Biodiversity, Community Structure and Bioassessment of Water Quality in Thong Pha Phum District, Western Thailand

Phannee Sa-ardrit[1]*, F.W.H. Beamish[2] and Chunte Kongchaiya[2]
[1]Prince of Songkla University, Songkhla, [2]Burapha University, Chonburi
*sa_koy@hotmail.com

Biodiversity of benthic macroinvertebrates ranged from 35 to 44 families per reference site in each of four rivers. Numerically dominant families were similar across reference sites. At the level of Order, Ephemeroptera contributed the greatest number of individuals and Annelida, the least. Benthic macroinvertebrates varied greatly from 18 to 40 families among the nine assessment sites. Overall, number of individuals, taxa and families within Diptera, Ephemeroptera, and Trichoptera was the higher at reference sites. Assemblage structures were similar between reference and assessment sites.

Water was not found to be significantly impaired at any site. Some bioassessment indices suggested water at reference sites to be less impaired than that at assessment sites. In the next time period identification of all taxa from a larger geographic area will be completed and applied to existing bioassessment models and, if desirable, a new model developed for Thailand.

Key words: Western Thailand, benthic macroinvertebrates, bioassessment, water quality

Introduction

Water quality is a valued public resource providing a myriad of services, often with conflicting consequences. Thus, the immeasurable value of water for drinking may be compromised by the discharge of noxious substances into the same watershed. Historically, water quality monitoring has relied on chemical testing with limitations that include cost, time and detection. Impacts on water quality resulting from non chemical activities will not be detected. Physical alterations such as habitat destruction through sedimentation, flow and temperature alterations and drainage activities are typically undetected by chemical monitoring programs. Biological observations are more dependable than chemical tests because they show the accumulation of effects over time whereas chemical tests apply only to the moment of sampling.

Water and habitat quality can also be measured by quantifying the occurrence or abundance of aquatic organisms living in the waterway. The occurrence of specific species in a river or stream signals unimpaired conditions while the presence of others signals impairment. Biological methods to measure water quality began almost 100 years ago (Forbes and Richardson, 1913). When studying the effect of organic wastes discharged from the city of Chicago, they recognized that individual benthic species were associated with specific water quality conditions. Unpolluted sites were associated with a variety of gill-breathing insects such as stoneflies, mayflies and caddisflies that require relatively high concentrations of dissolved oxygen. Organically polluted sites were characterized by tubificid worms, leeches and some chironomid taxa that could tolerate low levels of oxygen. Biotic indices have been developed more recently to summarize the information provided by the indicator species concept into a single number that indicated the degree of organic pollution (Beck, 1955; Beak, 1964; Chandler, 1970; Hilsenhoff, 1982; and others).

Assessment of water quality to assure the continuation of the expected goods and services solely by chemical analyses is the traditional method but is fraught with difficulties and is unreliable. A reliable and efficient approach to habitat quality assessment is based on the resident animals themselves and their habitat preferences. Thus, the occurrence of individual species or communities of benthic macroinvertebrates and zooplankton in a river or stream may signal unimpaired water while the presence of others may signal impairment. A number of diverse bioassessment protocols have been developed based on species richness, indicator species, diversity and similarity indices, and multimetric procedures but virtually all have been developed for temperate waterways.

Thailand has a large number of creeks, streams and rivers which for the most part are heavily exploited for the goods and services they can provide. These same waterways provide habitat for a hugely diverse taxa of vertebrate and invertebrate animals whose full taxonomy is not yet described. The habitats are known but for a few and even for these much remains to be learned. While this information awaits learning, the water quality of many waterways will continue to deteriorate with no perceptible effort being made to reverse this dangerous downward trend. The status of other aquatic vertebrates and the much greater diversity of invertebrates are even more critical. Conservation efforts must be made if Thailand's rich fauna is to be maintained into the future.

The objectives of this study thus were 1) to measure the structure of communities of benthic macroinvertebrates and zooplankton (cladocera) representative of a variety of habitats ranging from pristine to polluted (domestic and agriculture, wastes, sedimentation) from streams in Thong Pha Phum District and surrounding area, 2) to describe each habitat on the basis of a number of physicochemical characteristics, 3) to test correlations between biological indicators and physicochemical characteristics using species richness, biotic (e.g. Hilsenhoff, 1982, 1987), diversity (Wiener, 1948; Shannon, 1949), similarity indices (e.g. Morisita-Horn in Wolda, 1981; Novak and Bode, 1992), and multimetric methods (e.g. Karr, 1990, 1991; Wright, 1995; Barbour et al., 1997; Griffiths, 1999; Davies, 2000), and 4) to develop a relatively simple bioassessment method to evaluate ecosystem health of Thailand streams and rivers.

Study Sites

Thong Pha Phum District, western Thailand, has a large number of creeks, streams and rivers. These watersheds discharge into Khao Leam reservoir and eventually into the Kwai Noi River which for the most part is heavily exploited for the goods and services it provides. Samples were collected from 25 sites in 11 streams ranging from 1st to 4th order and flowing through regions that are lightly to moderately exploited for agriculture, road construction and human habitation. (Fig. 1) Sites judged on the basis of visual appearance of the water and landscape to be only lightly exploited were considered reference sites (n = 8). The remaining 17 sites were considered assessment sites and varied from unimpaired to moderately impaired as a consequence of the type and level of exploitation.

Reference sites (8 sites from 8 streams) in first to fourth (1st to 4th) order streams and rivers were located in relatively pristine forests, often in a National Forest, with little to no evidence of human habitation. First and second order stream sites were selected in Nhong Pring, Pak Khok 1 and Yot Ong Thi, respectively with three third order sites in Phasadukrang, Choung Khao, and Lin Thin 1 rivers. U Long, and Wang Kiang provided 4th order sites. Sites in Phasadukrang, Choung Khao, Lin Thin1, U Long, and Wang Kiang were downstream from comparatively pristine forest regions, not subjected to more than light exploitation and were without road access.

Water in reference sites was clear, free from noxious odors and appeared visually to be of good quality. This was supported by the chemical composition of water (Table 1). There was a general pattern of increase in dissolved oxygen, nitrate, and phosphate between 1st and 4th order stream sites but otherwise obvious differences were not found among the physico-chemical measurements (Table 1). BOD, a measure of the oxygen consumed by organic matter, was low at all reference sites confirming their choice. In contrast, where streams receive runoff from agricultural land and domestic and industrial areas high in organic content, BOD values can be expected to be quite high.

At reference sites, riparian cover varied from 5-85%. Highest riparian cover was found at third order stream sites, 25-85%, followed by first, second, and fourth order sites which ranged form 40-80, 10-40, and 5-10%, respectively. Velocity and discharge varied directly with stream order from 18-107 cm/s and 17-2601 l/s, respectively (Table 1). Macrophyte cover varied from 30-50% in first order, 0-50% in second and third order, and 0-5% in fourth order stream. Dominant particle sizes were largest in fourth and third order stream sites where velocity was high. In fourth order streams, dominant particle size ranged from 5.1-150 mm while in third order streams it varied from 3.1-150 mm. Dominant particle sizes were smaller in first and second order streams and ranged from 5-3.1 mm and 3.1-60 mm, respectively.

Assessment sites (17 sites from 11 streams) in 1st to 4th order streams and rivers were selected on the basis of their location with respect to potential sources of impairment including agriculture (plants or/and animals), human habitation, and road construction (Table 2). Potential sources of impairment were not considered to be significantly different among stream order. Three relative levels of visual impairment (unimpaired, slightly impaired and moderately impaired) were used to classify each assessment site. Reference sites were all evaluated as unimpaired. It is important to note that for this report the categories of impairment for Thong Pha Phum streams should not be

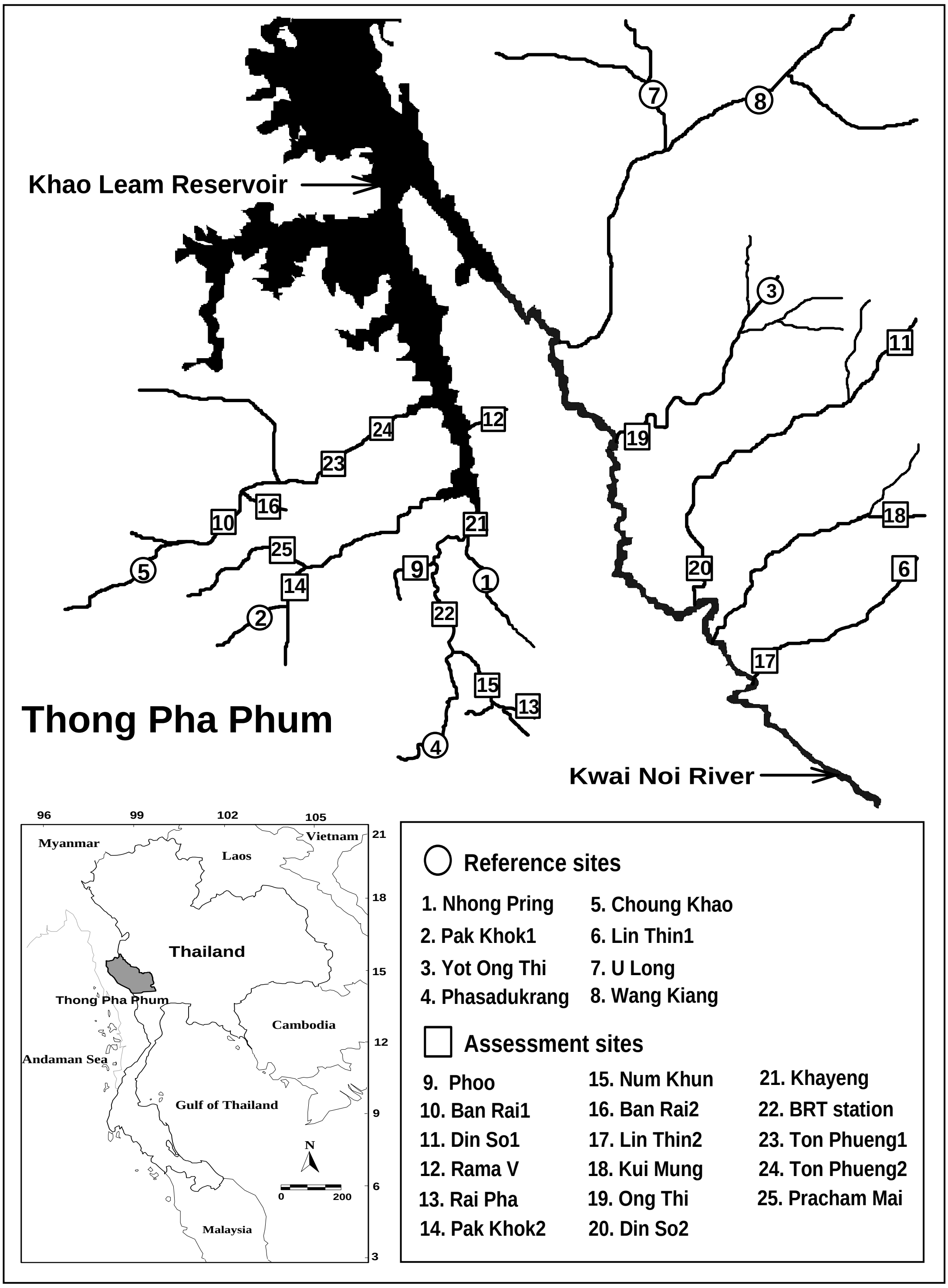

Figure 1. Map of sampling sites in Thong Pha Phum District, Western Thailand. Circles represent reference site (1-8). Squares represent assessment site (9-25).

Table 1. Physicochemical characteristics for reference sites in Thong Pha Phum District, Western Thailand.

Station	Velocity (cm/s)	Discharge (l/s)	Temperature (°C)	Turbid (NTU)	Conductivity (µS)	pH	Dissolved oxygen (mgO_2/L)	Ammonia (μgNH_3-N/L)	Nitrate (μgNO_3-N/L)	Nitrite (μgNO_2-N/L)	Total iron (µgFe/L)	Alkalinity (mg/L, pH 4.5)	Phosphate ($\mu gPO_4/L$)	BOD (mg/L)	Visual evaluation of quality
1st order stream															
Nhong Pring	35	288	24.4	5	630	8.0	6.1	10	400	3	200	355	33	112	good
2nd order stream															
Pak Khok 1	41	206	26.4	8	124	7.6	7.1	20	500	4	305	72	15	63	good
Yot Ong Thi	18	17	25.8	*	401	7.9	7.1	40	1,100	6	220	240	70	71	good
3rd order stream															
Phasadukrang	37	571	24.1	11	48	7.1	7.4	20	633	3	253	26	77	72	good
Choung Khao	56	497	24.1	6	121	7.8	7.5	0	800	5	173	77	162	83	good
Lin Thin1	30	160	24.1	*	354	8.1	7.4	0	1,600	5	100	219	190	50	good
4th order stream															
U Long	107	2,601	25.5	*	238	8.2	8.3	10	1,800	4	280	144	50	67	good
Wang Kiang	20	534	25.7	*	234	7.9	8.3	0	2,800	5	260	146	600	40	good

* Equipment failure

Table 2. Source of impairment in each assessment site.

Stream	Source of impairment		
	Agriculture	Human Habitation	Road construction
1st order stream			
Phoo	moderate	slight	slight
Ban Rai1	slight	high	slight
Din So1	slight	high	slight
Rama V	slight	moderate	slight
2nd order stream			
Rai Pha	high	high	slight
Pak Khok2	slight	high	slight
3rd order stream			
Num Khun	moderate	high	slight
Ban Rai2	moderate	high	slight
Lin Thin2	moderate	moderate	slight
Kui Mung	moderate	moderate	slight
Ong Thi	high	high	slight
Din So2	high	moderate	slight
4th order stream			
Huai Khayeng	moderate	moderate	slight
BRT station	high	high	slight
Ton Phueng1	high	high	slight
Ton Phueng2	slight	Slight	absent
Pracham Mai	moderate	moderate	slight

directly equated to those elsewhere in Thailand especially in more industrial regions.

The quantity and quality of the allothonous contributions at the assessment sites can be expected to be reflected in the physico-chemical composition of the water and substrate (Table 3). Turbidity tended to be higher in assessment than reference sites. Assessment sites were often in close proximity to unfinished or gravel roads or near agricultural and urban areas and the recipient of runoff heavily laden with silt. Ambient oxygen concentrations were quite variable among the assessment sites, some being lower than reference sites and others being about the same or even higher. Sites with very high oxygen were also rich in aquatic plants, and plant nutrients including phosphate and nitrate (Table 3). The abundant plant biomass at these sites clearly contributed to the ambient oxygen concentration during the daylight hours when measurements were made.

Riparian and macrophyte cover, dominant particle size, velocity, and discharge among 1st to 4th order streams was similar in assessment and reference sites. Conductivity, pH, dissolved oxygen, ammonia, nitrate, nitrite, total iron, alkalinity, phosphate, and BOD varied considerably among the assessment sites. They did not relate to stream order but were often higher than the equivalent chemical at reference sites (Table 3).

Methodology

Bioassessment of water quality in Thong Pha Phum District was investigated on the basis of benthic macroinvertebrates and zooplankton (cladocerans) and a large number of physicochemical factors. Benthic macroinvertebrates were sampled from riffle habitats, using two Surber samplers and a D- frame dip net, both fitted with 500 µm mesh netting, along a 50 m length of stream at each site. The substratum was disturbed by hand (Surber) and by foot (D-net) to dislodge macroinvertebrates while holding the collecting net downstream. Qualitative samples were taken with sieves from the rocks and stones also to examine for macroinvertebrates. After sampling, the contents of the net were emptied into a bucket and rinsed with water. After elutriation to remove the majority of inorganic material, the entire sample was placed onto a 500 µm sieve before pouring it into a sample container and preserving in 95% alcohol. Cladocera were collected using a Schindler-

Table 3. Physicochemical characteristics for assessment sites in each stream order in Thong Pha Phum District, Western Thailand.

Station	Velocity (cm/s)	Discharge (l/s)	Temperature (°C)	Turbid(NTU)	Conductivity (uS)	pH	Dissolved oxygen (mgO_2/L)	Ammonia (μgNH_3-N/L)	Nitrate (μgNO_3-N/L)	Nitrite (μgNO_2-N/L)	Total iron (μgFe/L)	Alkalinity (mg/L, pH 4.5)	Phos phate (μgPO_4/L)	B O D (mg/L)	Visual evaluation of quality
1 st order stream															
Phoo	19	327	30	*	370	8.5	8.0	60	200	5	100	240	30	70	slight
Ban Rai1	24	71	26.7	24	154	7.0	7.5	80	2,400	12	160	138	30	112	moderate
Din So1	20	75	24.8	*	331	8.1	8.3	0	1,800	2	210	240	20	**	moderate
Rama V	35	51	27.4	6	595	8.2	7.9	40	700	10	30	383	260	**	slight
2 nd order stream															
Rai Pha	13	120	26.4	29	397	8.0	5.7	90	1,100	8	690	265	270	**	moderate
Pak Khok2	54	164	26.9	27	216	7.2	3.7	25	600	4	170	123	68	81	moderate
3 rd order stream															
Num Khun	41	585	26.1	21	374	7.9	6.1	90	173	5	600	257	137	87	slight
Ban Rai2	21	21	27.5	11	395	7.6	1.8	20	800	5	610	240	290	**	moderate
Lin Thin2	40	180	26.7	*	470	8.1	9.3	10	1,300	5	110	292	80	65	slight
Kui Mung	4	87	27.6	*	649	7.2	3.4	20	2,300	7	60	408	250	60	slight
Ong Thi	57	530	27.8	*	395	8.0	6.9	50	1,100	6	420	238	50	53	moderate
Din So2	35	314	26.3	*	366	7.9	6.9	50	1,200	4	280	218	50	71	slight
4 th order stream															
Huai Khayeng	50	793	26.9	16	195	7.8	6.8	35	333	5	480	119	87	110	slight
BRT Station	44	1,156	26.5	16	263	8.0	7.5	23	567	4	457	153	66	96	slight
Ton Phueng1	40	1,319	26.7	12	108	7.3	7.1	20	1,000	4	505	76	95	67	slight
Ton Phueng2	40	113	25.2	11	125	7.2	5.6	0	1,500	3	930	80	140	**	slight
Pracham Mai	51	1,136	31.2	2	116	8.5	9.5	0	2,300	6	160	62	130	**	slight

*, ** Equipment failure

Patalas trap (10 L) fitted with a 30 μm site and a qualitative sample was taken by plankton net also of 30 μm mesh. Benthic cladocerans were collected with two Surber samplers also fitted with 30 μm mesh net. Samples were immediately preserved in 5% formalin.

Benthic macroinvertebrates (n=36) and cladocerans (n=72) were collected three times from six stream sites, Phasadukrang in Aug-04, Nov-04, April-05, Num Khun, Huai Khayeng, BRT station, Nhong Pring, and Choung Khao in Aug-04, Nov-04, Feb-05. Four sites were collected two times, Pak Khok1, Pak Khok2, and Ton Phueng1 in Aug-04, Nov-04, and Ban Rai2 in Nov-04 and Feb-05. The remaining fifteen sites were collected once.

Data was analyzed for community structure using PC-ORD program version 3.2. Canonical Correspondence analysis (CCA) was applied to examine correlation between biotic and physicochemical parameters. The same data was processed according to biological measurements such as species richness, biotic indices, BioMap Index and metrics for assessing water quality in Thong Pha Phum District.

Results

Currently, approximately one half of all benthic macroinvertebrate samples have been identified. Samples have been identified to the lowest practical taxonomic level, often to genus. However, for this report taxa are given only at the level of Family as this is the taxonomic level used most often in modern bioassessment studies. A full taxonomic account will be provided in the final report. Cladoceran samples will be identified after the benthic macroinvertebrates samples are completed. A total of 55 families of benthic macroinvertebrates have been identified from the reference sites (Table 4). The number of taxa from individual sites ranged from 35 to 44 among the reference sites and were only slightly higher for the sites on the 3rd and 4th order streams than those at 1st and 2nd order stream sites (Table 4). The total number of families within each of the major orders showed no obvious pattern of change between the 1st and 4th order stream sites. Indeed, the major families were similar across all reference sites. The total numbers of individuals by Order were highest in Ephemeroptera, especially family Baetidae and Leptophlebiidae. Second highest numbers were in Tricoptera, especially family Hydropsychidae, followed by Diptera. In contrast, total taxa and number of individuals was lowest in Annelida.

A general comparison of benthic macroinvertebrates in Thong Pha Phum streams suggest a similar structure across reference sites with those from unimpaired streams elsewhere in Asia, particularly south east Asia, with Ephemeroptera and Trichoptera being particularly well represented in terms of number of families and individuals. The taxa from temperate streams is also similar in many respects but differs in having a richer fauna of Plecoptera than occurs in tropical streams, undoubtedly related to their affinity for cold water (Dudgeon, 1999). Thus, in the Ravella River in Northern Italy, most abundant macroinvertebrates belonged to the orders: Ephemeroptera, Plecoptera, Tricoptera, and Diptera while the least abundant were in the Order Coleoptera (Ravera, 2001). In Argentina, the dominant taxa in streams, contaminated by urban and industrial effluents were chironomids (Order Diptera), followed by the coleopterans in the families Hydrophilidae, Elmidae and Dytiscidae (Capitulo et al., 2001). In the present study the macroinvertebrate fauna from the sites evaluated as impaired was similar both in composition and abundance to that found in Argentinian streams.

Benthic macroinvertebrates across the nine assessment sites were represented by a total of 53 families (Table 5) and varied greatly among sites from 18 to 40 families with an average of 30. Overall the number of taxa was higher in the reference than assessment sites with the average for the former being 39. The number of individuals was also highly variable but tended to be higher at the reference sites. Within orders, the numerically dominant families were similar across reference and assessment sites, although the total number of families within the orders Diptera, Ephemeroptera and Trichoptera was the higher across the reference sites. Assemblage structures were similar between reference and assessment sites with the greatest relative abundance in the order Ephemeroptera, especially the families Baetidae and Leptophlebiidae. Relative abundance was high also in Trichoptera, especially the family Hydropsychidae, followed by Diptera and lowest in Annelida. These results suggest that none of the sites was severely impaired.

Biological methods to assess water quality are many. Perhaps the simplest methods

Table 4. Relative abundance of benthic macroinvertebrates (number/ 0.09 m^2) in 1^{st} to 4^{th} order stream from reference sites in Thong Pha Phum District, Western Thailand.

Taxa	1^{st} order	2^{nd} order	3^{rd}- 4^{th} order stream	
	Nhong Pring	**Pak khok 1**	**Phasadukrang**	**Choung Khao**
Order Coleoptera (Beetles):				
Family Elmidae	21	20	21	102
Family Helodidae	48		1	9
Family Hydrophilidae	2		7	7
Family Psephenidae	32	27	68	46
Order Diptera (Flies):				
Family Athericidae	1	11		63
Family Ceratopogonidae	1	2	1	2
Family Chironomidae (Midges)				
Subfamily Chironominae	37	45	6	40
Subfamily Diamesinae		4		
Subfamily Tanypodinae	2	5	1	15
Family Culicidae (Mosquitoes)	8	15	1	18
Family Muscidae-Anthomyiidae	13	9	1	10
Family Simulidae (Black flies)	203	10	5	63
Family Tipulidae	10	4	2	17
Order Ephemeroptera (Mayflies):				
Family Baetidae	220	51	37	538
Family Caenidae	16	37	3	13
Family Ephemerellidae	21	48	50	78
Family Ephemeridae		1	1	5
Family Heptageniidae	181	21	26	253
Family Leptophlebiidae	256	56	65	176
Family Polymitarcyidae			3	1
Family Prosopistomatidae			4	
Order Hemiptera (Bugs):				
Family Belostomatidae			2	
Family Gerridae	5		4	6
Family Naucoridae	1		5	14
Family Veliidae			1	
Order Lepidoptera (Butterfies):				
Family Pyralidae		3	14	22
Order Megaloptera:				
Family Corlydalidae	6	6	4	15
Order Odonata:				
Suborder Anisoptera (Dragonflies):				
Family Calopterygidae	15			2
Family Corduliidae	2	6	1	
Family Gomphidae	6	20	41	94
Suborder Zygoptera (Damselflies):				
Family Chlorocyphidae		1		3
Family Euphaeidae	131	86	10	92

Table 4. (continued)

Taxa	1st order	2nd order	3rd- 4th order stream	
	Nhong Pring	Pak khok 1	Phasadukrang	Choung Khao
Order Plecoptera (Stoneflies):				
Family Nemouridae				30
Family Peltoperlidae			8	7
Family Perlidae	1	7	26	64
Order Tricoptera (Caddisflies):				
Family Calamoceratidae	1			
Family Glossosomatidae				1
Family Goeridae		1		
Family Helicopsychidae	20		6	
Family Hydropsychidae	6	149	39	405
Family Hydroptilidae		9	5	2
Family Leptoceridae				4
Family Philopotamidae	36	5		4
Family Polycentropodidae	9	2	1	6
Family Psychomyiidae		7	8	104
Family Rhyacophilidae				1
Family Stenopsychidae			22	
Crustaceans:				
Crab	9	4	6	3
Shrimp	118	2	9	9
Mollusca:				
Family Bithyniidae			2	
Family Corbiculidae	2	1		
Family Planorbidae	1			1
Family Thiaridae	46	6	10	5
Annelids:				
Leeches	11			1
Worms	29	2		1
Total Taxa	37	35	40	44
Total Number	1,527	683	527	2,352
Total (all reference sites)	← 55 →			

compare number of taxa between a reference and assessment site, the assumption being a direct association with water quality. On the basis of the number of taxa, the reference sites contained about 40 taxa whereas the number at the assessment sites varied from 18 to 40, suggesting a degree of impairment among sites (Table 5). Another relatively simple method plots cumulative abundance of individuals against taxa rank or order among sites, an example of the latter being the k-dominance curves. Here a difference in the slope of the curves indicates a difference in community structure, thought also to reflect a difference in water quality. Comparisons of the relationships between taxa rank and % cumulative abundance among the reference and assessment sites in this study did not indicate differences in benthic macroinvertebrate communities (Fig. 2) in contrast to other bioassessment methods and appears not to be a sensitive bioassessment method for Thai streams.

Biotic indices have long been used to convert biological data into a measure of water quality. Biotic indices take many forms. One of the simplest biotic indices is the EPT Index

Table 5. Relative abundance of benthic macroinvertebrates (number/ 0.09 m^2) in 1st to 4th order stream from assessment sites in Thong Pha Phum District, Western Thailand.

Taxa	1st order		2nd order	3rd order	4th order stream				
	Rama V	**Ban Rai 1**	**Pak Khok 2**	**Nam Khun**	**Huai Khayeng**	**BRT station**	**Ton Phueng1**	**Ban Rai 2**	**Pracham Mai**
Order Coleoptera (Beetles):									
Family Elmidae	1	4	3	62	28	10	86	116	41
Family Gyrinidae					2				
Family Helodidae	49	4	4	14	11	3	11	12	2
Family Hydrophilidae		6	1	2	2	2	3		3
Family Psephenidae	1		19	38	163	15	57		15
Order Diptera (Flies):									
Family Athericidae	1		25		6	3	3	1	
Family Ceratopogonidae	1		3	2	4	3	4	2	1
Family Chironomidae (Midges)									
Subfamily Chironominae	40	2	49	19	97		93	31	8
Subfamily Diamesinae									
Subfamily Tanypodinae	24		11	2	11		13	12	7
Family Culicidae (Mosquitoes)	1	1	5	5	16	3	15	10	6
Family Muscidae-Anthomyiidae	8		6	2	7		1		
Family Simulidae (Black flies)		66	14	185	21	8	364	14	2
Family Tipulidae			6	5	9	15	11	13	7
Order Ephemeroptera (Mayflies):									
Family Baetidae	26	15	126	148	204	85	268	44	127
Family Caenidae	107	50	67	57	44	10	101	179	7
Family Ephemerellidae			10	2	35	15	7	1	6
Family Ephemeridae							7	17	
Family Heptageniidae		2	35	17	65	15	380	9	38
Family Leptophlebiidae	10	1	18	1	57	20	94	51	50
Family Polymitarcyidae		1							
Order Hemiptera (Bugs):									
Family Belostomatidae								1	
Family Gerridae		5	3	3		1	5		
Family Naucoridae				10	26	30			16
Family Veliidae		2							
Order Lepidoptera (Butterfies):									
Family Pyralidae		5	15	3	7	3	1	1	1
Order Megaloptera:									
Family Corlydalidae			2	1	1	3	7	2	
Order Odonata:									
Suborder Anisoptera (Dragonflies):									

Table 5. (continued)

Taxa	1st order		2nd order	3rd order	4th order stream				
	Rama V	Ban Rai 1	Pak Khok 2	Nam Khun	Huai Khayeng	BRT station	Ton Phueng1	Ban Rai 2	Pracham Mai
Family Calopterygidae			11			5		33	
Family Corduliidae			16	5	1		1		
Family Gomphidae	1	1	14	17	16	6	3	2	2
Family Macromiidae		1							
Suborder Zygoptera (Damselflies):									
Family Amphipterygidae				7			1		
Family Chlorocyphidae			5				5		
Family Euphaeidae	2		14	23	8	5	89	10	4
Order Plecoptera (Stoneflies):									
Family Perlidae		1	3	1	51	6	9		35
Order Tricoptera (Caddisflies):									
Family Brachycentridae				1					
Family Helicopsychidae				7					
Family Hydropsychidae		18	89	107	160		101	34	
Family Hydroptilidae			3	9	5	4	1		1
Family Leptoceridae			3	2				12	
Family Odontoceridae				1					
Family Philopotamidae		1	1	18	9		12		
Family Polycentropodidae			2	2	2		1		
Family Psychomyiidae			2	2	5		1		
Family Xiphocentronidae				4					
Crustaceans:									
Crab	2		6	2	3		8	16	1
Shrimp			2	2		2		16	
Ostracod		1	1			1	2	3	
Mollusca:									
Family Ancylidae			5			2		2	
Family Corbiculidae				9	1				
Family Sphaeriidae				6					
Family Thiaridae	54	3		41	35	11		1	99
Annelids:									
Leeches	2	1	1				3	9	2
Worms	1		1		2	2	21	6	10
Total Taxa	18	22	38	40	34	28	36	30	25
Total Number	331	191	601	844	1114	288	1789	660	491
Total Taxa (all study sites)	←				53				→

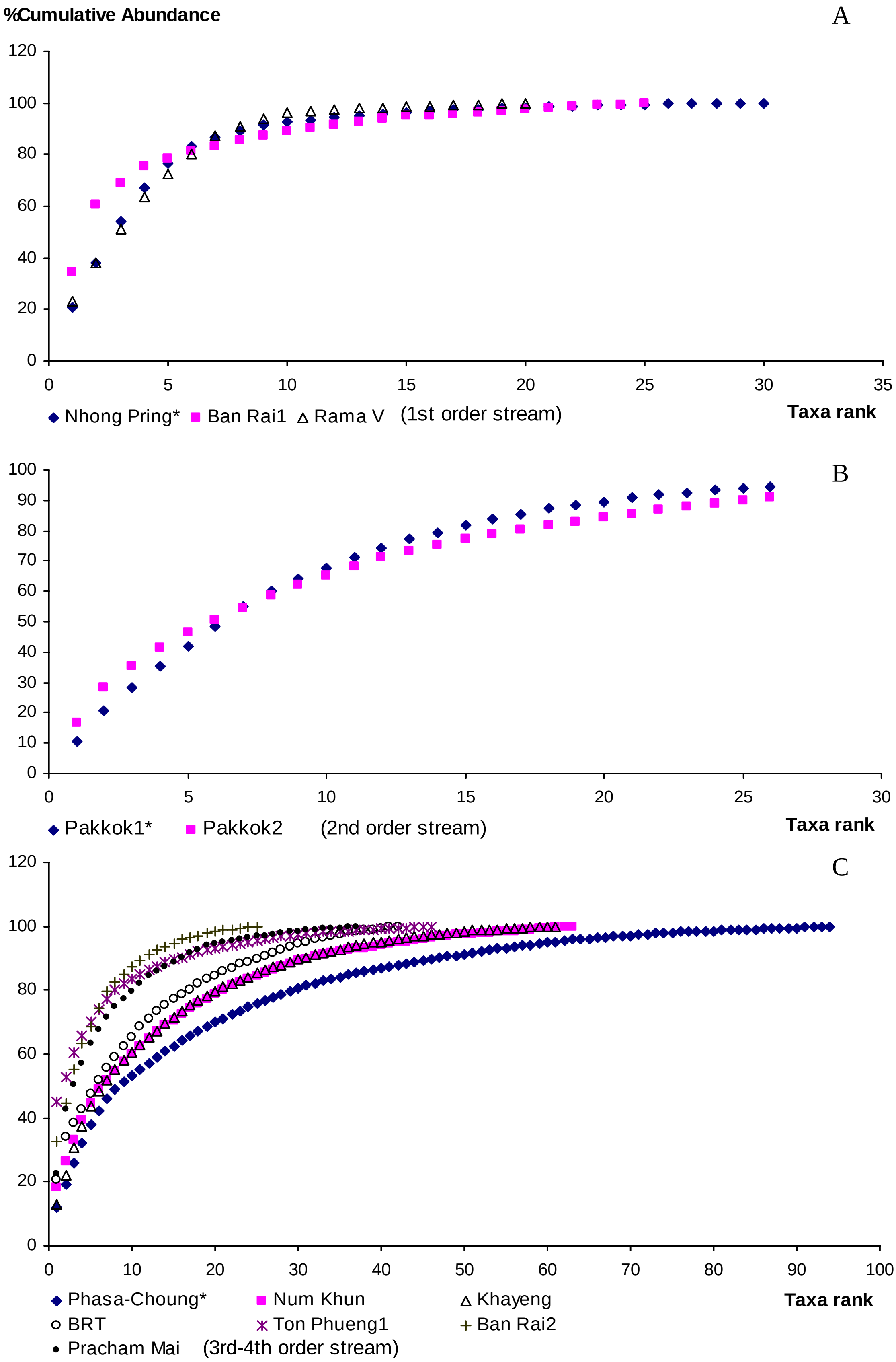

Figure 2. Relation between taxa rank (x-axis) and % cumulative abundance (y-axis) in each order stream. A, B, and C present reference site (*) and assessment sites in 1st, 2nd, and 3rd-4th order streams, respectively.

Table 6. Comparative results of several biotic indices where UN indicated unimpaired, IM (impaired), SI (slightly impaired).

Station	Visual evaluation	Taxa Richness	Number of Individuals	BioMap Index		EPT Index	RBP II
				WQI (d)	WQI (q)		
1 st order stream							
Nhong Pring*	UN	37	1,527	IM	UN	UN	UN
Rama V	SI	18	331	IM	UN	UN	IM
Ban Rai1	IM	22	191	IM	UN	UN	IM
2 nd order stream							
Pak khok 1*	UN	35	683	UN-IM	UN	UN	UN
Pak khok 2	IM	38	601	UN-IM	UN	UN	UN
3 rd order stream							
Phasadukrang*	UN	40	527	UN	UN	UN	UN
Choung Khao*	UN	44	2,352	UN	UN	UN	UN
Nam Khun	SI	40	844	UN	UN	UN	UN
Ban Rai2	IM	30	660	IM	UN	IM	IM
4 th order stream							
Huai Khayeng	SI	34	1,114	UN	UN	UN	UN
BRT station	SI	28	288	UN	UN	IM	IM
Ton Phueng1	SI	36	1,789	UN	UN	SI	UN
Pracham Mai	SI	23	491	UN	UN	UN	UN-IM

which is the sum of all taxa of Ephemeroptera, Plecoptera and Trichoptera in an assessment site expressed as a percentage of those in one or more reference sites. In this study, assessment sites scoring <70% were considered moderately impaired, 70-90 %, slightly impaired and >90%, unimpaired (Plafkin et al., 1990). With this scoring criteria and relative to fauna from reference sites of the same stream order, five assessment sites were evaluated as unimpaired, Rama V, Ban Rai1, Pak Khok2, Nam Khun, Huai Khayeng, and Pracham Mai. Ton Phueng1 was scored as slightly impaired. The remaining two, Ban Rai2 and BRT Station, were scored as moderately impaired (Table 6).

BioMap Index (Griffiths, 1999; Biological Monitoring and Assessment Program) evaluates the impact of point-source and diffuse-source pollution on water quality. It incorporates information about the ecological requirements of individual macroinvertebrates with a measure of their density using either quantitative [WQI (d)] or qualitative [WQI (q)] samples to assess water quality (Table 7). Application of the qualitative BioMap Index to the assessment sites examined so far in Thong Pha Phum District indicates all to be unimpaired. In contrast, the quantitative BioMap Index suggests some impairment among the reference and assessment sites, although less frequent among the former (Table 7). The sometimes divergent assessments among the qualitative and quantitative methods of BioMap is of some concern and will be closely monitored as the number of completed sites increases. It does appear that water quality assessments using BioMap, are independent of season based on the sites examined to the present.

Recently, metrics were developed for bioassessment purposes. The Rapid Bioassessment Protocol II (RBP II; Plafkin *et al.*, 1990) is the example chosen for this study. The eight metrics each focus on some level of biological impairment of the benthic community such as the absence of pollution-sensitive macroinvertebrate taxa. The data analysis scheme used in RBP II integrates several community, population, and functional parameters into a single evaluation of biotic integrity. Each metric measures a different component of community structure and has a different range of sensitivity to pollution stress. Further, each metric is based on the less rigorous taxonomic level of family. Application of the RBP II metrics to the assessment sites relative to the reference site(s) from the same order stream indicates four sites to be unimpaired, Pak Khok 2, Nam Khun, Huai Khayeng, and Ton Phueng 1. Four sites scored as moderately impaired, Rama V, Ban Rai 1, BRT station and Ban Rai 2 and one, Pracham Mai, was equivocal (Table 8).

Table 7. BioMap index (Griffiths 2001). Quantitative samples collected by surber sampler are given by WQI (d) and qualitative samples collected by D-frame dip net are given by WQI (q). For 1st and 2nd order streams (bankfull width of 4 to 16 m), values <10 indicate impaired (IM) for WQI (d), <2.6 for WQI (q), >12 indicate unimpaired (UN) for WQI (d), and >3 for WQI (q). For 3rd and 4th order streams (bankfull width of 16 to 64 m), values <7 indicate impaired for WQI (d), <2 for WQI (q), >9 indicate unimpaired for WQI (d), and >2.4 for WQI (q). UN-IM value of WQI indicated between unimpaired and impaired value. * indicated reference sites.

Station	Month	WQI (d)	WQI (q)
1 st order stream			
Nhong Pring*	Aug, 04	7.9 (IM)	5.0 (UN)
	Nov, 04	8.9 (IM)	7.1 (UN)
	Feb, 05	6.5 (IM)	7.3 (UN)
Rama V	Feb, 05	6.7 (IM)	3.8 (UN)
Ban Rai1	Aug, 04	7.6 (IM)	6.0 (UN)
2 nd order stream			
Pak khok 1*	Aug, 04	10.2 (UN-IM)	7.7 (UN)
	Nov, 04	10.0 (UN-IM)	7.5 (UN)
Pak khok 2	Aug, 04	11.4 (UN-IM)	6.7 (UN)
	Nov, 04	9.2 (IM)	7.1 (UN)
3 rd order stream			
Phasadukrang*	Aug, 04	12.7 (UN)	8.2 (UN)
	Nov, 04	13.1 (UN)	7.5 (UN)
Ban Choung Khao*	Aug, 04	11.8 (UN)	9.0 (UN)
	Nov, 04	12.1 (UN)	8.0 (UN)
	Feb, 05	10.8 (UN)	7.8 (UN)
Nam Kun	Aug, 04	9.7 (UN)	7.0 (UN)
	Nov, 04	10.4 (UN)	7.5 (UN)
4 th order stream			
Huai Khayeng	Aug, 04	10.0 (UN)	5.8 (UN)
	Nov, 04	10.2 (UN)	7.7 (UN)
BRT station	Nov, 04	11.0 (UN)	7.2 (UN)
Ton Phueng1	Aug, 04	11.3 (UN)	7.5 (UN)
	Nov, 04	9.7 (UN)	7.2 (UN)
	Feb, 05	7.9 (UN-IM)	6.7 (UN)
Ban Rai2	Nov, 04	6.8 (IM)	6.2 (UN)
	Feb, 05	6.6 (IM)	6.4 (UN)
Pracham Mai	Feb, 05	9.4 (UN)	8.2 (UN)

Canonical Correspondance Analysis (CCA) is another method with the potential for application in water quality evaluation. In this study, CCA of all sites, both reference and assessment, recognized three assemblages of benthic macroinvertebrates (Fig. 3). Assemblage 1 contained 4 sites, assemblage 2, 4 sites, and assemblage 3, 5 sites. Stream order was not important to assemblage composition. CCA allowed for an examination of the correlations among species, sites, and environmental factors (Fig. 3A). The main factors affecting composition of benthic macroinvertebrates were alkalinity, discharge, conductivity, phosphate, ammonia, and velocity, respectively. Taxa within assemblage 1 were positively related with alkalinity and conductivity, and negatively with velocity. Assemblage 2 represented sites where phosphate and ammonia occurred in high concentration, often associated with high ambient organic content and impaired water quality. Of the 4 sites in assemblage 2, Rama V and Ban Rai 2 were considered impaired by at least some of the other tests applied. However, the other 2 sites in assemblage 2, Pak Khok 2 and Pracham Mai were not considered impaired by the other tests. Further, Ban Rai 1 and BRT station, considered impaired by some of the other tests were not included in assemblage 2. Taxa in assemblage 3 were positively related with velocity, and negatively related with alkalinity and conductivity.

CCA was also useful in identifying the environmental factors important to the presence of the benthic macroinvertebrates found in this study (Fig. 3B). Thus, for example, trichopterans in the family Polycentropodidae and ephemeropterans in the families Baetidae and Heptagenidae were abundant where discharge was high and ammonia and phosphate low. In contrast, when conductivity

Table 8. Values for metrices for reference and assessment sites to be used in the Rapid Bioassessment Protocol II (Plafkin et al. 1990), Total score showed score from total percentage values of assessment site to reference site by Rapid Bioassessment Protocol II (where total score >79% indicate unimpaired (UN), and 29-72% moderately impaired (MI).

Matric	Reference sites				Assessment sites								
	1st order	2nd order	3rd-4th order		1st order		2nd order	3rd-4th order					
	Nhong Pring	Pak Khok 1	Phasadu krang	Choung Khao	Rama V	Ban Rai 1	Pak Khok 2	Nam Khun	Ban Rai 2	Huai Khayeng	BRT Station	Ton Phueng1	Pracham Mai
1. Taxa Richness	37.00	35.00	40.00	44.00	18.00	22.00	38.00	40	30	34	28	36	25
2. Family Biotic Index	4.34	3.85	3.52	3.84	5.60	5.40	4.60	4.8	5.0	4.3	4.4	4.5	4.6
3. Ratio of Scrapers/ Collector	0.55	0.49	0.94	0.74	0.50	0.20	0.60	0.5	0.4	0.8	0.8	0.7	0.6
4. Ratio of EPT and Chironomid	0.95	0.69	0.98	0.88	0.90	1.00	1.00	0.9	0.9	0.9	1	0.9	0.9
5. % Contribution of Dominant	16.76	21.82	12.90	22.87	32.30	34.60	21.00	21.9	27.1	18.3	29.5	21.2	25.9
6. EPT Index (%)	-	-	-	-	109.09	145.45	600.00	152.38	66.67	104.76	67	76.19	114.29
7. Community Loss Index	-	-	-	-	1.10	0.90	0.10	0.2	0.6	0.3	0.6	0.3	0.8
8. Ratio of Shredders/Total	0.00	0.09	0.06	0.05	0.12	0.07	0.13	0.05	0.09	0.11	0.08	0.06	0.04
Total score	-	-	-	-	62.5	56.25	87.50	81.25	56.25	87.5	62.5	81.25	75
Assessment of water quality	-	-	-	-	MI	MI	UN	UN	MI	UN	MI	UN	UN-MI

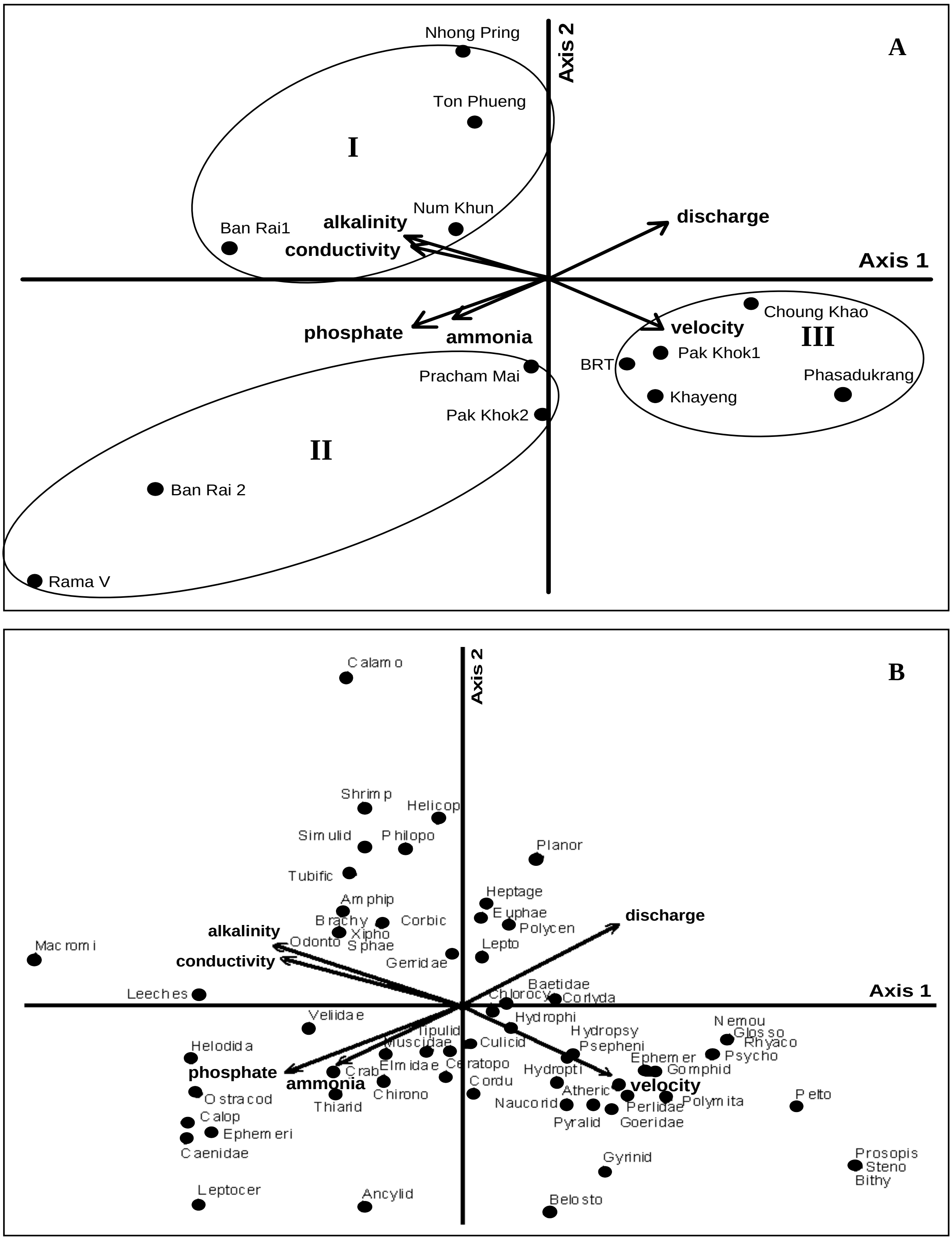

Figure 3. CCA showing correlation between sites (A), species (B) and environmental gradients (arrow lines-A & B) (Monte Carlo test; $p = 0.002$, eigenvalue axis1 = 0.24, eigenvalue axis 2 = 0.18, Pearson correlation: $r^2 = 1.00$). Solid circles represent sites (A), solid circles represent species (B), and arrows lines, environmental gradients (A&B). Length of lines reflect strength of their effect. Sites and lines (A) and Species and line (B) in same quadrate show positive correlations whereas a negative correlation is indicated where in an opposite quadrate.

and alkalinity were high and velocity, low, blackfly larvae (Simulidae), water striders (Gerridae) and tubificids (Chironomidae), all in the order Diptera, were abundant along with trichopterans in the family Xiphocentronidae. Information produced by CCA is potentially extremely useful in assigning sensitivity and tolerance values to the Thai fauna of macroinvertebrates. Tolerance and sensitivity values are necessary for many bioassessment models. In the present study, sensitivity and tolerance values had to be adopted from North American fauna as they are not currently available for Thai fauna.

Discussion and Conclusion

In summary, our study on bioassessment of water quality in Thong Pha Phum District on benthic macroinvertebrate showed similarity of biodiversity and composition of benthic macroinvertebrate in reference and study sites. For biotic indices and the multivariate method study sites could not be obviously separated from reference sites. For metrics, study site were unimpaired and modestly impaired. In the next time period we will complete the identification all taxa of benthic macroinvertebrates and cladocerans from Thong Pha Phum District, western Thailand.

Moreover, we expect to sample a few more sites, particularly in severely disturbed areas outside Thong Pha Phum District. We will continue to apply existing assessment models to evaluate ecosystem health including one developed in Australia and recently applied in Indonesia (Sudaryanti et al,. 2001). It is quite possible that no existing model will exactly fit the situation in Thailand, requiring us to either modify existing models or to develop a new model specifically for Thailand.

Acknowledgements

This work was supported by the TRF/BIOTEC Special Program for Biodiversity Research and Training grant and PTT Pubic Company Limited BRT R_247005. We wish to extend our appreciation to the Biology and Aquatic Sciences Departments, Burapha University, for the loan of equipment.

References

Barbour, M.T., J. Gerritsen, B.D. Synder and J.B. Stribling. 1997. Revision to: Rapid bioassessment protocols for use in streams and rivers: periphyton, benthic macroinvertebrates, and fish. EPA-841-D-97-002. Environmental Protection Agency, U.S.

Beak, T.W. 1964. Biological measurements of water pollution. *Chemical Engineering Progress* 60: 39-43.

Beck, W.M. 1955. Suggested method for reporting biotic data. *Sewage and Industrial Wastes* 27: 1193-1197.

Capitulo, A.R., M. Tongorra and C. Ocon. 2001. Use of benthic macroinvertebrates to assess the biological status of Pampean streams in Argentina. *Aquatic Ecology* 35: 109-119.

Chandler, J.R. 1970. A biological approach to water quality management. *Water Pollution Control* 4: 415-422.

Davies, P.E. 2000. Development of a national bioassessment system (AUSTRIVAS) in Australia. *In* Wright, J.F., D.W. Sutcliffe and M.T. Furse (eds.). Assessing the Biological Quality of Freshwaters. RIVPACS and other Techniques, pp. 113-124. Freshwater Biological Association Ambleside.

Dudgeon, D. 1999. Tropical Asian Streams: Zoobent Ecology and Conservation. Hong Kong Univer Press, Aberdeen, Hong Kong.

Forbes, S.A. and R.E. Richardson. 1913. Studies on the biology of the upper Illinois River. *Bulletin of the Illinois State Laboratory of Natural History* 9: 481-574.

Griffiths, R.W. 1999. BioMap: Bioassessment of water quality. The Centre for Environmental Training, Niagara College, Glendale Campus, Niagara-on-the Lake, Ontario. 110 p.

Hilsenhoff, W.L. 1982. Using a biotic index to evaluate water quality in streams. Wisconsin Department of Natural Resources, Madison, Wisconsin. Technical Bulletin No. 132.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. *Great Lakes Entomology* 20: 31-39.

Karr, J.R. 1990. Biological integrity and the goal of environmental legislation: lessons for conservation biology. *Conservation Biology* 4: 244-250.

Karr, J.R. 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications* 1: 66-84.

Novak, M.A. and R.W. Bode. 1992. Percent model affinity: a new measure of macroinvertebrate community composition. *Journal of the North American Benthological Society* 11: 80-85.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross and R.M. Hughes. 1990. Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish. Assessment and Watershed Protection Division, Washington, D.C.

Ravera, O. 2001. A comparison between diversity, similarity and biotic indices applied to the macroinvertebrate community of a small stream: the Ravella River (Como Province, Nortern Italy). *Aquatic Ecology* 35: 97-107.

Shannon, C.E. 1949. A mathematical theory of communication. *Bell System Technical Journal* 27: 379-423, 623-656.

Sudaryanti, S., Y. Trihadiningrum, B.T. Hart, P.E. Davies, C. Humphrey, R. Norris, J. Simpson and L. Thurtell. 2001. Assessment of the biological health of the Brantas River, East Java, Indonesia using the Australian River Assessment System (AUSRIVAS) methodology. *Aquatic Ecology* 35: 135-146.

Wiener, N. 1948. Cybernetics, or control and communication on the animal and the machine. M.I.T. Press, Cambridge, Massachusetts.

Wolda, H. 1981. Similarity indices, sample size and diversity. *Oecologia* 50: 296-302.

Wright, J.F. 1995. Development and use of a system for predicting macroinvertebrates in flowing waters. *Australian Journal of Ecology* 20: 181-197.