

Zooplankton Assemblages in a Heavily Polluted River Ecosystem (Pinang River, Malaysia): Impacts of Anthropogenic Stressors on the Communities

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ABSTRACT

River ecosystems are among the most affected habitats globally due to various anthropogenic stressors such as pollution, habitat degradation, hydromorphological alterations and impervious cover due to urbanization. It remains largely unknown how and to what extent zooplankton communities are affected by these stressors in a heavily polluted river ecosystem. This study investigated the abundance and distribution of zooplankton species and the factors affecting their abundance and distribution in Pinang River. A total of 29 taxa of zooplankton were recorded, which includes 27 taxa of Rotifera and two taxa of Copepoda. Among rotifers, the order Bdelloidea had the highest relative abundance (64.79%), followed by *Testudinella* sp. and *Lecane* sp. with 10% relative abundance respectively. Spearman's correlation coefficient showed that the zooplankton abundance was negatively correlated with total dissolved solids and conductivity ($P < 0.01$). Much higher total dissolved solids and water conductivity, much lower zooplankton abundance. This condition is probably to be unfavorable to the zooplankton population as it is attributed to the presence of extreme anthropogenic activities along the river that cause runoff with high suspended matter. Thus, variations in zooplankton biodiversity reflect the deterioration of water quality in the polluted river ecosystem.

Key words : Anthropogenic, Abundance, Rotifera, Copepoda, Bdelloidea

Introduction

River ecosystems are subject to multiple anthropogenic stressors that threaten their ecological status, affect biodiversity and the ecosystem services they provide. Pollution, habitat degradation, hydromorphology alterations, impervious coverage (e.g. urban areas), loss of riparian zones and urbanized floodplains are major stressors for river ecosystems (Sabater *et al.*, 2019). The river always responds to disturbance stressors as it usually occupies the lowest-lying areas of the landscape, sinking various chemical pollutants from both point and non-point sources (Woodward *et al.*, 2012).

Pinang River (5°24' 52.2'N 100 °19'45.12'E) is categorized under Class IV by Malaysian Drainage and Irrigation Department (DID), indicating one of the polluted rivers in Penang state and Malaysia. The river is located on the northwest coast of Peninsular Malaysia within the city of Georgetown and is surrounded by high-rise apartments and office building blocks. It is a central water resource for domestic, industrial and irrigation purposes and plays an important role in the assimilation of industrial and municipal wastewater, manure discharge, runoff from agricultural fields, roadways and streets. According to Khoo (2007), fishing villages were established along the Pinang River in the 18th century,

providing the villagers with a continuous supply of freshwater for fishing and day-to-day activities to the villagers. However, urbanization has taken over the surrounding river area with the construction of office blocks and high-rise residential buildings lining the river banks. Urban development results in soil erosion and sedimentation, while inefficient waste disposal systems from the market, food outlets, and abattoirs lead to waste and sewage ending up in the river (Mohd Saad *et al.*, 2006). As a result, the problem of water pollution has been exacerbated. In 1999, the water quality analysis carried out by the Drainage and Irrigation Department (DID) resulted in the classification of Pinang River as Class IV, which is highly polluted following the proposed Interim National Water Quality Standard for Malaysia (Mohd Saad *et al.*, 2006). In fact, the river is known to the locals as the dirtiest river in Penang and one of the most polluted rivers in Malaysia (Sibert, 2015). The contaminants have primarily had a massive impact on the freshwater community, including those of ecological importance, such as plankton (Jin *et al.*, 2017). However, it is still unknown how communities can continue to exist in this disturbed lotic ecosystem.

Some zooplankton species are also known as a pollution indicator because they may respond to various disturbances, such as contamination and acidification (Armored and Korman, 1993). Apart from that, they are a good indicator of the nutrient changes in the aquatic ecosystem. According to Khalifa *et al.* (2015), zooplankton is useful in predicting long-term changes in the ecosystem through the assessment of water quality.

Changes in zooplankton abundance and distribution along the Pinang River are expected to be associated with water quality deterioration due to the continuous increase in the number of pollutants received. Therefore, studies on the abundance and distribution of zooplankton species would provide benchmarks for the affected water bodies. The aim of this study is to identify the abundance and distribution of zooplankton species and the factors affecting their abundance and distribution. This study is vital to provide information on the deterioration of water bodies in the Pinang River.

Materials and Methods

Study site

The Pinang River (5°24'52.2" N & 100°19'45.12" E) is

considered to be one of the most polluted river systems in Malaysia. It runs through the city of Georgetown on Penang Island, with a population of about 198 298 (Department of Statistics Malaysia, 2020), located on the northwest coast of Peninsular Malaysia. The total area of the Pinang river basin is about 50.97 km and its length is approximately 3.1 km that flows eastward. It has six tributaries named Air Terjun River, Kecil River, Air Putih River, Air Hitam River, Dondang River, and Jelutong River (Salih *et al.*, 2013). A tropical climate prevails in the Penang, characterized by warm and humid throughout the year. Annual precipitation rates are about 2706.76 mm with the temperatures range between 29-35 °C during the day. It has two distinct seasons, namely wet seasons (March-April and July-October) and dry seasons (May-June and November-February) (Nurul-Ruhayu and Yahya, 2013).

Pinang River is a central water resource for domestic, industrial and irrigation purposes and plays an important role in the assimilation of industrial and municipal wastewater, manure discharge, runoff from agricultural fields, roadways and streets. It is closed to the various types of industry such as car service centre, furniture store, vending machine and chemicals suppliers. Urbanization has contributed significantly to the increase in water pollution of the Pinang River. As a result, the problem of water pollution has been exacerbated. In 1999, the water quality analysis carried out by the Drainage and Irrigation Department (DID) resulted in the classification of Pinang River as Class IV, which is highly polluted following the proposed Interim National Water Quality Standard for Malaysia (Mohd Saad *et al.*, 2006). In fact, the river is known to the locals as the dirtiest river in Penang and one of the most polluted rivers in Malaysia (Sibert, 2015).

Sampling stations were carefully chosen to represent downstream, midstream, and upstream by comparing the elevations. The upstream has a greater elevation (39.4 feet) than midstream (32.8 feet) and downstream (16.4 feet). The sampling stations were labeled: Station 1 (downstream; 5°24'7.8336" N & 100°19' 55.7364" E), Station 2 (midstream; 5°24'18.3276" N & 100°19'30.8892" E), and Station 3 (upstream; 5°24'32" N & 100°19'18.2222" E), as shown in Figure 1. The distance between the sampling stations was approximately 2250 m.

Measurement of environmental variables

Field sampling was conducted on a monthly basis

from October to December 2018. The sampling session was started around 0800 hrs local time at Station 1, followed by Station 2 and 3. Samplings on October was conducted during low tide while November and December were conducted during high tide. All sampling stations particularly Station 1, which is close to the estuary were underwater at all times, including low tide. The tide in the estuary is of the semi-diurnal type that having two high tides and two low tides each day. The multi-parameter YSI 556 Multi Probe System was used to measure water temperature (WT), dissolved oxygen (DO), total dissolved solids (TDS), salinity, and conductivity while the HACH sension1 Portable pH meter was used to measure pH. Turbidity was measured and recorded using the Vernier Turbidity Sensor

(TRB-BTW) after calibration of the sensor using the 100 NTU StabCal® Formazin Standard.

Water sample collection and analyses

Simple surface-grab sampling is the method chosen for collecting water that is most appropriate for the river ecosystem (Martin *et al.*, 1992; Nollet and De Gelder, 2014). 1.5 L plastic sample bottles were used to store river water in accordance with minimal standards of APHA (1999). In order to prevent contamination due to surface scum, debris and bottom deposits, samples were collected no closer than 30 cm to the surface or bottom of the river (Nollet and De Gelder, 2014). After collecting samples, the bottles were stored in an icebox to stabilize the samples. Upon arrival at the laboratory, the samples

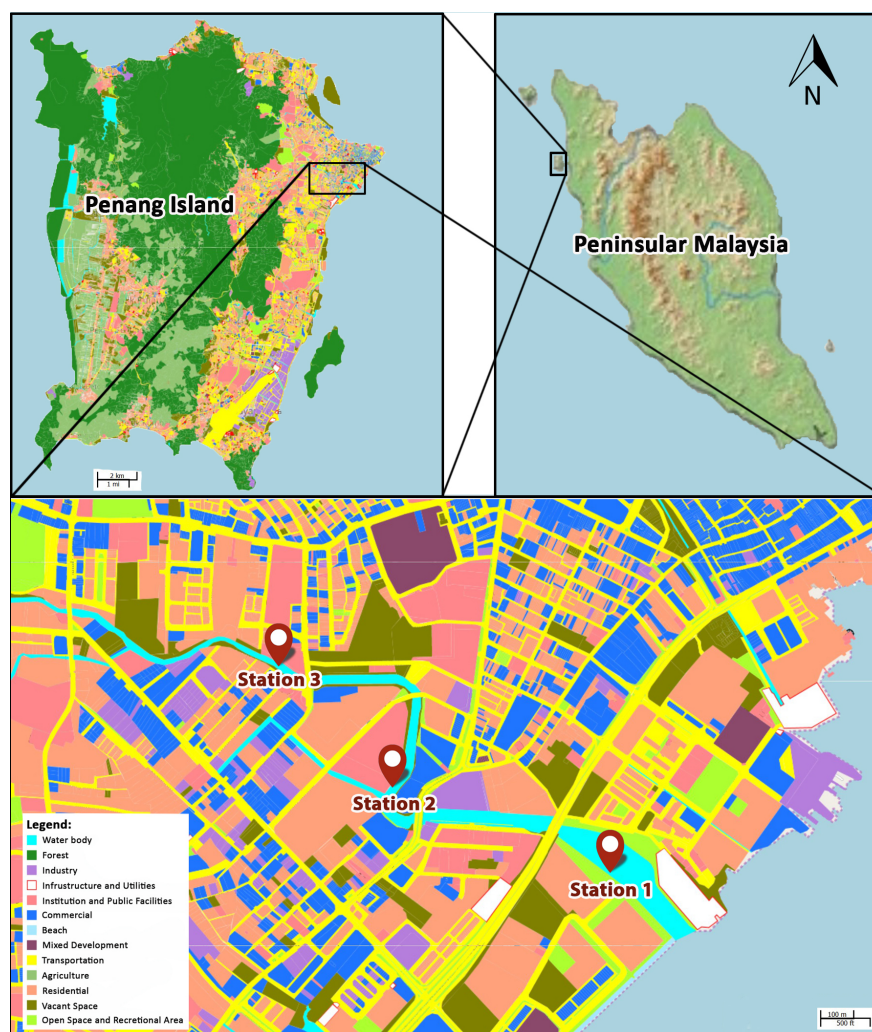


Fig. 1. Map of Pinang River with the sampling stations (Pulau Pinang Town and Country Planning Department, 2018).

were placed in the freezer to reduce any biological activity or degradation. The exposure of any light to the samples was minimal. In the laboratory, the parameters of chlorophyll-a, total suspended solids (TSS), ammonium-nitrogen ($\text{NH}_4^+\text{-N}$), nitrite-nitrogen ($\text{NO}_2^-\text{-N}$) and orthophosphates ($\text{PO}_4^{3-}\text{-P}$) were analyzed following the methods from Adams (1990).

Zooplankton collection and analyses

Zooplankton samples were collected along the shore no closer than 30 cm to the surface or bottom of the river at each station. The locations were chosen based on accessibility and safety to conduct water quality measurement and collection. 40 L of river water was collected at each sampling station using a 5 L Van Dorn water sampler and filtered through the Wisconsin plankton net with a mesh size of 35 μm . The filtrate was then transferred to 100 mL of polyethylene bottle and stored with 70% ethanol for zooplankton analysis. All sample bottles were properly capped and labelled. Three sample replicates were collected at each sampling station. The replicates were collected across the station at the same spot, a similar span of time specified for the original sample, using the same techniques and the same type of equipment. Replicate samples provide estimates of the sample variability within the area.

The sample bottle was slowly shaken in the laboratory to ensure that the specimen was evenly distributed. One mL of the sample was then placed on a Sedgwick-Rafter counting cell using an adjustable volume pipette. Coverslip was used to cover the sample at an angle of 45 degrees to prevent the formation of air bubbles. The sample was left to settle for about 5 min and specimens were observed under a compound microscope (Olympus Model BX41-CCD) equipped with a camera at various magnifications (4x, 10x and 20x). Images were captured, and specimens were identified based on the taxonomic keys, diagrams, and descriptions of Shiel (1995) and Idris (1983). The zooplankton abundance was calculated using the Hauser (1981) formula.

Statistical analyses

IBM Statistical Package for the Social Sciences (SPSS) Version 24 was used to analyze the data collected. A repeated measures two-way analysis of variance (ANOVA) was used to detect the significant differences in physicochemical parameters and zooplankton abundance among the sampling stations and

monthly intervals. Shapiro-Wilk normality test was performed to test normality while Levene's test was conducted to test homogeneity of variance. An analysis of Spearman's correlation was also carried out to reveal possible correlations between variables. Ecological indices including the Shannon Wiener Diversity Index (H') and the Margalef Index (R) were used to measure the species diversity and the richness of zooplankton community at the study sites, while the Pielou's Evenness Index (J') was used to measure the equitability and uniformity of the species observed.

Results

Physicochemical parameters

Table 1 displays the average physicochemical parameters for all sampling stations during the study. In October, Station 1 recorded the highest mean value for almost all parameters except $\text{NH}_4^+\text{-N}$ and $\text{NO}_2^-\text{-N}$. In November, Station 1 recorded the highest temperature, TDS, salinity, and conductivity, while Station 2 showed the highest measurements for DO, pH, chlorophyll-a and $\text{NH}_4^+\text{-N}$. Turbidity, TSS, $\text{NO}_2^-\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ was relatively highest at Station 3. In December, Station 1 recorded the highest mean values for temperature, salinity, conductivity, TSS and pH while Station 2 showed the highest mean values for $\text{NH}_4^+\text{-N}$ and $\text{NO}_2^-\text{-N}$. Other parameters (DO, turbidity, TSS, chlorophyll-a, and $\text{PO}_4^{3-}\text{-P}$) occurred at Station 3 at the highest level. Based on the results of two-way repeated measures ANOVA analysis, there was a significant difference of physicochemical parameters between sampling months and stations (Table 2).

Zooplankton composition and abundance

A total of 29 taxa of zooplankton were identified (Table 3). Rotifera was the most representative group on richness (27 taxa), followed by Copepoda (2 taxa). Among rotifers, the order Bdelloidea had the highest relative abundance (64.79%), followed by *Testudinella* sp. and *Lecane* sp. with 10% relative abundance respectively. High diversity (19 taxa) was recorded at Station 3, followed by 14 taxa at Station 2, and only 7 taxa were found at Station 1. Station 3 also recorded the highest abundance throughout the sampling months (October: $21668 \pm 563 \text{ ind/m}^3$; November: $40833 \pm 12365 \text{ ind/m}^3$; December: $33333 \pm 1307 \text{ ind/m}^3$) followed by Station 2 and Sta-

Table 1. Mean $\pm$ SE value of physicochemical parameters in Pinang River

Parameter	Month/Station								
	October			November			December		
	Station 1	Station 2	Station 3	Station 1	Station 2	Station 3	Station 1	Station 2	Station 3
Temperature ($^{\circ}\text{C}$)	29.16 $\pm$ 0.30	28.25 $\pm$ 0.42	27.44 $\pm$ 0.17	30.03 $\pm$ 0.08	27.26 $\pm$ 0.02	28.00 $\pm$ 0.07	29.56 $\pm$ 1.06	28.05 $\pm$ 0.04	29.21 $\pm$ 0.02
DO (mg/l)	3.66 $\pm$ 0.39	2.38 $\pm$ 0.20	2.87 $\pm$ 0.21	0.22 $\pm$ 0.04	2.29 $\pm$ 0.00	2.67 $\pm$ 0.09	1.23 $\pm$ 0.69	0.85 $\pm$ 0.17	2.32 $\pm$ 0.11
TDS (g/l)	15.35 $\pm$ 6.45	13.78 $\pm$ 4.38	0.09 $\pm$ 0.00	24.54 $\pm$ 0.04	0.68 $\pm$ 0.02	0.11 $\pm$ 0.00	20.55 $\pm$ 9.93	2.39 $\pm$ 0.28	0.10 $\pm$ 0.00
Conductivity ($\mu\text{S}/\text{cm}$)	25269.67 $\pm$ 10817.15	21840.00 $\pm$ 7658.14	139.00 $\pm$ 1.73	41383.67 $\pm$ 102.44	11197.33 $\pm$ 692.86	176.00 $\pm$ 8.71	34530.67 $\pm$ 17131.37	353.94 $\pm$ 54.97	162.00 $\pm$ 2.65
Salinity (ppt)	13.80 $\pm$ 6.24	13.21 $\pm$ 3.86	0.06 $\pm$ 0.00	23.81 $\pm$ 0.04	0.51 $\pm$ 0.02	0.11 $\pm$ 0.00	20.05 $\pm$ 10.30	1.81 $\pm$ 0.21	0.07 $\pm$ 0.00
pH	7.74 $\pm$ 0.18	7.51 $\pm$ 0.24	7.48 $\pm$ 0.02	7.24 $\pm$ 0.02	6.91 $\pm$ 0.29	6.95 $\pm$ 0.10	7.68 $\pm$ 0.06	7.11 $\pm$ 0.03	6.82 $\pm$ 0.04
Turbidity (NTU)	63.53 $\pm$ 1.97	37.07 $\pm$ 3.96	22.10 $\pm$ 1.71	7.83 $\pm$ 0.03	7.80 $\pm$ 0.06	36.50 $\pm$ 0.06	6.80 $\pm$ 0.32	8.10 $\pm$ 2.61	10.67 $\pm$ 3.23
TSS (g/l)	0.0345 $\pm$ 0.0030	0.0141 $\pm$ 0.0009	0.0138 $\pm$ 0.0010	0.0121 $\pm$ 0.0020	0.0102 $\pm$ 0.0004	0.0597 $\pm$ 0.0010	0.0092 $\pm$ 0.0006	0.0120 $\pm$ 0.0005	0.0192 $\pm$ 0.0030
Chl. <i>a</i> (mg/l)	0.0028 $\pm$ 0.0006	0.0001 $\pm$ 0.0000	0.0001 $\pm$ 0.0000	0.0016 $\pm$ 0.0007	0.0042 $\pm$ 0.0020	0.0037 $\pm$ 0.0010	0.0035 $\pm$ 0.0020	0.0012 $\pm$ 0.0001	0.0042 $\pm$ 0.0010
NH ₄ ⁺ -N ($\mu\text{g}/\text{l}$)	0.08 $\pm$ 0.01	0.64 $\pm$ 0.33	0.67 $\pm$ 0.35	2.93 $\pm$ 0.67	2.99 $\pm$ 0.60	2.91 $\pm$ 0.64	6.50 $\pm$ 2.06	6.68 $\pm$ 1.94	6.48 $\pm$ 2.05
NO ₃ ⁻ -N ($\mu\text{g}/\text{l}$)	5.33 $\pm$ 1.44	7.09 $\pm$ 4.26	3.47 $\pm$ 0.29	4.13 $\pm$ 0.04	4.70 $\pm$ 0.01	6.74 $\pm$ 0.02	6.40 $\pm$ 0.06	24.95 $\pm$ 0.22	3.68 $\pm$ 0.05
PO ₄ ³⁻ -P ($\mu\text{g}/\text{l}$)	0.285 $\pm$ 0.007	0.205 $\pm$ 0.003	0.185 $\pm$ 0.010	0.048 $\pm$ 0.005	0.016 $\pm$ 0.007	0.218 $\pm$ 0.004	0.077 $\pm$ 0.003	0.039 $\pm$ 0.002	0.173 $\pm$ 0.003

tion 1.

Statistical analysis of the two-way repeated measures ANOVA revealed that there was a significant difference in the zooplankton abundance between sampling stations ($F_{2,12} = 26.13$, $P < 0.01$, $\eta_p^2 = 0.81$). This study rejected the null hypothesis that there is no difference in zooplankton abundance in the sampling stations throughout the study periods. In contrast, there was no significant difference in the zooplankton abundance between sampling stations and months ($F_{4,12} = 3.84$, $P > 0.01$, $\eta_p^2 = 0.56$). Regarding the species number, the analysis revealed that there was a significant interaction between sampling stations and months ($F_{4,12} = 17.93$, $P < 0.01$, $\eta_p^2 = 0.86$). This effect indicated that the profile of ratings for species number in sampling stations was different for Station 1, 2 and 3 throughout the sampling months.

Spearman's correlation coefficient (Table 4) showed that the zooplankton abundance was negatively correlated with TDS ($r = -0.674$, $P < 0.01$) and conductivity ($r = -0.766$, $P < 0.01$), but significantly positive correlation with NH₄⁺-N ($r = 0.516$, $P < 0.01$). For the values of ecological indices (Table 5), the highest value for the Shannon Wiener Index (H') occurred in December at Station 3 (8.02). Both the Margalef Index (R') and the Pielou Index (J') showed the highest value at Station 3 in October, with values 3.51 and 2.57, respectively.

Discussion

Physicochemical parameters assessment

The minimum requirement for dissolved oxygen in the water for aquatic life in rivers should be above 4 mg/l (Maun and Moulton, 1991), but none of the measurements recorded in this study achieved this level, which indicates very poor water quality in the Pinang River. The concentration of dissolved oxygen is affected by many factors, such as the flow of the river and the presence of organic pollution. Low concentrations of dissolved oxygen may indicate that the use of dissolved oxygen by the microorganism to breakdown the organic matter from organic pollutants (Mohd Saad *et al.*, 2006) originated in residential and industrial areas along the Pinang River.

High TDS measurements at the sampling station illustrate the significant contribution of anthropogenic activities from multiple sources, including agricultural runoff, domestic sewage, and wastewater

outflow, which contained high levels of decaying organic matter. The transport of high suspended solids, metals, metalloids and dissolved organic matter from upstream to downstream is likely to result in higher TDS measurements at Station 1. In fact, a wide range of biological, chemical, and physical processes contribute to the composition and transport of TDS in stream systems (Butler and Ford, 2018).

The pH most optimal for most river organisms between 6.5 to 8.2 (Ibrahim and Kutty, 2013) and the range of the current study is consistent with their findings. The pH-level trends recorded in the water samples increases from upstream to the downstream of the sampling station. Seawater has a slightly alkaline pH level of between 7.5 and 8.5, which corresponds to salinity, TDS, and conductivity as ions, such as calcium carbonate ions are usually alkaline. In addition, pH levels could indicate a point source of pollution with chemicals from upstream agricultural runoff, wastewater discharge and industrial runoff (Yunus and Nakagoshi, 2004). According to Galbrand *et al.* (2007), the possibility of any acidic groundwater leakage is high when the river banks are poorly buffered with the development encroaching to the sides of the banks and wastewater outflow remains uncontrolled. This condition is remarkably similar to the current state of the Pinang River.

The concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_2^-\text{-N}$, and $\text{PO}_4^{3-}\text{-P}$ in the river are important indicators of water pol-

lution due to anthropogenic activities. High concentrations of the parameters in the samples collected indicate a constant point source of pollution, possibly from industrial and domestic sewage or untreated wastewater exported to the river.

Zooplankton distribution and abundance

According to Moss (2010), the major groups of zooplankton in the freshwater ecosystem are Rotifera, Cladocera and Copepoda. In this current study, only two major groups present in samples collected in the Pinang River which were 94% Rotifera and 6% Copepoda. No Cladocera has been observed and this is probably due to the types of the water body as stated by Viroux (2002) that lotic water is an inhospitable environment for the cladocerans development. The water velocity in streams and rivers affects the cladocerans distribution as they have weak swimming abilities and are more likely to be found more in a lentic ecosystem such as the reservoir (Sa-Ardri and Beamish, 2005).

Based on the classification of the Water Quality Index (WQI) by the Department of Environment (DOE), Pinang River is considered to be polluted on the basis of its riverine zoning, which falls under Class III (Nurul-Ruhayu *et al.*, 2015). The condition would have a massive impact on the distribution and composition of zooplankton along the Pinang river. Several species from Rotifera group such as *Asplanchna* sp., *Trichocerca* sp., *Filinia* sp., *Branchionus angularis*, and *Keratella* sp. are identified as a good

Table 2. P-values obtained from two-way repeated measures ANOVA to detect the interaction of physicochemical parameters on sampling stations and months in Pinang River

Parameters	Station					Station x Month				
	df	Error df	F	P	Partial Eta Squared	df	Error df	F	P	Partial Eta Squared
Temperature (°C)	2	6	16.75	0.00*	0.85	4	6	1.57	0.30	0.511
DO (mg/l)	2	6	1.72	0.26	0.36	4	6	5.34	0.04	0.78
TDS (g/l)	2	8	44.63	0.00*	0.92	4	8	4.31	0.04	0.68
Conductivity (µS/cm)	1	8	41.14	0.00*	0.91	2	8	8.51	0.03	0.81
Salinity (ppt)	2	8	42.45	0.00*	0.91	4	8	4.61	0.03	0.70
pH	2	8	20.38	0.00*	0.84	4	8	10.01	0.00*	0.83
Turbidity (NTU)	2	8	1.80	0.23	0.31	4	8	5.53	0.02	0.73
TSS (g/l)	2	6	9.79	0.01*	0.77	4	6	9.66	0.01*	0.87
Chl. <i>a</i> (mg/l)	2	8	0.28	0.77	0.07	4	8	3.96	0.05	0.66
$\text{NH}_4^+\text{-N}$ (µg/l)	1	5	0.28	0.62	0.05	2	5	0.04	0.96	0.02
$\text{NO}_2^-\text{-N}$ (µg/l)	2	6	15.38	0.00*	0.84	4	6	10.94	0.01*	0.88
$\text{PO}_4^{3-}\text{-P}$ (µg/l)	2	8	14.10	0.00*	0.78	4	8	6.83	0.01*	0.77

Notes.

* The mean difference is significant at the 0.01 level

Table 3. The occurrence of zooplankton taxa at all sampling stations in Pinang River

Group	-Order	Family	Species	Month/ Station								
				October			November			December		
				ST 1	ST 2	ST 3	ST 1	ST 2	ST 3	ST 1	ST 2	ST 3
Rotifera	Bdelloidea	Philodinidae	-	-	+	-	+	+++	-	++	++	+
			<i>Rotaria</i> sp.	-	-	-	-	+	-	-	+	+
	Collotheceae	Collotheceidae	<i>Collothea</i> sp.	-	-	-	-	+	-	-	-	+
			<i>Conochilus</i> sp.	-	-	-	-	-	+	-	-	+
	Flosculariacea	Filiniidae	<i>Filinia</i> sp.	-	-	-	-	+	-	-	-	+
			<i>Testudinella</i> sp.	+	+	-	-	-	-	+	+	+
	Ploumida	Asplanchnidae	<i>Asplanchnopus</i> sp.	-	-	+	-	-	-	-	-	-
			<i>Asplanchna</i> sp.	+	-	-	-	-	-	-	+	-
	Branchionidae	Branchionidae	<i>Anuraeopsis fissa</i>	-	-	+	-	+	-	-	-	-
			<i>Branchionus angularis</i>	-	-	-	-	-	-	-	-	+
			<i>Brachionus</i> sp.	-	+	-	-	-	-	-	-	-
			<i>Keratella</i> sp.	-	-	-	-	-	-	-	-	+
			<i>Lecane bulla</i>	-	-	+	-	-	-	-	-	-
			<i>Lecane closteroerca</i>	-	-	-	-	-	-	-	+	+
Copepoda	Lepadellidae	Lepadellidae	<i>Lecane</i> sp.	-	+	-	-	-	-	-	+	-
			<i>Colurella</i> sp.	-	-	-	-	-	-	-	+	-
	Mytilinidae	Mytilinidae	<i>Lophocharis</i> sp.	-	-	-	-	-	-	-	-	+
			<i>Mytilinaa bisulcata</i>	-	-	-	-	-	-	-	+	-
	Notommatidae	Notommatidae	<i>Cephalodella</i> sp.	-	-	-	-	-	+	-	-	+
			<i>Eosphora</i> sp.	-	-	-	-	-	-	-	+	-
	Epiphanidae	Epiphanidae	<i>Monommata</i> sp.	-	-	+	-	-	-	+	-	-
			<i>Notommata</i> sp.	-	-	+	-	-	-	+	+	-
	Synchaetidae	Synchaetidae	<i>Proalides</i> sp.	-	-	-	-	-	-	+	-	-
			<i>Synchaeta</i> sp.	-	-	+	-	-	-	-	-	-
	Trichocercidae	Trichocercidae	<i>Tetrastiphon</i> sp.	-	-	-	-	+	-	-	-	-
			<i>Trichocerca pusilla</i>	-	-	+	-	-	-	-	-	-
	Cyclopoida	Cyclopoida	<i>Trichocerca</i> sp.	-	-	+	-	-	-	-	-	-
			-	-	-	-	-	-	+	-	-	-

Notes.

- absent; + present (1- 10%); ++ common (11-60%); +++ abundant (61-100%)

Table 4. Spearman's correlation coefficients between physicochemical parameters and zooplankton abundance in Pinang River

Parameter	r_s / Sig.	Temperature	DO	TDS	Conductivity	Salinity	pH	Turbidity	TSS	Chl. <i>a</i>	NH ₄ ⁺ -N	NO ₂ -N	PO ₄ ³ -P	Zoo
Temperature	r_s Sig.	1.000	-0.456*	0.648**	0.471*	0.718**	0.250	-0.187	-0.182	0.163	0.274	-0.045	0.074	-0.227
DO	r_s Sig.	-0.456*	1.000	0.000	0.013	0.000	0.208	0.349	0.363	0.417	0.166	0.825	0.713	0.256
	r_s Sig.	0.017	0.000	-0.248	0.053	-0.285	0.285	0.473*	0.473*	0.217	-0.633**	-0.183	0.307	-0.139
TDS	r_s Sig.	0.648**	-0.248	1.000	0.768**	0.982**	0.548**	-0.127	-0.404*	-0.104	-0.052	0.080	-0.056	-0.674**
	r_s Sig.	0.000	0.212	0.000	0.000	0.000	0.003	0.527	0.036	0.607	0.798	0.690	0.781	0.000
Conductivity	r_s Sig.	0.471	0.053	0.768**	1.000	0.762**	0.585**	0.035	-0.278	-0.159	-0.356	-0.311	0.163	-0.766**
	r_s Sig.	0.013	0.794	0.000	0.000	0.000	0.001	0.861	0.161	0.428	0.068	0.114	0.415	0.000
Salinity	r_s Sig.	0.718**	-0.285	0.982**	0.762**	1.000	0.538**	-0.137	-0.397*	-0.081	-0.013	0.056	-0.068	-0.657**
	r_s Sig.	0.000	0.150	0.000	0.000	0.000	0.004	0.495	0.040	0.687	0.947	0.782	0.736	0.000
pH	r_s Sig.	0.250	0.285	0.548**	0.585**	0.538**	1.000	-0.026	-0.511**	-0.071	-0.330	-0.043	-0.173	-0.439*
	r_s Sig.	0.208	0.149	0.003	0.001	0.001	0.000	0.898	0.006	0.726	0.093	0.830	0.387	0.022
Turbidity	r_s Sig.	-0.187	0.473*	-0.127	0.035	-0.137	-0.026	1.000	0.665**	-0.218	-0.763**	-0.152	0.823**	-0.185
	r_s Sig.	0.349	0.013	0.527	0.861	0.495	0.898	0.000	0.000	0.275	0.000	0.449	0.000	0.355
TSS	r_s Sig.	-0.182	0.359	0.404*	-0.278	-0.397*	-0.511**	0.665**	1.000	0.188	-0.355	-0.137	0.776**	0.162
	r_s Sig.	0.363	0.066	0.036	0.161	0.040	0.006	0.000	0.000	0.348	0.069	0.497	0.000	0.418
Chl. <i>a</i>	r_s Sig.	0.163	0.217	-0.104	-0.159	-0.081	-0.071	-0.218	0.188	1.000	0.418*	0.135	-0.027	0.386*
	r_s Sig.	0.417	0.277	0.607	0.428	0.687	0.726	0.275	0.348	0.000	0.030	0.501	0.894	0.809
NH ₄ ⁺ -N	r_s Sig.	0.274	-0.633**	-0.052	-0.356	-0.013	-0.330	-0.763**	-0.355	0.418*	1.000	0.380	-0.571**	0.516**
	r_s Sig.	0.166	0.000	0.798	0.068	0.947	0.093	0.000	0.069	0.030	0.000	0.051	0.002	0.006
NO ₂ -N	r_s Sig.	-0.045	-0.183	0.080	-0.311	0.056	-0.043	-0.152	-0.137	0.135	0.380	1.000	-0.169	0.360
	r_s Sig.	0.825	0.362	0.690	0.114	0.782	0.830	0.449	0.497	0.501	0.051	0.000	0.400	0.065
PO ₄ ³ -P	r_s Sig.	0.074	0.307	-0.056	0.163	-0.068	-0.173	0.823**	0.776*	-0.027	-0.571**	-0.169	1.000	-0.110
	r_s Sig.	0.713	0.119	-0.781	0.415	0.736	0.387	0.000	0.000	0.894	0.002	0.400	0.000	0.584
Zoo	r_s Sig.	-0.227	-0.139	-0.674**	-0.766**	-0.657**	-0.439*	-0.185	0.162	0.386*	0.516**	0.360	-0.110	1.000
	r_s Sig.	0.256	0.490	0.000	0.000	0.000	0.022	0.355	0.418	0.046	0.006	0.065	0.584	0.000

Notes.

** Correlation is significant at 0.01 level (2-tailed)

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

bioindicator for eutrophic water, as reported by Zannatul and Muktadir (2009). These species are recognized as indicators of high turbidity and high suspended solids. In fact, the Rotifera composition is significantly higher in the river because of its adaptability to the surroundings and can tolerate environmental stressors such as temperature rise and eutrophication (Gillooly, 2000). Besides, rotifers are relatively small, fast-reproducing and may promote rapid population development (Gillooly *et al.*, 2002).

Ismail and Zaidin (2015) recorded 24 species of zooplankton in Burung River, Balik Pulau and the number of species is slightly lower than the current study. Order Bdelloidea has contributed to the highest abundance at all sampling stations throughout the study period. It is because Bdelloidea could reproduce exclusively as female and undergo a life cycle of parthenogenesis that alternates between two reproductive modes (presence and absence of males) leading to a rapid reproductive rate (Min and Park, 2009).

Copepoda contributes only 6% of the total abundance and most of the specimen was found in the samples collected at Station 1, near the river mouth of the Pinang River. According to Johan, Charnov, West, Savage and Brown (2013), 1465 ind/m³ of copepods were collected at the river mouth of the Kemena River in Bintulu, where the abundance was slightly lower than the Pinang River at 3332 ind/m³. Species richness also varied as the Kemena River recorded 13 species of copepods while the Pinang River recorded only 2 taxa. Another study by Zaleha, Sulong, Mohd Lokman, Kamaruzaman and Mohd Afendy (2008), at the estuarine of Pahang coasts, reported 17 families and 25 species of copepods. The differences in the total number of species of copepod and taxa are probably due to the differ-

ent characteristics of the estuarine environment with different ranges of salinity that influence the distribution (Hwang *et al.*, 2000).

Water quality is an important factor in determining the zooplankton abundance in the river. Salinity is the amount of salt dissolved in the water body and some zooplankton can tolerate a high level of salinity, especially in the estuary. This study found that zooplankton abundances have a strong negative correlation with salinity ($r = -0.657$). Station 1 showed a high salinity measurement compared to the other stations as it was located at the river mouth, which subjected to daily tides and water flowing from the ocean.

Conductivity and TDS have a strong negative correlation between zooplankton abundance, $r = -0.766$ and $r = -0.674$, respectively. In November, there was no zooplankton recorded in the samples collected at Station 1 and the reading of both conductivity and TDS was the highest (41384 $\mu\text{S}/\text{cm}$ and 25 g/l, respectively). This condition is probably unfavorable to the zooplankton population. High TDS measurements in the rivers are attributed to the presence of extreme anthropogenic activities along the river that cause runoff with high suspended matter (Al-Badaai *et al.*, 2013).

Results of the Spearman correlation showed a negative correlation ($r = -0.439$) between zooplankton abundance and pH measurement. High pH measurement causes a decrease in the abundance of zooplankton species. At Station 1, pH measurements were high throughout the study as this area receives many wastewater discharges from nearby industries.

The Simpson index in this study shows mostly lower values (0.00-0.40) and only one high value (0.89) was recorded at Station 3 in November. If the

Table 5. Temporal and spatial variations of zooplankton ecological indices in Pinang River

Month	Station	Diversity Index	Richness Index	Evenness Index
		Shannon Wiener (H')	Margalef (R)	Pielou (J')
October	1	0.64	0.91	0.58
	2	1.04	1.44	1.39
	3	2.03	3.51	2.57
November	1	0.00	0.00	0.00
	2	1.29	1.94	0.42
	3	0.27	2.89	0.07
December	1	1.59	2.17	0.70
	2	1.53	2.55	0.43
	3	8.02	2.98	2.17

value is high, the probability of selecting the same species in the sample is low as the high value indicates that the communities are mature and stable. Thus, dominance is shared by a larger number of species, while the near-zero value indicates that the community is in a stress condition (Ismail and Zaidin, 2015). The result of the Pielou Index in this study showed that only some of the values are more than 0.5, indicating that the zooplankton community is balances throughout the study period. Some values with less than 0.5 may indicate the presence of ecological stress with the occurrence of a few dominant species at the study site. Station 3 in November showed a high diversity index ($H' = 0.89$) but a low species evenness ($J' = 0.07$) contributes to the highest total zooplankton abundance ($40833 \pm 9363 \text{ ind/m}^3$).

Conclusion

River ecosystems are categorized as one of the freshwater ecosystems that are sensitive to multiple environmental stressors. Zooplankton communities may be a useful tool for accessing the ecological status of the river ecosystem. This study showed that zooplankton reflects the status of the Pinang River water body through changes in its community structure, the distribution pattern and the number of sensitive genera and species present. Physicochemical parameters are interrelated, which changes as most of the time, one parameter would alter almost all of the other parameters. Therefore, changes in physicochemical parameters may affect the distribution and abundance of zooplankton. However, other factors such as anthropogenic sources, monsoon seasons, fluctuation in tides, nutrient concentration and light availability should also be considered in this study to provide supplementary information about water quality status and zooplankton distribution in the Pinang River.

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