Chiang Mai J. Sci. 2017; 44(4) : 1356-1366
http://epg.science.cmu.ac.th/ejournal/
Contributed Paper

Use of Benthic Macroinvertebrates as Bioindicators of Anthropogenic Impacts on Water Quality of Mae Klong River, Western Thailand

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Received: 30 November 2015
Accepted: 5 July 2016

ABSTRACT

This research aimed to assess the anthropogenic impacts on benthic macroinvertebrate communities and the water quality in the Mae Klong River in Western Thailand. Samples were collected on six separate occasions from seven sampling sites between July 2011 and April 2012. All environmental variables except nitrate nitrogen were found to be significantly different depending on sampling sites ($p<0.01$) and seasons ($p<0.05$). The presence of a total of 8,901 benthic macroinvertebrates and 146 taxa was confirmed by examination of the aquatic insects and annelids that were found in the seven sampling sites. Sensitive taxa in the orders Ephemeroptera, Plecoptera and Trichoptera were more abundant at upstream collection points compared to downstream sites. Substrate disturbance from dam construction was the main cause of reduction in the diversity of benthic macroinvertebrates at the upstream sites. Additionally, organic loading caused a reduction in the abundance and taxa richness of the samples collected at the downstream sites. A significant negative correlation ($p<0.01$) between total suspended solids, biochemical oxygen demand and ammonium nitrogen and the benthic macroinvertebrate communities and biotic indices ($BMWP^{Thai}$ and ASPT) indicated the anthropogenic impact existent in upstream and downstream locations of the Mae Klong River. However, the water quality of the Mae Klong River was assessed using ASPT and PBI indices that ranged in level from polluted to clean.

Keywords: anthropogenic impact, benthic macroinvertebrate, biotic indices, water quality

1. INTRODUCTION

At present, river and stream ecosystems are being placed under serious pressure by human activities. The ecosystems are directly and negatively affected by the large amounts of wastewater introduced into them from point and non-point sources. The non-point sources of pollution originate from the urbanisation and agricultural activities that promote nutrient enrichment and pesticides contamination in the surface water [1]. While industrial effluents are a major source of pollution and have caused slime growth, thermal impact and scum formation as well as colour problems, they also increase the amount of toxic substances being injected into the river and stream water [2]. All of the above contribute to water supply degradation, negatively affect aquatic ecosystems, and have a negative impact on human health. Therefore, monitoring the health of streams and rivers is extremely important [3].

The Mae Klong River is an important water resource in Western Thailand. The river originates from the confluence of the Khwae Yai and Khwae Noi Rivers in Kanchanaburi Province. It runs through the provinces of Ratchaburi and Samut Songkram for about 140 km before eventually flowing into the Gulf of Thailand [4]. The Mae Klong River supplies water for a range of activities such as agriculture, irrigation, and industrial purposes as well as being central to the livelihoods of the people who live near and depend on the river. More than 100 industrial factories, large fields of rice paddy and sugarcane cultivation are located along both sides of the river [5]. Therefore, effluents from the various activities in the area have been discharged directly into the river and resulted in the presence of heavy metals, pesticides and domestic wastewater contamination [6].

Normally, the monitoring of water quality in Thailand is based on physicochemical parameters [3]. A water quality classification tool has been developed and established by the Pollution Control Department [7]. Twenty-eight physical, chemical and biological factors were selected for the purpose of classifying water quality, with emphasis on the chemical factors [3]. Chemical and physical factors reflect the actual conditions at the time of sampling [8]. On the other hand, biological factors present the possibility of detecting changes in water quality from the time of sampling as well as over a longer period of time since before the sampling was done [9, 10].

Various groups of aquatic organisms can be used as bioindicators of environmental and ecological changes. Examples of these organisms include benthic diatoms, macrophytes, macroalgae and fish [11]. However, benthic macroinvertebrates have been used most commonly in published literature [12] because they are typically found in habitats along the river, display limited movement, and have a long life cycle in aquatic ecosystems as well as being relatively sensitive to environmental stress [13]. As such, they were employed as bioindicators of the water quality in the Ping River of Northern Thailand [14, 15]. Consequently, benthic macroinvertebrates have been used as an important tool in the evaluation of water quality. This study was aimed at assessing anthropogenic impact on the water quality of the Mae Klong River by using benthic macroinvertebrates as bioindicators.

2. MATERIALS AND METHOD

2.1 Sampling Sites

This study was conducted in the Kanchanaburi and Ratchaburi Provinces of Western Thailand. Seven sampling sites (S1-S7) in the study area were selected (Figure 1). S1 was situated on the Khwae Yai River and located downstream from Tha Tung Na Dam. The substrate type for this site was gravel with various aquatic plants in the literal zone. S2 was located on the Khwae Noi River and upstream of the junction between the Khwae Yai and Khwae Noi Rivers. The surface water along this site was covered by aquatic macrophytes, especially water hyacinth. Common human activities at this site included rafting and sightseeing. S3 was located about 0.5 km downstream from the Mae Klong Dam. During the sampling period, a hydropower plant was being constructed at the dam (from September 2008 to July 2013) [16]. The substrates at this site consisted mainly of clay and rock. S4 was located about 1.0 km upstream from a pulp and paper mill. The substrates consisted mainly of gravel, cobble and clay near the sides of the river. S5 was situated about 2.0 km downstream from the previous location (S4) with substrates consisting mainly of gravel, clay and aquatic macrophytes. The remaining two sites (S6 and S7) were located on the Mae Klong River in Ban Pong District, Ratchaburi Province. S6 was located about 6 km upstream from the city of Ban Pong, while S7 was located in the city of Ban Pong where the main feature was represented by a market. Substrate types in these 2 sites consisted mainly of sediment, clay and various littoral aquatic plants.

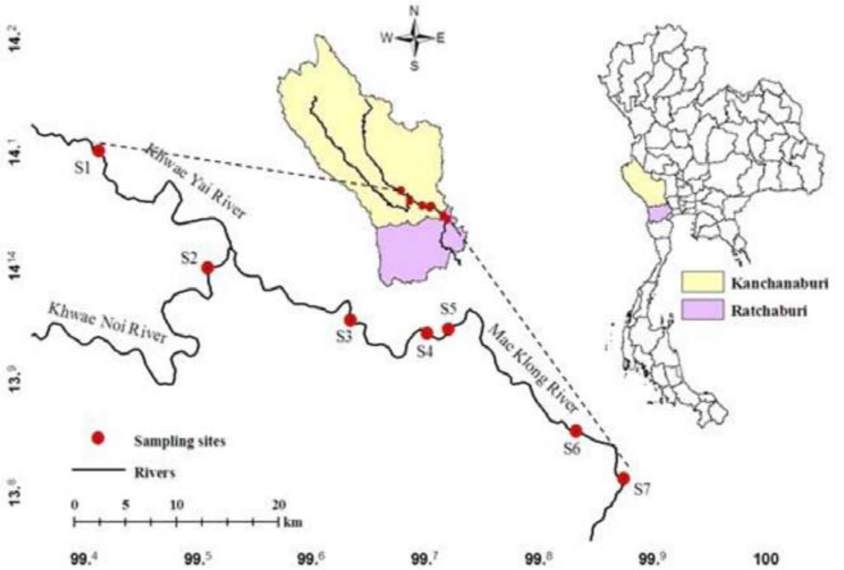

Figure 1. Seven sampling sites along the Khwae Yai, Khwae Noi and Mae Klong Rivers in Kanchanaburi and Ratchaburi Provinces, Western Thailand.

2.2 Water Quality Measurement

Three replicate water samples were collected between July 2011 and April 2012 on six separate occasions. Samples were collected in July and August 2011 during the rainy season, December 2011 and January 2012 during the cool-dry season, and March and April 2012 during the hot-dry season. Water samples were collected from about 20 cm under the surface for storage in 1 L polyethylene bottles. Samples were kept in a cool box at a temperature below 4 °C for determination of certain environmental variables in the laboratory including alkalinity (mg/l as $CaCO_3$), suspended solid (SS), ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), soluble reactive phosphorus (SRP) and biochemical oxygen demand (BOD_5) following standard method procedures [17]. Three replicates of some parameters were used to measure the conditions in the field at each study site, including water temperature through the use of a mercury glass thermometer, velocity by a velocity meter, conductivity and total dissolved solids by multi-parameter analyser (Consort C 330). Additionally, pH by multi-parameter analyzser (WTW pH/Cond 340i/SET) and dissolved oxygen by azide modification method [17].

2.3 Benthic Macroinvertebrates Sampling and Identification

A D-frame net (0.5 mm^2/mesh) was used to collect benthic macroinvertebrates from several habitats [18]. All samples were preserved in 4% formalin and brought to the laboratory for sorting and identification. In the laboratory, the preserved samples were washed with tap water and sorted under a stereomicroscope. All sorted specimens were preserved with 80% ethanol before identification. The specimens were identified to at least family level or the lowest possible level.

2.4 Data Analysis

The biological assessment of anthropogenic activities on water quality was based on abundance (A), taxa richness (TR), abundant percentage of order Ephemeroptera, Plecoptera and Trichoptera (%EPT); abundant percentage of Oligochaetes and Chironomids (% OC) and Shannon-Wiener diversity index (H'). The water quality of each sampling site was assessed using Average Score per Taxon (ASPT) and Ping Biotic Index (PBI). Both biotic indices were computed from the ratio between the tolerant score of $BMWP^{Thai}$ and PTVs to the number of families and number of macroinvertebrates, respectively [18, 19].

2.5 Statistical Analysis

The significant differences identified between sampling sites in terms of environmental variables and biological properties were assessed by one-way analysis of variance (one-way ANOVA) or Kruskal-Wallis test depending on the normality of data. Among them, velocity, suspended solids, taxa richness, total abundance (log10 transformed), % EPT and ASPT indicated the normal distribution and they were examined by one-way ANOVA. The remaining parameters were examined by non-parametric Kruskal-Wallis test.

3. RESULTS AND DISCUSSION

3.1 Environmental Variables

All environmental variables other than NO_3^--N were found to be significantly different between the seven sampling sites and seasons. The concentration of NO_3^--N tended to increase at downstream sites of the Mae Klong River. Meanwhile, velocity showed no significant differences between seasons. Mean values for conductivity and TDS tended to be lower at the upstream sites and increased at the downstream sites, especially in the rainy season. However, alkalinity was higher at Site S1, with the highest SS detected at Site S3. The DO was lower at Site S1 than at other sites, while BOD_5 revealed an increase in the hot-dry season, representing higher values at Site S6 and lower values at Site S4 (Table 1). Nutrient concentrations did not exceed the surface water quality standard of Thailand [7].

Table 1. Mean values (±SD) of the environmental variables at each sampling site for the entire sampling period.**P*<0.05; ***P*<0.01; ****P*<0.001; NS = not significant.

Site	S1	S2	S3	S4	S5	S6	S7	P value
Water temperature (°C)	26.92±2.08	28.00±1.07	28.16±1.21	29.01±2.12	28.08±2.23	28.83±1.56	29.39±1.5	**
Velocity (m/s)	0.45±0.18	0.17±0.04	0.31±0.08	0.33±0.08	0.33±0.11	0.44±0.07	0.19±0.07	***
Conductivity (μs/cm)	280.33±12.86	168.45±25.06	223.53±27.31	225.88±31.54	317.78±110.12	248.33±34.45	251.06±34.02	***
TDS (mg/l)	148.39±6.64	89.77±13.01	118.28±14.35	120.2±16.67	165.5±51.48	137.25±15.38	133.5±17.93	***
SS (mg/l)	14.17±8.27	23.33±12.27	40.67±14.85	20.39±8.96	19.17±9.80	15.5±11.17	17.22±12.90	***
Alkalinity (mg/l)	135.72±12.72	85.72±20.33	105.61±14.52	104.94±16.89	113.06±15.85	107.78±14.68	110.0±16.84	***
pH	7.45±0.12	7.33±0.21	7.5±0.12	7.51±0.16	7.47±0.17	7.36±0.13	7.35±0.1	***
DO (mg/l)	4.34±0.61	6.75±0.67	7.34±0.56	7.54±0.33	7.48±0.30	5.96±0.66	6.18±0.35	***
BOD_5 (mg/l)	1.38±1.06	1.06±0.94	2.13±1.59	1.00±0.6	1.47±0.77	2.23±0.93	1.4±1.04	**
NH_4^+-N (mg/l)	0.19±0.09	0.11±0.06	0.17±0.05	0.12±0.05	0.13±0.05	0.23±0.13	0.12±0.05	**
NO_3^--N (mg/l)	0.76±0.46	0.82±0.39	0.63±0.43	0.49±0.28	0.82±0.59	0.86±0.45	0.85±0.58	NS
SRP (mg/l)	0.16±0.07	0.09±0.05	0.1±0.06	0.11±0.07	0.13±0.06	0.11±0.07	0.09±0.05	*

3.2 Benthic Macroinvertebrate Communities

A total of 8,901 benthic macroinvertebrates and 146 morphotaxa from 8 insect orders including Ephemeroptera, Odonata, Plecoptera, Hemiptera, Trichoptera, Lepidoptera, Coleoptera, Diptera as well as 2 classes of Annelida (Oligochaeta and Hirudinea) were collected from the seven sampling sites along the Mae Klong River and its tributaries. All of the benthic macroinvertebrate samples were dominated numerically by the orders Ephemeroptera (33.8 %), Hemiptera (29.03 %) and Diptera (23.40 %). Among them, Chironominae (Chironomidae: Diptera) was the most abundant, followed by *Cloeon* sp. (Baetidae: Ephemeroptera) and *Synaptpnecta* sp. (Micronectidae: Hemiptera) at 19.10%, 11.28% and 8.25%, respectively. The most diverse benthic macroinvertebrates were represented by the orders Coleoptera (31 taxa), Hemiptera (29 taxa) and Odonata (28 taxa).

Mean values (±SD) for benthic macroinvertebrates and biological indices at each sampling site are presented in Table 2. The analysis of variance indicated that total abundance, taxa richness, % EPT, Ephemeroptera taxa, Plecoptera taxa, Trichoptera taxa, BMWP^{Thai} and ASPT were significantly different among the seven sampling sites, while % OC, H' index and PBI revealed no significant differences. The highest total abundance and taxa richness were evident at Site S7. Additionally, the highest % EPT occurred at Site S3 along with the lowest % OC. However, Plecoptera taxa, Trichoptera taxa, Ephemeroptera taxa, BMWP^{Thai} and ASPT were significantly higher at two upstream sites (S1 and S4) compared with certain downstream sites (S6 and S7).

Table 2. Mean values (±SD) of benthic macroinvertebrate communities and biological indices in each sampling site for the entire sampling period *< 0.05; **< 0.01; ***< 0.001; NS = not significant.

	S1	S2	S3	S4	S5	S6	S7	P value
Total abundance	99.89±89.92	50.56±38.46	44.94±71.40	54.00±30.21	73.11±95.45	36.67±33.26	135.33±182.20	*
Taxa richness	12.83±5.86	10.33±4.92	6.06±6.11	11.61±3.77	10.17±5.96	6.78±3.19	13.00±7.01	*
%EPT abundance	43.63±28.67	41.93±28.02	83.74±21.19	47.18±29.75	36.85±18.62	26.89±27.84	31.01±26.93	**
%OC abundance	23.49±26.01	30.69±23.75	7.45±13.96	29.23±23.71	26.28±22.81	32.32±29.63	15.90±15.44	NS
EPT taxa	4.11±3.20	2.22±1.55	2.00±1.57	3.44±1.54	1.94±1.21	1.44±1.04	2.06±1.00	**
Ephemeroptera taxa	3.28±2.54	2.83±.1.79	3.50±3.20	4.67±2.07	3.28±2.76	1.72±1.56	2.83±1.62	*
Plecoptera taxa	0.28±0.46	0.06±0.23	0.00	0.17±0.38	0.06±0.23	0.00	0.00	*
Trichoptera taxa	1.72±1.84	0.50±0.98	0.06±0.23	1.00±1.08	0.22±0.43	0.33±0.49	0.22±0.55	**
Shannon	0.75±0.22	0.68±0.28	0.38±0.39	0.80±0.19	0.72±0.21	0.56±0.22	0.78±0.22	NS
BMWP^{Thai}	43.00±21.65	30.72±16.78	14.78±16.65	38.00±17.13	27.78±12.01	16.44±10.17	34.28±16.54	**
ASPT	5.14±0.64	4.53±0.61	4.31±0.90	5.16±0.84	4.61±0.93	3.96±0.65	4.31±0.51	***
PBI	4.23±0.45	4.14±0.59	4.22±0.25	3.66±1.06	4.41±0.33	4.30±0.15	4.23±0.27	NS

3.3 Anthropogenic Impacts on Benthic Macroinvertebrate Communities

Lower levels of total abundance, taxa richness and H' index of benthic macroinvertebrates occurred at Sites S3 and S6 with higher SS and BOD_5 levels, respectively. The reduction in benthic macroinvertebrates at Site S3 was a direct effect of the increase in SS from habitat disturbance during the period of dam construction [20]. SS affected the benthic macroinvertebrates by increasing abrasion, clogging the respiration of gills and/or disturbance on feeding of the collector and filter feeder. Therefore, this site presented the lowest taxa richness (Table 2) and was dominated by the family Caenidae (*Caenodes* sp.; Table 3), which have operculate gills to protect SS attraction on their tracheal gills [13]. Alternatively higher values of BOD_5 were observed at Site S6. This indicated that the site was contaminated by organic pollution [18], which affected the benthic macroinvertebrate communities by decreasing the values of abundance and diversity [21]. Moreover, the percent abundance of Chironomids and Oligocheats were the highest at this site. They are known to be indicators of poor water quality [22]. The increasing of conductivity, nutrient loading, BOD_5 and decreasing of DO at the downstream sites (S5, S6 and S7) were caused by the introduction of municipal waste and untreated industrial effluents into the river [23]. These significantly affected the abundance and richness of sensitive species in the orders Trichoptera and Plecoptera. This was evident by the absence of Plecopteran species in Sites S6 and S7. Additionally, only one individual insect was collected from Site S5 during all sampling periods. This was indicative of the increasing amounts of pollution at upstream sites compared to downstream sites in the Mae Klong River [24]. Moreover, the dominant substrate types in downstream sites were sediment and clay. This agreed with previously reported information that an increase of fine sediment is significantly and negatively related with Trichoptera and Plecoptera taxa [25].

Values for both abundance and taxa richness in the sensitive orders Ephemeroptera, Plecoptera, Trichoptera were found to be higher at upstream sites of the Mae Klong River and its tributaries along with higher oxygen levels. Sites S3 and S4 were dominated by *Caenodes* sp., *Cloeon* sp. and *Nigrobaetis* sp., respectively. This indicated that high oxygen levels with rapidly flowing water are important factors for sensitive taxa using plastrons, spiracular gills and tracheal gills [26]. In contrast, EPT abundance and richness were found to have decreased at the downstream sites with low oxygen levels. This result is similar to the report by Throne and Williams [14]. EPT taxa were found in abundance at upstream sites in Chiang Mai, where there was less of an impact from pollution than other sites located downstream from the junction of the polluted Kha Canal and Ping River. Moreover, a reduction in the EPT taxa at downstream sites of the Mae Klong River was similar to the finding reported at the Langat River in Malaysia, which is indicative of the presence of environmental pollution occurring upstream and flowing to downstream sites [20]. Only Site S1 was found to have a low oxygen level of 4.34 mg/l, which was represented by the dominance of chironomids (Table 3). Lower oxygen levels identified by Leelahagriengkrai and Peerapornpisal [27] were found to have occurred because the site was situated downstream from the Tha Tung Na Dam. As a result, water originating from the bottom of the dam lacked oxygen concentration [26]. However, the abundance and richness of EPT were found to be higher. This was revealed to be in agreement with the finding of the Juru River in Malaysia [28], where higher values of EPT were found to have occurred at upstream sites with the same oxygen levels as Site S1.

The relationship between environmental variables and biological properties were analysed using the Spearman Correlation. Moreover, 18 dominant taxa, which have more than 1 % of the relative abundances, were used in ordination analysis (Table 3). The length of the first axis of detrended correspondence analysis (DCA) was 3.22, which recommended that correspondence analysis (CA) was more suitable to this analysis [29]. The study of the relationship between environmental variables and biological properties may improve understanding of environmental stresses according to various environmental variables related to pollution and affecting organisms in aquatic ecosystems [26].

Table 3. Relative abundances of 18 benthic macroinvertebrate taxa in seven sampling sites.

Taxa	S1	S2	S3	S4	S5	S6	S7
Ephemeroptera							
Baetis sp.	0.966	0.124	0.955	0.809	0.876	0.281	0.135
Nigrobaetis sp.	1.550	0.562	0.775	2.056	0.798	0.281	0.629
Heterocloeon sp.	0.146	0.000	0.000	0.539	0.438	0.000	0.000
Cloeon sp.	1.809	2.988	0.629	0.337	2.382	0.539	2.595
Labiobaetis sp.	0.045	0.180	0.146	0.427	0.202	0.056	0.090
Caenodes sp.	0.202	0.180	3.134	0.281	0.326	0.146	0.438
Odonata							
Protoneuridae	0.685	0.281	0.045	0.315	0.921	0.135	1.146
Hemiptera							
Naboandelus sp.	0.191	0.000	0.000	0.022	0.595	0.000	1.562
Rheumatogonus sp.	0.022	0.000	0.000	0.360	0.202	1.067	0.112
Ventidius sp.	0.022	0.000	0.000	0.258	1.584	0.573	0.157
Synaptonecta sp.	1.348	0.360	0.944	0.034	0.011	0.000	5.550
Micronecta sp.	0.550	0.067	0.270	0.067	0.000	0.022	6.044
Sigara sp.	0.202	0.236	0.045	0.022	0.011	0.000	3.325
Diptera							
Orthochladinae	0.213	0.652	0.090	0.191	0.629	0.270	0.247
Chironominae	6.112	2.371	0.326	2.831	3.809	2.202	1.449
Tanypodinae	0.101	0.180	0.011	0.169	0.101	0.202	0.809
Oligochaeta							
Tubificidae	0.708	0.393	0.045	0.067	0.022	0.101	0.169
Enchytraeidae	0.775	0.180	0.034	0.045	0.000	0.090	0.034

The ordination analysis indicated that most downstream sites were placed by tolerant taxa (Chironominae, Orthocladinae, Tanypodinae and hemipteran species) related with SRP, NO_3^--N, BOD_5, electric conductivity and TDS. Meanwhile, sensitive taxa were distributed in the upstream sites (Figure 2). However, seasonal variations might affect the biological data. Kosnicki and Sites suggested that samples should be measured over the course of the year for consistency with regards to seasonal variation [30]. Moreover, a correlation between the biological indices and environmental variables clearly supported the anthropogenic impact from upstream areas to downstream areas of the Mae Klong River. Reductions in values for total abundance, taxa richness, EPT taxa, diversity, $BMWP^{Thai}$ and ASPT revealed a strongly negative correlation (p<0.01) with SS, BOD_5 and NH_4^+-N (Table 4). This indicated that habitat disturbances at Site S3 and organic loading in the vicinity of the downstream sites are primary influences on benthic macroinvertebrate communities and the water quality of the Mae Klong River. The poor water quality at downstream sites was found to be similar to previous reports [5] for other rivers, such as the Chao Phraya River [24]. However, the water quality of the Mae Klong River was classified to Class 3 surface water quality standard of Thailand based on beneficial use [7]. This was similar to other rivers, *i.e.* the middle part of the Tha Chin River, Pa Sak River and Lop Buri River in the central part of Thailand [31].

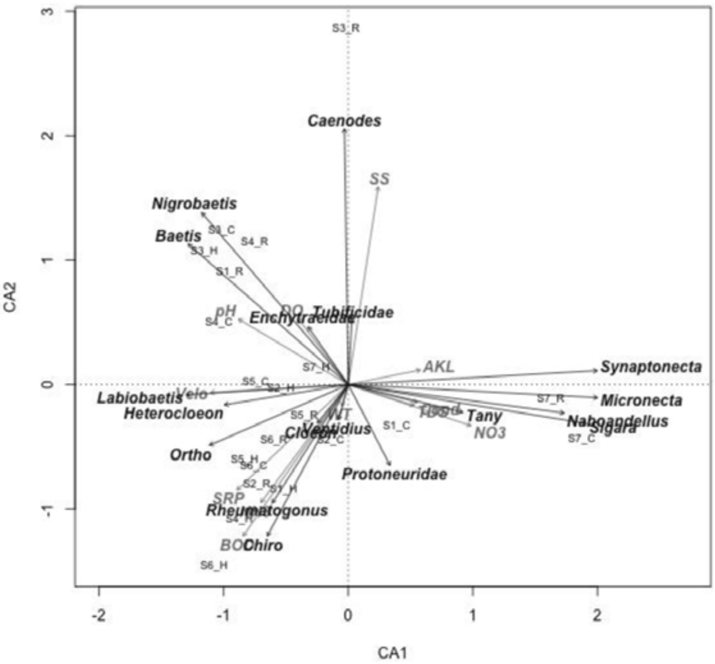

Figure 2. CA ordination diagram of sampling sites in each season (R = rainy, C = cool dry, H = hot dry), benthic macroinvertebrates and environmental variables of the Mae Klong River and its tributaries.

Table 4. Spearman correlation coefficients between the biological properties and environmental variables.

	W-temp	Velocity	Cond	TDS	SS	Alkalinity	pH	DO	BOD_5	NO_3^--N	NH_4^+-N	SRP
Total abundance	0.118	-0.043	0.116	0.081	-0.320**	0.075	-0.069	-0.168	-0.156	-0.017	-0.098	0.083
Taxa richness	0.166	-0.092	0.093	0.056	-0.320**	0.072	-0.044	-0.114	-0.274**	-0.009	-0.243**	0.165
% EPT	-0.069	0.074	-0.250**	-0.272**	0.152	-0.238**	0.226*	0.199*	0.018	-0.234**	-0.180*	0.017
% OC	0.132	0.092	0.011	-0.007	-0.309**	0.022	0.083	0.04	0.041	-0.016	0.085	0.172
EPTtaxa	0.006	0.073	0.038	0.011	-.177*	0.039	.189*	-0.035	-.248**	-0.087	-.242**	0.141
Ephemeroptera taxa	0.078	-0.012	-0.06	-0.094	-0.125	-0.093	0.108	0.119	-0.196*	-0.133	-0.301**	0.11
Plecoptera taxa	-.220*	0.268**	0.128	0.125	-0.013	0.159	0.283**	-0.065	-0.144	-0.204*	-0.117	0.073
Trichoptera taxa	-0.099	0.183*	0.111	0.105	-0.176*	0.155	0.188*	-0.109	-0.154	-0.039	-0.09	0.159
Shannon	0.210*	-0.095	0.143	0.112	-0.307**	0.101	0.001	-0.048	-0.297**	0.026	-0.286**	0.185*
$BMWP^{Thai}$	0.08	-0.052	0.15	0.119	-0.342**	0.12	0.021	-0.121	-0.333**	-0.041	-0.246**	0.119
ASPT	-0.164	0.031	0.085	0.066	-0.021	0.126	0.163	-0.031	-0.320**	-0.115	-0.192*	-0.085
PBI	0.03	0.052	0.081	0.086	-0.033	-0.011	0.027	-0.077	0.053	0.016	0.026	-0.068

* correlation is significant at 0.05 level
** correlation is significant at 0.01 level

4. Conclusion

The anthropogenic impact on benthic macroinvertebrate diversity and the water quality of the Mae Klong River increased from upstream sites to downstream sites. The results revealed that total abundance, taxa richness, % EPT abundance, EPT taxa and biotic indices tended to decrease from the upstream sites to the downstream sites. Moreover, a negative correlation between biological properties and environmental variables such as suspended solid, biochemical oxygen demand and ammonium nitrogen supported the notion that water quality decreased as a result of human activities. Therefore, benthic macroinvertebrates can be used as biological monitors for the Mae Klong River and its tributaries.

Acknowledgments

The authors are grateful to the National Research University (NRU), the Center of Excellence on Environmental Health and Toxicology (EHT), and the Center of Excellence on Entomology and Application as well as the Graduate School of Chiang Mai University for providing financial support. Thanks are also extended to the members of the Freshwater Biomonitor Research Laboratory, who helped with the field sampling process. Additionally, gratitude is expressed toward the Environmental Science Program, Faculty of Science, Chiang Mai University for generously providing use of the research facility.

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