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Impacts of agricultural land use on stream benthic macroinvertebrates in tributaries of the Mekong River, northeast Thailand

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Abstract. Ecological impacts of non-intensive agricultural activities on stream community, especially in headwater streams adjacent to conserved areas, are poorly known in Thailand. We investigated the impacts of non-intensive agricultural activities on stream habitat characteristics and benthic macroinvertebrate community in the headwater streams, tributaries of the Mekong River, northeast Thailand. We compared the streams running through forests in National Parks and Wildlife Sanctuaries and those through agricultural areas. Twenty kick samples of benthic macroinvertebrates were collected using a D-frame dipnet (0.3 m wide, 450 μm mesh size) from each sampling site. Sixteen physicochemical parameters of stream characteristics were measured. The results suggested that this disturbance had an impact on stream habitats more than its community. Agricultural land use altered the streams to be wider, deeper, and more discharged with less percentage of riparian coverage and high water temperature. Benthic macroinvertebrate composition did not differ in both areas, but intolerant benthic fauna decreased, while tolerant taxa were predominant and more abundant in the agricultural areas. In this study, water velocity and water temperature are the major important variables related to the distribution of benthic macroinvertebrates.

Key Words: benthic macroinvertebrates, agriculture, headwater stream, Thailand.

Introduction. Benthic macroinvertebrates are defined as organisms that inhabit at the bottom substrates such as sediment, debris, logs, macrophytes, filamentous algae, etc. of freshwater habitat for at least of their life cycle (Rosenberg & Resh 1993). They are the important biological components of lotic ecosystems and enable distribution in microhabitats of streams and rivers (Hauer & Resh 2006). They serve as an intermediate role in the trophic level between primary producers and higher consumers which directly provide food for fish and some aquatic vertebrates (Cummins 1996; Hauer & Resh 2006). They also play an active role in nutrient cycle, primary production, detritus decomposition process and translocation of matters in the freshwater stream ecosystem (Wallace & Webster 1996; Covich et al 1999). In addition, benthic macroinvertebrate communities are widely used as biological monitoring of running water quality and/or habitat quality (Hellawell 1986; Rosenberg & Resh 1993; Fenoglio et al 2002; Hering et al 2004; Bonada et al 2006; Resh 2008; Norris & Barbour 2009).

It is well known that water velocity and temperature, altitude, season, characteristics of microhabitats and riparian forests, and dissolved matter strongly influence both the structures and communities of benthic macroinvertebrates in streams (Hynes 1970). In addition, interactions within stream channel, hyporheic zone and flooding zone also affect the structures of microhabitats, distribution and richness of macroinvertebrates (Hauer & Resh 2006). It also causes the difference of structures and functional feeding groups (FFGs) components of macroinvertebrates in stream orders according to River Continuum Concept (Vannote et al 1980). However, the studies of the benthic macroinvertebrate communities are heavily towards small streams in temperate regions (Dudgeon & Bretschko 1996; Feminella 1996). In tropical regions, a few studies have been carried out on diversity, structure and functional community of stream benthic fauna. For instance, Dudgeon (1984) surveyed the longitudinal and temporal changes in functional organization of macroinvertebrate communities in the Lam Tsuen River, Hong Kong, whereas Yule & Pearson (1996) looked at the aseasonality of benthic invertebrates in a tropical stream on Bougainvill Island, Papua New Guinea. Yule et al (2009) found that shredders in highland sites showed higher abundance and diversity than those of low land sites of Malaysian peninsular. Edia et al (2007) reported that Diptera and Ephemeroptera were the richest taxon diversity in little anthropogenic disturbance streams of coastal rivers of southeast Ivory Coast. According to Simberloff & Abele (1982); Soule (1991); Prendergast et al (1993) and Pressey et al (1993), protected areas are areas dedicated to the protection and maintenance of biological diversity, preventing loss of species and subspecies, and have an important ecological role in the land due to their functions as a biological corridor and a source of faunistic recolonisation. Previous studies have indicated that the occurrences of diversity and community structures of macroinvertebrates in the streams of protected areas were found more often than those of unprotected areas (Mancini et al 2005; Abellan et al 2007; Boonsoong & Sangpradub 2008; Pramual & Kuvangkadilok 2009). The influence of environmental variability on macroinvertebrate community, however, has scarcely been explored with respect to agricultural land use in headwater streams, northeast Thailand. In Thailand, many forest areas were protected as National Parks and Wildlife Sanctuaries. These areas will be well protected by laws as conserved areas. However, just outside of these areas, there are non-intensive agricultural activities by farmers. Ecological impacts of these activities are poorly known in Thailand. The objective of the present study was to assess the impact of non-intensive agricultural land use on physicochemical variables and benthic macroinvertebrate assemblage in headwater streams, tributaries of the Mekong River, northeast Thailand.

Material and Method

Study sites. The study area was located in northeast Thailand and at latitude 16º 30´-18º 28´ N, longitude 103º 15´-104º 30´ E. Twenty-five sampling sites were selected from the headwater streams, tributaries of the Mekong River as shown in Figure 1. Twelve sites were surrounded by forest areas in National Parks and Wildlife Sanctuaries whereas thirteen sites out of the conserved areas were influenced by various levels of anthropogenic stressors, mainly in agricultural areas. The major agricultural activity comprised rice, cassava, sugarcane, rubber trees, and orchards, including grazing cattle. However, the activities depended on seasons and could be categorized as non-intensive agriculture. The streams of all conserved or protected sites flow through deciduous dipterocarp forests, dry evergreen forests and mix deciduous forests. Typical riparian vegetation consisted of *Ficus* spp. and native flora.

Sampling and laboratory procedures. Macroinvertebrates were collected seasonally (hot, rainy and cool seasons) from each site using a D-frame dip net (0.3 m wide, 450 μm mesh) during 2005, 2006 and 2007. A total of 20 kicks were collected proportionately from all major habitat types over the length of the reach. For example, if the habitat in the sample reach is 50% of cobble, then 50% or 10 kicks should be taken in cobble substrate habitat. Contents of all 20 kicks were pooled into a single sample and preserved in 70% ethanol. In the laboratory, 300 individuals fixed-count sub-sampling were used according to Boonsoong et al (2009). All organisms from the sorted sub-samples were identified as the lowest possible taxonomic level, usually genus or species except for Annelida (class), Acarina (order), Collembola and Coleoptera (families). Identifications were based on Dudgeon (1999); Merritt & Cummins (1996); Morse et al (1994); Sangpradub & Boonsoong (2006). Voucher specimens have been deposited in Freshwater Biology Laboratory, Department of Biology, Faculty of Science, Khon Kaen University, Thailand.

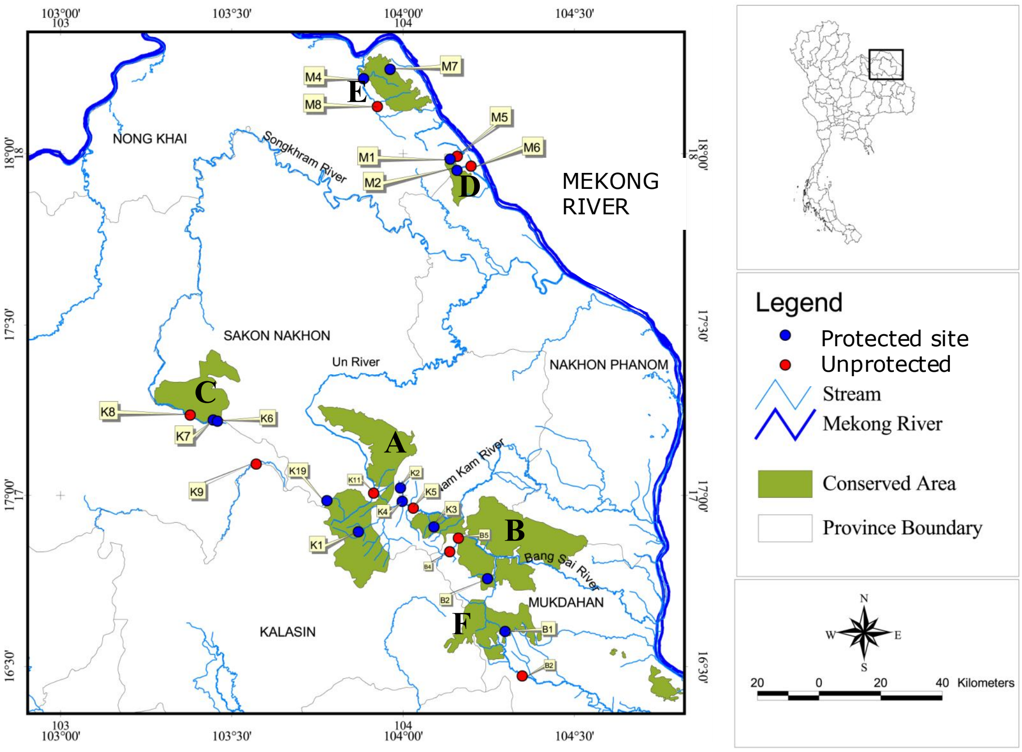

Figure 1. Map of study sites in tributaries of the Mekong River, northeast Thailand, with location of 25 sampling sites in protected areas (National Parks: A, B, C and D; and Wildlife Sanctuaries: E and F) and non-intensive agricultural areas.

Chemical variable parameters of water quality were measured along with the collection of benthos at each of the sampling sites. The measurements were done prior to the benthos collection. *In situ* measurements included Dissolved Oxygen (DO) (mg/L) and water temperature (ºC) with a YSI Dissolved Oxygen Meter Model 57, pH with the sensionTM[1] Portable pH meter, electoconductivity (µS/cm) and total dissolved solids (TDS) (mg/L) with Fisher Scientific method 09-326-2. Suspended solid (mg/L), turbidity (FAU), nitrate (mg/L NO^{3-}-N) and orthophosphate (mg/L PO_4^{3-}) were measured using Hach DR/2010 spectrophotometer model 49300-00, BOD_5 (mg/L) was determined as the difference between initial and 5-day oxygen concentrations in bottles after incubation at 20 ºC, and chlorophyll *a* (µg/L) was measured with an extracted-methanol method (APHA, AWWA & WPCF 1998). The physical properties of streams such as altitudes of locations (m a.s.l.), width (m) and the depth (m) of streams, channel morphology, bank structure, riparian vegetation, percentage canopy cover, light intensity (Lux), and water discharge (cm^3/sec) at each sampling site were also assessed.

Data analysis. Means and ranges of all measured environmental variables were calculated for all study sites in order to describe the variation in environmental variables across sites. The relationships among environmental variables were analyzed using Pearson's correlation. Principle components analysis (PCA) was used to describe the major environmental variables among sites. It reduced the numbers of environmental variables into groups of independent components. Variables were examined for normal distribution. Any variables not normally distributed were subjected to $\log_{10}$ transformation prior to entering PCA. The principle components axes (PCs) with eigenvalues greater than 1.0 were retained as variables. Pearson's correlations were used to detect the relationships between principle components and the environmental variables (McCreadie et al 2006). Multiple linear regression analysis was used to examine the relationship between spatial distribution and the PCs. Maximum likelihood estimation was applied to assess the significance of the predictor. Macroinvertebrate taxa that were present at a frequency higher than 20% of the sampling sites were used for regression analysis. Linear regression was used to test the relationship between taxa richness and the PC score (physiochemical parameters of the sampling sites).

Benthic macroinvertebrate assemblage was examined using the pooled data of all sampling occasions. The analysis of similarities (ANOSIM) test was used to determine the significant differences in benthic macroinvertebrate assemblage and environmental variable conditions between the forest and agricultural areas (Clarke & Warwick 1994). ANOSIM analyses were carried out using PAST version 1.93 (Hammer et al 2009). Discriminant function analysis (DFA) was used to determine the factor that most significantly contributed to differentiation between protected and unprotected areas. Two-way ANOVA was used to detect the differences among sampling seasons (cool, hot and rain) in forest types, if they accepted H1 hypothesis then Student's sample *t*-test was used to determine the differences of taxa richness, and each individual taxon between the forest and agricultural areas. Canonical correspondence analysis (CCA) was used to explore the relationship between environmental variables and macroinvertebrate assemblages. The CCA was carried out using the program PC-ORD (version 5.10) (McCune & Mefford 2006). The Monte Carlo permutation test with 498 runs was used to test whether or not the benthic macroinvertebrates were related to the environmental variables.

Results

Effect of land use on environmental condition of streams. T-test revealed that stream width, depth, discharge, altitude, pH, electroconductivity, Dissolved Oxygen, temperature and percentage of riparian coverage differed significantly between the forest and agricultural areas as shown in Table 1.

Principle component analysis of all sampling occasions yielded five principle components with eigenvalues >1.0 which explained 65.77% of the variance of the physicochemical variables. The five PCs axis accounted for 22.41%, 13.56%, 13.16%, 10.24% and 8.39% of the variances, respectively as presented in Table 2. Pearson's correlation coefficient revealed that sites with higher PC1 were larger, deeper and faster, with low TDS. Sites with higher PC2 score were higher in air and water temperature. Sites with higher PC3 were high in BOD and pH, but lower in nitrate nitrogen and orthophosphate. Sites with higher in PC4 score had higher altitude, higher riparian coverage and lower BOD. Sites with high PC5 score had a higher conductivity and chlorophyll *a*. Width, depth, current velocity, discharge, DO and total dissolved solid were the major variables among sites. PC1 described the characteristics of stream in agricultural land use with degraded water quality. ANOSIM test indicated a significant difference in physicochemical variables between the forest and agricultural streams. Regression analysis between total taxa and PCs revealed total taxa=1.347-0.039PC1-0.018PC2 (F=5.54, df=2, 122; p<0.01; R^2_{adj}=7.5%).

Macroinvertebrate assemblages and ecological conditions. A total of 30,882 individuals belonging to 164 taxa, 108 families and 20 orders of benthic macroinvertebrates were found as presented in Table 3 and Appendix 1. The most diverse groups of benthic faunas were Diptera and Trichoptera (27 taxa each) and followed by Ephemeroptera (25 taxa) and Hemiptera (24 taxa), respectively. Taxa richness and abundance of benthic macroinvertebrates were not significantly different between both areas (p>0.05).

Table 1

Mean±SD, range and independent sample *t*-test of physicochemical variables in the forest and agricultural streams, tributaries of the Mekong River, northeast Thailand

Parameters	Forest area		Agricultural area		t-test	P-value
	Mean± SD	Range	Mean± SD	Range		
Width (m)	3.34±3.05	(0.5-17.7)	5.52±4.33	(0.4-20.0)	-3.14	0.001
Depth (cm)	26.61±16.18	(5.0-100.0)	46.97±68.97	(6.7-433.3)	-2.02	0.023
Current velocity in riffles (m/s)	0.97±1.02	(0.1-3.9)	0.76±0.83	(0.1-3.9)	1.21	0.115
Discharge (cm^3/s)	95.24±245.73	(0.4-1,564.8)	136.65±271.74	(0.5-1286.7)	-0.84	0.202
Altitudes of study reach (m a.s.l.)	255.76±41.89	(175.0-330.0)	189.98±51.97	(102.0-260.0)	7.24	0.000
pH (SU)	7.23±0.51	(6.3-8.6)	7.02±0.41	(5.9-7.9)	2.37	0.010
Electroconductivity (µS/cm)	59.74±43.16	(13.2-222.3)	76.93±46.51	(22.8-216.7)	-2.01	0.024
Water temperature (°C)	24.52±2.45	(19.6-30.4)	25.78±2.47	(20.2-31.1)	-2.70	0.004
Dissolved Oxygen (mg/L)	7.35±1.25	(4.7-10.1)	6.92±1.14	(3.9-9.8)	1.91	0.029
BOD (mg/L)	1.38±0.74	(0.3-3.7)	1.57±0.73	(0.1-3.1)	-1.35	0.090
NO_3^- (mg/L)	1.76±2.54	(0.03-10.07)	1.49±2.01	(0.10-8.33)	0.62	0.268
PO_4^{3-} (mg/L)	0.06±0.05	(0.10-0.22)	0.07±0.07	(0.01-0.043)	-0.58	0.283
Total dissolved solid (mg/L)	43.19±29.02	(8.8-137.2)	40.64±22.83	(11.7-131.3)	0.52	0.301
Chlorophyll *a* (µg/L)	1.33±2.70	(0.2-18.9)	1.48±2.32	(0.1-17.4)	-0.32	0.373
Air temperature (°C)	26.64±2.81	(21.0-34.5)	27.91±3.65	(18.0-36.0)	-2.10	0.019
Riparian coverage (%)	27.67±16.70	(0.0-50.0)	16.84±22.58	(0.0-80.0)	2.93	0.002

ANOSIM indicated a significant difference (R=0.2897, $p<0.05$) in macroinvertebrate assemblage composition between the forest and agricultural streams. Environmental condition and taxa richness differed significantly between the two areas (R=0.4562, $p<0.05$). DFA based on stream conditions indicated that most streams (71.7%) could be correctly assigned with 75.5% and 68.8% of stream sites correctly assigned as the forest and agricultural streams, respectively as shown in Table 4. The standardized canonical discriminant function coefficient indicated that altitude, width, depth, water temperature, electroconductivity and pH are the most important environmental conditions which contributed to the differentiation of the streams in the forest and agricultural areas. Both *t*-test and PCA test supported this result. It showed that the streams in the agricultural land use are larger, deeper, with high discharge and electroconductivity. In contrast, DO and pH were higher in the forest streams, which have more riparian coverage. DFA based on taxa richness showed that the overall of the percentage correctly assigned was 79.6%. The correctly assigned of the streams in forest areas (77.6%) was less than agriculture areas (81.3%) as presented in Table 4. The standardized canonical discriminant function coefficient indicated that *Cloeodes* sp., Decapod Parathelphusidae, *Thalerosphyrus* sp., Leptophlebiid mayfly, Veneroida bivalve *Corbicula* and *Macrostemum* sp. are the most important taxa contributing to the differentiation between the forest and agricultural areas as shown in Table 4. *Cloeodes* sp., *Thalerosphyrus* sp., Leptophlebiid mayfly and *Macrostemum* caddisfly predominated in the forest streams, while Parathelphusidae and *Corbicula* sp. were more abundant in the agricultural streams as presented in Tables 3 and 4.

Table 2

Results of PCA and Pearson's correlation coefficient between stream variables and principle components (PCs) for all collections

Variable	*Stream sites*		*Principle components*				
	Min-Max	*Mean±SE*	*PC1*	*PC2*	*PC3*	*PC4*	*PC5*
Width (m)	0.4-20	4.57±0.37	0.764**	0.271*	-0.007	-0.300*	-0.041
Depth (cm)	5.0-433.3	38.14±5.06	0.744**	-0.078	-0.070	-0.227*	0.168
Current velocity (m/s)	0.08-3.94	0.85±0.09	0.691**	0.207	0.116	0.369**	-0.295*
Discharge (cm^3/s)	0.35-1564.83	118.69±24.50	0.960**	0.170	0.035	-0.045	-0.076
Altitude (m)	102-330	218.50±5.44	-0.169	-0.223*	0.165	0.678**	-0.101
pH	5.86-8.61	7.11±0.04	0.021	-0.060	0.741**	0.148	-0.174
Electroconductivity (µS/cm)	13.25-222.3	69.48±4.30	-0.031	0.265*	-0.107	-0.151	0.597**
Water temperature (°C)	19.63-31.07	25.24±0.24	0.205	0.877**	0.083	-0.117	0.038
Dissolved Oxygen (mg/L)	3.93-10.07	7.10±0.11	0.289*	-0.293*	0.551**	-0.215	0.116
BOD (mg/L)	0.07-3.69	1.48±0.07	-0.034	-0.192	0.333**	-0.652**	-0.105
NO_3^- (mg/L)	0.03-10.07	1.61±0.21	0.155	-0.326**	-0.762**	0.123	-0.028
PO_4^{3-} (mg/L)	0.01-0.43	0.07±0.01	-0.127	-0.077	-0.629**	-0.127	-0.247*
Total dissolved solid (mg/L)	8.84-137.2	41.75±2.41	-0.713**	0.104	-0.160	-0.064	-0.250*
Chlorophyll *a*	0.1-18.9	1.42±0.23	0.112	-0.008	0.197	0.122	0.797**
Air temperature (°C)	18-36	27.36±0.32	0.023	0.851**	0.060	-0.056	0.194
% riparian coverage	0-80	21.54±1.96	-0.108	-0.394**	0.182	0.564**	0.003
% Variable explained in PCA							
Proportion			22.41	13.56	13.16	10.24	8.39
Cumulative			22.41	33.97	47.13	57.37	65.77

* = p<0.05, ** = p<0.01

Table 3

Benthic macroinvertebrate faunas in the forest and agricultural streams in northeast Thailand during November 2005-2007

Taxa	Forest areas (Mean±SD)	Agricultural areas (Mean±SD)	t-test	P-value
Total taxa	23.65±5.96	23.81±7.46	-0.12	0.451
Annelida	0.47±0.54	0.50±0.50	-0.53	0.279
Nematomorpha	0.10±0.31	0.09±0.29	0.15	0.442
Basematophora	0.06±0.24	0.05±0.21	0.33	0.369
Mesogastropoda	0.53±0.62	0.98±0.86	-3.12	0.001
Neogastropoda	0.00±0.00	0.03±0.18	-1.43	0.079
Arcoida	0.02±0.14	0.05±0.21	-0.75	0.228
Unionoida	0.00±0.00	0.03±0.18	-1.43	0.079
Veneroida	0.18±0.39	0.39±0.49	-2.42	0.009
Acarina	0.04±0.20	0.08±0.27	-0.81	0.210
Decapoda	0.90±0.87	1.28±0.90	-2.28	0.012
Coleoptera	2.84±1.71	3.06±1.45	-0.76	0.225
Collembolla	0.04±0.20	0.05±0.21	-0.15	0.439
Diptera	3.33±1.43	3.53±1.60	-0.70	0.242
Ephemeroptra	6.86±2.15	5.89±2.57	2.12	0.018
Hemiptera	2.27±1.62	1.88±1.56	1.30	0.098
Lepidoptera	0.57±0.61	0.25±0.56	2.86	0.003
Odonata	1.27±1.15	1.38±1.23	-0.48	0.315
Orthoptera	0.22±0.47	0.19±0.39	0.46	0.325
Plecoptera	0.53±0.50	0.34±0.48	2.00	0.024
Trichoptera	3.43±2.10	3.77±2.25	-0.81	0.209

Table 4

Results of discriminant function analysis (DFA) of the correspondence between benthic macroinvertebrate taxon and area types (forest or agriculture) of the streams in northeast Thailand, November 2005-2007

Summary statistic	Discriminant variables			
	Stream conditions		faunal taxa	
% Correct (*N*)				
Forest (49)	75.5		77.6	
Agriculture (64)	68.8		81.3	
Total (113)	71.7		79.6	
Standardized coefficient[a]	Altitude	0.838	*Cloeodes* sp.	0.482
	Width	-0.414	Parathelphusidae	-0.360
	Depth	-0.379	*Thalerosphyrus* sp.	0.352
	Water temperature	-0.335	Leptophlebiidae	0.351
	Electroconductivity	-0.334	*Corbicula* sp.	-0.346
	pH	0.292	*Macrostemum* sp.	0.292

[a] Only the first five variables and taxa that have the highest absolute values of the standardized coefficient are present

CCA indicated that discharge, velocity, altitude, pH, TDS, width and nitrate nitrogen were the most important predictors of the macroinvertebrate assemblages as shown in Figure 2. Relationship between species and environmental condition was high (>0.76) for the first three CCA axes. It showed that the measured environmental variables were sufficient to explain much of the benthic macroinvertebrate assemblage. The Monte Carlo permutation test also supported the relationship between the environmental condition and species ($p<0.05$). In contrast, TDS, current velocity, pH and water temperature were the most important factors on the CCA Axis I and Axis II, respectively. The lower side of the biplot was composed of the sites with high altitude and pH, which were the characteristics as found in the forest streams. Macroinvertebrate taxa such as *Neoperla* (Plecoptera), *Cloeodes* (Ephemeroptera) and *Thalerosphyrus* (Ephemeroptera) predominated at these sites. In contrast, Leptophebiidae (Ephemeroptera) and *Corbicula* (Veneroida) were abundant in the agricultural sites as shown in Figure 3.

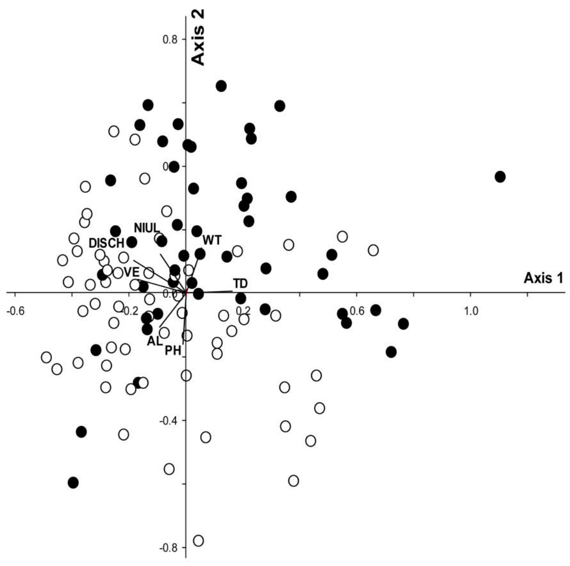

Figure 2. Ordination diagram of the first two axes of canonical correspondence analysis (CCA) of 113 sampling collections. Direction and length of straighten lines denoted the strength of the environmental condition (open circle = forest streams, closed circle=agricultural streams, AL=altitude, DISCH=discharge, NIUL= nitrate-Nitrogen, PH=pH, TD=total dissolved solid, VE=current velocity, WT=water temperature).

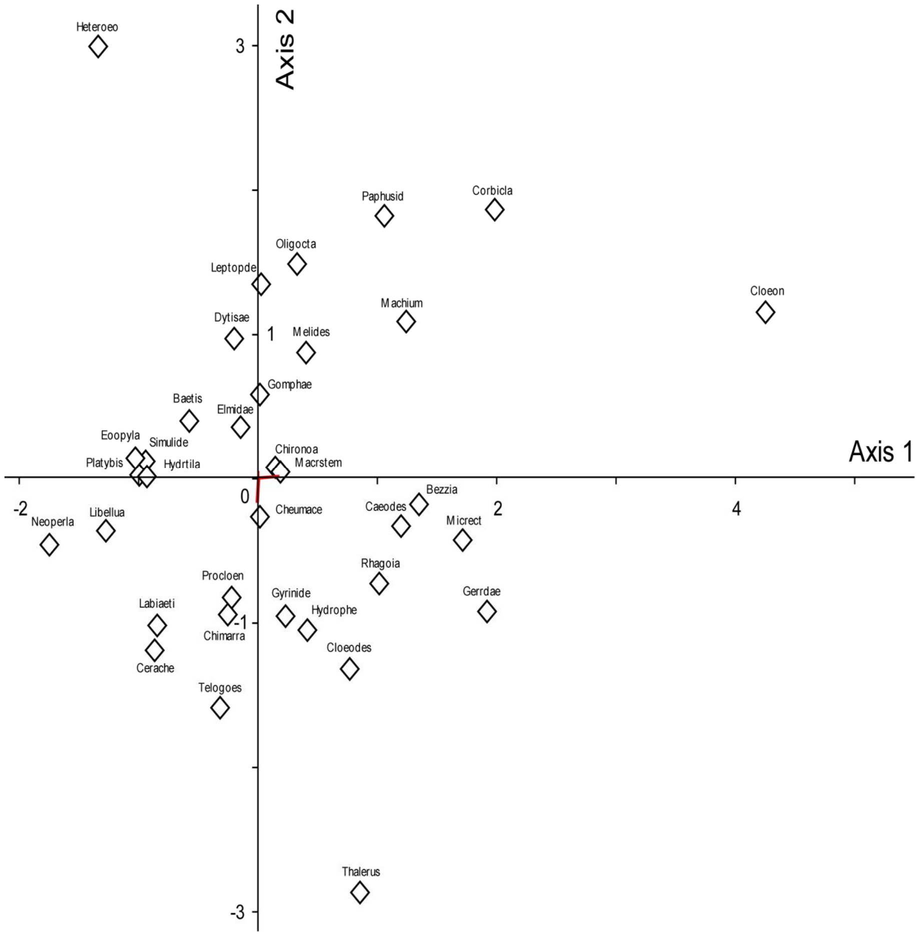

Figure 3. Ordination diagram of the first two axes of canonical correspondence analysis (CCA) of 35 taxa of benthic macroinvertebrates.

Discussion. Agricultural activity altered stream conditions from high percentage of riparian coverage, narrower and shallower streams to low percentage of riparian coverage with wider and deeper streams. Less percentage of riparian coverage caused water temperature to be higher. Electroconductivity of water increased and DO decreased in the agricultural streams. DFA indicated that stream width, water depth, water temperature, pH and electroconductivity were the major variables with a significant difference between the sites in forest and agricultural streams. Percentage of riparian coverage was high while water temperature was low in the forest sites. These findings are agreed with those of Busulwa & Bailey (2004), Kasangaki et al (2008) and Pramual & Kuvangkadilok (2009) who reported low water temperature in the forest streams of Ruwenzori Mountains of Uganda, Bwindi Impenetrable National Park, Uganda and protected areas of northeast Thailand. In the forest sites, heavy shading lead to relatively low water temperature and low primary production (Marlier 1973; Welcomme 1979, 1985; Welcomme & de Merona 1988). In the present study, Chlorophyll *a* between the forest and agricultural streams did not differ significantly, but it tended to lower in the forest streams. This result supports the previous findings. Kasangaki et al (2008) also showed that the reduced temperature in the forest streams is a result of shading by riparian vegetation that prevented light penetration, resulting in low water temperature.

Appendix 1

Abundance of benthic macroinvertebrates in the forest (For) and agricultural (Agr) streams, northeast, Thailand (Sum For = sum of benthos abundance in forest streams; Sum Agr = sum of benthos abundance in the agricultural streams; Sum All= sum of all benthos founded)

Taxa	Cold 05-07		Hot 06-07		Rain 06-07		Sum For	Sum Agr	Sum All
	For	Agr	For	Agr	For	Agr			
Oligochaeta	46	21	10	130	62	43	118	194	312
Hirudinidae	1	0	0	0	0	0	1	0	1
Nematomorpha	7	3	0	3	2	2	9	8	17
Ferrisia baconi	0	1	0	0	1	0	1	1	2
Pila sp.	0	9	0	0	0	0	0	9	9
Pomacea sp.	0	15	0	1	0	2	0	18	18
Clea sp.	0	1	0	0	0	2	0	3	3
Lacunopsis sp.	8	2	0	0	0	16	8	18	26
Lymnaea (Radix) sp.	0	2	0	0	0	0	0	2	2
Melanoides sp.	139	122	8	307	109	252	256	681	937
Indoplanorbis exustus	0	0	2	0	7	6	9	6	15
Trochotaia sp.	1	3	0	1	0	0	1	4	5
Idiopoma sp.	0	4	0	0	0	1	0	5	5
Mekongia sp.	0	29	0	0	0	78	0	107	107
Viviparidae	0	8	0	4	1	0	1	12	13
Filopaludina sp.	0	3	0	2	0	0	0	5	5
Pseudodon sp.	0	1	0	1	0	0	0	2	2
Scaphula sp.	0	6	1	16	0	0	1	22	23
Corbicula sp.	5	17	2	52	3	11	10	80	90
Amphizoidae	0	2	0	0	0	0	0	2	2
Carabidae	0	4	0	1	4	0	4	5	9
Dryopidae	1	1	0	0	0	2	1	3	4
Dytiscidae	40	50	1	13	44	55	85	118	203
Elmidae	121	113	28	124	172	113	321	350	671
Gyrinidae	12	31	4	29	4	11	20	71	91
Halipildae	2	0	0	0	0	0	2	0	2
Hydraenidae	13	9	0	2	0	7	13	18	31
Hydrophilidae	44	30	1	10	24	8	69	48	117
Hygrobiidae	3	1	0	4	0	0	3	5	8
Hydrochidae	0	2	0	0	0	0	0	2	2
Lampyridae	3	3	0	2	0	0	3	5	8
Omophronidae	0	0	0	1	0	0	0	1	1
Psephenidae	26	2	4	0	3	0	33	2	35
Scirtidae	1	0	0	8	2	5	3	13	16
Staphylinidae	2	35	0	1	2	11	4	47	51
Isotomidae	0	5	0	0	1	0	1	5	6
Gecarcinucidae	5	0	0	0	4	0	9	0	9
Macrobrachium sp.	62	171	62	50	41	124	165	345	510
Parathelphusidae	5	26	2	21	5	55	12	102	114
Caridina sp.	1	62	0	0	31	88	32	150	182
Acarina	0	0	0	5	3	5	3	10	13

Appendix 1 (Cont.)

Taxa	Cold 05-07		Hot 06-07		Rain 06-07		Sum For	Sum Agr	Sum All
	Pro	Un	Pro	Un	Pro	Un			
Atrichop sp.	5	2	0	1	1	0	6	3	9
Suragina sp.	5	3	0	2	0	0	5	5	10
Blephariceridae	1	0	0	0	0	0	1	0	1
Ceratopogonidae	3	3	3	3	1	4	7	10	17
Bezzia sp.	18	26	9	35	4	12	31	73	104
Culicoides sp.	0	1	0	2	0	8	0	11	11
Atrichopogon sp.	2	1	0	7	1	1	3	9	12
Chaoborus sp.	0	3	5	1	0	10	5	14	19
Chironomidae	1679	2229	617	1703	444	346	2740	4278	7018
Stenochironomus sp.	3	5	4	1	1	1	8	7	15
Culicidae	1	1	44	21	1	0	46	22	68
Anopheles sp.	0	7	0	0	0	0	0	7	7
Dixidae	0	1	0	4	0	0	0	5	5
Dolichopodidae	1	0	0	1	4	4	5	5	10
Empididae	0	0	0	2	0	2	0	4	4
Hemerodromia sp.	2	3	0	1	0	0	2	4	6
Ephydridae	2	0	0	0	2	6	4	6	10
Muscidae	0	0	1	5	0	0	1	5	6
Psychodidae	0	0	6	1	1	1	7	2	9
Sciomyzidae	0	0	0	0	1	0	1	0	1
Simulium sp.	908	1112	116	195	127	242	1151	1549	2700
Odontomyia sp.	2	0	0	1	0	1	2	2	4
Stratiomys sp.	0	0	0	1	0	0	0	1	1
Tabanidae	0	1	0	1	2	2	2	4	6
Tipulidae	3	20	0	4	2	3	5	27	32
Antocha sp.	1	2	0	0	1	0	2	2	4
Hexatoma sp.	3	3	2	12	4	2	9	17	26
Tipula sp.	2	3	1	2	0	0	3	5	8
Acentrella sp.	5	29	0	5	68	6	73	40	113
Baetis sp.	275	516	8	139	168	207	451	862	1313
Cloeodes sp.	154	14	13	16	34	8	201	38	239
Cloeon sp.	6	102	85	28	19	20	110	150	260
Labiobaetis sp.	53	105	0	102	240	218	293	425	718
Heterocloeon sp.	159	221	0	0	292	276	451	497	948
Platybaetis sp.	490	550	3	93	1262	448	1755	1091	2846
Procloeon sp.	94	3	16	38	39	6	149	47	196
Pseudocentroptiloides sp.	4	6	0	0	0	6	4	12	16
Caenodes sp.	382	515	127	317	32	92	541	924	1465
Caenoculis sp.	4	6	12	11	3	2	19	19	38
Clypeocaenis sp.	30	50	0	62	28	1	58	113	171
Ephemera sp.	14	3	0	21	1	0	15	24	39
Cinygmina sp.	6	11	0	3	4	4	10	18	28
Rhithrogena sp.	0	0	0	0	2	0	2	0	2
Thalerosphyrus sp.	265	93	1	26	34	10	300	129	429

Appendix 1 (Cont.)

Taxa	Cold 05-07		Hot 06-07		Rain 06-07		Sum For	Sum Agr	Sum All
	Pro	Un	Pro	Un	Pro	Un			
Leptophlebiidae	42	9	36	31	231	12	309	52	361
Chroroterpes sp.	24	22	19	53	0	0	43	75	118
Choroterpides sp.	1	0	0	0	0	0	1	0	1
Isca sp.	1	1	0	0	0	0	1	1	2
Habrophlebiodes sp.	7	1	0	0	0	0	7	1	8
Thraulus sp.	13	4	0	3	6	0	19	7	26
Povilla heardi	2	2	0	0	0	3	2	5	7
Teloganodes sp.	80	45	3	16	33	16	116	77	193
Tricorythus sp.	0	3	0	0	3	0	3	3	6
Micronecta sp.	172	87	172	139	54	35	398	261	659
Gerridae	35	40	8	6	2	20	45	66	111
Helotrephidae	7	24	6	1	7	1	20	26	46
Mesovelia sp.	0	0	0	1	0	1	0	2	2
Ctenipocoris sp.	0	0	0	0	2	0	2	0	2
Helocoris sp.	0	1	0	0	1	0	1	1	2
Naucoris sp.	2	1	0	1	0	2	2	4	6
Cercotmetus sp.	0	1	0	0	0	0	0	1	1
Ranatra sp.	0	1	0	1	0	0	0	2	2
Aphelonecta sp.	1	18	2	1	0	1	3	20	23
Notonecta sp.	0	0	13	0	0	0	13	0	13
Nychia sp.	1	8	0	0	0	0	1	8	9
Hebridae	4	2	1	2	2	0	7	4	11
Hyrcanus sp.	4	4	4	0	36	1	44	5	49
Herbrus sp.	0	0	2	0	0	0	2	0	2
Nieserius sp.	14	4	0	0	1	2	15	6	21
Merragata sp.	1	0	0	0	0	1	1	1	2
Timasius sp.	4	0	0	1	1	2	5	3	8
Hydrometra sp.	1	0	0	1	0	0	1	1	2
Veliidae	2	3	0	1	0	0	2	4	6
Microvelia sp.	3	6	0	0	0	0	3	6	9
Rhagovlia sp.	28	9	0	31	9	7	37	47	84
Strongylovelia sp.	0	0	0	0	0	1	0	1	1
Tetraripis sp.	0	0	0	0	0	1	0	1	1
Perittopus sp.	0	2	0	0	0	0	0	2	2
Eoophyla sp.	5	3	0	4	28	7	33	14	47
Elophila sp.	2	0	0	0	5	1	7	1	8
Paracymoriza sp.	7	3	0	0	3	1	10	4	14
Potamomusa sp.	1	0	0	1	0	2	1	3	4
Amphipterygidae	1	2	0	0	0	1	1	3	4
Aeshnidae	2	2	0	0	2	0	4	2	6
Calopteryidae	0	0	0	0	3	6	3	6	9
Chlorocyphidae	3	4	0	1	0	2	3	7	10
Coenagrionidae	0	1	0	0	0	0	0	1	1
Corduliidae	2	8	5	0	2	5	9	13	22
Euphaenidae	6	6	0	11	2	1	8	18	26

Appendix 1 (Cont.)

Taxa	Cold 05-07		Hot 06-07		Rain 06-07		Sum For	Sum Agr	Sum All
	Pro	Un	Pro	Un	Pro	Un			
Gomphidae	6	12	0	5	4	21	10	38	48
Libellulidae	58	89	2	29	26	12	86	130	216
Megaprodagrionidae	1	1	2	0	6	6	9	7	16
Platycnemidae	0	0	1	0	0	0	1	0	1
Protoneuridae	0	1	1	3	1	9	2	13	15
Macromiidae	0	0	0	0	2	3	2	3	5
Blaberidae	2	5	0	0	10	3	12	8	20
Tetrigidae	3	0	0	1	0	4	3	5	8
Tridactylidae	1	2	0	0	2	0	3	2	5
Neoperla sp.	28	56	2	41	187	28	217	125	342
Anisocentropus sp.	0	0	0	1	1	0	1	1	2
Pseudoneureclipsis sp.	8	0	0	0	2	0	10	0	10
Ecnomus sp.	10	2	2	2	2	0	14	4	18
Goera sp.	0	1	0	0	0	1	0	2	2
Amphipsyche sp.	1	127	0	9	0	8	1	144	145
Ceratopsyche sp.	1084	1096	1	238	152	67	1237	1401	2638
Cheumatopsyche sp.	426	743	2	74	101	55	529	872	1401
Macrostemum sp.	17	271	5	54	8	0	30	325	355
Hydroptilidae	1	3	1	5	0	0	2	8	10
Hydroptila sp.	96	27	7	8	27	14	130	49	179
Orthotrichia sp.	7	6	0	19	18	10	25	35	60
Oxyethira sp.	1	0	0	0	0	1	1	1	2
Stactobia sp.	9	0	0	0	1	0	10	0	10
Helicopsyche sp.	22	2	7	1	4	7	33	10	43
Lepidostoma sp.	0	1	0	0	0	0	0	1	1
Leptoceridae	0	9	0	9	1	0	1	18	19
Ceraclea sp.	6	6	0	2	0	0	6	8	14
Oecetis sp.	10	7	0	7	1	2	11	16	27
Leptocerus sp.	7	7	0	5	3	11	10	23	33
Setodes sp.	1	7	1	1	2	0	4	8	12
Tripletides sp.	2	1	0	0	1	1	3	2	5
Chimarra sp.	186	155	46	214	9	4	241	373	614
Polycentropodidae	0	0	1	0	0	0	1	0	1
Psychomyidae	2	5	0	2	1	0	3	7	10
Odontoceridae	7	12	0	4	0	0	7	16	23
Marilia sp.	0	0	2	1	0	0	2	1	3
Rhyacophila sp.	1	0	0	0	0	0	1	0	1
Total	7611	9425	1552	4696	4353	3245	13516	17366	30882

In this study, low conductivity values were ranged between 13.2 to 222.3 µS/cm. Means of conductivity in the forest and agricultural streams were 59.74 and 76.93 µS/cm. Agricultural sites generally had higher conductivity value. Pramual & Kuvangkadilok (2009) reported that the values of conductivity in the agricultural areas of northeast Thailand were two-fold higher than those in the forest streams. Our finding was about 1.3 times, but it was significantly different between sites. This result was consistent with other studies. Conductivity and water temperature were higher in the agricultural streams, where less riparian vegetation was found (Kasangaki et al 2008; Pramual &

Kuvangkadilok 2009; Lorion & Kennedy 2009). In addition, water temperature is known to have significant influence on benthic macroinvertebrate growth, fecundity and their survival (Sweeney 1993). In another discovery in this study, Ephemeroptera, Plecoptera and Lepidoptera decreased in the agricultural streams, while mollusks (Mesogastropoda and Veneroida), Decapoda and Trichoptera increased in the agricultural streams. Seven genera of snails were found only in the agricultural streams. They were scrapers feeding on algae. Hydropsychid caddisfly larvae increased in a large numbers in the agricultural streams. This caddisfly family is a tolerant group which is able to exploit in less disturbed areas (Dudgeon 1999). CCA indicated that the crab Parathelphusidae (order Decapoda) and *Corbicula* (mollusk order Veneroida) preferred high water temperature and TDS, which are the characteristics of agricultural streams. Mayfly nymphs *Thalerosphyrus* and *Cloeodes* (order Ephemerotera) predominated in the forest streams. Hellawell (1986) pointed out that Ephemeropteran and Plecopteran are the intolerant groups, and their numbers usually decreased in the agricultural streams. Hamada et al (2002) and Allan (2004) stated that riparian forest provides shading and organic matters for benthic macroinvertebrates dwelling in the stream. The results of the present study supported these previous findings. The riparian vegetation removal increased water temperature. This may reduce the richness of local species and eliminate the intolerant taxa from a stream. Nutrient and chlorophyll *a* were not significantly different between the agricultural and forest streams. In this study; however, both parameters tended to increase in the agricultural streams. Algae and diatoms need nutrient for their growth and they are fed by scrapers. *Eoophyla* (order Lepidoptera), *Simulium* (order Diptera), *Platybaetis* (order Ephemeroptera) and *Hydroptila* (order Trichoptera) are scrapers which correspond well to an increase in nitrate nitrogen and discharge in agricultural streams. The results agree with Lorion & Kennedy (2009) who reported that scrapers can exploit in-stream primary production. Streams with riparian vegetation support a greater diversity of benthic macroinvertebrates in tropical streams as in India (Subramanian et al 2005), Indonesia (Dudgeon 2006), Costa Rica (Lorion & Kennedy 2009). In addition, Pramual & Kuvangkadilok (2009) found that black flies *Simulium* was more diverse in the forest streams than those in the agricultural streams of Thailand. In this study, diversity of benthic macroinvertebrates was not so greatly different as the previous studies, but individuals of intolerant taxa (Ephemeroptera and Plecoptera) decreased in agricultural streams while those of tolerant taxa (Mollusk and Decapoda) increased. From our finding, we show that non-intensive agriculture activity in headwater streams results in a slight difference in diversity and assemblage of benthic macroinvertebrates.

Conclusions. The results of this study suggested that agricultural land use directly affects stream width, water depth and water velocity. Removing of riparian vegetation may cause a reduction of percent riparian coverage, resulting in high temperature. Nutrient input into water degraded water quality and increased the conductivity and chlorophyll *a*. In this study, discharge was the most important variable related to distribution of benthic macroinvertebrates. Differentiation of the physicochemical parameters in the streams between the agricultural and forest areas affected benthic macroinvertebrate assemblage. It was found that intolerant fauna decreased while the tolerant taxa increased in the agricultural streams. Anthropogenic activity by non-intensive agricultural land use had less impact on structure and composition of benthic macroinvertebrates than habitat characteristics.

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