-0.74^{***}	-0.18^{ns}	-0.22^{ns}
Polymorphanisus sp.	-0.43^{ns}	0.47^{*}	-0.42^{ns}	0.43^{ns}	0.27^{ns}	-0.38^{ns}	-0.19^{ns}	-0.25^{ns}	-0.13^{ns}	-0.22^{ns}	-0.75^{***}	-0.18^{ns}	-0.21^{ns}
Beraeidae	-0.47^{*}	-0.44^{*}	0.35^{ns}	0.50^{*}	0.54^{*}	0.88^{***}	-0.29^{ns}	-0.74^{***}	0.92^{***}	-0.82^{***}	0.13^{ns}	-0.81^{***}	-0.66^{**}
Polycentropodidae	-0.45^{*}	-0.19^{ns}	0.11^{ns}	0.62^{**}	0.52^{*}	0.54^{*}	-0.31^{ns}	-0.83^{***}	0.69^{***}	-0.73^{***}	-0.14^{ns}	-0.77^{***}	-0.70^{***}
Limnebiidae	0.03^{ns}	-0.40^{ns}	0.05^{ns}	0.47^{*}	0.26^{ns}	0.44^{*}	-0.15^{ns}	-0.53*	0.47*	-0.39^{ns}	0.05^{ns}	-0.48*	-0.47*
Tipulidae	-0.44^{*}	0.49^{*}	-0.42^{ns}	0.43^{ns}	0.26^{ns}	-0.43^{ns}	-0.20^{ns}	-0.28^{ns}	-0.16^{ns}	-0.22^{ns}	-0.74^{***}	-0.18^{ns}	-0.22^{ns}
Simuliidae	-0.36^{ns}	0.55^{**}	0.24^{ns}	0.54^{*}	0.47^{*}	0.75^{***}	-0.25^{ns}	-0.75^{***}	0.80^{***}	-0.73^{***}	0.11^{ns}	-0.71^{***}	-0.77^{***}
Pentaneura spp.	-0.73^{***}	-0.13^{ns}	0.08^{ns}	0.76^{***}	0.68^{***}	0.59^{**}	-0.40^{ns}	-0.89^{***}	0.78^{***}	-0.92^{***}	-0.34^{ns}	-0.88^{***}	-0.79^{***}
Parachironomus spp.	-0.68^{***}	-0.24^{ns}	0.14^{ns}	0.74^{***}	0.67^{***}	0.67^{***}	-0.38^{ns}	-0.91^{***}	0.84^{***}	-0.92^{***}	-0.22^{ns}	-0.87^{***}	-0.82^{***}
Ceratopogonidae	-0.78^{***}	0.02^{ns}	0.01^{ns}	0.74^{***}	0.68^{***}	0.46^{*}	-0.39^{ns}	-0.85^{***}	0.69^{***}	-0.89^{***}	-0.43^{ns}	-0.83^{***}	-0.72^{***}

Note: Wd: River width, Dep: Depth, Tem: Temperature, Vel: Water velocity, Con: Conductivity, Amm: Ammonia, Pho: Phosphate, Nrt: Nitrate, Tbt: Turbidity, TSS: Total suspended solids. Values given are the correlation coefficients (r) and their levels of significance (^{ns} $p > 0.05$, $^{*}p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

TABLE 2
The Pearson's correlation coefficients analysis between the physico-chemical factors (with log10 transformed) and the distributions of each macrobenthic invertebrate (with fourth-root transformed) at the 7 stations of Sg. Semenyih in June, 1997

	Wd (m)	Dep (m)	Tem (°c)	Vel (m/s)	DO (mg/L)	pH	Con (μmhos)	BOD_3 (mg/L)	Amm (mg/L)	Pho (mg/L)	Nrt (mg/L)	Tbt (FTU)	TSS (mg/L)
Empididae	-0.28^{ns}	-0.29^{ns}	0.28^{ns}	0.48^{*}	0.44^{*}	0.67^{***}	-0.22^{ns}	-0.55^{*}	0.71^{***}	-0.58^{**}	0.09^{ns}	-0.62^{**}	-0.39^{ns}
F. m. martensi	-0.37^{ns}	-0.50^{*}	0.30^{ns}	0.28^{ns}	0.34^{ns}	0.61^{**}	-0.19^{ns}	-0.33^{ns}	0.60^{**}	-0.60^{**}	0.08^{ns}	-0.59^{**}	-0.49^{*}
M. turberculata	-0.41^{ns}	0.01^{ns}	0.32^{ns}	0.17^{ns}	0.33^{ns}	0.45^{*}	-0.15^{ns}	-0.20^{ns}	0.47^{*}	-0.39^{ns}	0.06^{ns}	-0.35^{ns}	-0.04^{ns}
C. javanica	-0.29^{ns}	-0.63^{**}	0.73^{***}	0.39^{ns}	0.47^{*}	0.23^{ns}	-0.51^{*}	-0.22^{ns}	0.18^{ns}	-0.27^{ns}	-0.33^{ns}	-0.33^{ns}	-0.33^{ns}
L. *hoffmeisteri*	0.77^{***}	0.26^{ns}	-0.35^{ns}	-0.81^{***}	-0.91^{***}	-0.43^{*}	0.63^{**}	0.72^{***}	-0.54^{*}	0.84^{***}	0.73^{***}	0.79^{***}	0.70^{***}
L. *hoffmeisteri* (Juvana)	0.71^{***}	0.24^{ns}	-0.32^{ns}	-0.77^{***}	-0.91^{***}	-0.45^{*}	0.56^{**}	0.69^{***}	-0.52^{*}	0.83^{***}	0.73^{***}	0.74^{***}	0.64^{**}

Note: Wd: River width, Dep: Depth, Tem: Temperature, Vel: Water velocity, Con: Conductivity, Amm: Ammonia, Pho: Phosphate, Nrt: Nitrate, Tbt: Turbidity, TSS: Total suspended solids. Values given are the correlation coefficients (r) and their levels of significance (^{ns} $p > 0.05$, $^{*}p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

TABLE 3a

Multiple Linear Stepwise Regression Analysis between the dependent variables (macrobenthic invertebrates with fourth-root transformed) and the independent variables (physico-chemical parameters with log10 transformed) at the 7 stations of Sg. Semenyih in June, 1997

Taxa	a	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	r^2	r	F	P
Emp	0.41	1.13 Amm								0.50	0.71	19.08	P< 0.001
Pis	15.19	-9.66 Vel	-0.55 Con	-5.36 BOD_3						0.74	0.86	16.28	P< 0.001
Leu	3.26	-1.60 Wd	1.46 Amm	0.57 TSS						0.70	0.84	13.26	P< 0.001
Oph	4.52	-2.38 Wd	0.57 Amm	0.98 TSS						0.49	0.70	5.51	P< 0.01
Pen	-1.17	2.50 Wd	0.79 Vel	-0.95 Tbt						0.83	0.91	27.17	P< 0.001
MT	3.65	-1.62 Wd	0.88 Amm	1.04 TSS						0.65	0.81	10.37	P< 0.001
Lim	-1.17	2.50 Wd	0.79 Vel	-0.95 Tbt						0.83	0.91	27.17	P< 0.001
Fmm	4.08	-1.22 Dep	-8.96 DO	1.71 BOD_3	-1.67 Pho					0.71	0.84	9.74	P< 0.001
Polyc	-3.92	5.83 Con	-3.08 BOD_3	1.04 Pho	-2.00 Tbt					0.82	0.91	17.75	P< 0.001
Lep	12.60	0.78 Dep	-14.91 pH	-0.82 BOD_3	-0.36 Nrt					0.58	0.76	5.51	P< 0.01
Bat	92.61	-93.02 Tem	-3.51 Vel	88.95 pH	-15.58 Con	2.69 TSS				0.82	0.91	14.06	P< 0.001
HA	38.02	-9.71 Tem	-13.47 DO	-17.67 pH	-1.01 Pho	-1.24 Nrt				0.89	0.94	24.20	P< 0.001
Pent	15.90	-3.15 Wd	-17.30 Tem	11.09 Con	-3.13 BOD_3	-2.40 Tbt				0.97	0.98	104.82	P< 0.001
Bae	7.63	3.01 Dep	-18.04 pH	3.96 Con	-1.27 Nrt	-1.62 TSS				0.86	0.93	19.15	P< 0.001

Note: Pis: *Piscicola* sp., Bat: *Batrachobdella* sp., Pen: *Penaeus* sp., Bae: Baetidae, Lep: Leptophlebiidae, Leu: *Leucorrhinia* sp., HA: *Hydropsyche annulata*, Oph: *Ophiogomphus* sp., Polyc: Polycentropodidae, Lim: Limnebiidae, Pent: *Pentaneura* spp., Emp: Empididae, Fmm: *Filopaludina martensi martensi*, MT: *Melanoides turberculata*,
Wd: River width (m), Dep: Depth (m), Tem: Temperature (°C), Vel: Water velocity (m/s), Con: Conductivity (μhmos), Amm: Ammonia (mg/L), Pho: Phosphate (mg/L), Nrt: Nitrate (mg/L), Tbt: Turbidity (FTU), TSS: Total suspended solids (mg/L)

TABLE 3b
The Multiple Linear Stepwise Regression Analysis between the dependent variables (macrobenthic invertebrates with fourth-root transformed) and independent variables (physico-chemical parameters with log10 transformed) at the 7 stations of Sg. Semenyih in June, 1997

Taxa	a	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	r^2	r	F	P
Cera	27.02	1.23 Dep	-5.72 DO	-29.84 pH	0.81 Amm	-2.02 Pho				0.93	0.96	39.54	P< 0.001
Tipu	45.39	0.85 Dep	-8.25 Tem	-15.83 DO	-27.07 pH	-1.39 Pho	-1.45 Nrt			0.91	0.95	23.48	P< 0.001
LM	228.87	-106.8 Tem	-3.48 Vel	-63.72 DO	-5.13 Con	3.32 Pho	5.95 Nrt			0.99	0.99	232.39	P< 0.001
LMj	261.75	-105.7 Tem	-2.58 Vel	-87.98 DO	-13.36 Con	3.19 Pho	6.54 Nrt			0.98	0.99	121.66	P< 0.001
MS	-21.19	-3.09 Wd	-7.72 Tem	34.54 pH	7.22 Con	-5.84 BOD_3	1.30 Amm			0.99	0.99	178.26	P< 0.001
Polym	46.84	-1.99 Wd	-22.45 Tem	-22.57 DO	5.03 Con	-2.83 Nrt	-0.82 Tbt			0.94	0.97	38.55	P< 0.001
Ber	-29.21	6.09 Tem	26.46 pH	-1.87 BOD_3	0.53 Amm	-0.50 Pho	0.85 Nrt			0.99	0.99	174.85	P< 0.001
Hep	9.30	1.01 Dep	-1.11 Vel	-16.84 DO	5.19 Con	-3.17 BOD_3	-2.05 Nrt	-1.58 Tbt		0.91	0.95	17.79	P< 0.001
Cae	22.68	-1.10 Wd	-18.41 Tem	-7.81 DO	7.02 Con	-1.37 Nrt	-0.95 Tbt	-1.38 TSS		0.98	0.99	55.25	P< 0.001
AM	-39.08	0.57 Wd	41.26 pH	1.55 Con	-2.45 BOD_3	0.33 Nrt	1.20 Tbt	-1.93 TSS		0.98	0.99	98.28	P< 0.001
Simu	-34.00	0.73 Wd	-0.68 Dep	34.39 pH	2.10 Con	-1.83 BOD_3	0.65 Tbt	-1.45 TSS		0.97	0.98	65.70	P< 0.001
Cj	-136.9	4.46 Wd	-2.46 Dep	86.62 Tem	25.37 DO	-10.52 Con	-1.41 Nrt	1.06 Tbt		0.95	0.97	38.13	P< 0.001
Para	-24.50	-4.02 Wd	-19.08 Tem	1.04 Vel	50.54 pH	11.85 Con	-6.22 BOD_3	1.09 Amm	-1.18 TSS	0.99	0.99	212.10	P< 0.001

Note: Tipu: Tipulidae, Simu: Simuliidae, Para: *Parachironomus* spp., Cera: Ceratopogonidae, Cj: *Corbicula javanica*, LM: *Limnodrilus hoffmeisteri*, LMj: *L. hoffmeisteri* (Juvana), Cae: Caenidae, Hep: Heptageniidae, MS: *Macrostemum similior*, AM: *Amphipsyche meridiana*, Polym: *Polymorphanisus* sp., Ber: Beraeidae,
Wd: River width, Dep: Depth, Tem: Temperature, Vel: Water velocity, Con: Conductivity, Amm: Ammonia, Pho: Phosphate, Nrt: Nitrate, Tbt: Turbidity, TSS: Total suspended solids

conclusion that St-4 was a slightly polluted site as *C. javanica* could still survive in this system. However, since our knowledge of freshwater mollusks in our local ecoregion is extremely scarce, further studies are still needed to confirm this hypothesis. Based on the MLSRA, river width, nitrate and turbidity were also included in this study, apart from the above-mentioned parameters.

At the downstream stations (Stations 5-7), Oligochaeta were predominately found. In general, all the physico-chemical parameters, including low DO (Lang, 1985), seemed to be significantly correlated to *L. hoffmeisteri*, except for river depth and temperature. As for *L. hoffmeisteri* (Table 2c), the density and distribution were found to significantly and positively correlate with river width, conductivity, BOD3, concentrations of phosphate and nitrates, turbidity and TSS of the river waters. On the other hand, their densities were shown to be significantly ($p<0.001$) but negatively correlated with water velocity and DO. All the above correlation pairings indicated that *L. hoffmeisteri* is a good bioindicator of the polluted condition at Semenyih River.

It must be noted that the factors identified by the MLSRA are in fact the most important factors amongst all the physico-chemical parameters recorded in this study, and therefore, it was assumed that there are cause-and-effect relationships between them. The researcher also judge that other factors might presumably be contributive to the dependent variable (macrobenthic invertebrates) and those factors were unfortunately not included in this study.

CONCLUSION

Based on the correlation analysis and MLSRA, river width, total suspended solid, turbidity, BOD_3, orthophosphate, nitrate and conductivity were found to have increased with the increasing distance from Semenyih Dam (St-1). On the contrary, water velocity, DO, ammonia and pH showed a reverse pattern. In this study, BOD_3, orthophosphate, total suspended solids, and turbidity were identified as the most important correlates with the community diversity for macrobenthic invertebrates amongst the 13 physico-chemical parameters using the MLSRA. Therefore, the positive relationships between the distribution of sensitive bioindicator species, as well as good water quality and the negative relationships between the distribution of resistant bioindicator species and poor water quality suggest the value of using bioindicator species for Malaysian rivers.

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