Impact of anthropogenic disturbance on benthic macroinvertebrate assemblages in the Phong River, Northeastern Thailand

[1]Kannika Sirisinthuwanich, [2,3]Narumon Sangpradub, [2]Chutima Hanjavanit

[1] Department of Biology, Faculty of Science, Khon Kaen University, Thailand; [2] Applied Taxonomic Research Center, Department of Biology, Faculty of Science, Khon Kaen University, Thailand; [3] Centre of Excellence on Biodiversity, Bangkok, Thailand. Corresponding author: N. Sangpradub, narumon@kku.ac.th

Abstract. The study was carried out to investigate benthic macroinvertebrate structure in relation to three different land uses. Benthic macroinvertebrates and physico-chemical parameters of the water were were recorded seasonally from 9 sampling sites along the Phong River during cold, hot and rainy seasons of 2012 and 2013. Fourteen physico-chemical parameters of the water were also measured. A total of 35,391 individuals were found. Three phyla, 19 orders, 70 families and 121 genera of benthic macroinvertebrates were identified. The water quality of intensive agricultural sites showed significantly higher mean values of BOD_5, EC, TDS, turbidity, SS, nitrate-nitrogen, orthophosphate, ammonia-nitrogen and chlorophyll a than those of the urban and industrial sites. Moreover, the results of CCA also clearly illustrated that the tolerant taxa (SF. Chironominae, Oligochaeta, *Pomacea* and *Filopaludina*) mainly occurred in the intensive agricultural sites, that they were indicators of fair to poor water quality. Regarding the functional feeding groups (FFGs), collectors were more abundant in the urban sites, while scrapers increased in the intensive agricultural sites. The result from this study showed that the use of benthic macroinvertebrates is reliable indicator to detect the impact of anthropogenic disturbance in the Phong River.

Key Words: bioassessment, collectors, intolerant taxa, tolerant taxa, water quality.

Introduction. Benthic macroinvertebrates are considered effective indicators of quality of rivers worldwide (Resh & Jackson 1993; Varnosfaderany et al 2010; Aura et al 2011). In Asian countries, benthic macroinvertebrates are increasingly studied such as Thorne & Williams (1997), Mustow (2002), Azrina et al (2006), Meng et al (2009) and Huang et al (2015). Xu et al (2014) conducted a study in 14 rivers in China with different pollution levels, the result revealed that water quality could be assessed by using benthic macroinvertebrates.

Water pollution in Thailand is largely associated with anthropogenic disturbances from point and non-point sources (Morse et al 2007; PCD 2014). Point sources of pollution include domestic sewage and industrial wastes, released directly into rivers, while fertilizer and herbicide runoff represent important non-point sources (Boonsoong et al 2010). Phong River, a tributary of Mekong River, is the main river in Khon Kaen Province in Northeastern Thailand. It is a highly polluted tributary by urbanization, agriculture and industries in the northeast, especially the lowland river (PCD 2014). Water pollution in the Phong River started in 1986 and the situation became more severe in 1992. Moreover, a large number of fish in floating cages culture were devastated in 1997 which received effluent industrial waste from the pulp and paper mill factory into the Phong River (Sangsurasak et al 2006), and this has occurred repeatedly many years and several times of the year (Mungkarndee 2002). As such, regulations and water treatment processes have been more strictly followed by industrial plants before releasing water into the river (Ministry of Natural Resources and Environment 2016). In Thailand, the national standard assessment of water quality are based only on chemical characteristics, total coliform and fecal coliform bacteria, which are sometimes inadequate for detecting ecological integrity (PCD 2014). The PCD has installed a real time water quality warning system at five villages located along the river downstream of Ubolratana reservoir where more disturbances usually occurred. These villages were affected by different activities, e.g., community, industrial plants, and agriculture, respectively. This is the main focus of the present study by examining the three major sources of river pollution, which are urban, industry and agriculture. However, studies on benthic macroinvertebrate assemblages in the Phong River are still handful. Among a few of them, a number of studies concerning biological assessment and monitoring have been carried out in the last ten years (Inmuong et al 1997; Sangpradub et al 1998; Hanjavanit & Tangpirotewong 2007). Unfortunately, knowledge is fragmented due to the lack of continuity monitoring. Therefore, this study aims to fill this gap by focusing the impact of pollution on the benthic macroinvertebrate assemblages among three different land uses and physico-chemical parameters of (1) the urban sites, (2) the industrial sites and (3) the intensive agricultural sites and their functional feeding group of the Phong River.

Material and Method

Study area. The Phong River originates from seepage in the Phu Kradueang National Park, Loei Province, Thailand and flows through Ubolratana reservoir in Khon Kaen Province. It is 230 km in length with a catchment area of 2,142 km^2 (Figure 1). The study area lies between 16°22'-16°46'N and 102°37'-102°56' E and ranges in altitudes from 149 to 181 m.a.s.l. It was classified into three land uses: urban (sites PO01 to PO03) downstream from Ubolratana reservoir, industrial (sites PO04 to PO06) and the intensive agricultural (sites PO06 to PO09). Urban sites include residential areas and non-intensive agriculture. The industrial sites include factories (e.g. a pulp and paper mill, an electricity plant, piggery farms, whiskey factory and sugar factory), and non-intensive agriculture. Finally, the intensive agricultural sites (PO07 to PO09), these sites are included an agricultural area, which is mainly used for growing crops such as rice, cassava, sugar cane and eucalyptus (Khon Kaen University 1995). All sampling sites were selected according to the differences in land use as shown in Table 1. The field sampling was collected in cold, hot and rainy seasons of 2012 and 2013.

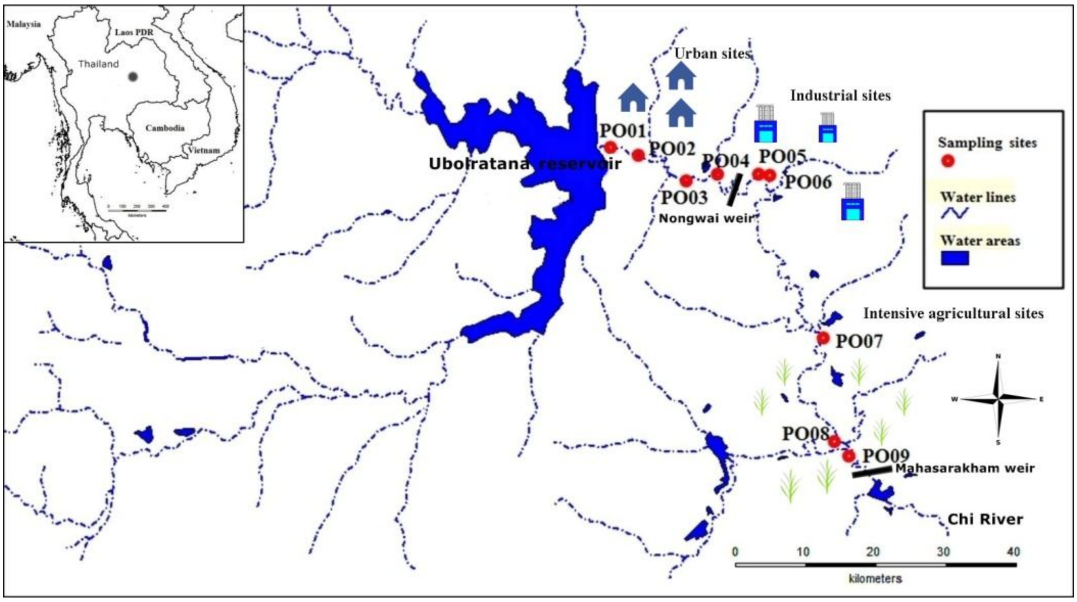

Figure 1. Map showing locations of the sampling sites (PO01-PO09) along the Phong River, Thailand.

Table 1

Phong River sampling site description

Site	*Site code*	*Altitude (masl)*	*Latitude, longitude*	*Land use*
Urban sites	PO01	181	16°46′30.16″ N 102°37′42.39″ E	Residential area, agriculture.
	PO02	171	16°45′49.36″ N 102°40′04.14″ E	Residential area, agriculture.
	PO03	172	16°43′46.11″ N 102°43′26.48″ E	Residential area, agriculture.
Industrial sites	PO04	170	16°43′52.23″ N 102°46′16.60″ E	Agriculture, pulp and paper mill factory, an electricity plant.
	PO05	159	16°44′01.41″ N 102°49′09.97″ E	Agriculture, piggery farm. Whiskey factory.
	PO06	156	16°43′46.84″ N 102°50′07.07″ E	Agriculture, sugar factory.
Intensive agricultural sites	PO07	172	16°31′06.63″ N 102°53′55.14″ E	Residential area, intensive agriculture, fish cage cultures.
	PO08	160	16°23′28.06″ N 102°55′20.76″ E	Intensive agriculture, fish cage cultures, treated municipal sewage.
	PO09	149	16°22′44.28″ N 102°56′10.99″ E	Residential area, intensive agriculture.

Environmental parameters sampling and habitat assessment. Physico-chemical parameters (14) of water quality analysis were collected for three replicates at each sampling site. Depth (m) and velocity ($m\ s^{-1}$) was measured using Flow velocity indicator Gurley Precision Instruments, Model 1100. Water temperature (°C) and dissolved oxygen (DO, $mg\ L^{-1}$) were measured in situ with YSI Dissolved Oxygen meter Model 550A. Biochemical oxygen demand (BOD_5, $mg\ L^{-1}$) was determined as the difference between initial and 5 day oxygen concentrations in a dark bottle, after incubation at 20°C. pH, electrical conductivity ($\mu s\ cm^{-1}$) and total dissolved solids (TDS, ppm) were measured with pH/EC/TDS meter model HI 98129. Turbidity (FAU), suspended solids ($mg\ L^{-1}$), nitrate-nitrogen ($mg\ L^{-1}$ NO_3^-N, ascorbic acid method), orthophosphate ($mg\ L^{-1}$ PO^{3-}_4, cadmium reduction method) and ammonia-nitrogen ($mg\ L^{-1}$ NH_3-N, the Nessler method) were measured by using the Hach DR/2010 spectrophotometer model 49300-00. Chlorophyll a ($\mu g\ L^{-1}$) was measured with an extracted-methanol method (APHA AWWA WPCF 1998). Collecting water sample in plastic bottles and storing samples at 4°C. Accuracy check followed by standard additions method of procedures manual.

The visual-based habitat assessment at each site was performed following a non-wadeable habitat index (NWHI) such as riparian width, large woody debris (LWD), aquatic vegetation, bottom deposition, bank stability, thalweg substrate and off-channel habitat. NWHI scores are ranged from 0-100 points. The quality of habitat was rated as excellent (84-100), good (56–83), fair (28-55) and poor condition (0-27) (Wilhelm et al 2005).

Benthic macroinvertebrate sampling. On each bank within 500 m reach length, 6 transects were applied (Flotemersch et al 2006). Benthic macroinvertebrates were obtained with 6 sweeps at each transect that proportionately included snags, macrophytes and silty bottom by using a D-frame dip net (0.3 m wide, 450 μm mesh). All samples were combined into a single sample and preserved immediately with 70% ethanol. In the laboratory, specimens were rinsed in 500 μm mesh sieve, and large organic materials were discarded. All organisms from the sorted sample were identified to genus level except Oligochaeta (Class) and Diptera (Subfamily) based on Morse et al

(1994) and Sangpradub & Boonsoong (2006). Functional feeding groups and habit data were assigned to each taxon based on Morse et al (1994).

Data analysis. Oneway ANOVA was used to determine the difference in physico-chemical characteristics among the three major different land uses. Canonical correspondence analysis (CCA) was used to find the relationship between environmental variables and benthic macroinvertebrate assemblages. Biological data were log(X+1) transformed prior to canonical correspondence analysis. A Monte Carlo permutation test with 998 random permutations was used to examine a statistical significance of the model determination. Multivariate analyses were performed by using PC-ORD ver.5 (McCune & Mefford 2006).

Results and Discussion

Environmental parameters of the sampling sites. Oneway ANOVA showed significant difference of depth, water temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, suspension solids (SS), orthophosphate, ammonia-nitrogen and chlorophyll a between the urban, industrial and intensive agricultural sites in all sampling occasions ($p<0.05$) (Table 2). Furthermore, BOD_5, EC, TDS, turbidity, SS, nitrate-nitrogen, orthophosphate, ammonia-nitrogen and chlorophyll a, which are associated with human activities, were higher in the intensive agricultural sites. It indicated more degraded water quality due to anthropogenic disturbance in the intensive agricultural sites than the urban and industrial sites. However, EC was slightly different from the previous report of Hanjavanit & Tungpirotewong (2007). The average EC values from the present study showed that the urban sites were below those in the reservoir (153.07 μs cm^{-1}), industrial sites (191.42 μs cm^{-1}) and intensive agricultural sites that were below the factories (374.39 μs cm^{-1}). Industrial sites were also surrounded by industrial factories including pulp and paper mill factory, whiskey factory and sugar factory which have led to the elevation of electrical conductivity, which was higher than the urban sites. In addition, high nitrate-nitrogen and orthophosphate was higher due to the fertilizer application to promote agricultural products (Simachaya 2002; PCD 2014). This finding is in agreement with the study of Black et al (2010), Hoang et al (2010) and Egler et al (2012) who stated that increasing in values of nitrate-nitrogen and orthophosphate was caused by the use of fertilizers in agricultural activity. This is some evidence of non-point source pollution, particularly the agricultural land uses (Maidment & Saunders 1996).

The result of the habitat quality showed that the total habitat scores were higher in the urban sites than those of the industrial and intensive agricultural sites and were significantly different between three land uses ($p<0.05$) (Table 2 and 3). It may be due to the fact that the urban sites had a good riparian coverage and an abundance of submerged plants, which provide microhabitats for refuge and forage of benthos. Also, habitat has more effect on the distribution of aquatic Heteroptera than the water quality (Suksai et al 2016). Also, Boonsoong & Braasch (2012), stated that *Compsoneuriella* (sensitive mayfly nymphs) prefer clinging to submerged vascular plants and submerged roots of tree standing at the river banks. In addition, our observation indicated that *Compsoneuriella* was found in some sampling sites (PO03, PO06, PO07 and PO09), where microhabitats are abundant with aquatic plants. Noticeably, the increasing riparian vegetation clearing had also caused an increasing amount of soil erosion indicating the higher value of turbidity, suspended solids and dissolved inorganic in the intensive agricultural sites. In the present study, WQI (water quality index) based on measured 7 parameters; water temperature, DO, BOD_5 , pH, NO_3-N, PO_4^{-3} and turbidity indicated that the water quality class was rated as good in the urban sites (Table 2) (PCD 2014; Sirisinthuwanich et al 2016).

Table 2

Mean ± Standard deviation (SD) of physico-chemical parameters of the water, total taxa, total individuals, total habitat scores, water quality index (WQI) and the result of post hoc tests among the three land use sites are indicated by different letter superscripts (all sampling sites/ 6 occasions)

Parameters	*Urban sites*	*Industrial sites*	*Intensive agricultural sites*	*P-value*
Depth (m)	4.80 ± 1.59^{a}	4.04 ± 1.93^{ab}	3.38 ± 1.21^{b}	0.036*
Velocity (m s^{-1})	0.15 ± 0.06^{a}	0.13 ± 0.05^{a}	0.15 ± 0.08^{a}	ns
Water temperature (^{o}C)	27.95 ± 2.02^{a}	29.43 ± 2.39^{b}	30.09 ± 1.68^{b}	0.009*
Dissolved oxygen (mg L^{-1})	5.27 ± 0.92^{a}	5.43 ± 1.48^{a}	4.86 ± 1.35^{a}	ns
BOD5 (mg L^{-1})	1.24 ± 0.51^{a}	1.54 ± 0.32^{b}	1.68 ± 0.46^{b}	ns
pH	7.47 ± 0.49^{a}	7.64 ± 0.52^{a}	7.52 ± 0.62^{a}	ns
Electrical conductivity (µs cm^{-1})	153.07 ± 9.43^{a}	191.42 ± 5.98^{a}	374.39 ± 1.89^{b}	0.00*
Total dissolved solids (ppm)	84.26 ± 10.20^{a}	114.35 ± 28.73^{a}	204.20 ± 11.18^{b}	0.00*
Turbidity (FAU)	8.74 ± 5.21^{a}	8.83 ± 6.75^{a}	38.44 ± 25.69^{b}	0.00*
Suspended solids (mg L^{-1})	6.15 ± 3.50^{a}	4.48 ± 2.07^{a}	28.26 ± 20.38^{b}	0.00*
Nitrate-nitrogen (mg L^{-1})	0.10 ± 0.06^{a}	0.14 ± 0.10^{ab}	0.33 ± 0.54^{b}	ns
Orthophosphate (mg L^{-1})	0.15 ± 0.06^{a}	0.25 ± 0.22^{a}	0.84 ± 0.94^{b}	0.001*
Ammonia-nitrogen (mg L^{-1})	0.06 ± 0.03^{a}	0.09 ± 0.08^{a}	0.60 ± 1.19^{b}	0.037*
Chlorophyll a (µg L^{-1})	2.19 ± 1.12^{a}	1.34 ± 0.83^{a}	8.11 ± 1.35^{b}	0.024*
Total taxa	37.89 ± 8.63^{a}	30.72 ± 9.10^{b}	26.89 ± 9.45^{b}	0.002*
Total individuals	888.39 ± 496.62^{a}	512.05 ± 258.78^{b}	632.39 ± 456.49^{ab}	0.028*
Total habitat scores	59.17 ± 4.46^{a}	58.11 ± 4.48^{a}	46.83 ± 7.50^{b}	0.00*
Water quality index (WQI)	Good	Good to fair	Fair to poor	–

ns - non significant difference, * - significant difference at $p<0.05$.

Table 3

Habitat assessment of the study sites along the Phong River (total habitat score is given in parenthesis)

Site code	*Riparian width (25)*	*Large woody debris (LWD) (20)*	*Aquatic vegetation (20)*	*Bottom deposition (10)*	*Bank Stability (10)*	*Thalweg substrate (10)*	*Off-channel habitat (5)*	*Habitats score (100)*
PO01	20	10	14	7	7	3	3	64
PO02	22	7	12	6	7	2	4	60
PO03	21	8	13	6	6	4	3	61
PO04	23	6	14	6	6	4	4	63
PO05	18	7	10	6	5	4	2	52
PO06	19	9	12	5	6	4	3	58
PO07	11	4	6	6	6	5	3	41
PO08	7	3	14	5	5	2	2	38
PO09	14	11	10	5	7	5	2	54

Table 4

Correlation, eigenvalues and variance explained for the first two axes of canonical correspondence analysis (CCA) of benthic macroinvertebrates and environment variables in the Phong River

Variable	*Axis 1*	*Axis 2*
Eigenvalue	0.21	0.146
Variance in species data % of variance explained	9.0	6.2
Cumulative % explained	9.0	15.2
Pearson correlation, taxa-environments	0.951	0.89

Benthic macroinvertebrate assemblages. A total of 35,391 individuals of benthic macroinvertebrates were found. Three phyla, 19 orders, 70 families and 121 genera were identified. Taxa were most diverse in Order Coleoptera (20 taxa), followed by Odonata (19 taxa), Hemiptera (17 taxa) and Diptera (14 taxa), respectively. This corresponded with the studies in Langat River (Azrina et al 2006), the Juru River (Al-Shami et al 2011) in Malaysia and the Du River in Vietnam (Hoang et al 2010). These studies reported that Odonata, Coleoptera, Hemiptera, Ephemeroptera and Diptera generally occurred along Asian countries lowland rivers. Moreover, it was found that most diverse and abundance of macroinvertebrates occurred more in the urban sites (37 taxa, 888 individuals) than in the industrial (30 taxa, 512 individuals) and intensive agricultural sites (26 taxa, 632 individuals) of the Phong River. Number of taxa and its respective abundances were highest at urban sites and decreased significantly at the industrial and intensive agricultural sites ($p<0.05$) (Table 2) and in accord with those of Al-Shami et al (2011) and Egler et al (2012). Higher diversity in the urban sites was consistent with the result of water quality, indicating lower value of BOD_5, EC and nutrient concentrations. Also, the most abundant and diverse taxa corresponded with the multihabitats as previously mentioned. However, anthropogenic modification has altered assemblage composition in the agricultural sites. There are increased in abundance and richness of Family Leptophlebiidae (Order Ephemeroptera) and *Corbicula* (Getwongsa et al 2010). In agricultural sites of Brazil, predominant taxa were F. Baetidae (Order Ephemeroptera) and Family Glossosomatidae (Order Trichoptera) (Egler et al 2012).

Relationship between benthic macroinvertebrates and environmental variables. According to the canonical correspondence analysis (CCA), benthic macroinvertebrates were significantly related with the environmental parameters ($p<0.05$). The correlation coefficient values between the species-environment to axis 1 and axis 2 were 0.951 and 0.890, respectively (Table 4). The cumulative percentage variance of the species-environment relation explained by the first two axes was 15.2%. The CCA showed that the sampling sites were clustered into two groups (Figure 2). The first group was composed of the intensive agricultural sites (PO07-PO09), where surrounded by paddy, cassava and sugar cane fields. These sites were classified into fair to poor water quality; SS, orthophosphate, turbidity, ammonia-nitrogen, EC, TDS, chlorophyll a, BOD_5 and nitrate-nitrogen were higher in group I of ordination than group II. Input of nitrate-nitrogen and orthophosphate, because they were closely associated with the use of fertilizers from agricultural land use. This finding was supported by Hengrasmee et al (1989) who noted that herbicides and fertilizers increased along the Phong River, especially the sites below the sugar factory, where land uses were modified for intensive agriculture. Also, EC, TDS and SS indicated organic waste that is caused by industrial runoff. Ammonia-nitrogen was released from residential area where the observed levels in the downstream of river exceeded the standard value (>0.50 mg L^{-1}). These results are in the line with the report of PCD (2014) revealing that the water quality problems of the Phong River are caused by community sewage (NH_3-N), drainage and soil erosion in agricultural areas consisting mostly of paddy fields.

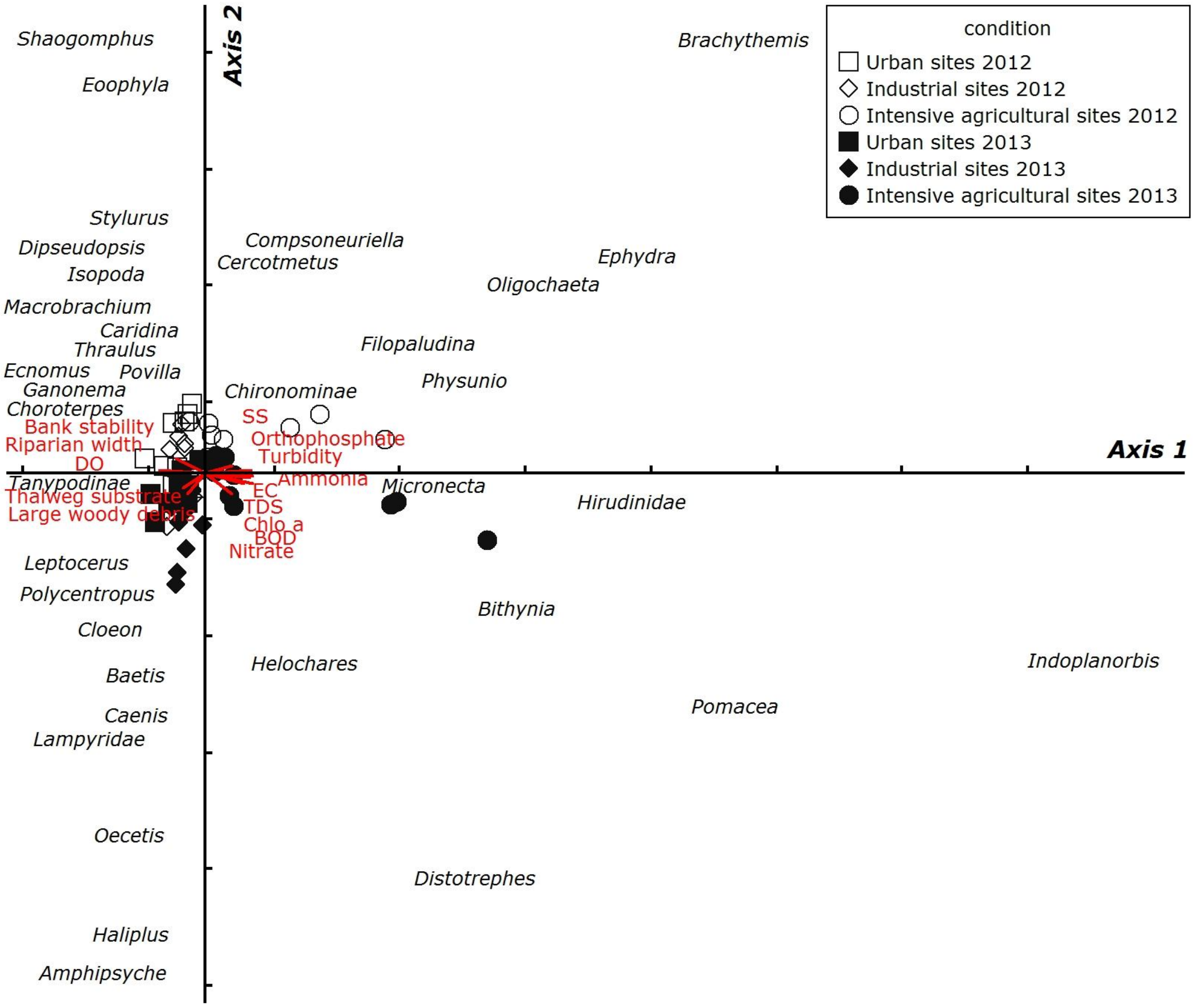

Figure 2. CCA ordination analysis showing three different land use sites aggregate in the ordinal space based on physico-chemical parameters and 37 taxa of benthic macroinvertebrates data of the Phong River during the cold, hot and rainy seasons of 2012 to 2013.

Additionally, the higher abundance of tolerant taxa in CCA axis 1 is also highlighted in the intensive agricultural sites. Our results suggest that the nine physico-chemical parameters (e.g. BOD_5, EC, TDS, turbidity, SS, nitrate-nitrogen, orthophosphate, ammonia-nitrogen and chlorophyll a) were the evidence of more anthropogenic impact. Group I is mainly composed of tolerant taxa with tolerance values 2-3 included Chironomidae, Oligochaete and *Pomacea* (Blakely et al 2014). According to Jackson et al (2010) and Płociennik & Karaouzas (2014), Chironomidae and Oligochaete were highly tolerant to organic pollutions, and they preferred relatively soft bottom sediments. Generally, Chironomid larvae have haemoglobin that helps transport and store oxygen in low oxygen environments (Barbour et al 1996; Cranston 2004). The way in which the study's results correspond to previous study of Sriariyanuwath et al (2015) who reported that Subfamily Chironominae were very tolerant group, which found at the study sites, that had a high values of SS, turbidity, EC, TDS and orthophosphate. On the other hand, Subfamily Tanypodinae was found abundant in the urban sites. This finding is correspondent with Odume & Muller (2011), who reported that Tanypodinae larvae are indicated to be sensitive to water quality degradation. In addition, high abundant of *Pomacea* was a tolerance indicator for contamination of nutrient concentrations and was found abundant in macrophytes, especially in *Eichhornia crassipes* (Carlsson & Lacoursiere 2005). The results of the present study was corresponded to the previous study of Carlsson et al (2004), reporting that the high abundance of *Pomacea* was correlated to nutrient enrichment. Whereas, the second group consisted of the sites of the urban (PO01-PO03) and industrial sites (PO04-PO06). However, all industrial sites of the 2013 had a tendency to be separated from the second group of which the degraded water quality was identified. The urban sites were classified into good water quality, while industrial sites were classified into good to fair water quality.

Group II indicated that the bank stability, riparian width, DO, large woody debris (LWD) and the thalweg substrate were higher value in biplot. According to the result of CCA axis 2, the riparian width, bank stability and abundant macrophytes along the river margins provides relative more heterogenous microhabitat (Kaufmann 2000; Meng et al 2009). Riparian width is important not only for the reduction of soil erosion by increasing bank stability and input coarse organic matter, but also for the decrease of water temperature through shading in the river habitat (Kaufmann 2000). Also, the number of LWD is an important component. Nakano et al (2008) stated that it provides suitable habitats for macroinvertebrates. Also, thalweg substrate (the flow path of the deepest water in a river channel) also provides more habitat for aquatic insect larvae (Wilhelm et al 2005).

Moreover, the CCA also clearly demonstrated the spatial variation of benthic macroinvertebrate assemblages. The following patterns of the CCA ordination showed that the intolerant groups occurred at the urban and industrial sites in which Ephemeroptera and Trichoptera taxa were found. They consisted of mayfly nymphs including *Choroterpes*, *Thraulus* have tolerance values 10. Whereas, caddisfly larvae which included *Dipseudopsis, Ecnomus* and *Leptocerus* have tolerance values 6-7 (Blakely et al 2014). These groups were widely distributed in the urban and industrial sites, which was very sensitive to low oxygen levels due to the fact that decreasing oxygen concentration had impact on many aquatic larvae, especially gill-breathing insect adaptation (Goodnight 1973). This finding is in line with Spies et al (2006) and Pereira et al (2012), who stated that caddisfly larvae can be used for potential of habitat integrity and is likely to be related to riparian vegetation and anthropogenic influence. Furthermore, our results support the findings of Xu et al (2014), who indicated that Family Leptophlebiidae is the indicators for very good or good water quality. However, Ephemeroptera and Trichoptera are generally considered sensitive to environmental disturbances. In contrast, Family Baetidae (*Cloeon* and *Baetis*) and Caenidae (*Caenis*) (Order Ephemeroptera) are well known to tolerant the low level of oxygen and high nutrient enrichment (Harrington & Born 2000). These two Ephemeropteran families occurred both in the urban and industrial sites.

Functional feeding groups (FFGs). Distributions of FFGs are closely related with food resources and provide habitat's information about environment condition along the river. Energy source from fine particle organic matter (FPOM) is available in the river (Vannote et al 1980). An analysis of FFGs based on individual numbers showed that collectors (20.52%), scavengers (15.84%), predators (5.66%), filterers (2.97%) and scrapers (2.41%) were dominant in the urban sites. However, collectors (10.81%) also had the highest percentages in the intensive agricultural sites followed by predators (8.22%), scavengers (7.59%) and scrapers (3.38%), respectively (Figure 3). In regard to the functional feeding groups (FFGs) of the Phong River, collectors were abundant not only in the urban sites but also in both the industrial and intensive agricultural sites. These include *Cloeon* (Family Baetidae), *Caenis* (Family Caenidae), *Choroterpes* (Family Leptophlebiidae) and Family Chiromomidae, of which substrates was mainly composed of sandy loam. The high proportion of collector was probably related more with multihabitats in the urban sites, which are an energy source from fine particle organic matter and which are available for collectors (Flotemersch et al 2006; Jiang et al 2011). A large number of *Caridina* occurred in the urban sites, resulting in a relatively higher proportion of scavengers. Lehman (1998) stated that *Caridina* plays a role in a trophic relation between fish and lower trophic level. Moreover, they are an important in detritus process. Many reports revealed that predators were most abundant including aquatic Hemiptera and dragonfly larvae. They play important roles as biocontrol in the aquatic ecosystem. Dragonfly larvae are important predators of various macroinvertebrates including mosquito immature (Quiroz-Martinez & Rodriguez-Castro 2007), while a high abundance of scrapers (*Filopaludina* and *Pomacea*) occurred in the intensive agricultural sites. The increase of orthophosphate, nitrate-nitrogen and chlorophyll a, as well as the existence of light is the result of the reduction of shading in the agricultural sites, positively influencing the growth of algae and diatom. Thus, algae and diatom are major food available for scrapers (Bis et al 2000; Pereira et al 2012). Lastly, the few shredders occurred in only low abundance, which belongs to the genera with Family Scirtidae (Order Coleoptera) and Family Crambidae (Order Lepidoptera). Similar findings were previously reported from China. Jiang et al (2011) revealed that shredders were quite less abundant along the Chishui basin, which resulted in the degradation of leaf litter input. Collectors and scavengers represented a relatively large proportion in the urban sites, whereas, predators and scrapers were increasingly abundant in the intensive agricultural sites. In the industrial sites, no FFGs dominate but percentage of each feeding group was relatively low.

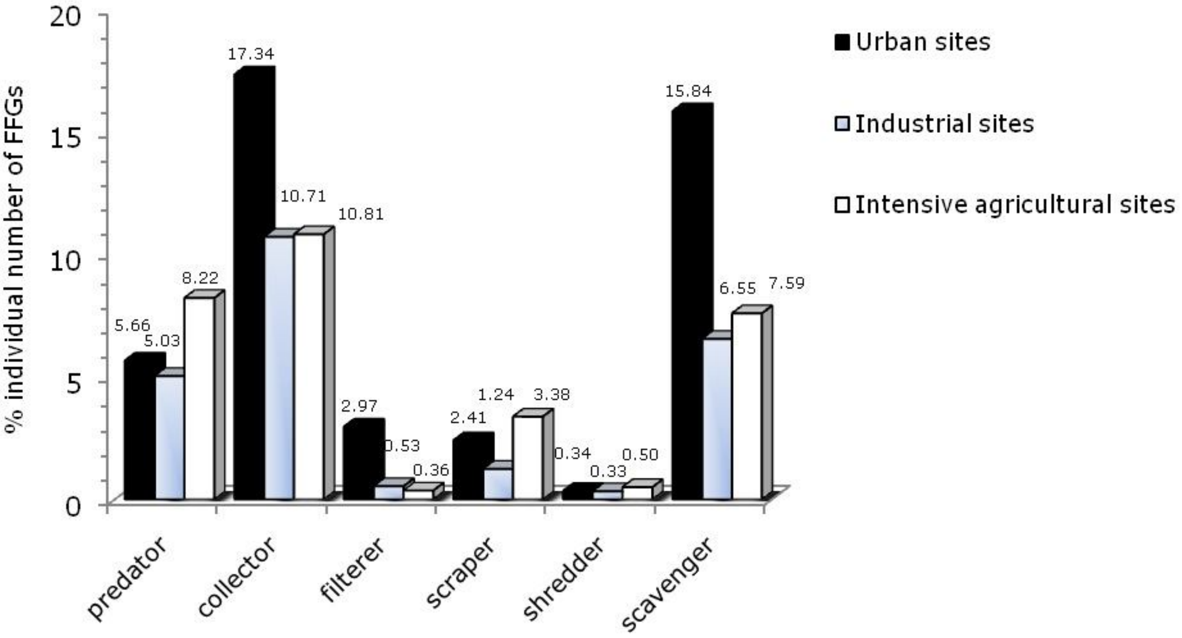

Figure 3. Percentage individual number of functional feeding groups of benthic macroinvertebrates between the urban, industrial and intensive agricultural sites in the Phong River.

Conclusions. The water quality of three different land uses became increasingly polluted in the urban, the industrial and the intensive agricultural sites, respectively, and this is caused by various human activities. The intensive agricultural sites presented high values of nutrient concentrations. Obviously, physico-chemical parameters and benthic macroinvertebrate assemblages showed the same pattern according to the results of the CCA ordination. The finding from the CCA ordination indicated that tolerant taxa including Oligochaeta, Chironominae, *Filopaludina* and *Pomacea* were reliable indicators of fair to poor water quality in the intensive agricultural sites. In addition, the intolerant taxa including *Choroterpes*, *Thraulus*, *Dipseudopsis*, *Ecnomus* and *Leptocerus* were abundant in the urban and the industrial sites that they were indicators of good to fair water quality. These two taxa groups can be used as indicators to assess the river condition. Also, the difference of functional feeding groups is likely to support the differences of anthropogenic impact among the three different land uses. Therefore, using benthic macroinvertebrate assemblages for water quality assessment in the Phong River is promising. Therefore, benthic macroinvertebrate assemblages may be option for water quality assessment except the use of only physico-chemical parameters.

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References

Al-Shami S. A., Md Rawi C. S., Ahmad A. H., Hamid S. A., Mohd Nor S. A., 2011 Influence of agricultural, industrial, and anthropogenic stresses on the distribution and diversity of macroinvertebrates in Juru River Basin, Penang, Malaysia. Ecotoxicology and Environmental Safety 74:1195-1202.

Aura C. M., Raburu P. O., Herrmann J., 2011 Macroinvertebrates' community structure in Rivers Kipkaren and Sosiani, River Nzoia basin, Kenya. Journal of Ecology and the Natural Environment 3(2):39-46.

Azrina M. Z., Yap C. K., Ismail A. R., Ismail A., Tan S. G., 2006 Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Pennisular Malaysia. Ecotoxicology and Environmental Safety 64:337-347.

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

Bis B., Zdanowicz A., Zalewski M., 2000 Effects of catchment properties on hydrochemistry, habitat complexity and invertebrate community structure in a lowland river. Hydrobiologia 422/423:369-387.

Black R., Moran P., Frankforter J., 2010 Response of algal metrics to nutrients and physical factors and identification of nutrient thresholds in agricultural streams. Environmental Monitoring and Assessment 175(1):397-417.

Blakely T. J., Eikaas H. S., Harding J. S., 2014 The Singscore: a macroinvertbrate biotic index for assessing the health of Singapore's streams and canal. Raffles Bulletin of Zoology 62:540-548.

Boonsoong B., Sangpradub N., Barbour M. T., Simachaya W., 2010 An implementation plan for using biological indicators to improve assessment of water quality in Thailand. Environmental Monitoring and Assessment 165:205-215.

Boonsoong B., Braasch D., 2012 Heptageniidae (Insecta, Ephemeroptera) of Thailand. ZooKeys 272:61-93.

Carlsson N. O. L., Bronmark C., Hansson L.-A., 2004 Invading herbovory: The golden apple snail alters ecosystem functioning in asian wetlands. Ecology 85(6):1575-1580.

Carlsson N. O. L., Lacoursiere J. O., 2005 Herbivory on aquatic vascular plants by the introduced golden apple snail (*Pomacea canaliculata*) in Lao PDR. Biological Invasions 7:233-241.

Cranston P. S., 2004 Insecta: Diptera, Chironomidae. In: The freshwater invertebrates of Malaysia and Singapore. Yule C. M., Yong H. S. (eds), Academy of Sciences, Malaysia, pp. 711-735.

Egler M., Buss D. F., Moreira J. C., Baptista D. F., 2012 Influence of agricultural land-use and pesticides on benthic macroinvertebrate assemblages in an agricultural river basin in southeast Brazil. Brazillian Journal of Biology 72(3):437-443.

Flotemersch J. E., Blocksom K. A., Hutchens J. J., Autrey B. C., 2006 Development of a standardized large river bioassessment protocol (LR-BP) for macroinvertebrate assemblages. River Research and Applications 22:775-790.

Getwongsa P., Hanjavanit C., Sangpradub N., 2010 Impacts of agricultural land use on stream benthic macroinvertebrates in tributaries of the Mekong River, northeast Thailand. AES Bioflux 2(2):97-112.

Goodnight C. J., 1973 The use of aquatic macroinvertebrates as indicators of stream pollution. Transactions of the American Microscopical Society 92(1):1-13.

Hanjavanit C., Tangpirotewong N., 2007 Comparison of benthic macroinvertebrate community structure in relation to different types of human disturbance along the

Pong River, Khon Kaen Province. KKU Research Journal 12:402-419. [In Thai with English abstract].

Harrington J., Born M., 2000 Measuring the health of California streams and rivers. A methods manual for water resource professionals, citizen monitors and natural resource students. Report, Sustainable Land Stewardship International Institute, Sacramento, California, USA.

Hengrasmee S., Kukusamude C., Comemhenk T., Mahachai R., Choosri T., Wongphathanakul W., Nontaso N., Kindarojana J., 1989 [Impact of industry and agriculture on water quality in Nam Phong basin]. KKU Research Journal 17(1):50-57. [In Thai].

Hoang T. H., Lock K., Dang K. C., De Pauw N., Goethals P. L. M., 2010 Spatial and temporal patterns of macroinvertebrate communities in the Du river basin in northern Vietnam. Journal of Freshwater Ecology 25:637-647.

Huang Q., Gao J., Cai Y., Yin H., Gao Y., Zhao J., Liu L., Huang J., 2015 Development and application of benthic macroinvertebrate-based multimetric indices for the assessment of streams and rivers in the Taihu Basin, China. Ecological Indicators 48:649-659.

Inmuong Y., Sangpradub N., Inmuong U., 1997 [River water qualities: a new assessment method by integrating physicochemical and biological variables with multivariate analyses]. Thailand Journal of Health Promotion and Environmental Health 20(1):15-30. [In Thai].

Jackson J. K., Battle J. M., Sweeney B. W., 2010 Monitoring the health of large rivers with macroinvertebrates: do dominant taxa help or hinder the assessment. River Research Application 26:931-947.

Jiang X., Xioang J., Xie Z., Chen Y., 2011 Longitudinal patterns of macroinvertebrate functional feeding groups in a chineses river system: a test for river continuum concept (RCC). Quaternary International 244:289-295.

Kaufmann P. R., 2000 Physical habitat characterization-non-wadeable rivers. In: Surface waters: Field operations and methods for measuring the ecological condition of Non-wadeable rivers and streams. Lazorchak J. M., Hill B. H., Averill D. K., Peck D. B., Klemm D. J. (eds), EPA 620/R-00/007, Environmental Monitoring and Assessment Program, Office of Research and Development, US Environmental Protection Agency, Cincinnati.

Lehman J. T., 1998 Environmental change and response in East African Lakes. Kluwer Academic Publishers. The Netherland, 239 pp.

Maidment D. R., Saunders W. K., 1996 Non-point source pollution assessment of the San Antonio-Nueces Coastal Basin, University of Texas, Texas, 24 pp.

McCune B., Mefford M. J., 2006 PC-ORD. Mutivariate analysis of ecological data. Version 5. MjM Software, Gleneden Beach, Oregon, USA.

Meng W., Zhang N., Zhang Y., Zheng B., 2009 Integrated assessment of river health based on water quality, aquatic life and physical habitat. Journal of Environmental Sciences 21:1017-1027.

Morse C. J., Lianfang Y., Lixin T., 1994 Aquatic insects of China useful for monitoring water quality. Hohai University Press, Nanjing, China, 570 pp.

Morse J. C., Bae Y. J., Munkhjargal G., Sangpradub N., Tanida K., Vshivkova T. S., Wang B., Yang L., Yule C. M., 2007 Freshwater biomonitoring with macroinvertebrates in East Asia. Frontiers in Ecology and the Environment 5:33-42.

Mungkarndee P., 2002 Study of quality of the Pong River ecosystem. Research Report, Khon Kaen University, 37 pp.

Mustow S. E., 2002 Biological monitoring of river in Thailand: use and adaptation of BMWP score. Hydrobiologia 479(1):191-229.

Nakano D., Nagayama S., Kawaguchi Y., Nakamura F., 2008 River restoration for macroinvertebrate communities in lowland rivers: insights from restorations of the Shibetsu River, north Japan. Lanscape Ecological Engineering 4:63-68.

Odume O. N., Muller W. J., 2011 Diversity and structure of Chironomidae communities in relation to water quality differences in the Swartkops River. The Physics and Chemistry of the Earth 36:929-938.

Pereira L. R., Cabette H. S. R., Juen L., 2012 Trichoptera as bioindicators of habitat integrity in the Pindaı´ba river basin, Mato Grosso (Central Brazil). Annales de Limnologie – International Journal of Limnology 48:295–302.

Płociennik M., Karaouzas I., 2014 The Chironomidae (Diptera) fauna of Greece: Ecological distributions and patterns, taxalist and new records. Annales de Limnologie – International Journal of Limnology 50:19-34.

Quiroz-Martinez H., Rodriguez-Castro A., 2007 Aquatic insects as predators of mosquito larvae. Journal of the American Mosquito Control Association 23(2):110–117.

Resh V. H., Jackson J. K., 1993 Rapid assessment approaches to biomonitoring using benthic macroinvertebrates. In: Freshwater biomonitoring and benthic macroinvertebrates. Rosenberg D. M., Resh V. H. (eds), pp. 195–233, Chapman and Hall, New York.

Sangpradub N., Inmuong C., Hanjavanit C., Inmuong U., 1998 A correlation study between freshwater benthic macroinvertebrate fauna and environmental quality factors in Nam Pong Basin. Research report submitted to TRF [Thailand Research Fund].

Sangpradub N., Boonsoong B., 2006 Identification of freshwater invertebrates of the Mekong River and its tributaries. Mekong River Commission, Vientiane, 274 pp.

Sangsurasak C., Hsieh H. N., Wongphathanakul W., Wirojanagud W., 2006 Water quality modeling in the Nam Pong River, Northeast Thailand. Science Asia 32:71-81.

Simachaya W., 2002 Water quality monitoring and modeling application in Thailand. Third World Water Forum Session October 16-17, 2002, the United Nation University Center in Tokyo, Japan, pp. 1-12.

Sirisinthuwanich K., Sangpradub N., Hanjavanit C., 2016 Development of biotic index to assess the Phong and Cheon rivers' healths based on benthic macroinvertebrates in Northeastern Thailand. AACL Bioflux 9(3):680-694.

Spies M. R., Froehlich C. G., Kotzian C. B., 2006 Composition and diversity of Trichoptera (Insecta) larvae communities in the middle section of the Jacui river and some tributaries, State of Rio Grande do Sul, Brazil. Iheringia Série Zoologia 96(4):389-398.

Sriariyanuwath E., Sangpradub N., Hanjavanit C., 2015 Diversity of chironomid larvae in relation to water quality in the Phong River, Thailand. AACL Bioflux 8(6):933-945.

Suksai B., Sangpradub N., Zettel H., 2016 Assemblage of aquatic Heteroptera (Gerromorpha and Nepomorpha) in relation to microhabitats in the Phong River, Northeast Thailand. Entomological Research 46(2):93-106.

Thorne R. S. T., Williams W. P., 1997 The response of benthic macroinvertebrates to pollution in developing countries: a multimetric system of bioassessment. Freshwater Biology 37:671-686.

Vannote R. L., Minshall G. W., Cummins K. W., Sedell J. R. , Cushing C. E., 1980 The river continuum concept. Canadian Journal of Fisheries and Aquatic Science 37:130-137.

Varnosfaderany M. N., Ebrahimi E., Mirghaffary N., Safyanian A., 2010 Biological assessment of the Zayandeh Rud River, Iran, using benthic macroinvertebrates. Limnologica 40:226-232.

Wilhelm J. G. O., Allan J. D., Wessell K. J., Merritt R. W., Cummins K. W., 2005 Habitat assessment of non-wadeable rivers in Michigan. Environmental Management 36:592-609.

Xu M., Wang Z., Duan X., Pan B., 2014 Effects of pollution on macroinvertebrates and water quality bio-assessment. Hydrobiologia 729:247-259.

*** APHA AWWA WPCF, 1998 Standard methods for examination of water and waste water (20th edition). Washington DC: American Public Health Association, American Water Work Association and Water Pollution Control Federation, 541 pp.

*** Khon Kaen University, 1995 Project report on action plan for rehabilitation and treatment of water quality of Pong river. Khon Kaen: Center for Research of Environmental Management.

*** Ministry of Natural Resources and Environment, 2016 Available at: http://www.ratchakitcha.soc.go.th/DATA/PDF/2559/E/129/17.PDF. Accessed: December, 2016.

*** PCD (Pollution Control Department), 2014 Thailand state of pollution report 2014. Pollution Control Department, Ministry of Science Technology and Environment, 190 pp.

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Authors:
Kannika Sirisinthuwanich, Khon Kaen University, Faculty of Science, Department of Biology, Thailand, Khon Kaen 40002, e-mail: nuynuy99@hotmail.com
Narumon Sangpradub, Khon Kaen University, Faculty of Science, Department of Biology, Applied Taxonomic Research Center, Thailand, Khon Kaen 40002; Centre of Excellence on Biodiversity, Thailand, Bangkok 10330, e-mail: narumon@kku.ac.th
Chutima Hanjavanit, Khon Kaen University, Faculty of Science, Department of Biology, Applied Taxonomic Research Center, Thailand, Khon Kaen 40002, e-mail: chuhan@kku.ac.th

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