Do Environmental Factors Influence the Distributions and Diversity of Tropical Macroinvertebrate Assemblages?: A Case Study of Mae Taeng River Basin, Northern Thailand

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Abstract

Biodiversity loss caused by environmental changes has been increased year by year. The aquatic ecosystems have been impacted as habitats are modified, most likely by human activities. Few studies have examined how biological assemblages at different spatial scales are determined by environmental gradients. We aim to understand the influence of environmental factors on the distribution and diversity of macroinvertebrates in Northern Thailand. A total of 21,391 individuals belonging to 79 families in 15 orders were identified. The order Diptera is one of the most abundant taxa in this study (family Chironomidae). The cluster analysis of macroinvertebrates and environmental factors clearly divides the areas into two groups of disturbed (downstream) and undisturbed (headstream) stations. CCA results revealed that the turbidity, conductivity and BOD are the most important factors that could influence macroinvertebrate assemblages in this study. The results also provided the basic information about the ecological status as monitored by the distribution of organisms in aquatic systems. However, it is necessary to increase data reliability by continuing to monitor other biological communities in the long-term in order to define adequate strategies for diagnosing the integrity of stream ecosystems.

Keywords: Macroinvertebrate diversity; Environmental factors; Spatial distribution

Introduction

Among our natural resources, the rivers are one of the important aquatic ecosystems supporting diverse life forms (Xiong et al., 2016). They provide habitats and food to aquatic organisms. Recently, great attention has been paid to the loss of biodiversity in freshwater ecosystems as aquatic organisms are threatened by anthropogenic stressors (Aschonitis et al., 2016; Cai et al., 2017). In Thailand, most of the freshwater resources are used to irrigate more than 5 million hectares of agricultural land and others industrial and urban areas. Not only is there the consumption by these activities, but the waste water from them also leads to a range of adverse effects on the environment, from cellular effects in organisms to effects at the level of the whole ecosystems (Tagun and Boxall, 2018). Furthermore, there are effects on wildlife species either by direct exposure or through bioaccumulation in the food web causing loss of biodiversity and malfunctioning, and the restructuring of aquatic ecosystems (Giorgio et al., 2016).

Macroinvertebrates play important roles in aquatic ecosystems as they are key components of aquatic food webs relating to organic matter and nutrient resources (Fu et al., 2016). They are diverse, abundant and closely linked to environmental factors as well as sensitive to pollution and show rapid response to external disturbances (Beauger, Delcoigne, Voldoire, Serieyssol, & Peiry, 2015; Giorgio et al., 2016). Hence, macroinvertebrates are widely used as a bioindicator of water quality and have been used in biomonitoring to assess the ecological health of aquatic systems worldwide (Clews et al., 2014). In Thailand, even though there are several studies on macroinvertebrate diversity, but the relationships between macroinvertebrate communities and different stressors at different spatial scales rarely studied in Thailand (Prommi and Payakka, 2015; Thanee and Phalaraksh, 2012) as those studies have been focused on water quality and macroinvertebrate. Therefore, in order to improve and implement this aspect in monitoring programs as a tool to protect aquatic ecosystems, it is necessary to understand which factors influence macroinvertebrate assemblages at different spatial scales (Jun et al., 2016; Silva et al., 2014). By understanding the associations between macroinvertebrate assemblages and environmental factors, one could predict and evaluate the level of human impacts on aquatic ecosystems (Silva et al., 2014).

The aims of the present study were :(i) to assess the anthropogenous influences on the composition and spatial distribution of macroinvertebrate communities and (ii) to characterize the distribution and assemblage structure of macroinvertebrates in tropical areas as the Northern Thailand lotic ecosystems.

Therefore, this study may help refine the impact assessment procedure of aquatic environment and to identify the pattern of environmental factors that may affect the aquatic ecosystems.

Methods and Materials

This study was conducted along Mae Taeng river basin which is located in Chiang Mai Province, the North of Thailand. Mae Taeng river basin ranges in altitude from 341 to 868 m above mean sea level and covers 190,000 hectares at latitude 19 ^{0}N and longitude 98 ^{0}E. Three streams in three microbasins were investigated in this study (Table 1 and Figure1).

The sampling was conducted along nine sites in three microbasins based on upstream-to-downstream flows of the principal anthropogenic pressure of Mae Taeng river basin. The three main stations areas were locate in an intensive agricultural areas of Mae Taeng sub basin include Mae Hoa at San Pa Yang (SPY), Mae Ping at Choe le (CHL) and Pang Ma Kuay (PMK). Three areas are located in intensive agricultural areas. Samples were collected in August 2015 (rainy), November (cold) and February (cold-dry) of 2016. Environmental parameters including altitude (m), river width (m) and land use were observed. Air temperature (^{0}C), water temperature (^{0}C), dissolved oxygen (mgL^{-1}), water velocity (mS^{-1}), pH and electric conductivity (μ S.cm^{-1}) were also measured in the field during sampling. Other abiotic factors were also measured including biochemical oxygen demand (mgL^{-1}) and analyses were performed of dissolved inorganic nutrients ammonium, NH_4^+; nitrite, NO_2^- and soluble reactive phosphorus, PO_4^{3-} (APHA, 2005)

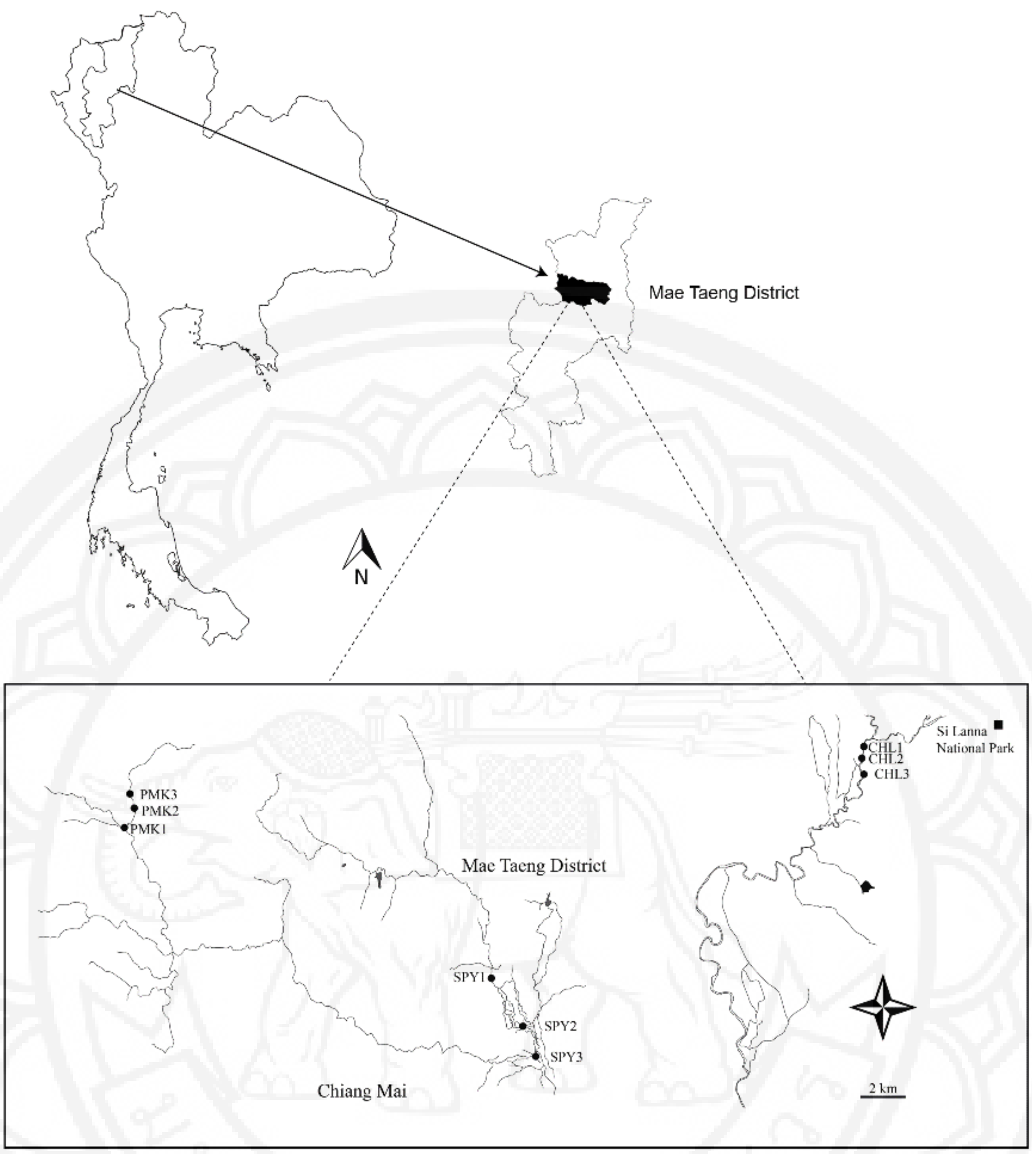


Figure 1 Map of Mae Taeng showing the study area. Circles indicate the sampling sites.

Sampling and identification

Six replicates of macroinvertebrates at each site were sampled in August 2015 and November and February 2016 using the multi-habitat sampling technique described by Wang et al., (2012) which provides a more comprehensive sampling of total richness than fixed area sampler (Harrington et al., 2016; Resh and Rosenberg., 1984). The sampling at each site was undertaken using a standard pond net (mesh size, 250 μm) with the total time of 3 minutes per replicate for the total of 6 replicates at each site (three replicates left-hand side and three replicates right-hand side). The samples were preserved in 4% formaldehyde. In the laboratory, the samples were washed and all the macroinvertebrates were sorted under a stereoscopic microscope (Tomanova et al., 2006). The taxonomical identification was conducted to the family level using taxonomic references by Merritt and Cummins (1996), Dudgeon (1999).

Data analysis

The discrepancies in the environmental variables and macroinvertebrate communities between the stations were identified using One-Way ANOVA test in order to test the differences. When the ANOVA test was significant ($p<0.05$), Tukey's multiple comparison tests were conducted (Jun et al., 2016). Prior to the examination of diversity, Shannon-Wiener diversity and evenness index was used to assess the well-being of the habitat. The univariate measures including the abundance and number of macroinvertebrate species were used to indicate macroinvertebrate community structure among site. The environmental variables data were transformed ($\log_{10}(x+1)$) to remove differing scales of measurement (Li et al., 2016). A cluster analysis by Ward's method was used to classify the environmental variables and the macroinvertebrate communities (Cao et al., 1997; Czerniawska-Kusza, 2005). Macroinvertebrates were assessed for their composition such as relative abundance to explore the dominant taxa at stations via Heat map (Giorgio et al., 2016; Sharifinia et al., 2016). Canonical correspondence analysis (CCA) was performed to show the relationship between macroinvertebrate communities and environmental variables and to identify which environmental factors influence the organisms by using the vegan package in R program. All data analyses were performed by R studio 3.3.0.

Results

Chemical-physical parameters

The chemical and physical variables in each sampling site are summarized in Table 1. According to the results, the water quality parameters varied widely among the three microbasins, but all three remained within the range of standard surface water quality. The results revealed that the average chemical concentration and physical parameters were generally lowest in PMK and highest in CHL and SPY, respectively. It can be explained that the water quality in PMK station was better than in CHL and SPY. In addition, the conductivity and total dissolved solid were significantly different between sites. Conductivity values were lowest at the 1st order stream (PMK) and highest at the 3rd order stream (SPY).

Macroinvertebrate assemblages

A total of 21391 individuals belonging to 79 families in 15 orders were identified in nine stations from three microbasins. Most of these were aquatic insects (96%) including Diptera (35.9%), and Ephemeroptera (35.8%) were the most numerically abundant, followed by Hemiptera (11.9%), Trichoptera (6.9%), Odonata (4.1%), Coleoptera (1.0%), Plecoptera (0.1%), Lepidoptera (0.1%) and non-aquatic insects (4.1%). The most abundant macroinvertebrate taxonomic groups were Diptera and Ephemeroptera (Table 2).

Table 1. Environmental data (mean (± SD), n=3) of three microbasins in Mae Taeng river basin, Northern Thailand

Parameter/Stations	CHL1	CHL2	CHL3	SPY1	SPY2	SPY3	PMK1	PMK2	PMK3
Width (m)	3	5	5	4-5	3-4	3-4	1-2	1-2	1-2
Stream order	2nd	2nd	2nd	3rd	3rd	3rd	1st	1st	1st
Latitude	19.15	19.14	19.13	19.06	19.04	19.03	19.11	19.12	19.13
Longitude	99.00	99.00	99.00	98.85	98.86	98.87	98.70	98.70	98.70
Elevation (m)	346	341	343	372	354	353	845	868	859
Air temp. (^{0}C)	29.6 (± 2.0)	28.0 (± 1.0)	30.4 (± 2.1)	27.7 (± 3.0)	24.4 (± 5.3)	25.6 (± 4.2)	25.2 (± 2.0)	24.6 (± 2.7)	24.5 (± 6.1)
Water temp. (^{0}C)	27.7 (± 1.0)	27.1 (± 1.3)	27.9 (± 0.3)	24.7 (± 1.9)	24.2 (± 3.2)	24.6 (± 3.1)	23.0 (± 3.4)	23.7 (± 2.5)	22.3 (± 4.5)
DO (mgL^{-1})	7.48 (± 1.3)	7.32 (± 1.1)	7.22 (± 1.7)	6.50 (± 0.9)	6.01 (± 1.5)	6.84 (± 0.6)	8.07 (± 0.6)	8.07 (± 0.6)	7.33 (± 0.6)
BOD (mgL^{-1})	1.00 (± 0.6)	0.96 (± 0.3)	1.20 (± 1.5)	2.00 (± 2.2)	1.61 (± 0.7)	2.42 (± 1.6)	0.86 (± 0.2)	0.67 (± 0.3)	0.41 (± 0.2)
Water velocity (mS^{-1})	0.44 (± 0.1)	0.38 (± 0.1)	0.48 (± 0.1)	1.02 (± 0.6)	0.80 (± 0.2)	0.30 (± 0.2)	0.49 (± 0.2)	0.65 (± 0.1)	0.62 (± 0.1)
pH	7.81 (± 0.4)	7.54 (± 0.6)	7.71 (± 0.6)	7.29 (± 0.8)	7.65 (± 0.8)	7.86 (± 0.8)	7.81 (± 0.6)	7.70 (± 0.6)	7.93 (± 0.7)
Conductivity (μscm^{-1})	281.8 (± 57.1)	287.9 (± 63.2)	282.2 (± 65.2)	206.4 (± 47.5)	222.2 (± 54.3)	143.8 (± 14.1)	49.44 (± 10.9)	66.35 (± 7.8)	59.78 (± 19.2)
Turbidity (NTU)	135 (± 213)	106 (± 153)	165 (± 264)	39 (± 36.8)	42 (± 44.4)	45 (± 33)	9.3 (± 7.5)	14.3 (± 7.0)	14.3 (± 9.0)
TDS (mgL^{-1})	246.3 (± 50)	250.8 (± 54.1)	250.6 (± 57.9)	180.6 (± 41.7)	194.2 (± 45.1)	143.5 (± 17.5)	43.1 (± 9.6)	58.3 (± 6.7)	52.9 (± 17.4)
NO_3^- (mgL^{-1})	0.63 (± 0.3)	0.41 (± 0.3)	0.20 (± 0.2)	0.75 (± 0.07)	0.43 (± 0.3)	0.56 (± 0.3)	0.43 (± 0.3)	0.37 (± 0.3)	0.31 (± 0.3)
NH_4^+ (mgL^{-1})	0.23 (± 0.1)	0.39 (± 0.1)	0.33 (± 0.1)	0.19 (± 0.2)	0.20 (± 0.2)	0.33 (± 0.2)	0.23 (± 0.2)	0.32 (± 0.2)	0.22 (± 0.1)
PO_4^{3-} (mgL^{-1})	0.36 (± 0.3)	0.35 (± 0.1)	0.96 (± 0.7)	0.18 (± 0.1)	0.27 (± 0.1)	0.24 (± 0.1)	0.21 (± 0.1)	0.33 (± 0.1)	0.36 (± 0.3)

Table 2 Number of taxa and individuals from each taxonomic group for all sampling sites

Taxonomic group	Number of families	Total abundance	% Total abundance
Oligochaeta	1	65	0.3
Hirudinae	1	14	0.1
Coleoptera	8	221	1.0
Diptera	7	7571	35.9
Ephemeroptera	10	7645	35.8
Hemiptera	12	2550	11.9
Lepidoptera	1	29	0.14
Megaloptera	1	7	<0.1
Odonata	15	887	4.1
Plecoptera	2	15	0.1
Trichoptera	15	14	6.9
Decapoda	2	42	0.2
Basommatophora	1	36	0.2
Mesogastropoda	2	538	2.5
Veneroida	1	182	0.8
Total	79	21391	100

In terms of the macroinvertebrate distribution among sampling sites, we used Heat map to illustrate the distribution and relative abundance (Figure 2). The overall faunal abundance in all sampling sites were dominated by Baetidae (6391 individuals) and Chironomidae (6132 individuals). The most commonly distributed were Chironomidae, Baetidae, and Corixidae which were found at every site and in all seasons. However, the site specific orders such as Viviparidae and Hydrobiidae were found only at site CHL in all seasons.

Spatial scale and composition among sites and seasons

As seen in Table 3, the number of macroinvertebrate individuals was highest at CHL (10928), followed by PMK (6443) and SPY (4020), respectively. The highest number of individuals was recorded during the dry season (9376), followed by cool-dry (8195) and rainy season (3820) respectively. The evenness index value among stations and seasons were ranged between 0.458 - 0.547 but the number of taxa show highest number at PMK and Cool-Dry season, 60 and 64 taxa respectively.

With regards to diversity, the highest diversity values were recorded at PMK and CHL stations at 2.186 and 2.185, respectively. However, the diversity index showed similar results across the seasons.

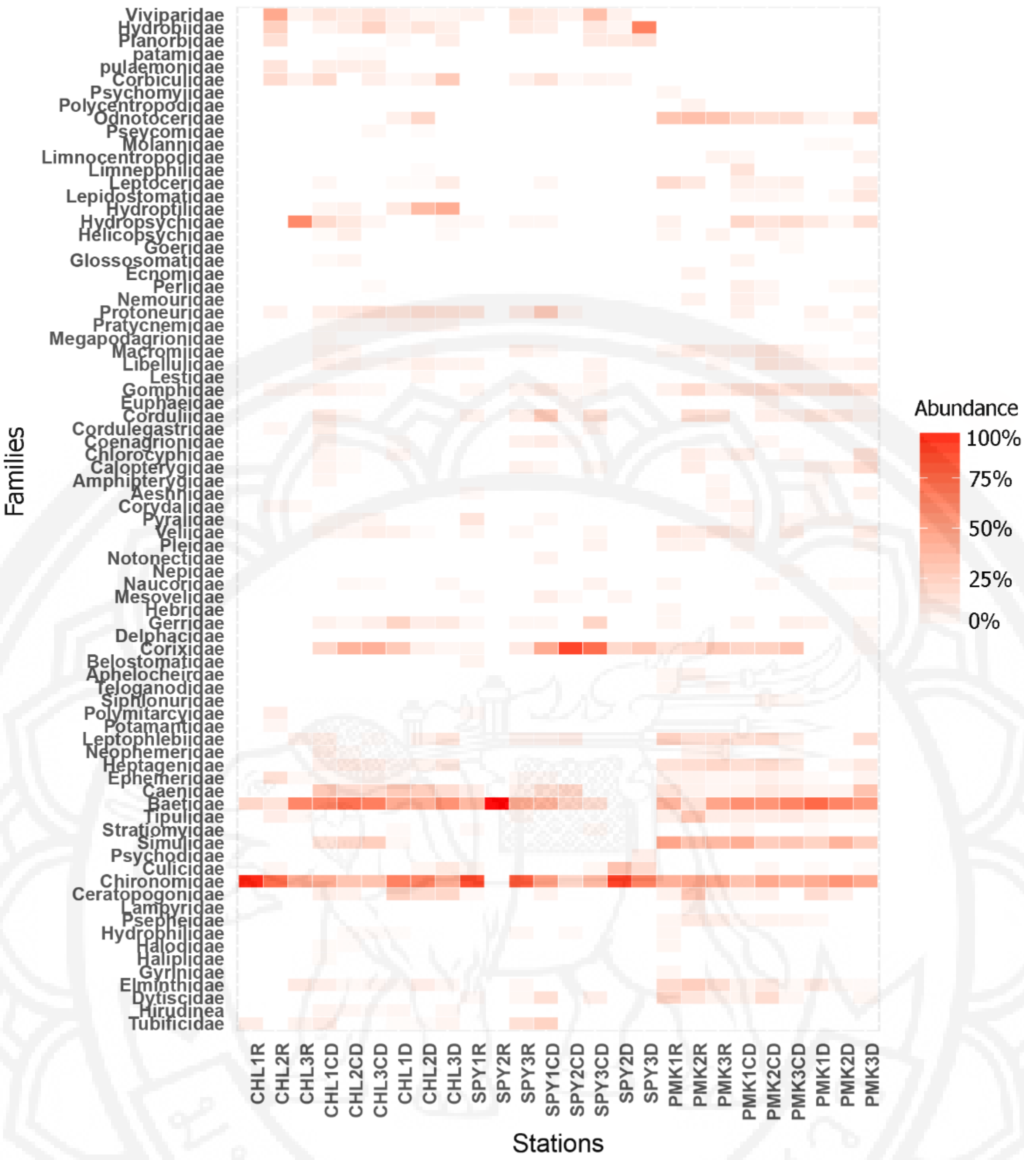
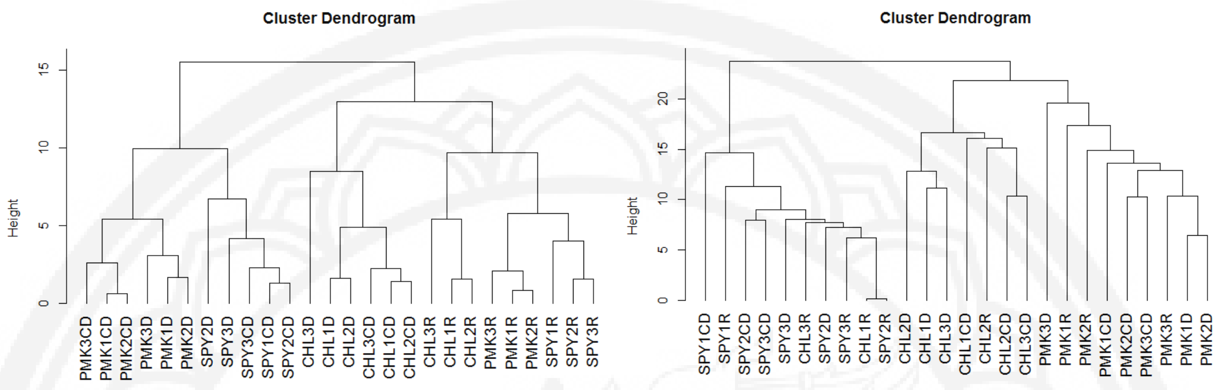


Figure 2 Heat map showing the abundance of macroinvertebrate taxa at each station and season

Table 3 Number of individual and taxa (family-level), Shannon diversity index and Pielou's evenness index of macroinvertebrates among station and seasons

	Individual	Diversity Index	Evenness	Taxa
Station				
CHL	10928	2.185	0.547	54
SPY	4020	1.711	0.458	41
PMK	6443	2.186	0.534	60
Season				
Rainy	3820	2.071	0.508	59
Cool-dry	8195	2.177	0.523	64
Dry	9376	2.094	0.520	56

A cluster dendrogram was produced (Figure 3A) with a set of environmental variables. The result showed that the station categories can be classified based on physical-chemical parameter. Group A is composed of the upstream area (1^{st} and 2^{nd} order) that representative of a low-value environmental parameters or smaller impact to water quality and includes PMK in the dry and cool-dry seasons and SPY in dry season. Group B was composed of the rainy season of CHL, PMK and SPY stations as well as CHL in the cool-dry and dry seasons. On the other hand, site classification from cluster analysis based on macroinvertebrates also revealed two large groups. Group A represents stations in which numerous macroinvertebrates were found and group B represents stations in which were found small numbers of macroinvertebrates (Figure 3B).



3A 3B

Figure 3 The cluster analysis based on physical–chemical parameters (3A) and based on macroinvertebrates among stations and seasons (3B)

The CCA was performed to clarify how macroinvertebrates were distributed according to environmental gradient at different stations. The results from the CCA analysis showed that conductivity, TDS, BOD, NO_3^-, NH_3^- and PO_4^{3-} (Figure 4) were the most important predictors of macroinvertebrate assemblage. The first four CCA axes had very high specie-environment correlation (>0.860) which suggests that the measured environmental variables were strongly related to macroinvertebrate assemblage variation (Kasangaki, Chapman, & Balirwa, 2008). In the first axis, BOD and NO_3 were the most important factors and positively associated with tolerant macroinvertebrate families such as Psychodidae, Notonectidae and Mesovelidae (Blakely, Eikaas, & Harding, 2014; Mustow, 2002). The bottom section of the CCA plot had high conductivity, total dissolved solids and BOD. The taxa dominating this cluster included high tolerant taxa such as mosquito larvae Culicidae, Planorbidae, Mesovelidae and Tubificidae. The upper section of CCA plot corresponded with PMK site in all seasons (1^{st} order stream). These sites were characterized by low conductivity and TDS. Sites in this category were dominated by sensitive taxa such as Nemouridae, Siphlonuridae, Plelidae and Corydalidae.

The canonical correspondence analysis was used to test whether the species are different along the gradient by ANOVA permutation test. The results showed that the difference was highly significant (F=1.8394, p=0.003). It could be said that in this study the species assemblages were different according to environmental factors (Table 4).

The permutation test on the first (F=5.302, p=0.004) and second (F=4.495, p=0.001) CCA axes were highly significant. Furthermore, the results revealed that the three environmental parameters were highly significant to the macroinvertebrate assemblage—turbidity (F=3.318, p=0.016), conductivity (F=2.619, p=0.018) and BOD (F=2.505, p=0.013) (Table 4).

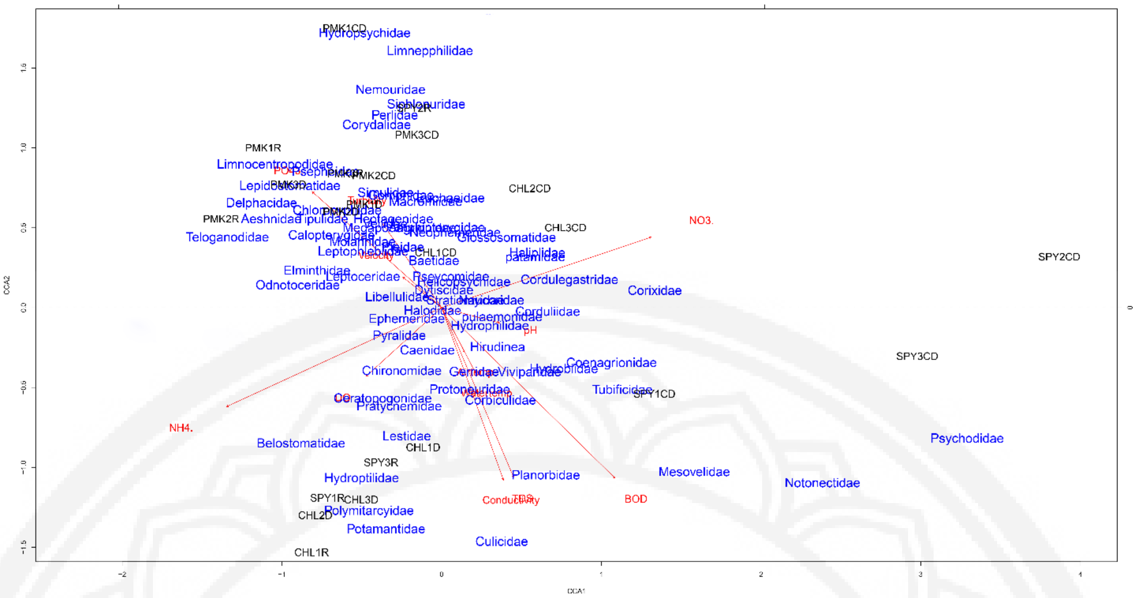


Figure 4 Scatterplot based on the CCA of macroinvertebrates among the stations correlated with the environmental variables to the ordination of axes 1 and 2

Table 4 The summary of environmental variable test with ANOVA

Environmental variables	Df	Chi Square	F	p-value
Model	12	1.16015	1.8394	0.003**
Residual	13	0.68329		
Air temperature	1	0.07527	1.4320	0.243
Water temperature	1	0.03943	0.7501	0.793
Turbidity	1	0.17441	3.3181	0.016 *
Velocity	1	0.06010	1.1434	0.416
pH	1	0.06524	1.2412	0.365
Conductivity	1	0.13770	2.6198	0.018 *
TDS	1	0.10944	2.0822	0.091
DO	1	0.09747	1.8544	0.092
BOD	1	0.13167	2.5051	0.013 *
NO_3^-	1	0.09735	1.8520	0.052
NH_4	1	0.09135	1.7380	0.108
PO_4^{3-}	1	0.08073	1.5359	0.163

** Significant at $p \leq 0.01$, * significant at $p \leq 0.05$

Discussion

Physical and chemical parameters toward biological traits

The major goal of this study was to test whether environmental factors influence the distribution and diversity of macroinvertebrate assemblages in upstream Northern Thailand. Our results showed that the physical and chemical parameters in Mae Taeng microbasins during 2015 to 2016 varied among stations and might affect organism distribution as per our hypothesis.

The grouping of the stations obtained using cluster analysis based on physicochemical variables (Figure 3A) revealed that there were two large groups. One group contained high values of environmental variables, while the other group contained low values of physical and chemical variables.

These results clearly demonstrated that the season affected physical and chemical parameters, such as high turbidity and conductivity in the rainy season due to communities' and agricultural runoff (Riens et al., 2013; Von Bertrab et al., 2013; Withers and Hodgkinson, 2009). However, the results also showed the differences between two groups. The low-impact sites included PMK, an upstream area, in the dry and cool-dry season. Meanwhile, the other group included areas that were not upstream and contained huge communities and agricultural activities that are related to greater impact on water quality. This can be simply explained that the PMK station is located at a headwater stream which has a small size, and in an undisturbed riparian's area. Even in the rainy season, the impact from runoff on headwater streams is modest compared to larger streams or rivers according to the river continuum concept (Greathouse and Pringle, 2006; Ilg and Castella, 2006; Jonsson et al., 2017).

On the other hand, the results of macroinvertebrate clustering revealed two groups, one containing a high number of macroinvertebrates, namely, the PMK and CHL stations, and the other containing low individual number of macroinvertebrates (Figure 4). This finding shows that the taxa and number of individual macroinvertebrates within the stations were variable. Presumably, this is owing to the heterogeneous physical and chemical properties among the locations. In addition, the locations were structurally complex and different anthropogenically. This complexity was reflected in the PMK stations, the headwater area where the water body contained low physical and chemical properties. This characteristic could be used as an indication of good water quality. This site also had the highest abundance and diversity of macroinvertebrates. It can be explained that this sampling station is located in an agro-forest which may have acted as a buffer zone protecting organisms from anthropogenic runoff. The importance of buffer zone to aquatic organisms had been addressed by previous studies (de Snoo and de Wit, 1998; Mc Conigley, Lally, Little, O'Dea, & Kelly-Quinn, 2017; Zhang et al., 2017).

Macroinvertebrate assemblage and diversity

The major group of macroinvertebates in this study was aquatic insects including order Diptera (35.9%) and order Ephemeroptera (35.8%). This almost certainly reflects that these two orders are cosmopolitan and have varied distribution. Particularly, order Diptera is one of the most cosmopolitan and diverse among insect groups throughout the environmental optima. The adaptation of this organism has developed a relatively good dispersal ability during both larvae and adult phase (Arva, Specziar, Eros, & Toth, 2015). Therefore, it is not surprising that we found chironomids of the order Diptera to be the abundant and dominant family in every station. Acosta and Prat (2010) reviewed the abundance of Chironomidae along high altitude streams in Peru and found that in headwaters, this organism is related to the interaction between simultaneous flow and intermittent flow of water, the riparian vegetative cover and the type of bottom substratum. Also, Beatidae is one of the most common and diverse family among macroinvertebrates and plays a key role in freshwater ecosystems as consumer of periphyton and particulate matter (Culp and Scrimgeour, 1993; Stauffer-Olsen et al., 2017).

According to the relationship between organisms and environmental factors based on CCA (canonical correspondence analysis), the first two axes (axis 1 and axis 2) primarily reflected abiotic factors including turbidity, conductivity and biochemical oxygen demand which are highly important predictors in this study of macroinvertebrate structure. It can be simply explained that the gastropods Planobidae as well as the mosquito larvae Culicidae are closely related to high turbidity and conductivity. They are frequently reported to be the dominant species in the downstream and as contaminating aquatic ecosystems (Amani, Yaghoobi-Ershadi, & Kassiri, 2014; Navarro et al., 2010; Yee et al., 2007). The distributions of Culicidae were often reported to have strongly positive relation with high conductivity and turbidity and low concentration of dissolved oxygen (Cyrino zequi et al., 2014; Dida et al., 2015; Neff and Jackson, 2011). This indicated that chemical factors in microhabitat are important variables in relation to the macroinvertebrate community. However, given that these are data from a one-year investigation, they provide no clear picture in terms of the spatial distribution pattern of macroinvertebrate assemblages.

Conclusion

Our finding clearly indicate that anthropogenous influences on the composition and spatial distribution of macroinvertebrate communities and effected characterize the distribution and assemblage structure of macroinvertebrates in tropical areas as the Northern Thailand. However, biodiversity pattern exhibited by macroinvertebrates assemblages are complex. In term of the complex is might be cause from multiple environmental variable. Therefore, we need to explore and conduct long-term monitoring which will lead to a construction of the pattern and distribution of macroinvertebrates. We hope these results represent an important broad scale environmental study that can help determine biodiversity and enhance regional biodiversity by revealing strong contrasts in environmental conditions.

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