COMPARATIVE ANALYSES OF BIOTIC INDICES BASED ON BENTHIC MACROINVERTEBRATES FOR STREAM WATER QUALITY ASSESSMENT AT TROPICAL STREAMS

Wong Andrew Bak Hui & Arman Hadi Fikri *
Institute for Tropical Biology and Conservation,
Universiti Malaysia Sabah,
88400, Kota Kinabalu, Sabah, Malaysia.
*Corresponding author: *arman@ums.edu.my*

ABSTRACT

Biotic indices application to other countries required testing and adaptations to local environments. However, their testing remains lacking in Malaysia. Therefore, this study analysed the performance of various biotic indices, in their sensitivity, responses, and seasonal stability. Fifteen sampling sites composed of reference and disturbed sites were selected and 14 indices were analysed for their performance. These indices include the Ephemeroptera, Plecoptera, and Trichoptera (EPT), Hilsenholf's Family Biotic Index (FBI), Original Biological Monitoring Work Party (BMWP), Original Average Score Per Taxa (ASPT), Thailand's Biological Monitoring Work Party (BMWP-Thai), Thailand's Average Score Per Taxa (ASPT-Thai), Vietnam's Biological Monitoring Work Party (BMWP-Thai), Vietnam's Average Score Per Taxa (ASPT-Viet), South Africa Score System Version 5 (SASS5), ASPT of South Africa Score System Version 5 (ASPT-SASS5), Stream Invertebrate Grade Number Average Level Version 2 (SIGNAL2), and Singapore's Biotic Index (SingScore), Malaysian Biological Monitoring Work Party (BMWP-My), and Malaysian Family Biotic Index (MFBI). Among the tested biotic indices, the EPT, BMWP-Thai, BMWP-Viet, SASS5, and BMWP-My were sensitive in discriminating the reference from disturbed sites. Most indices had significant linear relationships with phosphates, except the ASPT and ASPT-Thai. Meanwhile, EPT, BMWP-Viet, and BMWP-My were also associated with the habitat scores significantly. While only four biotic indices showed significant differences seasonally, the water quality classification between seasons was highly varied. In conclusion, EPT, BMWP-Viet, and BMWP-My showed better performances in discriminating the reference sites from disturbed sites, while associated with both phosphate and habitat score. As the water quality classification was highly varied seasonally, it is recommended to calculate the biotic indices during the dry season.

Keywords: Aquatic macroinvertebrates, bioassessment tools, responsiveness, seasonal variation

ABSTRAK

Penggunaan indeks biotik negara lain memerlukan ujian dan adaptasi kepada persekitaran tempatan. Namun kajian indeks biotik di Malaysia masih berkurangan. Maka, kajian ini menguji prestasi indeks biotik yang berbeza, dari segi kepekaan, tindak balas terhadap pengaruh tekanan persekitaran, dan kestabilan musim. Sejumlah 15 lokasi sungai merangkumi lokasi rujukan dan lokasi terganggu telah dipilih untuk menganalisis 14 indeks biotik yang dipilih. Indeks yang dikaji termasuk Ephemeroptera, Plecoptera, dan Trichoptera (EPT), *Hilsenholf's Family Biotic Index* (FBI), *Original Biological Monitoring Work Party* (BMWP), *Original Average Score Per Taxa* (ASPT), *Thailand's Biological Monitoring Work Party* (BMWP-Thai), *Thailand's Average Score Per Taxa* (ASPT-Thai), *Vietnam's Biological Monitoring Work Party* (BMWP-Thai), *Vietnam's Average Score Per Taxa* (ASPT-Viet), *South Africa Score System Version* 5 (SASS5), *ASPT of South Africa Score System Version 5* (ASPT-SASS5), *Stream Invertebrate Grade Number Average Level Version 2* (SIGNAL2), dan *Singapore's Biotic Index* (SingScore), *Malaysian Biological Monitoring Work Party* (BMWP-My) dan *Malaysian Family Biotic Index* (MFBI). Antara indeks biotik yang diuji ialah EPT, BMWP-Thai, BMWP-Viet, SASS5, dan BMWP-My adalah peka dalam membezakan lokasi rujukan dari lokasi terganggu. Kebanyakan indeks terdapat hubungan linear yang signifikan dengan fosfat, kecuali ASPT dan ASPT-Thai. Sementara itu, EPT, BMWP-Viet, dan BMWP-My indeks berhubung kait yang signifikan dengan skor habitat. Walaupun hanya empat indeks biotik menunjukkan perbezaan yang signifikan antara musim, perubahan pengkelasan kualiti air antara musim adalah sangat berbeza. Kesimpulannya, EPT, BMWP-Viet dan BMWP-My menunjukkan prestasi yang lebih baik dalam pembezaan lokasi rujukan dari lokasi terganggu, sementara itu juga berhubungkait dengan perubahan fosfat dan skor habitat. Berdasarkan klasifikasi kualiti air yang sangat pelbagai mengikut musim, adalah disarankan pengiraan biologi berdasarkan indeks biotik dilakukan pada musim kering.

Kata kunci: Makroinvertebrata akuatik, alat penilaian biologi, responsif, variasi musim

INTRODUCTION

Biotic index is a tool developed to access the water quality of the water bodies based on their biological communities such as fishes, benthic macroinvertebrates, and diatoms (Li et al. 2010; Zolkefli et al. 2020). The main principle for biological assessment is that healthy environment preoccupied with rich communities, while degradation of the environment shifted those communities to those dominated by few pollutant tolerant species. Taxon tolerance values are assigned based on their ability to tolerate the physicochemical changes (Chang et al. 2014; Chessman & McEvoy 1998; Mazzoni et al. 2014). Ultimately, the overall scores calculated based on the collected taxa from a river will reflect the quality of the freshwater environments (Li et al. 2010). Among these commonly used bioindicator groups, the benthic macroinvertebrates were widely studied and applied in bioassessment, as their advantageous features such as ubiquitous distribution, sedentary nature, easy and cheap to sample, and a wide spectrum of responses towards pollution (Barbour et al. 1999; Hauer & Resh 2007; Ochieng et al. 2019; Serrano Balderas et al. 2016).

Water quality assessment in Malaysia is mainly focusing on conventional physicochemical methods. The Water Quality Index (WQI) includes six parameters: pH, dissolved oxygen, biochemical oxygen demand (BOD5), chemical oxygen demand (COD), total suspended solids (TSS) and ammonia nitrogen to assess the water quality status of the stream and rivers in Malaysia (Arsad et al. 2012; Naubi et al. 2016; Zainudin 2010). The water quality biomonitoring and management in Malaysia is more focus on their values in human usage. This sole usage of physicochemical assessment provides a snapshot of the condition when the samples were taken. Whereas bioassessment provides a more efficient and lower cost compared to traditional water quality assessment (Elias et al. 2014). Direct assess and monitor the biological variables are capable of providing valuable information in water resources management, restoration programs and freshwater conservation (Carlson et al. 2018; Heino et al. 2003; Larsen 1997; Li et al. 2010).

In general, studies in Malaysia had directly applied the temperate biotic indices includes the FBI, BMWP and ASPT to assess the water quality based on freshwater macroinvertebrates (Azmi & Geok 2016; Harun & Fikri 2016; Mahazar et al. 2013; Tan & Beh 2015). These studies focused on the human impacts on freshwater communities while evaluating water quality status using the biotic indices. Tan and Beh (2015) had found the direct implementation of temperate biotic indices to be related to WQI. Yet implementation of these temperate biotic indices may raise the question of their precision and accuracy, due to the geographical difference the taxa available (Elias et al. 2014).

Numerous studies had been focused on the comparisons and performance of biotic indices in evaluating the water quality and organic pollution (Etemi et al. 2020; Ghani et al. 2018; Ochieng et al. 2020; Sandin & Johnson 2000; Semenchenko & Moroz 2005). Furthermore, the scoring systems were commonly being adopted and modified to reflect local taxa for their river quality assessment (Huong 2009; Mustow 2002). Study in evaluating their performances in assessing the Malaysia water quality status and their responses to different stressor types were limited. Currently, two studies (Ghani et al. 2018; Tan & Beh 2015) had found the biotic indices to be correlated to Malaysia’s WQI. Moreover, tolerance scores were assigned for benthic macroinvertebrates at Pahang River Basin, Malaysia, which could be used to calculate the Malaysian Family Biotic Index (MFBI) and Malaysian Biological Monitoring Work Party (BMWP-My) (Ghani 2016).

The optimal bioassessment tools would be developed based on local taxa by assigning appropriate tolerance scores. However, large numbers of samples are required to produce sufficient results statistically. Therefore, evaluating the performance of other region’s indices may be useful especially in developing countries, where biological monitoring is still in the early stage. Therefore, this study was aimed to analyse the performance of various biotic indices, in the aspect of index sensitivity, seasonal stability, and responses towards environmental stressor, for the water quality assessment of Malaysia’s streams.

MATERIAL AND METHODS

Study Area

The sampling areas located at Ranau-Telupid districts, Sabah, Malaysia which covers the area after Kundasang (Ranau Town) until the Terusan Sapi area. The main rivers at Ranau-Telupid districts include the Liwagu River, Sugut River, Labuk River, and Sapi River. The climate in these areas generally describes as hot and wet, considered as tropical rainforest climate, with an approximate average of 27°C temperature and 85% humidity throughout the year (Murtedza et al. 2002). Annual rainfall is generally greater than 2,000 mm and well distributed over the Ranau area (Murtedza et al. 2002).

Various land-use activities occurred at Ranau and Telupid area. The Liwagu river is at risk of water quality degradation due to intensive agriculture, tourism activities, and human settlements (Murtedza et al. 2002) located at Kundasang. Meanwhile, the Ranau area undergoes landscape changes due to logging activities, pulp mill, mining activities, and human settlements (Choo 2003; Murtedza et al. 2002). Part of Sugut River at Ranau was affected by the Mamut Copper mine. The area between Ranau and Telupid had less intensive agricultural activities, including paddy fields, hill rice, fruit orchards that were mostly cultivated by adjacent rural communities (Murtedza et al. 2002). Meanwhile, the Telupid area had an increasing conversion of land-use, from small scall agriculture to intensive monocultures, especially the oil palm plantations (Choo 2003; Murtedza et al. 2002).

A total of 15 sampling sites were selected from those areas, based on the type of land-uses surrounding the streams (Figure 1). Each of the sampling sites or reaches consisted of 100 meters reach. Seven reference sites (Tergorek, Kananapon, Bayaan, Moroli, Valanut, Matupang, and Paginatan) with the least human disturbances (near the village) were selected from the rural area. The remaining sampling sites were considered as disturbed sites due to the various human activities along the streams. Two sites at Liwagu stream were at the Ranau Town, located downstream of intensive agriculture of Kundasang area. One site, Kituntul located in Ranau town, surrounded by human settlements with patches of crops. Lastly, the Lohan site was surrounded by rural human settlement, though this stream was affected by the mining activities located in the upstream area. The remaining four sampling sites at Telupid namely the Telupid, Toniting, Bangau-Bangau, and Kibut, were had large scale oil palm plantations on both sides of the riparian area.

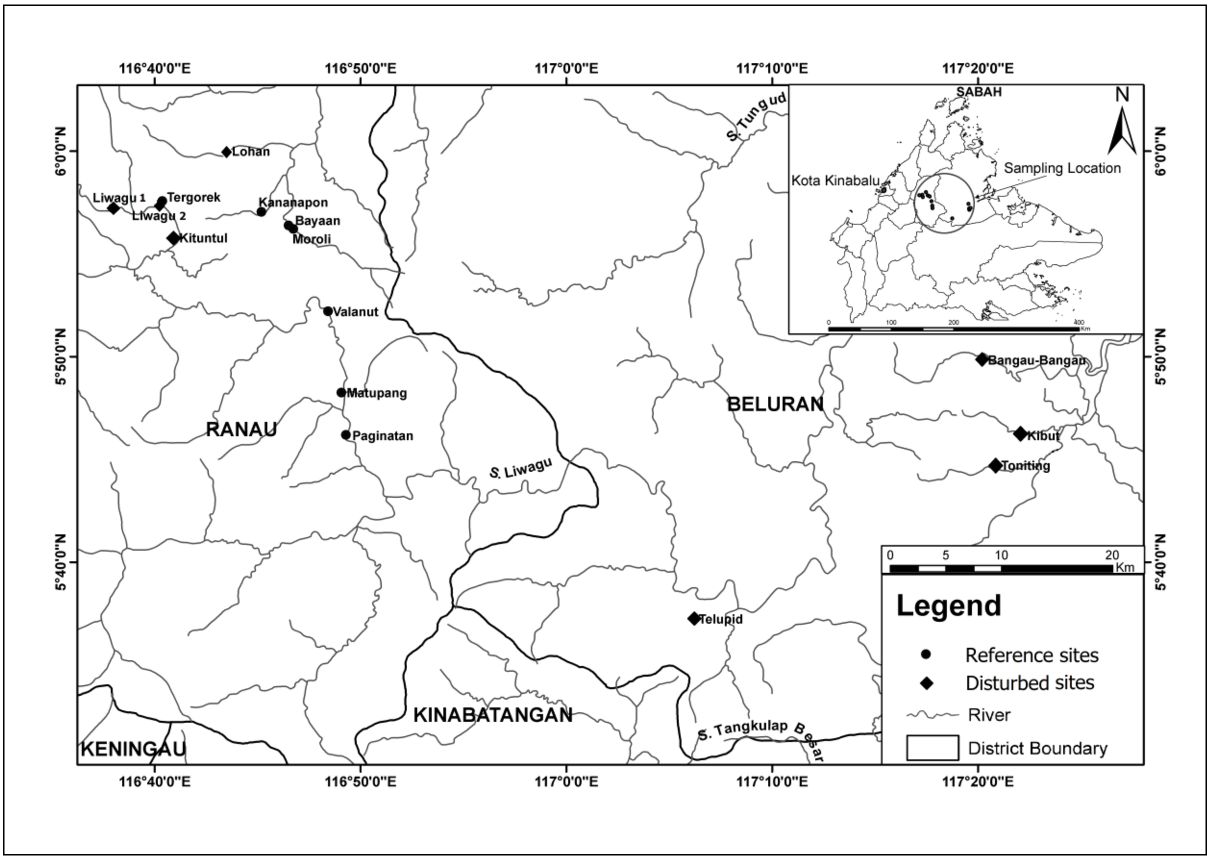

Figure 1. The selected sampling sites (reference and disturbed sites) at Ranau-Telupid, Sabah

For investigating the seasonal variation of biotic indices, the samplings were conducted during the dry season (May to September) and during the wet season (November to April) (Harun et al. 2015).

Environmental Variables
Three readings of the *in-situ* water quality parameters were recorded along the 100m stream reach using the YSI Pro-plus multiparameter water quality meter, YSI ProDSS Multiparameter Water Quality Meter, and CyberScan pH 300 Series pH Meter. These parameters include pH, water temperature (°C), dissolved oxygen (mg/L), and conductivity (µS/cm). Additional *ex-situ* water quality parameters such as total suspended solids, nitrate, phosphate, and ammonia nitrogen were measured based on the three water samples collected using the pre-rinsed 300ml high-density polyethylene (HDPE) bottles. The water samples were stored in the cooler box (6°C) to be analysed for the total suspended solids using the gravitational method (Abdullah 2012). Meanwhile, the phosphate (ascorbic acid method), nitrate (Cadmium Reduction Method) and ammonia nitrogen (Salicylate Method) were measured using the HACH 900 Calorimeter.

Meanwhile, the habitat quality was conducted based on the visual habitat assessment of the United State Environmental Protection Agency (USEPA) Rapid Bioassessment Protocol (Barbour et al. 1999). This assessment evaluating the habitat and riparian attributes of the selected sampling sites based on ten parameters, in order to provide an overall habitat score.

Samplings of Benthic Macroinvertebrates
The benthic macroinvertebrates were collected based on the multi-habitat approach of Rapid Bioassessment Protocols (Barbour et al. 1999), which is the stratified sampling of 20 different habitats. These habitats included riffles, runs, pools, leaf litters, and submerged roots. Benthic macroinvertebrates were sampled by disturbing the substrates or jabbing with Surber net with the sample frame of 0.3 x 0.3 m (12 x 12 inch). At riffles and runs, the sampled were taken by placing the net perpendicular to the current flow and the substrates inside the 0.3 x 0.3 m frame were disturbed for one minute. The surface of the larger substrate was brushed in front of the net with hands to dislodge the attached macroinvertebrates. After removed the large substrates, the remaining substrates were disturbed to detach the remaining benthic macroinvertebrates into the Surber net. For the pool area, the substrates were kicked while water was swept to collect the floating materials into the nets. The process of kicking and sweeping was repeated for one minute (Gillies et al. 2009)**.** The submerged root from the bank was sampled by jabbing the roots to dislodge the benthic macroinvertebrates into the net. The submerged leaf litter was sampled by collecting the leaf from an area of approximately 0.09 m^2. The 20 samples were pooled into one composite sample and sorted on the field in a white enamel pan. Sorted benthic macroinvertebrates were preserved in 95% ethanol and identified mostly family level using the identification keys from Morse et al. (1994), Ng et al. (2017) and Yule & Yong (2004).

Data Analyses
For this study, 14 biotic indices were calculated: Ephemeroptera, Plecoptera, and Trichoptera (EPT) index (Hazelton 2003; Smith et al. 2015), Hilsenholf's Family Biotic Index (FBI) (Hilsenhoff 1988), Original Biological Monitoring Work Party (BMWP) (Armitage et al. 1983), Original Average Score Per Taxa (ASPT) (Armitage et al. 1983), Thailand's Biological Monitoring Work Party (BMWP-Thai) (Mustow 2002), Thailand's Average Score Per Taxa (ASPT-Thai) (Mustow 2002), Vietnam's Biological Monitoring Work Party (BMWP-Thai) (Huong 2009), Vietnam's Average Score Per Taxa (ASPT-Viet) (Huong 2009), South Africa Score System Version 5 (SASS5) (Dickens & Graham 2002), ASPT of South Africa Score System Version 5 (ASPT-SASS5) (Dickens & Graham 2002), Stream Invertebrate Grade Number Average Level Version 2 (SIGNAL2) (Chessman 2003),

Singapore's Biotic Index (SingScore) (Blakely et al. 2014), Malaysian Family Biotic Index (MFBI), and Malaysian Biological Monitoring Work Party (BMWP-My) (Ghani 2016; Zakaria & Mohamed 2019). All these biotic indices were calculated using family taxonomic data, except for a few others group such as Oligochaeta in higher taxonomic level. Table 1 summarized the water quality classification of the biotic indices.

Table 1. Water quality classification of the biotic indices

Classes	**Excellent (E)**	**Good (G)**	**Fair (F)**	**Poor (P)**			
SingScore	>120	100-119	80-99	0-79			
Classes	Very Good (VG)	Good (G)	Moderate (M)	Poor (P)		Bad (B)	
BMWP*	>100	71-100	41-70	11-40		0-10	
ASPT*	>8.0	6.1-8.0	5.1-6.0	3.1-5.0		<3.0	
SIGNAL	>6.0	5.0-6.0	4.0-5.0	3.0-4.0		<3.0	
SASS5	>165	137-165	108-136	79-107		<79	
ASPT-SASS5	≥9.0	8.2-9.0	7.4-8.2	6.6-7.4		<6.6	
MFBI	>5.9	4.5-5.8	3.8-4.4	2.7-3.7		<2.7	
Classes	Excellent (E)	Very Good (VG)	Good (G)	Fair (F)	Fair poor (FP)	Poor (P)	Very Poor (VP)
FBI	0.00-3.75	3.76 -4.25	4.26 -5.00	5.01-5.75	5.76 - 6.50	6.51 -7.25	7.26-10.00

*BMWP-Thai, BMWP-Viet, ASPT-Thai, ASPT-Viet, and BMWP-My followed original BMWP and ASPT classification. Source: Hilsenholf (1988); Armitage (1983); Hoang (2009); Zakaria & Mohamed (2019)

The sensitivity of the biotic indices was evaluated by comparing their values between the reference and disturbed sites using both the Mann-Whitney U test and box plot. The box plot visualized the 25th percentile, median, and 75th percentiles value, where no overlap of the box plot indicates the ability of the biotic indices to discriminate the reference sites from disturbed sites (Barbour et al. 1999). In addition, the Mann-Whitney test was used to test the significant differences of the biotic indices between dry and wet seasons. Finally, Spearman correlation was used to analyze the linear response of biotic indices towards environmental variables. The box plots, Mann-Whitney test, and Spearman correlations were done by using IBM SPSS Version 20.

RESULTS

Benthic Macroinvertebrates

A total of 80 families were identified from the 13,419 individuals of benthic macroinvertebrates. The most dominant macroinvertebrate group was the Ephemeroptera (49.88%), which consisted of almost half of the total individuals (Figure 2). The second abundant group was Diptera (17.74%), followed by Trichoptera (10.43%) and Coleoptera (7.35%). Among the benthic macroinvertebrate groups, the least abundance was the Polychaeta (0.02%), which consisted of three individuals. For the non-insect of macroinvertebrate group, Gastropoda was abundant and composed 2.76% of the whole samples. This was followed by Decapoda (composed of aquatic shrimps and crabs) that contributed 1.48% of the total individuals.

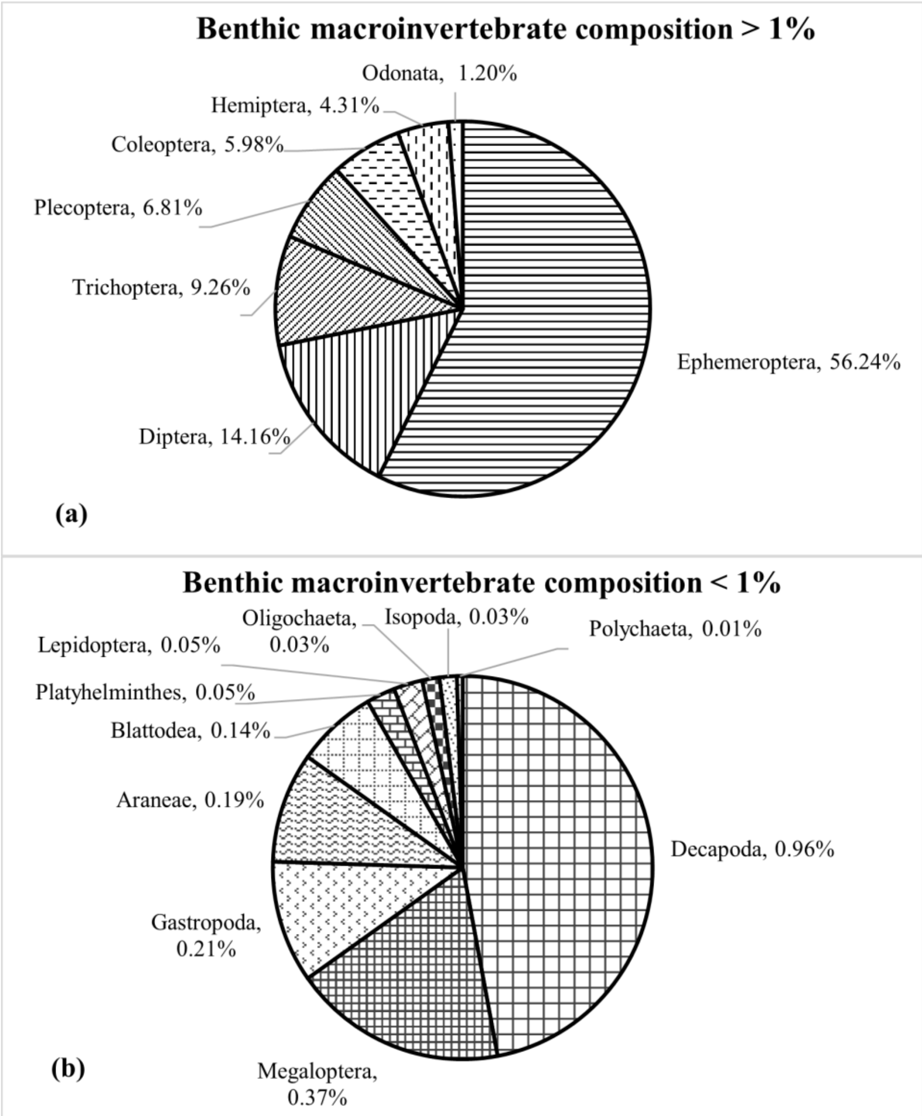

Figure 2. Major groups of benthic macroinvertebrates with (a) composition >1% and (b) composition <1%

The Sensitivity of the Biotic Indices

The sensitivity of the biotic indices was explored using the boxplot. The non-overlap of the boxplot interquartile between reference and disturbed sites showed their capability to discriminate between reference and disturbed sites. Only five out of the 14 indices showed to be sensitive enough to discriminate between the reference and disturbed sites (Figure 3).

Non-overlap indices included the EPT, BMWP-Thai, BMWP-Viet, SASS5, and BMWP-My, as shown in Figure 3(a-e). Meanwhile, the five indices (BMWP, ASPT, ASPT-Viet, SingScore, and ASPT-SASS5) shown a certain degree of overlap between the boxes of reference and disturbed sites, as shown in Figure 3(f-j). The Figure 3(k-n) showed that FBI, ASPT-Thai, SIGNAL2, and MFBI had the least sensitivity due to the high overlaps of the interquartile boxes between reference and disturbed sites.

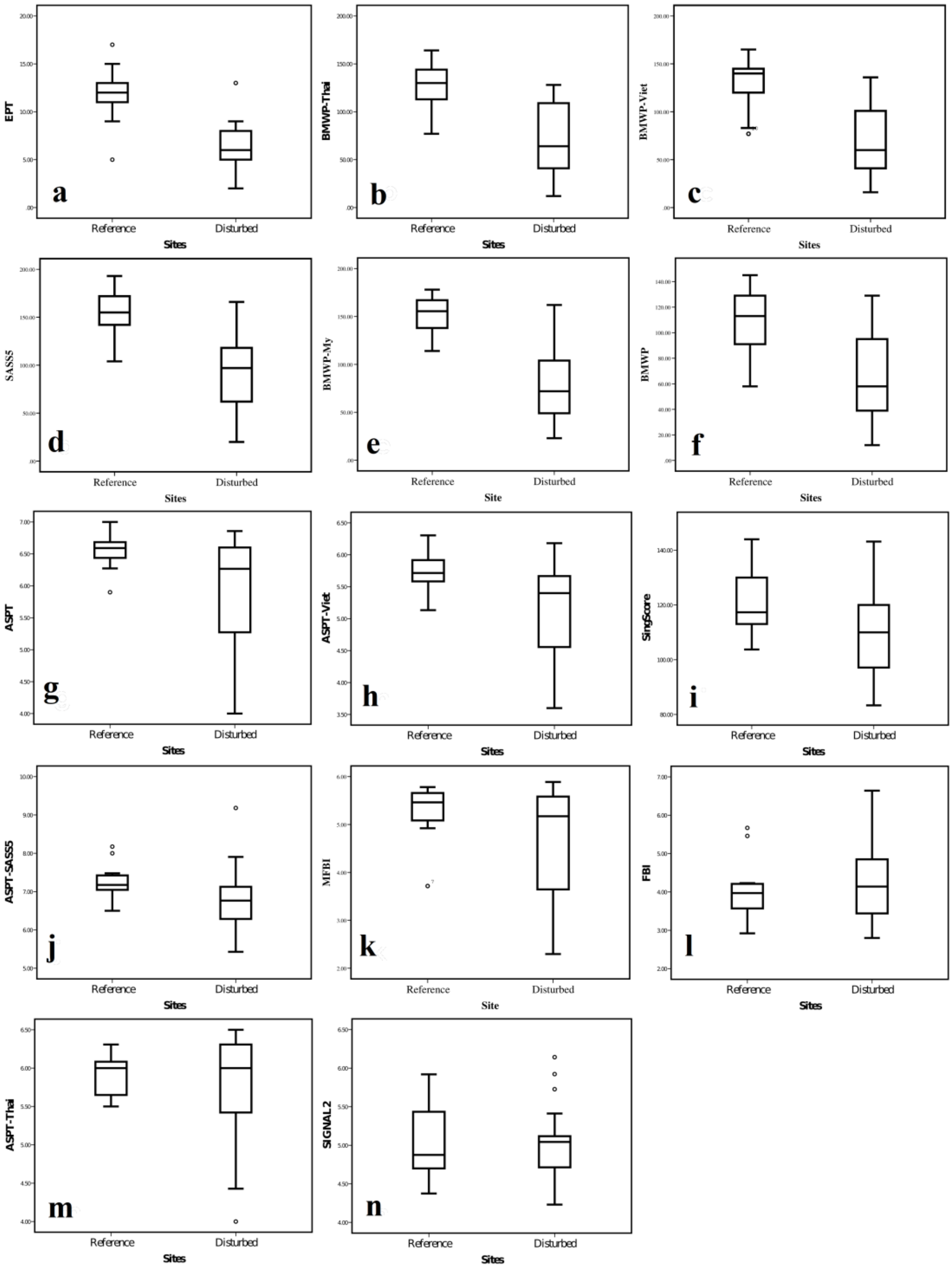

Figure 3. Non-overlap (a-e) and overlap (f-n) box plots of biotic indices between reference and disturbed sites. Boxes are interquartile ranges (25th percentile to 75th percentile); horizontal lines within the boxes are the median values; vertical lines are 1.5× the interquartile range; circles are outlier (values >1.5× the interquartile range)

Responses of Biotic Indices to Environmental Variables

The biotic indices were analysed with Spearman correlations for their responses towards the measured nine environmental variables (Table 2). Conventionally, correlation coefficient with more than 0.7 shows strong correlation, between 0.40 to 0.69 shows moderate correlation, while weak correlation has correlation coefficient less than 0.39 (Mukaka 2012;

Schober et al. 2018). Two biotic indices, the ASPT and ASPT-Thai have no significant relationship ($p>0.05$) with any measured environmental variables. Meanwhile, the remaining twelve biotic indices also showed no significant relationship with water temperatures, dissolved oxygen, conductivity, pH, nitrate, ammonia nitrogen, and total suspended solids.

Eleven biotic indices showed significant correlations ($p<0.05$) with the phosphate concentration. These included the EPT (r=-0.481), BMWP (r=-0.449), BMWP-Thai (r=-0.453), BMWP-Viet (r=-0.493), ASPT-Viet (r=-0.548), SingScore (r=-0.457), SIGNAL2 (r=-0.392), SASS5 (r=-0.462), ASPT-SASS5 (r=-0.553), and BMWP-My (r=-0.474) that showed moderate negative relationships with phosphate. High values of the biotic indices often indicate better water quality. As such, the increase of phosphate concentration would decrease the water quality and affecting the biological communities. Contrastly, the FBI had different scoring system, where lower value of the FBI indicates a better water quality. Therefore, it showed a positive weak correlation (r=0.357) with phosphate. Meanwhile, the ASPT, ASPT-Thai, and MFBI showed no significant correlation with phosphate.

Lastly, both EPT (r=0.530), and BMWP-My (r=-0.433) showed moderate positive correlations with the total habitat scores. This show that stream habitat quality is associated with water quality, as indicates by the increase in the biotic indices values. Meanwhile, the BMWP-Viet had significant weak relationships (r=0.370) with the total habitat scores.

Table 2. Spearman's correlation between biotic indices and environmental variables

Biotic Indices	Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	pH	Phosphate (mg/L)	Nitrate (mg/L)	Ammonia nitrogen (mg/L)	Total Suspended Solids (mg/L)	Habitat scores
EPT	-0.142	-0.097	-0.219	-0.041	-0.481**	-0.332	-0.068	-0.257	0.530**
FBI	-0.178	-0.130	0.069	-0.123	0.357*	0.167	0.328	0.298	-0.130
BMWP	-0.028	0.151	-0.293	-0.082	-0.449**	-0.115	-0.246	-0.212	0.262
ASPT	0.233	0.010	0.161	-0.053	-0.309	-0.261	0.011	-0.087	0.063
BMWP-Thai	-0.025	0.088	-0.313	-0.089	-0.453**	-0.188	-0.147	-0.193	0.311
ASPT-Thai	0.208	0.230	0.072	0.051	-0.289	0.016	-0.078	-0.265	-0.088
BMWP-Viet	-0.055	-0.015	-0.297	-0.110	-0.493**	-0.239	-0.148	-0.214	0.370*
ASPT-Viet	0.036	0.151	-0.119	-0.039	-0.548**	-0.184	-0.255	-0.307	0.245
SingScore	-0.248	0.155	-0.083	0.222	-0.457**	-0.077	-0.160	-0.222	0.220
SIGNAL2	-0.009	0.051	0.142	0.272	-0.392*	0.013	-0.095	-0.293	-0.013
SASS5	-0.044	-0.059	-0.253	-0.105	-0.462**	-0.168	-0.066	-0.147	0.343
ASPT-SASS5	-0.006	-0.062	-0.110	-0.051	-0.553**	-0.187	-0.041	-0.167	0.347
MFBI	0.083	0.153	-0.072	-0.038	-0.210	-0.348	0.076	-0.054	0.176
BMWP-My	-0.011	-0.044	-0.294	-0.185	-0.474**	-0.227	-0.151	-0.144	0.433*

Seasonal Performance and Water Quality Classification

The biotic indices were tested with Mann-Whitney U test, revealed that only BMWP ($U=52.5$; $p=0.015$), BMWP-Thai ($U=65$; $p=0.049$), SingScore ($U=31.5$; $p=0.001$), and SIGNAL2 ($U=53$; $p=0.014$) showed significant differences between dry and wet seasons. Most biotic indices showed varied classification seasonally, though dry season tends to produce better water quality classification (Figure 3). Better water quality classification during the dry season by all biotic indices ranged from two to seven sites. Most indices classified wet season with better water quality (varied from one to four sites), except BMWP, BMWP-Thai, SASS5, and BMWP-My index. Also, water quality classification based on ASPT type indices (ASPT, ASPT-Thai, ASPT-Viet, and ASPT-SASS5) gave lower classes when compared with BMWP types indices (BMWP, BMWP-Thai, BMWP-Viet, and SASS5).

The water quality classification based on biotic indices were summarized in Table 3. No sampling site with Very Good (VG) water quality when assessed using ASPT type indices. On the other hand, reference sites had Very Good (VG) to Good (G) based on BMWP type index classification during the dry season, although the water quality classes were lowered during the wet season.

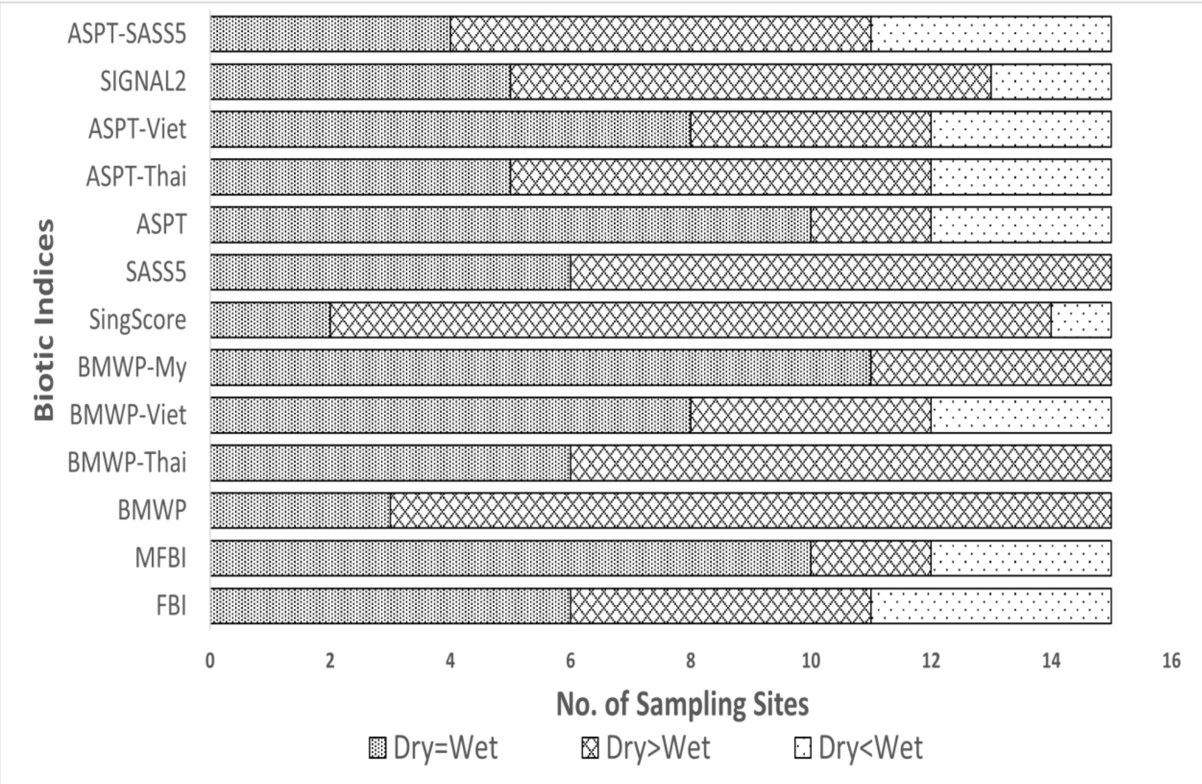

Figure 3. Number of sampling sites with equal (dry=wet), better (dry>wet) or lower (dry<wet) water quality classification between dry and wet seasons

Table 3. Comparison of Water Quality Classification Based on Biotic Indices between Dry and Wet Seasons (In Brackets). Excellent (E), Very Good (VG), Good (G), Moderate (M), Fair (F), Fair Poor (FP), Poor (P), Bad (B)

	Reference							**Disturbed**							
Sampling sites	**Tergorek**	**Kananapon**	**Bayaan**	**Moroli**	**Valanut**	**Paginatan**	**Matupang**	**Liwagu 1**	**Liwagu 2**	**Kituntul**	**Lohan**	**Telupid**	**Toniting**	**Bangau-Bangau**	**Kibut**
FBI	G(VG)	VG(E)	E(E)	E(E)	VG(VG)	VG(VG)	F(VG)	F(G)	G(FP)	G(P)	F(G)	E(VG)	E(E)	E(VG)	E(E)
SingScore	E(G)	E(G)	E(G)	E(G)	E(G)	E(G)	E(G)	E(F)	G(G)	G(F)	F(E)	E(G)	E(F)	G(F)	G(G)
BMWP	VG(M)	VG(G)	VG(M)	VG(G)	VG(VG)	VG(VG)	VG(M)	M(P)	P(P)	M(P)	M(P)	VG(G)	G(M)	G(M)	VG(M)
BMWP-Thai	VG(G)	VG(G)	VG(G)	VG(VG)	VG(VG)	VG(VG)	VG(G)	M(P)	P(P)	M(P)	M(M)	VG(VG)	VG(G)	VG(M)	VG(G)
BMWP-Viet	VG(G)	VG(VG)	VG(G)	VG(VG)	VG(VG)	VG(VG)	VG(VG)	M(P)	P(P)	M(M)	M(M)	VG(VG)	VG(G)	VG(M)	G(G)
SASS5	VG(P)	VG(G)	VG(P)	VG(G)	VG(G)	VG(G)	G(G)	B(B)	B(B)	B(P)	P(P)	G(M)	M(M)	G(P)	P(P)
ASPT	G(M)	G(G)	G(G)	G(G)	G(G)	G(G)	G(G)	M(P)	P(G)	M(M)	M(G)	G(G)	G(G)	M(G)	G(G)
ASPT-Thai	G(M)	G(M)	G(M)	G(G)	G(M)	M(M)	G(M)	M(P)	P(G)	M(M)	P(M)	G(G)	G(G)	M(G)	G(M)
ASPT-Viet	M(M)	G(M)	G(M)	G(M)	M(M)	M(M)	M(M)	M(P)	P(M)	P(P)	P(M)	M(G)	M(M)	M(M)	M(M)
ASPT-SASS5	M(B)	M(P)	M(P)	M(P)	M(B)	P(P)	P(P)	P(B)	B(P)	B(P)	B(VG)	P(P)	P(P)	P(B)	B(P)
SIGNAL2	G(M)	G(M)	G(M)	G(M)	G(M)	G(M)	G(M)	VG(M)	M(G)	M(G)	G(G)	G(G)	G(G)	M(M)	M(M)
MFBI	G(G)	G(G)	G(G)	G(G)	G(G)	G(G)	P(G)	P(M)	M(B)	G(B)	P(G)	G(G)	G(G)	G(G)	G(G)
BMWP-My	VG(VG)	VG(VG)	VG(VG)	VG(VG)	VG(VG)	VG(VG)	VG(VG)	P(P)	P(P)	M(M)	G(M)	VG(VG)	VG(G)	VG(M)	VG(G)

DISCUSSION

The robustness of biotic indices depended on their sensitivity, responses towards stressors, seasonal variability, and applicability in other regions. The sensitivity of the indices had been tested as the discriminatory power of the biotic indices in distinguishing between reference and disturbed sites (Barbour et al. 1996; Barbour et al. 1999; Sandin & Johnson 2000). This is important in preventing misclassification of water quality status due to over or underestimation. Biotic indices include the EPT, BMWP-Thai, BMWP-Viet, SASS5, and BMWP-My showed high sensitivity in separating the reference and disturbed sites (Figure 2). The BMWP, ASPT, ASPT-Viet, SingsScore, ASPT-SASS5 indices showed slightly lower sensitivity. Meanwhile, the FBI, ASPT-Thai, SIGNAL2, and MFBI indices were least sensitive, due to their distribution between reference and disturbed sites were largely overlapping.

Research on the biotic indices responses to stressors provides better understandings of the biotic-stressor relationships for effectively identify the cause of water quality degradation. Most of the biotic indices (except ASPT and ASPT-Thai) in this study showed negative responses to phosphate concentration. Excessive phosphate or phosphorus in freshwater is one of the major causes of nutrient pollution caused by non-point source runoff from agricultural and urban land-use (Davis et al. 2018; Xia et al. 2020). Also, the phosphorus concentration in freshwater was found to be one of the major stressors in structuring the macroinvertebrates communities in land-use watersheds (Zhang et al. 2012). Furthermore, biotic indices also found to be significantly correlated to the nutrient concentration, as documented in the past literature (Bae et al. 2011; Chessman 2003; Visinskiene & Bernotiene 2012)

Biotic index tolerance scores are generally assigned to detect organic pollution (Armitage et al. 1983; Hilsenhoff 1988). As the biotic indices calculated based on benthic macroinvertebrates, these indices might as well reflect the physical habitat condition of the freshwater environment. For instance, the Qualitative Habitat Evaluation Index (QHEI) was found to be correlated with the FBI, percentage of EPT, and taxa richness in a rural stream assessment (Gazendam et al. 2011). In this study, the EPT, BMWP-Viet, and BMWP-My indices also showed significant responses to the habitat scores, where better habitat quality leads to higher biotic index values. Local habitat quality involving the in-stream physical attributes and riparian buffer characteristics plays important roles in the distribution of benthic macroinvertebrates (Heatherly II & Whiles 2007; Maul et al. 2004; Moraes et al. 2014). Effects of hydromorphology were proven to contribute to the macroinvertebrate distribution (Lorenz et al. 2004; Zelnik & Muc 2020), together with the change in chemical properties as multiple stressors (Friberg et al. 2009; Shi et al. 2019).

In this study, EPT, BMWP-Viet, and BMWP-My performed better in discriminating the reference from disturbed sites and significantly associated with habitat quality and nutrient gradient. Lower taxonomic level of EPT index using the species richness had been used in North Carolina since 1970s together with other biotic indices for biological and water quality assessments (Lenat 1993; Lenat 1996). The EPT index was known to respond to nutrient enrichment (Fitzpatrick et al. 2001; Wagenhoff et al. 2016; Wallace et al. 1996). Besides, the EPT index was reported to be more powerful in detecting the impact of eutrophication or organic enrichment (Sandin & Johnson 2000). Furthermore, physical habitat factors were found to be more influential than the water quality factors in the EPT distribution of tropical headwater streams (Ferreira et al. 2014). This study results were similar as the EPT index showed higher correlation coefficient to habitat scores than phosphate concentrations. Although the EPT index used in this study were based on the family richness of the three sensitive insect groups, it remains useful as a biotic index.

BMWP-Viet had significant higher association to phosphate concentrations ($r=-0.493^{**}$, $p<0.01$) while weakly related to habitat scores ($r=0.370^{*}$, $p<0.05$). This may be explained by BMWP-Viet's tolerance scores were based on the original BMWP and other taxa were reassigned based on organic pollution in Vietnam streams (Huong 2009). Coincide with the study conducted by Ghani et al. (2018), the BMWP-Viet also showed better performance, as having similar and closely related classification based on the WQI.

Only one of the Malaysian biotic indices, the BMWP-My performed well in terms of sensitivity, responsiveness and seasonal stability. The BMWP-My had similar performance when compared to BMWP-Viet, where it is sensitive in discriminating reference from disturbed sites, responses to phosphate and habitat scores, as well as no significant differences between dry and wet seasons. The seasonal water quality classification of BMWP-My also only showed differences where dry seasons had better water quality classification than the wet season. Zakaria & Mohamed (2019) also concluded that BMWP-My was the most suitable index, comparing to BMWP, BMWP-Thai, and SingScore.

Surprisingly, the other two indices (SingScore and BMWP-Thai) from neighbour countries had less performance. SingScore index performance may be due to their designation of tolerance score based on urban stressors (Blakely et al. 2014), whereas no urban site was sampled for this study. BMWP-Thai and BMWP-Viet were both modified based on original tolerance scores of BWMP. The BMWP-Thai was not stable seasonally, as well as not responded towards the habitat scores. Higher tolerance scores of families such as Viviparidae Palaemonidae, Caenagrionidae, Corduliidae, and Libellulidae in BMWP-Thai may lead to higher water quality classification in disturbed sites. Compared to BMWP-Viet, BMWP-Thai also had lesser taxa assigned with tolerances scores.

Meanwhile, the FBI index performed poorly in terms of sensitivity, responsiveness, and seasonal variations. FBI's poor performances had been reported in Malaysia streams (Ghani et al. 2018). However, contrast finding of the FBI was reported by Arman et al. (2019), with consistent water quality classification and response to various chemical and physical habitat variables. Similarly, the MFBI, another index that incorporates relative abundances in its calculation also performed poorly. Previous findings at Pahang River Basin showed that the MFBI had better performance than another Malaysian biotic index, the BMWP-My (Ghani 2016). It is possible that not fixating the number of individuals for the benthic macroinvertebrates samples may affect the performance of this type of index.

Seasonal variation in biotic indices is often problematic as it confounds the comparison between multiple years and seasons (Stark & Philips 2009). The ability to conduct the bioassessment using the biotic indices at any time of the year is a desirable feature, as there is less time constraint in taking the biological samples. According to Zamora-Munoz et al. (1995), the significant seasonal variation of the biotic indices was more related to pollution instead of seasonality. However, seasonal variation of the biotic indices could also be influenced by the life cycles of benthic macroinvertebrates and the flow variability (Hilsenhoff 1988; Ridzuan et al. 2020; Stark & Philips 2009). In this study, even though only four indices: BMWP, BMWP-Thai, SingScore, and SIGNAL2 ($p<0.05$) shown statistical differences between dry and wet seasons, the water quality classification based on the biotic indices were much more varied. Based on the water quality classification of the biotic indices, the ASPT, BMWP-Viet, ASPT-Viet, and BMWP-My provided more consistent classification between dry and wet seasons (Figure 3). These illustrated the bioassessment based on biotic indices of different seasons prompt to confound the result interpretation for water quality monitoring and river management.

Despite only three biotic indices shown statistical differences between dry and wet season, seasonal variation in their water quality classification remained a problem. The obtained results were based on two data sets sampled once in each season. Thus, monthly variation should be tested in the future, to provide a better understanding of the seasonal factor on the performance of biotic indices. Another potential solution is to conduct sampling during the based flow condition of the dry season (Buss et al. 2015; Helson & Williams 2013) as anthropogenic impacts were more detectable to avoid other factors such as flood events and dilution effects (Baker et al. 2016; Kilonzo et al. 2014). Alternatively, the water quality rating could be modified and calibrated the biotic index upper and lowest threshold based on local disturbances. In addition, the water quality thresholds could be set seasonally.

CONCLUSION

Among the 14 tested biotic indices, EPT, BMWP-Viet, and BMWP-My showed better performance in terms of sensitivity and responses towards human disturbances. However, even these indices are subjected to seasonal variation, resulting in inconsistent water quality classification, which is one of the common criticisms regarding the biotic indices. As such, it is recommended to better perform the bioassessment using the biotic indices during the dry season, to avoid the problematic interpretation of biotic indices caused by seasonal variation. Finally, knowing the local performance of the foreign biotic indices would provide empirical data for any future biomonitoring program using benthic macroinvertebrate in the Malaysia river system.

ACKNOWLEDGEMENTS

This study was funded by the Fundamental Research Grant Scheme (FRGS-FRG0397-STWN-2/2014). We also appreciated the assists provided by the Institute for Tropical Biology and Conservation (ITBC) of Universiti Malaysia Sabah. Thanks also go to the Water Research Unit of Universiti Malaysia Sabah for kindly lending their water quality equipment during the final stage of samplings.

REFERENCES

Abdullah, M.H. 2012. *Principles in water quality analysis*. Penerbit Universiti Malaysia Sabah.

Arman, N.Z., Salmiati, S., Mohd Said, M.I. & Aris, A. 2019. Development of macroinvertebrate-based multimetric index and establishment of biocriteria for river health assessment in Malaysia. *Ecological Indicators* 104: 449–458.

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

Arsad, A., Abustan, I., Rawi, C.S.M. & Syafalni, S. 2012. Integrating biological aspects into river water quality research in Malaysia: an opinion. *OIDA International Journal of Sustainable Development* 4(2): 107-122.

Azmi, W.A. & Geok, H.A. 2016. aquatic insect communities in relation with water quality of selected tributaries of Tasik Tenyir Terengganu. *Journal of Sustainability Science and Management* 11(2): 11-20.

Bae, M.J., Kwon, Y.S., Hwang, S.J., Chon, T.S., Yang, H.J., Kwak, I.S., Park H.H., Ham, S.A. & Park Y.S. 2011. Relationships between three major stream assemblages and their environmental factors in multiple spatial scales. *Annales de Limnologie* 47: S91–S105.

Baker, K., Chadwick, M.A. & Sulaiman, Z.H. 2016. Eco-hydromorphic classification for understanding stream macroinvertebrate biodiversity in Brunei Darussalam, *Northern Borneo. Zoological Studies* 55: 37.

Barbour, M.T., Gerritsen, J., Griffith, G.E., Frydenborg, R., Mccarron, E. & Bastian, M.L. 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. *Journal of the North American Benthological Society* 15(2): 185-211.

Barbour, M.T., Gerritsen, J., Snyder, B.D. & Stribling, J.B., 1999. *Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish*. Washington: US Environmental Protection Agency.

Blakely, T.J., Eikaas, E.S. & Harding, J.S. 2014. The SingScore: A macroinvertebrate biotic index for assessing the health of streams and canals. *Raffles Bulletin of Zoology* 62: 540–548.

Buss, D.F., Carlisle, D.M., Chon, T.S., Culp, J., Harding, J.S., Keizer-Vlek, H.E., Robinson, W.A., Strachan, S., Thirion, C. & Hughes, R.M. 2015. Stream biomonitoring using macroinvertebrates around the globe: a comparison of large-scale programs. *Environmental monitoring and assessment* 187(1): 4132.

Carlson, P.E., Donadi, S. & Sandin, L. 2018. Responses of macroinvertebrates to small dam removals: implications for bioassessment and restoration. *Journal of Applied Ecology* 55(4): 1896-1907.

Chang, F.H., Lawrence, J.E., Rios-Touma, B. & Rehs, V.H. 2014. Tolerance values of benthic macroinvertebrates for stream biomonitoring: assessment of assumptions underlying scoring systems worldwide. *Environmental Monitoring and Assessment* 186: 2135–2149.

Chessman, B.C. 2003. New sensitivity grades for Australian river macroinvertebrates. *Marine and Freshwater Research* 54(2): 95-103.

Chessman, B.C. & McEvoy, P.K. 1998. Towards diagnostic biotic indices for river macroinvertebrates. *Hydrobiologia* 364: 169–182.

Choo, A. M. S. 2003. The impact of land use changes on the riverine environment of Liwagu-Labuk River Basin in Sabah. M.Sc Thesis, Universiti Malaysia Sarawak.

Davis, S.J., Ó hUallacháin, D., Mellander, P.E., Kelly, A.M., Matthaei, C.D., Piggott, J.J. & Kelly-Quinn, M. 2018. Multiple-stressor effects of sediment, phosphorus and nitrogen on stream macroinvertebrate communities. *Science of the Total Environment* 637–638: 577–587.

Dickens, C.W.S. & Graham, P.M. 2002. The South African Scoring System (SASS) version 5 rapid bioassessment method for rivers. *African Journal of Aquatic Science* 27: 1-10.

Elias, J.D., Ijumba, J.N. & Momboya, F.A. 2014. Effectiveness and compatibility of non-tropical bio-monitoring indices for assessing pollution in tropical rivers-a review. *International Journal of Ecosystem* 4(3): 128-134.

Etemi, F.Z., Bytyçi, P., Ismaili, M., Fetoshi, O., Ymeri, P., Shala-Abazi, A., Muja-Bajraktari, N. & Czikkely, M. 2020. The use of macroinvertebrate based biotic indices and diversity indices to evaluate the water quality of Lepenci river basin in Kosovo. *Journal of Environmental Science and Health Part A* 55(6): 748-758.

Ferreira, W.R., Ligeiro, R., Macedo, D.R., Hughes, R.M., Kaufmann, P.R., Oliveira, L.G. & Callisto, M. 2014. Importance of environmental factors for the richness and distribution of benthic macroinvertebrates in tropical headwater streams. *Freshwater Science* 33(3): 860-871.

Fitzpatrick, F.A., Scudder. B.C., Lenz, B.N. & Sullivan, D.J. 2001. Effects of multi-scale environmental characteristics on agricultural stream biota in eastern Wisconsin. *Journal of American Water Resource Association* 37:1489–1507.

Friberg, N., Sandin, L. & Pedersen, M.T. 2009. Assessing the effects of hydromorphological degradation on macroinvertebrate indicators in rivers: Examples, constraints, and outlook. *Integrated Environmental Assessment and Management* 5(1): 86–96.

Gazendam, E., Gharabaghi, B., Jones, F.C. & Whiteley, H. 2011. Evaluation of the qualitative habitat evaluation index as a planning and design tool for restoration of rural Ontario waterways. *Canadian Water Resources Journal* 36(2): 149-158.

Ghani, W.M.H.W.A. 2016 Development Of Malaysian Water Quality Indices Using Aquatic Macroinvertebrates Population Of Pahang River Basin, Pahang, Malaysia. PhD Thesis, Universiti Sains Malaysia.

Ghani, W.M.H.W.A., Kutty, A.A., Mahazar, M.A., Al-Shami, S.A. & Hamid, S.A. 2018. Performance of biotic indices in comparison to chemical-based Water Quality Index (WQI) in evaluating the water quality of urban river. *Environmental Monitoring Assessment* 190: 297.

Gillies, C.L., Hose, G.C. & Turak, E. 2009. What do qualitative rapid assessment collections of macroinvertebrates represent? A comparison with extensive quantitative sampling. *Environmental Monitoring Assessment* 149: 99-112.

Harun, S. & Fikri, A.H. 2016. Water quality monitoring in Sugut River and its tributaries. WWF-Malaysia Project Report, February.

Harun, S., Al-Shami, S.A., Dambul, R., Mohamed, M. & Abdullah, M.H. 2015. Water quality and aquatic insects study at the Lower Kinabatangan River Catchment, Sabah: In response to Weak la niña event. *Sains Malaysiana* 44(4): 545-558.

Hauer, F.R. & Resh, V.H. 2007. Benthic macroinvertebrates. In. Hauer, F.R. & Lamberti, G. A. (ed.). *Methods in Stream Ecology*, pp. 339-370. California: Academic Press.

Hazelton, P. 2003. *Analysis of Ephemeroptera, Plecoptera and Trichoptera (EPT) richness and diversity of Guilford Creek, Guilford, NY*. Oneonta: State University of New York.

Heatherly II,T. & Whiles, M.R. 2007. Relationships between water quality, habitat quality, and macroinvertebrate assemblages in Illinois Streams. *Journal of Environmental Quality* 36(6):1653-166.

Heino, J., Muotka, T., Mykrä, H., Paavola, R., Hämäläinen, H. & Koskenniemi, E. 2003. Defining macroinvertebrate assemblage types of headwater streams: implications for bioassessment and conservation. *Ecological Applications* 12(3): 842-852.

Helson, J.E. & Williams, D.D. 2013. Development of a macroinvertebrate multimetric index for the assessment of low-land streams in the neotropics. *Ecological Indicators* 29: 167-178.

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

Huong, H.T.T. 2009. Monitoring and assessment of macroinvertebrate communities in support of river management in northern Vietnam. PhD Thesis, Ghent University, Belgium.

Kilonzo, F., Masese, F.O.,Van Griensven, A., Bauwens, W., Obando, J. & Lens, P.N.L. 2014. Spatial–temporal variability in water quality and macro-invertebrate assemblages in the Upper Mara River basin, Kenya. *Physics and Chemistry of the Earth* 67–69: 93–104.

Larsen, D.P. 1997. Sample survey design issues for bioassessment of inland aquatic ecosystems. Human and Ecological Risk Assessment: *An International Journal* 3(6): 979-991.

Lenat, D.R. 1993. A biotic index for the Southeastern United States: derivation and list of tolerance values, with criteria for assigning water-quality ratings. *Journal of North American Benthological Society* 12(3): 279-290.

Lenat, D.R. 1996. History of the EPT taxa richness metric. *Bulletin of the North American Benthological Society* 13: 305-307.

Li, L., Zheng, B.H. & Liu, L.S. 2010. Biomonitoring and bioindicators used for river ecosystems: definitions, approaches and trends. *Procedia Environmental Sciences* 2: 1510–1524.

Lorenz, A., Hering, D., Feld, C.K. & Rolauffs, P. 2004. A new method for assessing the impact of hydromorphological degradation on the macroinvertebrate fauna of five German stream types. *Hydrobiologia* 516: 107–127.

Mahazar, A., Shuhaimi-Othman, M. & Kutty, A.A. 2013. Benthic macroinvertebrate as biological indicator for water quality in Sungai Penchala. *AIP Conference Proceedings* 1571: 602.

Maul, J.D., Farris, J.L., Milam, C.D., Cooper, C.M., Testa III, S. & Feldman, D.L. 2004. The influence of stream habitat and water quality on macroinvertebrate communities in degraded streams of northwest Mississippi. *Hydrobiologia* 518: 79-94.

Mazzoni, A.C., Lanzer, R. & Schafer, A. 2014. Tolerance of benthic macroinvertebrates to organic enrichment in highland. *Acta Limnologica Brasiliensia* 26(2): 119-128.

Moraes, A.B., Wilhelm, A.E., Boelter, T., Stenert, C., Schulz, U.H. & Maltchik, L. 2014. Reduced riparian zone width compromises aquatic macroinvertebrate communities in streams of southern Brazil. *Environmental Monitoring and Assessment* 186(11): 7063–7074.

Morse, J.C., Yang, L.F. & Tian, L.X. 1994. *Aquatic Insects of China Useful for Monitoring Water Quality*. Nanjing: Hohai University.

Mukaka, M.M. 2012. Statistics Corner: A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal* 24(3): 69-71.

Murtedza, M., Oksen, P. & Müller, T. 2002. Land use zones and land use conflicts in the Liwagu-Labuk River Basin, Sabah, East-Malaysia. Conference on International Agricultural Research for Development, Witzenhausen. 9-11 October.

Mustow, S.E. 2002. Biological monitoring of rivers in Thailand: use and adaptation of the BMWP score. *Hydrobiologia* 479: 191–229.

Naubi, I., Zardari, N.H., Shirazi, S.M., Ibrahim, N.F.B. & Baloo, L. 2016. Effectiveness of water quality index for monitoring Malaysian river water quality. *Polish Journal of Environmental Studies* 25(1): 231-239.

Ng, T.H., Dulipat, J., Foon, J.K., Lopes-Lima, M., Zieritz, A. & Liew, T.S. 2017. A Preliminary checklist of the freshwater snails of Sabah (Malaysian Borneo) deposited in the BORNEENSIS collection, Universiti Malaysia Sabah. *ZooKeys* 673: 105-123.

Ochieng, H., Odong, R. & Okot-Okumu, J. 2020. Comparison of temperate and tropical versions of Biological Monitoring Working Party (BMWP) index for assessing water quality of River Aturukuku in Eastern Uganda. *Global Ecology and Conservation* 23: e01183.

Ochieng, H., Okot-Okumu, J. & Odong, R. 2019. Taxonomic challenges associated with identification guides of benthic macroinvertebrates for biomonitoring freshwater bodies in East Africa: A review. *African Journal of Aquatic Science* 44(2): 113-126.

Ridzuan, D.S., Rawi, C.S.M. & Hamid, S.A. 2020. Seasonal influence on structuring aquatic insects communities in upstream rivers Belum-Temengor forest complex. *Serangga* 25(3): 101-115.

Sandin, L. & Johnson, R.K. 2000. The statistical power of selected indicator metrics using macroinvertebrates for assessing acidification and eutrophication of running waters. *Hydrobiologia* 422-423: 233-243.

Schober, P., Boer, C. & Schwarte, L.A. 2018. Correlation coefficients: Appropriate use and interpretation. *Anesthesia & Analgesia* 126(5): 1763-1768.

Semenchenko, V.P. & Moroz, M.D. 2005. Comparative analysis of biotic indices in the monitoring system of running water in a biospheric reserve. *Water Resources* 32(2): 200-203.

Serrano Balderas, E.C., Grac, C., Berti-Equille, L. & Armienta Hernandez, M.A. 2016. Potential application of macroinvertebrates indices in bioassessment of Mexican streams. *Ecological Indicators* 61: 558–567.

Shi, X., Liu, J.L., You, X.G., Bao, K. & Meng, B. 2019. Shared effects of hydromorphological and physico-chemical factors on benthic macroinvertebrate integrity for substrate types. *Ecological Indicators* 105: 406-414.

Smith, A.J., Rickard, S., Mosher, E.A., Lojpersberger, J.L., Heitzman, D.L., Duffy, B.T. & Novak, M.A. 2015. Bronx river-biological stream assessment. 1 May. NYS Department of Environmental Conservation Report.

Stark, J.D. & Phillips, N. 2009. Seasonal variability in the macroinvertebrate community index: Are seasonal correction factors required? *New Zealand Journal of Marine and Freshwater Research* 43(4): 867-882.

Tan, K.W. & Beh, W.C. 2015. Water quality monitoring using biological indicators in Cameron Highlands Malaysia. *Journal of Sustainable Development* 8(3): 28-42.

Visinskiene, G. & Bernotiene, R. 2012. The use of benthic macroinvertebrate families for river quality assessment in Lithuania. *Central European Journal of Biology* 7(4): 741-758.

Wagenhoff, A., Shearer, K. & Clapcott, J. 2016. A review of benthic macroinvertebrate metrics for assessing stream ecosystem health. 12 May. Environment Southland. Cawthron Report No. 2852.

Wallace, J.B., Grubaugh, J.W. & Whiles, M.R. 1996. Biotic indices and stream ecosystem processes: Results from an experimental study. *Ecological Applications* 6(1): 140-151.

Xia, Y.F., Zhang, M., Tsang, D.C.W., Geng, N., Lu, D.B., Zhu, L.F., Igalavithana, A.D., Dissanayake, P.D., Rinklebe, J., Yang, X. & Ok, Y.S. 2020. Recent advances in control technologies for non-point source pollution with nitrogen and phosphorous from agricultural runoff: Current practices and future prospects. *Applied Biological Chemistry* 63: 8.

Yule, C.M. & Yong, H.S. 2004. *Freshwater Invertebrates of the Malaysian Region*. Kuala Lumpur: Akademi Sains Malaysia.

Zainudin, E.Z. 2010. Benchmarking river water quality in Malaysia. *Jurutera* February: 12-15.

Zakaria, M.Z. & Mohamed, M. 2019. Comparative analysis of Biotic Indices in water quality assessment: Case study at Sg. Bantang, Johor. *Earth and Environmental Science* 269: 012047.

Zamora-Munoz Sainz-Cantero, C.E., Sanchez-Ortega, A. & Alba-Tercedor, J.C. 1995. Are biological indices BMWP and ASTP and their signifance regarding water quality seasonally dependent? Factors explaining their variation. *Water Resources* 29(1): 285-290.

Zelnik, I. & Muc, T. 2020. Relationship between environmental conditions and structure of macroinvertebrate community in a hydromorphologically altered pre-alpine river. *Water* 12(11): 2987.

Zhang, M., Wang, B.X., Han, M.H. & Wang, L.H. 2012. Relationships between the seasonal variations of macroinvertebrates, and land uses for biomonitoring in the Xitiaoxi River Watershed, China. *International Review of Hydrobiology* 97(3): 184-199.

Zolkefli, N., Sharuddin, S.S., Yusoff, M.Z.M., Hassan, M.A., Maeda, T. & Ramli, N. 2020. A review of current and emerging approaches for water pollution monitoring. *Water* 12: 3417.