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Functional Feeding Group (FFG) of Aquatic Macroinvertebrate in Middle Reach of Kerian River Basin of North Malaysia Peninsula

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Highlights

- Different patterns of FFG distribution reflect the habitat conditions of the river.
- Predators, mainly Odonata, Hemiptera and Coleoptera, were the most common group in middle reach of Kerian River Basin.
- Water parameters weakly influenced abundance of FFGs in all locations but food availability (i.e allochtonous organic matters and preys) most likely is the main factor limiting their distribution.

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Abstrak: Siasatan terhadap taburan dan kelimpahan kumpulan pemakanan makroinvertebrata akuatik di Sungai Bogak, Kerian dan Serdang di lembangan sungai Kerian menunjukkan terdapat 120 genera dari 59 keluarga dari 13 order makroinvertebrata. Pemangsa terutamanya Odonata, Hemiptera dan Coleoptera adalah kumpulan yang paling biasa dan didapati dalam kepadatan tinggi di Sungai Bogak (sungai yang diubah suai) dan Sungai Kerian (sungai utama). Kumpulan dominan kedua di kedua-dua sungai itu adalah pemungut-kumpul (Diptera dan Ephemeroptera) diikuti oleh pengikis (moluska). Pola kumpulan pemakanan yang berlainan diperhatikan di Sungai Serdang (anak Sungai Kerian). Kumpulan yang paling banyak adalah pemungut-kumpul, diikuti oleh pemangsa dan pengikis. Secara umum, kelimpahan pemangsa menunjukkan korelasi positif dengan kelimpahan mangsa mereka (kumpulan pemakanan lain). Kelimpahan pemangsa terutama di Sungai Bogak dan Kerian, sangat dipengaruhi oleh parameter seperti PO43-, NO3-N dan Zn. Kelimpahan pemungut-kumpul di sungai Serdang pula dipengaruhi oleh suhu dan halaju air, TSS, kekeruhan serta kandungan Mn dan Cu di dalam sedimen. Walau bagaimanapun, semua parameter air mempengaruhi secara lemah kelimpahan kumpulan pemakanan di semua lokasi. Banyak pemungut-kumpul di Sungai Serdang dikaitkan dengan air yang diperkaya oleh sisa antropogenik dari kawasan kediaman sekitar. Pada umumnya, kumpulan pemakanan yang dominan di setiap sungai mencerminkan pengaruh keadaan persekitaran yang berbeza dan ketersediaan sumber makanan di kawasan tersebut.

Kata kunci: Kumpulan Pemakanan, Makroinvertebrata Akuatik, Kelimpahan

Abstract: Investigations on the distribution and abundance of aquatic macroinvertebrates functional feeding group (FFG) in Bogak, Kerian and Serdang rivers of Kerian River Basin showed that there were 120 genera from 59 families of 13 orders of macroinvertebrates. Predator mainly Odonata, Hemiptera and Coleoptera was the most common group and found in high densities in Bogak River (modified river) and Kerian River (main river).

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The second dominant group in both rivers was collector-gatherer (Diptera and Ephemeroptera) followed by scraper (mollusks). A different pattern of FFG distribution was observed in Serdang River (tributary of Kerian River). The most abundant group was collector-gatherer, followed by predator and scraper. In general, predator abundance showed a significant positive correlation with their prey abundance (other feeding groups). Predator abundance especially in Bogak and Kerian rivers, was significantly influenced by parameters such PO_4^{3-}, NO_3^-N and Zn. In Serdang River, collector-gatherer abundance was affected by water temperature, velocity, TSS, turbidity, Mn and Cu content in the sediments. However, all water parameters weakly influenced the abundance of FFGs in all locations. High abundance of collector-gatherer in Serdang River was related to enriched water contributed by anthropogenic waste from surrounding residential areas. In general, dominant FFG in each river reflected the influence of different environmental conditions and availability of food sources in the area.

Keywords: Functional Feeding Group (FFG), Aquatic Macroinvertebrates, Abundance

INTRODUCTION

Malaysia, as one of the tropical countries, is diverse with freshwater habitats (e.g., rivers, lakes, streams, swamps, ponds, puddle as well as phytotelmata) which are home to variety of freshwater macroinvertebrates (Yule 2004). However, these aquatic organisms mostly are unknown and taxonomic knowledge to identify then to lower taxa (genus or species) is significantly scarce (Jacobsen *et al*. 2008; Morse *et al.* 2007).

In general, macroinvertebrates play a major role in the overall structure and function of aquatic ecosystem through conversion of carbon compound derived from allochthonous and autochthonous materials in their tissues (temporary storage), which eventuallyrelease into carbon dioxide (Cummins 1975). In aquatic food web, macroinvertebrates act as primary and secondary consumers and they are more attached to local habitats compared to larger mobile fishes (Cummins 1973; Jacobsen *et al*. 2008). Headwater streams are mainly populated by macroinvertebrates shredder that lives on allochthonous food source, that shift to higher proportion of autochthonous food feeder scrapper in middle reaches and collector in lower reaches of a river system (Hachmoller *et al*. 1991; Vannote *et al.* 1980). In this study, communities of macroinvertebrates living in differently polluted habitats were investigated for the impact of disturbances on the distribution and abundance of their functional feeding groups which indirectly indicated the status of the habitat as well as the water quality (Rawer-Jost *et al.* 2000). The FFG distribution in the aquatic ecosystems complements the conventional approach of chemical water quality monitoring for sustainable management of water resource.

MATERIALS AND METHODS

Study Area

Kerian River borders three states in the northern Malaysia Peninsula; Penang, Kedah and Perak at N05^{o} 10' longitude and E100^{o} 25' latitude. The Kerian River originates in Selama, Perak and Hulu Mahang, Kedah, with about 20 river tributaries. The river irrigates vast rice fields in the river basin. Kerian River Basin (KRB), covering an area of approximately 1418 km^2 (Yap 1990), is one of the largest river basins in the northern Malaysia Peninsula. The middle and downstream areas of KRB usually suffered from flood during wet season. Three rivers were selected for this study based on their locations and morphologies.

Bogak River (BR) is situated in lower part of middle reach of Kerian River Basin (N05^{o} 2' 34.92'', E100^{o} 31' 6.52''). This river has been modified into irrigation canal to irrigate paddy fields and oil palm plantations. This river is about 4.4 km long and approximately 15.5 m to 17.5 m wide. The water of this river is almost stagnant and an aquatic weed, *Cabomba* sp. almost completely covers the water surface.

Serdang River (SR) (N05^{o} 12' 20.84'', E100^{o} 36' 34.27'') is one of the tributaries of Kerian River. The substrate of the river was sandy, mixed with alluvial soil in some parts. This river passes through urban and residential areas collecting mainly anthropogenic wastes from both places. Some upstream areas are surrounded by oil palm (*Elaeis guineensis*) plantations. The water is shallow and river width ranges from 11 m to 12.5 m with a depth of 0.1 m to 1.5 m during rainy season. Water surface is completely exposed to sunlight. Submerged *Hydrilla* sp. is also found in this river.

Kerian River (KR) (N05^{o} 13' 39.49'', E100^{o} 41' 7.18'') is the main river in the Kerian River Basin. This river is mainly impacted by urban and agricultural activities. Few types of plants, *Melastoma malabathricum* (senduduk) and *Colocasia* sp. (keladi) grow along the river banks. It is a wide river (36 m to 49 m) with fast water current. River substrates are mainly sand and alluvial soil. This river suffers relatively serious bank erosion especially during wet season.

Sampling of Macroinvertebrates

The macroinvertebrates were sampled bimonthly using a modified kick sampling technique of Merrit *et al*. (1996) from June 2008 to August 2009. A D-pond aquatic net with 40 cm x 30 cm frame size, 50 cm long net of about 300 μm mesh equipped with a handle of about 1.5 m long was used to collected 10 samples at each locations. The net was randomly hauled along the river bank (in substrates and vegetation) to cover an area of approximately 1 m^2 for each sample. The samples were sorted and preserved in universal 75%–80% ethanol (ETOH). The specimens were identified following keys of Yule and Yong (2004), Merritt and Cummins (1996), Fernando and Cheng (1963), Morse *et al*. (1994) and Fonseka (2000).

Collected macroinvertebrates were categorised into appropriate functional feeding group (FFG) based on Cummins and Merritt (1996), Wallace and Webster (1996) and Cummins and Klug (1979). Taxa were assigned to respective groups based on their behaviour for food acquisition; (a) *scraper*, grazes upon organic films (algae) growing on cobbles and other substrate, (b) *predator*, chews or pierces on other invertebrate, (c) *shredder*, lives on coarse particulate organic matter mainly of allocthonous detritus and macrophytes including macroalgae, (d) *collector-filterer*, traps and feeds on suspended organic matter and (e) *collector-gatherer*, feeds on fine or very fine particulate organic matter. A parasitic leech was put in its own group since they feed on animal blood.

Measurement of Physicochemical Parameters and Biotic Integrity Analyses

Selected water and river physicochemical parameters such as pH, dissolved oxygen (DO), water temperature, velocity and river width and depth were measured *in-situ* (three replicates) using appropriate meters during macroinvertebrates samplings. Two water samples were brought to the laboratory in 500 ml polyethylene bottles for analysis of total suspended solid (TSS), turbidity, biochemical oxygen demand (BOD_3), chemical oxygen demand (COD), phosphorus (PO_4^{3-}), nitrate (NO_3^--N) and ammonia-nitrogen (NH_3-N).

About 500 g of river bottom sediment (upper 5 cm) was collected from each site during this study to assess the contamination of heavy metal. The sediment was air-dried, ground and sieved through 500 μm sieve. Four elements investigated were zinc (Zn), manganese (Mn), nickel (Ni) and copper (Cu). The non-residual metals in the sediment samples (three replicates) were analysed following the digestion method of Chester and Voutsinou (1981).

Rainfall Data

To associate macroinvertebrates abundance with their seasonal distribution, record of monthly rainfall amount and number of rain days during the study period were obtained from the Malaysian Meteorological Department. Rainfall data for Bogak River was taken from the JKR Bagan Serai Station (05° 1’ N, 100° 32’ E), Hospital Kulim station (05° 23’ N, 100° 33’ E) for Serdang River and Felda Ijok Station (05° 10’ N, 100° 46’ E) for Kerian River.

Statistical Analyses

Statistical analyses were run using IBM SPSS (Statistical Package for Social Sciences) version 22 (IBM, New York) for Windows®. The data contained many zero scores there were log transformed [log(x + 1)] prior to analysis. Differences in mean abundance of macroinvertebrates were subjected to one-way ANOVA. The relationships among functional feeding groups and the influences of environmental parameters were evaluated using the Spearman rank correlation (ρ). Meanwhile, significant difference of physicochemical parameters and rainfall volume received every month was evaluated using non-parametric Kruskal-wallis test and seasonal abundance of macroinvertebrate was determined using independence t-test.

RESULTS

Macroinvertebrates collected from the three stations during this study belong to 13 orders, 59 families and 120 FFG genera. There were significant differences of abundance of macroinvertebrates among sites (ANOVA, $F(2,237) = 22.743$, $p < 0.05$) and months sampled (ANOVA, $F(7,232) = 2.132$, $p < 0.05$). In the middle reach of KRB, predator was the most common group and was found in high densities in BR and KR. The second dominant group in both rivers was collector gatherer followed by shredder in BR and scraper in KR. However, different pattern of FFG distribution was observed in SR. The most abundant group was collector gatherer, followed by predator and shredder. Table 1 shows the densities (number of individual or abundance per m^2) of various functional feeding groups in their respective locations.

Table 1: Densities of macroinvertebrates per m^2 (mean ± SE) in the middle reach of Kerian River Basin according to their functional feeding group.

	Bogak River	%	Serdang River	%	Kerian River	%
Scraper	0.02 ± 0.016	0.12	1.07 ± 0.440	1.73	1.36 ± 0.236	12.36
Predator	12.63 ± 1.385	68.49	24.00 ± 2.418	38.95	7.71 ± 0.888	70.32
Shredder	0.74 ± 0.154	4.04	1.61 ± 0.305	2.61	0.13 ± 0.048	1.22
Collector-filterer	0.04 ± 0.022	0.24	0.20 ± 0.057	0.32	0.12 ± 0.047	1.11
Collector-gatherer	5.00 ± 0.800	27.11	34.73 ± 18.539	56.35	1.53 ± 0.244	13.98
Leech	0.00	0.00	0.02 ± 0.016	0.04	0.11 ± 0.033	1.01

Investigated physicochemical parameters are summarised in Table 2 and Table 3 displayed the Spearman rank correlation coefficient (ρ) between FFG and physicochemical parameters. In general, all water parameters weakly influence the abundance of the FFG ($\rho < 0.3$, $p = 0.01$). Among the FFGs, predator, scraper and collector gatherer were mostly influenced by physicochemical parameters. Both pH and COD weakly influence the main FFG groups (predator and collector gatherer) in KRB. Other parameters that possibly influenced predator abundance were PO_4^{3-}, NO_3^-N and Zn. Water temperature, velocity, TSS, turbidity and Mn also displayed weak correlations with the abundance of collector-gatherers. Scraper abundance in KRB showed weak relationship with Zn and DO content in the sediment and water respectively.

Table 2: Physicochemical parameters (Mean ± SE) in the three rivers of the KRB.

Water Parameter	Bogak River	Serdang River	Kerian River
pH*	5.61 ± 0.06	6.00 ± 0.03	6.02 ± 0.05
Dissolved oxygen (mg/l)*	3.69 ± 0.09	6.75 ± 0.09	6.72 ± 0.14
Water Temperature (°C)*	28.34 ± 0.29	27.79 ± 0.45	24.44 ± 0.18
Water velocity (ms^{-1})*	0.08 ± 0.01	0.53 ± 0.02	0.59 ± 0.01
Rainfall (mm)*	190.31 ± 14.78	224.96 ± 15.73	326 ± 15.49
Turbidity (NTU)	21.15 ± 1.18	28.76 ± 3.05	18.03 ± 1.16
Total suspended solid (mg/l)	23.00 ± 1.09	40.13 ± 5.04	34.25 ± 4.33
Biochemical oxygen demand (mg/l)*	1.86 ± 0.07	1.96 ± 0.13	1.00 ± 0.05
Chemical oxygen demand (mg/l)*	43.88 ± 0.68	51.38 ± 0.87	40.63 ± 0.71
Phosphorus (mg/l)*	3.31 ± 0.17	4.56 ± 0.27	3.48 ± 0.09
Nitrate (mg/l)*	0.11 ± 0.02	0.33 ± 0.02	0.20 ± 0.01
Ammonia-nitrogen (mg/l)*	0.09 ± 0.01	0.09 ± 0.01	0.06 ± 0.01
Zinc (Zn)*	53.58 ± 4.415	2.79 ± 0.093	11.75 ± 0.469
Manganese (Mn)*	114.59 ± 8.187	27.02 ± 2.214	97.02 ± 1.615
Nickel (Ni)	7.86 ± 0.382	6.39 ± 0.101	6.70 ± 0.088
Copper (Cu)	3.04 ± 0.160	ND	0.84 ± 0.063

*Significant difference ($p < 0.05$, Kruskal-Wallis test, *factor* = site, *df* = 2). ND: not detected (below the detection limits of the AAS).

Table 3: Spearman rank correlation coefficient (ρ) between functional feeding groups and physicochemical parameters. The BOD, NH_3-N and Ni show no significant influence on FFG abundance therefore excluded from the table.

Parameters	Predator	Collector-gatherer	Collector-filterer	Scraper	Shredder	Leech
pH	−0.204**	−0.123 *	0.050	−0.061	−0.064	0.167**
DO	0.055	−0.082	0.129*	0.223**	−0.013	0.069
Water Temperature	0.008	0.184**	0.007	−0.154*	0.101	−0.181**
Velocity	−0.084	−0.180**	0.171**	0.171**	−0.122*	0.141*
Turbidity	0.097	−0.132*	−0.038	−0.174**	−0.132*	0.047
TSS	−0.015	−0.158*	−0.052	0.195**	−0.185**	0.048
COD	0.209**	0.244**	0.126	−0.159*	0.019	−0.105
PO_4^{3-}	0.178**	0.048	0.053	0.030	0.005	0.072
NO_3^-N	0.128*	−0.065	0.056	0.095	0.065	0.127*
Zinc	−0.229**	−0.031	−0.046	−0.281**	−0.044	0.000
Manganese	−0.131	−0.175*	−0.171*	−0.028	−0.023	0.021
Copper	0.162	0.272**	0.075	−0.331**	0.194	−0.132

Notes: DO = Dissolved Oxygen; TSS = Total Suspended Solid; COD = Chemical oxygen demand; PO_4^{3-} = Phosphorus; NO_3^--N = Nitrate. * Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level

Seasonality was distinguishable in KRB as there was a significant difference of rainfall volume received every month (Kruskal-wallis, $\chi^2 = 15.829$, $p < 0.05$) as well as among sites ($\chi^2 = 36.769$, $p < 0.05$). In this study, amount of precipitation received more than 200 mm per month are considered as wet season. In BR, wet season occurred in August through December 2008 and from April until June 2009. SR has different fluctuation of rainfall with BR. This site received more rainfalls on April 2008, October 2008, April 2009 and August 2009. KR which is situated at higher altitude than other stations received more rainfalls and the wet season was longer. Less rain was recorded in June 2009. During other sampling months, there were heavy rains and this period was considered as wet season. There was a significant difference between mean abundance of macroinvertebrates in dry and wet season ($t = -3.251$, $p < 0.05$). The seasonal abundance of FFGs in the different seasons is shown in Fig. 1.

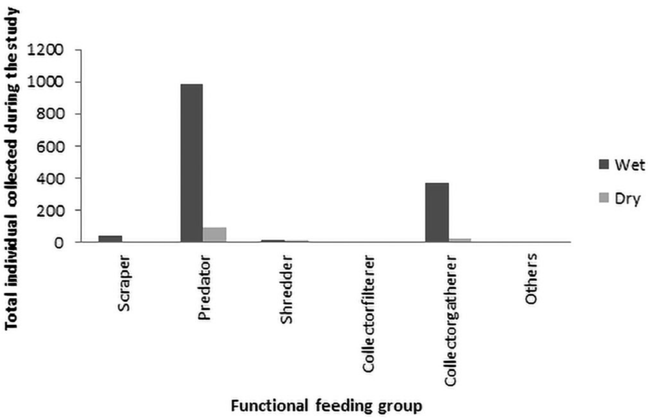
Functional feeding group ratios also used as indicators of stream ecosystem attributes in middle reach of KRB. Calculated ratios and their evaluations were displayed in Table 4 modified from Cummins *et al*. (2008). In general, river condition in KR was slightly different compared to other rivers with stable habitat and macroinvertebrates dependant on autochtonous input. Predator exist in high abundance compared to prey population in KRB and all rivers supply high FPOM especially depositional benthic FPOM suitable for collector-gatherer.

DISCUSSION

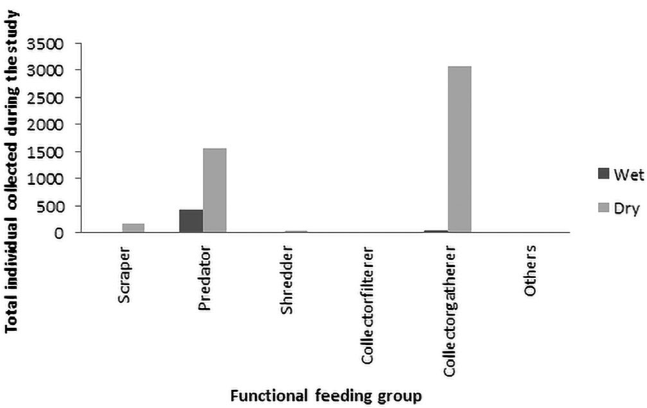
Macroinvertebrates evolved in morphology and behaviour for food gathering and these adaptations allowed them to be place into particular groups (i.e., FFGs). The FFGs are expected to occur in proportionately higher abundances in accumulation of particular food sources or associated with particular habitat type (Rosenberg *et al*. 2008) and perturbation in the community will result deviations from their expected abundances.

According to Barbour *et al*. (1996), shredder and scraper are more sensitive to environmental changes, while gatherer, filterer and predator, are tolerant to pollution. Galbrand *et al.* (2007) noted that shift in trophic structure are often indicative of a community responding to an overabundance of a particular food source or to disturbance. Based on the distribution of FFG in the three rivers, all rivers were polluted hence predator and collector gatherer were in high abundance.

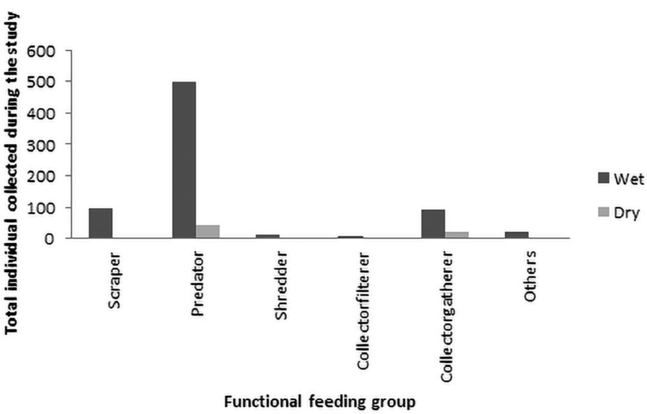
In the middle reach of KRB, collector gatherer consisted mostly of Diptera and Ephemeroptera. In SR, high abundance of collector gatherer, mostly *Chironomus* spp. (Diptera: Chironomidae), was related to availability of food source especially during dry period just after the flood recedes. According to Hawtin (1998), rotten logs, leaves and other organic matters will increase the soft sediments in the river which is favourable to several aquatic insects such as Chironomidae and aquatic earthworms. This situation showed that seasonality indirectly influence collector gatherer abundance. Chironomids commonly found



(a)



(b)



(c)

Figure 1: Total macroinvertebrate collected according to their FFG in wet and dry seasons.

Table 4: Functional feeding group ratios used as indicators of stream ecosystem attributes of Kerian River Basin.

Ecosystem parameter	General criteria for ratios	Calculated ratios			Evaluation
		BR	SR	KR	
Autotrophic/ Heterotrophic Index (P/R)	Autotrophic Ecosystem, > 0.75	0.09	0.06	0.76	KR was autotrophic stream, dependant on autochtonous input while other rivers were heterotrophic stream with allochtonous riparian organic matter input.
Shredder Index (CPOM/FPOM)	Normal shredder association linked to the riparian ecosystem, > 0.25	0.06	0.02	0.08	Very low shredder population in all rivers since food sources mainly in form of FPOM rather than CPOM which usually found higher in upper catchment.
Filtering Collector Index (TFPOM/ BFPOM)	Transport (in suspension) FPOM enriched, > 0.50	0.009	0.006	0.079	Sediments observed to be poor with transport FPOM but high depositional benthic FPOM suitable for collector gatherer.
Channel Stability Index	Stable substrates abundant, > 0.50	0.10	0.06	0.89	KR was stable habitat with abundant attachment site for macroinvertebrates, more woody debris compared to other rivers.
Predator-Prey Index (Top-down control)	Typical predator to prey balance, 0.10–0.20	2.17	0.64	2.37	Very high predator compared to prey population in all rivers.

in rivers that are associated with high organic pollution (Pinder 1986) such as in SR. Yamamuro and Lamberti (2007), found that this detritivore macroinvertebrates prefer sandy substrate with high level of benthic organic matter as it served as a better food than in the coarser substrate.

Meanwhile, predators mostly belonged to Odonata, Hemiptera and Coleoptera. Predator abundance in middle reach of Kerian River Basin shows a significant positive correlation with their potential prey abundance [scraper, shredder, and collector (gatherer and filterer)]. High numbers of potential prey lead to increase in the abundance of predators since their food searching was reduced (Bazzanti 1991). Predator abundance was high in BR and SR mainly due to high abundance of preys (mainly zooplankton) especially in the midst of aquatic vegetation. Consequently, aquatic vegetation is a favourable habitat to the climbing predator such as dragonfly larvae and freshwater prawn *Macrobranchium* sp. During wet season, although abundance of predator seems to be affected by flooding like any other FFGs but their abundance remained high in BR and SR as flooded riparian vegetation (shrubs and grasses) acted as refugia or migration corridor for these macroinvertebrates (Wantzen *et al*. 2008).

In KRB, scrapers were contributed mainly by freshwater snails and mayflies from family Heptagenidae together with water beetle from family Elmidae. Freshwater snails mainly found in rivers with sandy substrate (SR and KR). These macroinvertebrates scrapped algae attached on substrate surface. On the other hand, aquatic lepidopteran occurs only in BR and SR which corresponded with availability of aquatic weeds as hosts.

Among the variables, a heavy metal, Cu fairly influenced the abundances of collector gatherer and scraper. Cu is moderately soluble in water and binds easily to sediments and organic matter. Concentration of Cu is higher in plants and animals than in the water or sediments in which they live. However, Cu does not biomagnifies in food webs therefore provides the least influence on predators (Barwick & Maher 2003).

The distribution of macroinvertebrate functional feeding groups in running waters seems to reflect process-level aquatic ecosystem attributes (Rawer-Jost *et al.* 2000; Cummins *et al.* 2008). In KR, the habitat was more stable with high abundance of attachment site for its macroinvertebrates. According to FFG ratios, KR showed dependant on autochtonous (e.g., algae) input while other rivers were heterotrophic stream with allochtonous organic matter input (e.g. leaf packs and logs). Shredder in KRB was low in abundance associated with low CPOM. Based on Predator-Prey Index, very high predator compared to prey population recorded in all river. This index indicated that this group was tolerant to environmental changes and able to establish their population even with low number of prey. In general, FFG ratios show that linkages exist in middle reach of KRB between CPOM and shredders, between FPOM and collectors, and between primary production (e.g. periphyton) and scrapers.

CONCLUSION

The macroinvertebrates communities in the middle reach of KRB were dominated by predator, collector gatherer, and shredder followed by scraper. Predator community mainly inhabited river with a lot of preys around aquatic vegetations. Collector-gatherer and scraper were preferred habitat with sandy substrates and high depositional benthic FPOM. The presence of very high FPOM was a good indication of the organic pollution in KRB. Variation in FFG dominance in each river reflected the influence of different environmental conditions, habitat structures and availability of food sources in the area. Changes in aquatic ecosystem condition due to different human activities in each river alter the nutritional food base of FFGs led to shift in their dominance.

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