JFHB Journal of Food Health and Bioenvironmental Science

Journal of Food Health and Bioenvironmental Science
Journal homepage : http://jfhb.dusit.ac.th/

Morphological Gill Abnormalities in the Larvae of Hydropsychidae (Trichoptera: Insecta) for Assessment of Water Quality Variables

Amornrat Ninon & Taeng On Prommi*

Department of Biological Science, Faculty of Liberal Arts and Science, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom Province, 73140 Thailand

Article info

Article history:
Received: 6 December 2019
Revised: 25 December 2019
Accepted: 25 December 2019

Keywords:
Gills, Morphology, Trichoptera, Assessment, Water Quality

Abstract

The aim of this study was carried out to determine the morphological gill abnormalities in hydropsychid larvae in correlation with water quality in the three streams. Samples were collected in April, August and December 2015. In total, 841 individuals were caught belonging to 10 species. Gill abnormalities consisted of dark spots on the gill tufts and reduced numbers of gill filaments. The proportion of individuals with at least some abnormality (HAI), and the average number of abnormal gill tufts for all individuals (HYI) in the Huai Pakkok stream was higher than in the Huai Kayeng stream and the Huai U-Long stream. Physicochemical water quality was slightly differed in each sampling sites. The correlation between normal and abnormal gill morphology and physicochemical water quality parameters were analyzed. The normal and abnormal of *Potamyia phaidra* were correlated with conductivity, total dissolved solids, and alkalinity ($p<0.05$), whereas the *Cheumatopsyche lucida* were correlated with sulfate ($p<0.05$). The normal and abnormal of *Pseudoleptonema quinquefasciatum* and the normal of *Hydropsyche brontes* were correlated orthophosphate ($p<0.05$).

Introduction

The order Trichoptera consists of caddisflies, a group of insects that spend their larval phases in aquatic environments. High species diversity, various ecological and behavioural specializations and very strict environmental requirements, particularly along the longitudinal continuum, make caddisfly larvae excellent study organisms for environmental gradient studies (Morse, 2011; Holzenthal et al., 2007).

The gills of an aquatic macroinvertebrate are one of the most impacted structures on the body of the organism when the environment in which it lives is altered. They are especially sensitive due to their large surface area and their ability to accumulate compounds and gases (Laporte et al., 2002). One of the most important biological indicator taxa for water quality is Trichoptera (caddisflies). This group of insects is ideal because it is high in biodiversity, inhabits many ecological niches, and is abundant (Dohet, 2002; Resh, 1993; Rosenberg & Resh, 1993; Wiggins, 1996). However, many caddisfly species are known for their intolerance of habitat sedimentation and organic pollution (Barbour et al., 1999), and so their numbers may strongly diminish

* Corresponding Author
e-mail: faastop@ku.ac.th

downstream of habitat disturbances (Berlin & Thiele, 2002). In contrast, some species are more tolerant of organic pollution and may increase in abundance of such downstream disturbances (Barbour et al., 1999).

The caddisflies family Hydropsychidae have been increasingly utilized in biomonitoring and impact assessment of pollutants in rivers for several reasons (Vuori, 1994; 1995; Vuori & Kukkonen, 1996). First, hydropsychid larvae are widely distributed and abundant in many types of running waters. Second, they respond to variations in water quality and their autecology is well known enough for the impact of pollutants to be distinguished. Third, due to their robust body, hydropsychid larvae are easily handled and observed for morphological abnormalities. Fourth, the abnormalities in the hydropsychid tracheal gills, the ion-regulatory organ and the anal papillae can be attributed to a disruption of the respiratory and ion regulation functions. Fifth, the relatively large size facilitates sampling and analysis of the concentrations of chemicals in the larvae. Finally, the hydropsychid larvae as facultative filter feeders are more exposed to pollutants in seston, flowing water and the organic matter accumulated in riffle microhabitats. The gills of hydropsychid larvae are one of the most impacted structures on the body of the organism when the environment is altered. They are particularly sensitive due to their large surface area, which increase the accumulation of compounds and gases (Skinner & Bennett, 2007). Direct effluent discharges and agricultural runoff water mostly contain complex mixtures of contaminants that may produce new compounds due to breakdown and transformation processes and hence contribute to the complexity of the total toxin burden. By the employment of chemical and physical measurements only, the synergistic effect of pollution on its biotic community may not be fully and easily assessed (Resh & Jackson, 1993). In general, biological indicators provide a potential for direct observation of the overall effect of environmental contaminants by virtue of their role in aquatic ecosystems (Warwick, 1988). The purpose of this study was to investigate individual gill morphology alterations in hydropsychid larvae and to consider possible impacts of water quality parameters (e.g., dissolved oxygen (DO)), pH, water temperature, conductivity, total dissolved solids (TDS), sulfate and nutrients on gills morphological structure.

Materials and methods

1. Study area

We used the samples from streams in the Mae Klong watershed, which is the most important watershed in the western part of Thailand. The upstream area consists of the Khwae Noi and Khwae Yai rivers, namely, that run into the Khao Leam and Srinagarind Dam located in the upper region of Mae Klong watershed. The rivers are jointed downstream in Kanchanaburi Province, flowing through Ratchaburi and Samutsongkram provinces finally flowing into the Gulf of Thailand. The sampling sites were three streams on the upper reach of the Khwae Noi River, Kanchanaburi Province, Thailand, upstream from Khao Leam Dam: Huai U-Long (UL1), Huai Pakkok (PK1, PK2), and Huai Kayeng (KY1, KY2, KY3) (Fig. 1). These streams are major sources for household and irrigation water supply in Thong Pha Poom District, Kanchanaburi Province.

2. Physicochemical water quality parameters

Selected physicochemical water quality parameters were recorded directly at the sampling site and included pH (measured by a pH-meter Waterproof Model Testr30), water temperature (measured by a hand-held thermometer), and dissolved oxygen (DO, measured by a HACH® Model sensION 6 DO meter), total dissolved solid (TDS) and electrical conductivity (EC) (measured by a EURECH CyberScan CON110 conductivity/TDS meter). Water samples from each collecting period were stored in polyethylene bottles (500 mL). Ammonia nitrogen (NH_3-N), sulfate (SO_4^{2-}), nitrate-nitrogen (NO_3^--N), orthophosphate (PO_4^{3-}), and turbidity were determined in accordance with standard procedures (APHA., 1992). Alkalinity was measured by titration (APHA., 1992).

3. Sample collection and identification

The hydropsychid larvae were collected from mid- and downstream riffle areas of the three tributaries stream of the Mae Klong watershed in April, August and December 2015. Larvae were handpicked from stones, stone crevices, gravel, woody debris and other stable substrates. Sampling time of the larvae was restricted to one hour for standardization. The specimens were then preserved in 80% EtOH and brought to the laboratory where they were sorted to morphospecies using characters in the key for Thai caddisfly larvae as described in Prommi (2007). At the same sites where larvae and pupae were collected, adults were collected at the stream margin using black light traps operated from after sunset until morning.

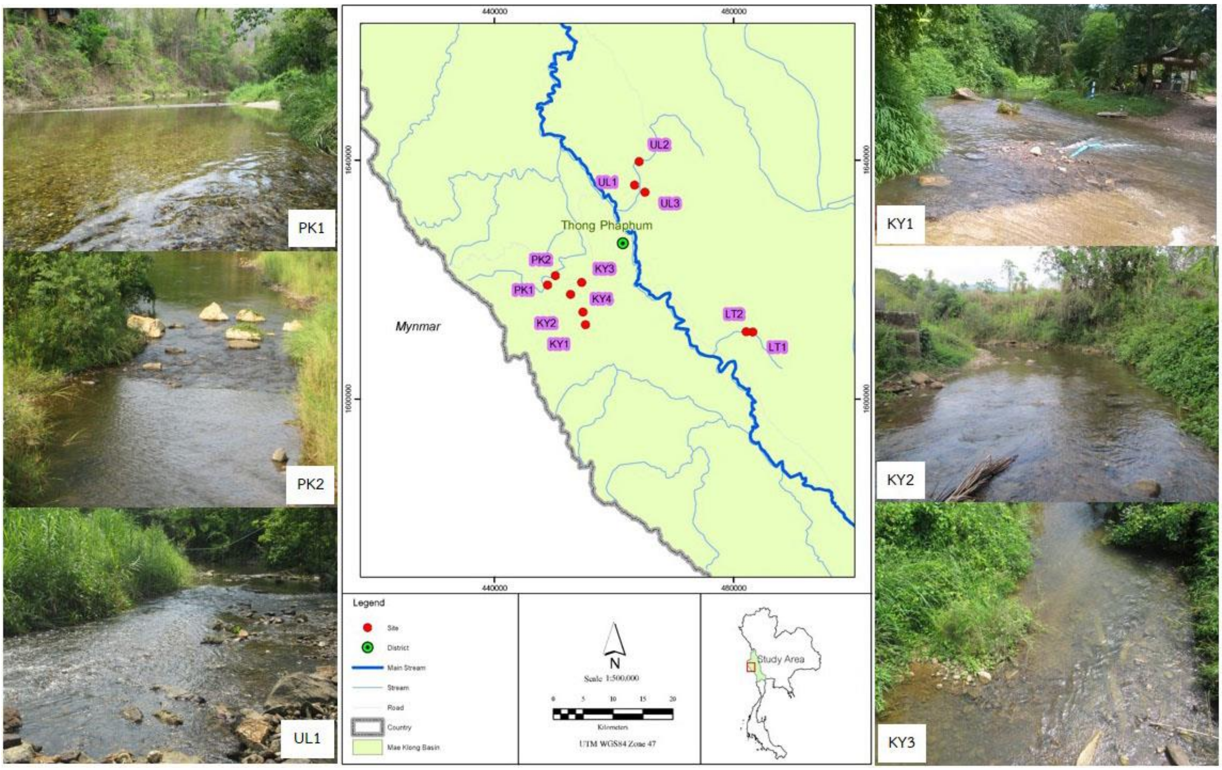

Fig. 1 Map of the Mae Klong watershed showing the sampling sites in three streams, Huai Kayeng (KY1, KY2 and KY3), Huai Pakkok (PK1, PK2) and Huai U-Long (UL1).

The immature forms were associated with adults using the metamorphotype method, which relies on the collection of a pharate male in its pupal exuviae and with shed larval sclerites within the pupal case or shelter (Milne, 1938; Wiggins, 1996).

4. Analyses

Structural changes in the hydropsychids gills were studied under a stereomicroscope and quantified using an ocular micrometer. Small and light pigmentation spots were considered part of natural variation and so were not categorized as a morphologically abnormal. Two biomarkers were evaluated: (1) Hydropsychid abnormality incidence (HAI), referring to the proportion of individuals with at least some abnormalities, and (2) Hydropsychid gill abnormality indice (HYI), referring to the average number of abnormal gill tufts for all individuals (Vuori, 1994; Vuori & Kukkonen, 1996). Correlations between all variables for water quality, and hydropsychid larvae were tested by Pearson product-moment correlation coefficient using SPSS v. 13.0 (http://www.spss.com/).

Results and discussion

1. Physicochemical parameters of water quality

Mean values of selected physicochemical parameters of water quality at n the three tributaries stream of Mae Klong watershed during this study are presented in Table 1.

The mean value of water temperature ranged from 25.22±2.28 (UL1) to 28.86±3.36°C (PK2). Temperatures were relatively lower during the wet season than during the dry season. The minimum (25.0ºC) and maximum temperatures (35.5ºC) were normal for tropical waters and were required for the normal growth of aquatic organisms. At the upstream site, the riparian areas were covered by vegetation that shaded the water and may have provided lower water temperatures. This is similar to reports of Hauer & Hill (1996) that a smaller watershed stream has lower temperature because the riparian trees help protect the water from heat.

The mean value of pH ranged from 8.26±0.10 (UL1) to 8.69±0.36 (KY1). The accumulation of free carbon dioxide due to reduced photosynthesis by phytoplankton and rooted macrophytes causes lower pH values in water while intense photosynthesis reduces free carbon dioxide content and results in higher pH values (Egborge, 1994; Gupta & Gupta 2006). The pH was decreased in the rainy season. This may be attributed to the increased organic matter washed into the stream by surface runoff during the wet season that tends to reduce dissolved oxygen through organic decomposition, reducing pH.

The mean value of dissolved oxygen ranged from 4.61±2.15 mg/L (KY2) to 5.90±1.74 mg/L (KY1). Sources of dissolved oxygen in aquatic environments include the atmosphere and photosynthesis and its concentration depends on its solubility (which decreases with increasing water temperature), while dissolved oxygen is reduced by respiration of submerged plants and animals and aerobic bacteria, including their metabolic activity in decomposing dead organic matter (Gupta & Gupta 2006). The water current at KY1 was high, resulting in a turbulent flow which increases oxygen in the water continually (Boulton & Brock 1999).

Mean electrical conductivity values ranged from 68.98±43.58 µS/cm (KY1) to 243.41±103.96 µS/cm (KY3). The mean total dissolved solids values ranged from 35.87±19.92 mg/L (KY1) to 121.79±51.91 mg/L (KY3). The total dissolved solids and electrical conductivity were highest in KY3 and lowest in KY1. The general trend in this study was that electrical conductivity tended to decrease in the dry season compared with the wet season. Increases in electrical conductivity could result from low precipitation, higher atmospheric temperature resulting in higher evapotranspiration rates and higher total ionic concentration, and saline intrusions from underground sources. It could also be due to a high rate of decomposition and mineralization by microbes and by nutrient regeneration from bottom sediments (Egborge, 1994). Also, electrical conductivity and total dissolved solids could be higher due to contamination of water from agricultural activities and industrial effluent that degrade water quality (Lenat & Crawford, 1994).

The mean turbidity values ranged from 4.11±4.00 NTU (PK1) to 27.56±26.94 NTU (UL1). The higher turbidity was recorded during the wet season and may have been due to heavy rainfall. This increase in suspended solids impeded light thereby increasing turbidity. The adverse effects of turbidity on freshwater include decreased penetration of light which then reduces primary and secondary production, increased adsorption of nutrient molecules to suspended materials which makes the nutrients unavailable for plankton production, decreased oxygen concentration, and clogged filter-feeding apparatus and digestive organs of planktonic organisms, which may adversely affect the production of larvae (Gupta & Gupta, 2006).

Mean alkalinity values ranged from 11.87±5.89 mg/L (PK1) to 35.47±9.20 mg/L (KY3). Water bodies in the tropics usually show wide fluctuations of total alkalinity, the values depending on the location, season, plankton population and nature of bottom deposition. Highly productive waters have alkalinity values above 100 ppm and for freshwater aquaculture the values should be between 40-200 ppm. Alkalinity values above 300 ppm have been reported to affect the spawning and hatching of freshwater fish adversely (Gupta & Gupta, 2006).

The mean dissolved nutrients, NH_3-N, PO_4^{3-}, and NO_3^--N concentrations varied from 0.18±0.07 mg/L (PK2) to 0.31±0.12 mg/L (KY1), 0.32±0.16 mg/L (PK1) to 0.93±0.57 mg/L (KY1), and 0.92±0.16 mg/L (PK2) to 1.54±0.45 mg/L (KY3), respectively. The mean concentration value of SO_4^{2-} ranged from 1.00±0.25 mg/L (PK1) to 5.00±0.25 mg/L (PK2). Nitrates are the most

Table 1 Physicochemical parameters at sampling sites on Mae Klong watershed, showing mean and standard deviation for each site in April, August and December 2015

Parameter/site	PK1	PK2	KY1	KY2	KY3	UL1
WT (ºC)	26.18 ± 2.44	28.86 ± 3.36	28.59 ± 5.65	28.07 ± 3.91	25.95 ± 1.20	25.22 ± 2.28
pH	8.50 ± 0.09	8.40 ± 0.15	8.69 ± 0.36	8.55 ± 0.11	8.45 ± 0.04	8.26 ± 0.10
DO (mg/L)	5.07 ± 2.21	5.23 ± 3.64	5.90 ± 1.74	4.61 ± 2.15	5.79 ± 1.28	5.74 ± 4.29
EC (µS/cm)	72.39 ± 20.46	114.08 ± 40.19	68.98 ± 43.58	238.43 ± 82.47	243.41 ± 103.96	239.22 ± 39.46
TDS (mg/L)	38.36 ± 7.78	55.28 ± 20.75	35.87 ± 19.92	113.33 ± 44.79	121.79 ± 51.91	119.94 ± 19.41
Turbidity (NTU)	4.11 ± 4.00	7.44 ± 4.44	6.22 ± 4.60	11.33 ± 10.37	6.33 ± 3.76	27.56 ± 26.94
Alkalinity (mg/L)	11.87 ± 5.89	15.13 ± 5.19	12.13 ± 1.31	30.67 ± 8.61	35.47 ± 9.20	32.67 ± 8.61
NH_3-N (mg/L)	0.26 ± 0.18	0.18 ± 0.07	0.31 ± 0.12	0.26 ± 0.06	0.26 ± 0.05	0.27 ± 0.21
PO_4^{3-} (mg/L)	0.32 ± 0.16	0.51 ± 0.16	0.93 ± 0.57	0.40 ± 0.15	0.39 ± 0.16	0.83 ± 0.80
NO_3-N (mg/L)	1.46 ± 0.46	0.92 ± 0.16	1.37 ± 0.63	1.21 ± 0.43	1.54 ± 0.45	1.24 ± 0.18
SO_4^{2-} (mg/L)	1.00 ± 0.25	5.00 ± 0.25	1.00 ± 0.41	4.00 ± 2.25	5.00 ± 3.25	2.00 ± 1.25

oxidized forms of nitrogen and the end product of aerobic decomposition of organic nitrogenous matter. Natural waters in their unpolluted state contain only minute quantities of nitrates. The highest nitrate values occurring during the monsoon/post monsoon season may be primarily due to organic materials being received from the catchment area during rainfall (Das et al., 1997). The increasing levels of nitrates are due to freshwater inflow, litter fall decomposition and terrestrial run-off during the monsoon/post monsoon season (Karuppasamy & Perumal, 2000). Another possible source of nitrate recruitment is through oxidation of ammonia from nitrogen to nitrite formation (Rajasegar, 2003). The low values during the summer/pre-monsoon period may be due to utilization of nitrates by phytoplankton as evidenced by high photosynthetic activity. In addition, nitrates may be obtained from natural and human activities, both from household wastes and from fertilizers used in agriculture, consistent with observations by Omernik (1977) who indicated that the levels of nutrients in streams were positively correlated with percentage of land in agriculture. Furthermore, although orthophosphate is usually a minor compound in nature (Jarvie et al., 2002), its higher values in stream water at our sampling sites was from agricultural fertilizers which are leached into water when it rains.

2. Biodiversity of Hydropsychidae

Eighteen species of adult hydropsychids were caught by light trapping in the three tributaries of Mae Klong watershed during this study. The most species rich genera were *Cheumatopsyche* (6 species), followed by *Macrostemum* (3 species), *Potamyia* (3 species), *Hydropsyche* (2 species), and *Amphipsyche, Diplectrona, Polymorphanisus,* and *Pseudoleptonema* (each 1 species) (Table 2).

Totally, 844 individual of hydropsychid larvae were collected in the three tributaries of Mae Klong watershed during this study (Table 3). Of these, 9 larvae were associated with identifiable adults of Hydropsychidae: *Cheumatopsyche copia, Cheumatopsyche lucida, Hydropsyche brontes, Hydropsyche camillus, Potamyia phaidra, Pseudoleptonema quinquefasciatum, Polymorphanisus astictus, Macrostemum floridum* and *Amphipsyche gratiosa* (Table 3). The most abundance of hydropsychids collected was found in KY1 (272 individuals) which was abundant than in PK2, PK3, KY1, KY2 and UL1 (224, 218, 92, 27 and 8 individuals, respectively).

Gills were considered impaired if they exhibited heavy darkening, malformation, and/or reduction of single gill tufts (Fig. 2). Darkening of the gills appeared to start either at the basal or distal ends. We considered minor darkening (often single pigmented spots) not to represent a morphological abnormality because potentially this might be induced by natural causes (Fig. 3). The HAI in Huai Pakkok (PK1, PK2) was 71.56% and 50%, in Huai Kayeng (KY1, KY2 and KY3) was 26.47%, 16.30% and 6.67% and in Huai U-Long was 12.5%. The HYI was highest value in Huai Pakkok (9.34%, 5.06%), followed by Huai Kayeng (4.83%, 1.53%, 0.46%) and Huai U-Long (0.8%) (Table 3). In this study, *Potamyia phaidra* larvae were most abundant in all streams and the gills of this species were most impaired.

Table 2 Checklist of adult Hydropsychidae at three streams, six sampling stations of the Mae Klong Watershed in April, August and December 2015

Species	Station
Amphipsyche gratiosa Navas 1922	KY1, KY2, PY2
Cheumatopsyche charites Malicky & Chantaramongkol 1997	PK1, PK2, KY1, KY2, UL1
Cheumatopsyche cocles Malicky & Chantaramongkol 1997	PK1
Cheumatopsyche lucida Ulmer 1907	PK1, UL1
Cheumatopsyche chrysothemis Malicky & Chantaramongkol 1997	KY2
Cheumatopsyche dubitans Moesly 1942	PK1, PK2
Cheumatopsyche globosa Ulmer 1910	PK1, KY2, UL1
Diplectrona gombak Olah 1993	KY2
Hydropsyche brontes Malicky & Chantaramongkol 2000	PY1, KY1
Hydropsyche camillus Malicky & Chantaramongkol 2000	KY1
Macrostemum dohrni Ulmer 1905	PK1
Macrostemum floridum Navas 1929	PK2, KY2, UL1
Macrostemum midas Malicky & Chantaramongkol 1998	PK1, PK2, KY1, KY2
Polymorphanisus astictus Navas 1923	PK1
Potamyia chaos Malicky & Thani 2000	PK1
Potamyia flavata Banks 1934	PK1
Potamyia phaidra Malicky & Chantaramongkol 1997	PK1, PK2, KY1, KY2
Pseudoleptonema quinquefasciatum Martynov 1935	PK1, PK2, KY1, KY2, UL1

3. Correlation between physicochemical parameters and hydropsychid larvae

The correlation between physicochemical water quality parameters and hydropsychid larvae were analyzed. The Hydropsychidae *Potamyia phaidra* were negatively correlated with electrical conductivity, total dissolved solids and alkalinity ($p<0.05$), whereas *Cheumatopsyche lucida* were negatively correlated with sulfate ($p<0.05$). The *Pseu. quinquefasciatum* and *Hydropsyche brontes* were negatively correlated with

Table 3 Total number of hydropsychid larvae collected in three streams, six sampling stations of the Mae Klong Watershed in April, August and December 2015

Site	Species	Total	Individual		Total gills	Gill abnormal	HAI (%)	HYI (%)
			Normal	Abnormal				
PK1	*Pseu. quinguefasciatum*	49	36	13	2796	27	26.53	0.96
	Hydropsyche brontes	21	7	14	630	38	66.66	6.03
	Hydropsyche camillus	1	0	1	30	1	100	3.33
	Polymorphanisus astictus	1	1	0	60	0	0	0
	Potamyia phaidra	148	66	82	4440	332	55.4	7.47
	Cheumatopsyche lucida	3	2	1	105	2	33.33	1.9
	Macrostemum floridum	1	0	1	29	7	100	24.14
PK2	*Potamyia phaidra*	181	38	143	5430	563	79	10.36
	Hydropsyche brontes	6	3	3	180	9	50	5
	Cheumatopsyche lucida	1	1	0	35	0	0	0
	Macrostemum floridum	6	1	5	174	29	83.33	16.66
	Hydropsyche camillus	23	18	5	690	12	21.74	1.74
	Pseu. quinguefasciatum	1	1	0	57	0	0	0
KY1	*Cheumatopsyche copia*	24	12	12	840	23	50	2.74
	Cheumatopsyche lucida	17	16	1	595	1	5.88	0.17
	Hydropsyche brontes	38	31	7	1140	15	18.42	1.32
	Macrostemum floridum	192	138	54	5568	356	28.12	6.39
	Potamyia phaidra	1	1	0	30	0	0	0
KY2	*Potamyia phaidra*	13	10	3	390	6	7.69	1.54
	Hydropsyche brontes	56	48	8	1680	19	14.29	1.13
	Pseu. quinguefasciatum	6	6	0	342	0	0	0
	Amphipsyche gratiosa	17	17	0	48	0	0	0
KY3	*Potamyia phaidra*	22	21	1	660	1	4.54	0.15
	Amphipsyche gratiosa	3	3	0	48	0	0	0
	Pseu. quinguefasciatum	2	2	0	114	0	0	0
UL1	*Pseu. quinguefasciatum*	5	5	0	285	0	0	0
	Hydropsyche camillus	3	2	1	90	3	33.33	3.33

Fig. 2 Hydropsychidae larvae, *Amphipsyche gratiosa* (left) and *Pseudoleptonema quinquefasciatum* (right) showing the impairment of gill morphology.

Fig. 3 Hydropsychidae larvae, *Cheumatopsyche lucida* (left) and *Macrostemum floridum* (right) species showing the normal gill morphology.

orthophosphate ($p<0.05$) (Table 4). The results suggest that physicochemical attributes such as electrical conductivity, total dissolved solids, alkalinity, orthophosphate, and sulfate significantly contributed to the impairment of hydropsychid larvae gills in the Mae Klong tributaries.

The biological method of water quality analysis has certain advantage over the physicochemical analysis. In particular, developing countries could benefit more from this type of analysis rather than using the costly physicochemical one. Among the various biological methods, incidence of deformities among benthic macroinvertebrates is getting due attention to assess the health of aquatic ecosystems. However, deformity could also result from factors other than pollution. That is why care has to be taken when associating deformity with pollution or environmental stress (Beneberu & Mengistou, 2014).

The previous study in gill morphology deformities in Hydropsychidae larvae have been reported by Prommi & Thamsenanupap (2013). This paper presents a quantitative study on gill abnormalities in population of

Table 4 Pearson's correlation coefficients between water quality variables and hydropsychid larvae impairment

Species	EC	TDS	Alkalinity	SO_4^{2-}	PO_4^{3-}
Potamyia phaidra (normal gills)	-0.916*	-0.907*	-0.855*		
Potamyia phaidra (gills abnormalities)	-0.854*	-0.845*	-0.836*		
Cheumatopsyche lucida (gills abnormalities)				-0.816*	
Pseu. quinquefasciatum (normal gills)					0.905*
Pseu. quinquefasciatum (gills abnormalities)					0.845*
Hydropsyche brontes (normal gills)					0.845*

Remarks: * : Significant at the 0.05 level, negative (-).
* : Significant at the 0.05 level, positive (+).

hydropsychid larvae in stream from Mae Klong watershed, and all showed heavily darkened, malformed and/or reduced single gill tufts. The gill pigmentation was obvious, starting from either basal or distal ends. Completely total dissolved solids, alkalinity and orthophosphate concentration were negatively correlated with gill abnormalities, whereas the pH and

Cu concentration parameters were positive correlated.

The capacity of water to accept hydrogen ions is called alkalinity and is important in the chemistry and biology of natural waters. Alkalinity serves as a pH buffer and reservoir for inorganic carbon, thus helping to determine the ability of water to support algal growth and other aquatic life. Alkalinity can be used as a measure of water fertility. The distinction between elevated pH and high alkalinity is important. The pH is an intensity factor whereas alkalinity is a capacity factor. The greater alkalinity and hardness in stream water most likely accounted for the reduced Cu toxicity observed in stream. Gauss et al. (1985) compared effects of Cu on chironomids in hard and soft water. They reported 96-h LC_{50} values of 17 µg Cu/Lin soft (43 mg/L $CaCO_3$) water and 98 µg Cu/L in hard (172 mg/L $CaCO_3$) water. In contrast from this study, the alkalinity in Huai Pakkok (PK1 and PK2) was the lowest, whereas Cu was the highest. Hardness was not measured in our streams and the influence of this parameter on observed Cu toxicity is unknown.

Elevated levels of total dissolved solids (TDS) have been suggested as stressors to aquatic life in Central Appalachian streams influenced by coal mining (Bodkin et al., 2007; Pond et al., 2008). In coalfield streams, TDS is most often dominated by the dissolved ions SO_4^{2-} and HCO_3^-, with elevated concentrations (relative to reference) of Ca^{2+}, Mg^{2+}, Na^+, K^+, and Cl^- also common (Pond et al., 2008; Mount et al., 1997). At present here, *Cheumatopsyche lucida* were negatively correlated with sulfate. This suggests that while the number of taxa present may increase with increasing TDS, abundance of individuals within the remaining species, and perhaps overall species abundance, may remain less affected, at least within the range of TDS.

Conclusion

The present study clearly indicated that the stream from Mae Klong watershed is experiencing pollution from domestic activities established near its vicinity. The domestic pollution load in the river can be witnessed by deformed structures manifested on hydropsychid gill morphology. Various forms of deformities were noted with highest incidence occurring on heavy darkening, malformation, and/or reduction of single gill tufts. Therefore, it is possible to conclude that morphological deformities among Hydropsychid larvae such as *Potamyia phaidra, Cheumatopsyche lucida, Pseu. quinquefasciatum* and *Hydropsyche brontes* can be a potential tool to assess the health of an aquatic ecosystem. However, future studies should focus not only on the field data but also on laboratory-based experiments on live hydropsychid larvae. With this approach, it is possible to explain the major environmental variables that can cause the highest rate of deformity among hydropsychids.

Acknowledgement

This research work was supported by the Faculty of Liberal Arts and Science, Kamphaeng Saen Campus, Kasetsart University.

References

American Public Health Association (APHA). (1992). *Standard methods for the examination of water and wastewater* (18th ed.). Washington, D.C.: American Public Health Association.

Barbour, M.T., Gerritsen, J., Snyder, B.D., & Stribling, J.B. (1999). *Rapid bioassessment protocols for use in streams and rivers: periphyton, benthic macroinvertebrates, and fis*h (2nd ed.). Washington, D.C.: Office of Water, US Environmental Protection Agency.

Berlin, A., & Thiele, V. (2002). Trichoptera in Assessment and Classification of Streams in the Lowlands of Northeastern Germany. In W. Mey (Ed.), *Proceedings of the 10th International Symposium on Trichoptera* (pp. 481-490). Potsdam, Germany: Nova Supplementa Entomologica, Kelten.

Beneberu, G., & Mengistou, S. (2014). Head capsule deformities in *Chironomus* spp. (Diptera: Chironomidae) as indicator of environmental stress in Sebeta River, Ethiopia. *African Journal of Ecology, 53,* 268–277.

Boulton, A.J., & Brock, M.A. (1999) *Australian freshwater ecology: Processes and management.* South Australia: Gleneagles Publishing Glen Osmond.

Bodkin, R., Kern, J., McClellan, P., Butt, A., & Martion, C. (2007). Limiting total dissolved solids to protect aquatic life, *Journal of Soil and Water Conservation, 62*(3), 57A–61A.

Das, J., Das, S.N., & Sahoo, R.K. (1997). Semidiurnal variation of some physicochemical parameters in the Mahanadi estuary, east coast of India. *Indian Journal of Marine Sciences, 26,* 323–326.

Dohet, A. (2002). Are Caddisflies an Ideal Group for the Assessment of Water Quality in Streams? In W. Mey. (Ed.), *Proceedings of the 10th International Symposium on Trichoptera* (pp. 481-490). Potsdam, Germany: Nova Supplementa Entomologica, Kelten.

Egborge, A.B.M. (1994). *Water pollution in Nigeria: Biodiversity and chemistry of Warri River.* Nigeria: Ben-Miller Books Nigeria.

Gauss, L.D., Woods, P.E., Winner, R.W., & Skillings, J.H. (1985). Acute toxicity of copper to three life stages of *Chiromus tentans* as affected by water hardness-alkalinity. *Environmental Pollution, 37,* 149–157.

Gupta, S.K., & Gupta, R.C. (2006). *General and applied ichthyology (fish and fisheries)*. Ram Nagar, New Delhi: S. Chand.

Hauer, F.R., & Hill, W.R. (1996). Temperature, light, and oxygen. In F.R. Hauer, & G.A. Lamberti (Eds.), *Methods in stream ecology* (pp. 93-106). NY: Academic Press.

Holzenthal, R.W., Blahnik, R.J., Prather, A.L., & Kjer, K.M. (2007). Order Trichoptera Kirby, 1813 (Insecta), Caddisflies. *Zootaxa, 1668,* 639-698.

Jarvie, H.P., Withers, P.J.A., & Neal, C. (2002). Review of robust measurement of phosphorus in river water: sampling, storage, fractionation and sensitivity. *Hydrology and Earth System Sciences, 6* (1), 113–132.

Karuppasamy, P.K., & Perumal, P. (2000). Biodiversity of zooplankton at Pichavaram mangroves, South India. *Advances in Bioscience and Biotechnology, 19,* 23–32.

Laporte, J.M., Andes, A., & Mason, R.P. (2002). Effects of ligands and other metals on the uptake of mercury and methylmercury across the gills and the intestine of the blue crab *(Callinectes sapidus). Comparative Biochemistry and Physiology (Part C), 131,* 185–196.

Lenat, D.R., & Crawford, J.K. (1994). Effects of land use on water quality and aquatic biota of three North Carolina piedmont streams. *Hydrobiologia, 294,* 185–199.

Milne, M.J. (1938) The metamorphotype method in Trichoptera. *Journal of the New York Entomological Society, 46,* 435–437.

Mount, D.R., Gulley, J.M., Hockett, J.R., Garrison, T.D., & Evans J.M. (1997). Statistical models to predict the toxicity of major ions to *Ceriodaphnia dubia, Daphnia magna* and *Pimephales promelas* (fathead minnows), *Environmental Toxicology and Chemistry, 16,* 2009–2019.

Morse, J.C. (2011). The Trichoptera world checklist. *Zoosymposia, 5,* 372–380.

Omernik, J.M. (1977). *Nonpoint sources-stream nutrient level relationship: A nationwide study. EPA-600/3-77–105.* Washington, D.C.: Environmental Protection Agency, Corvallis, Oregon.

Pond, G.J., Passmore, M.E., Borsuk, F.A., Reynolds, L., & Rose, C.J. (2008). Downstream effects of mountaintop coal mining: Comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools. *Journal of the North American Benthological Society, 27*(3), 717–737.

Prommi, T. (2007). *Taxonomy of Hydropsychidae (Trichoptera) in Mountain Streams of Southern Thailand* (Doctoral dissertation). Prince of Songkla University, Songkla, Thailand.

Prommi, T., & Thamsenanupap, P. (2013). Hydropsychid gill morphology (Insecta: Trichoptera) in association with water quality parameters. *Journal of Applied Science in Environmental Sanitation, 8*(2), 125–134.

Rajasegar, M. (2003). Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. *Journal of Environmental Biology, 24,* 95–101.

Rosenberg, D.M., & Resh, V.H. (1993). *Freshwater biomonitoring and benthic macroinvertebrates*. New York: Chapman and Hall.

Resh, V.H. (1993). Recent Trends in the Use of Trichoptera in water quality monitoring. In C. Otto (Ed.), *Proceedings of the 7th International Symposium on Trichoptera,* (pp. 14-21). Leiden, The Netherlands: Backhuys Publishers.

Resh, V.H., & Jackson, J.H. (1993). Rapid assessment approaches to biomonitoring using benthic macroinvertebrates. In D.M. Rosenberg, & V.H. Resh (Eds.), *Freshwater biomonitoring and benthic macroinvertebrates* (pp. 195-223). NY: Chapman and Hall.

Skinner, K.M., & Bennett, J.D. (2007). Altered gill morphology in benthic macroinvertebrates from mercury enriched streams in the Neversink Reservoir Watershed, New York. *Ecotoxicology, 16,* 311–316.

Vuori, K.M., (1994). Rapid behavioural and morphological responses of hydropsychid caddis larvae (Trichoptera, Hydropsychidae) to sublethal cadmium exposure. *Environmental Pollution, 84,* 291–299.

Vuori, K.M. (1995). Species and population specific responses of translocated hydropsychid lavae (Trichoptera, Hydropsychidae) to runoff from acid sulphate soils in the river Kyrönjoki, Western Finland. *Freshwater Biology, 33,* 305–318.

Vuori, K.M., & Kukkonen, J.V.K. (1996). Metal concentrations in *Hydropsyche pellucidula* larvae (Trichoptera, Hydropsychidae) in relation to the anal papillae abnormalities and age of exocuticle. *Water Research, 30*(10), 2265–2272.

Warwick, W.F. (1988). Morphological deformities in Chironomidae (Diptera) larvae as biological indicators of toxic stress. In M.S. Evans (Ed.), *Toxic contaminates and ecosystem health: A Great lakes focus* (pp. 281-230). NY: John Wiley and Sons.

Wiggins, G.B. (1996). *Larvae of the North American Caddisfly Genera (Trichoptera)* (2nd ed.). Canada: University of Toronto Press.