

BENTHIC DIATOMS IN THE PING RIVER AND ITS TRIBUTARIES IN MAE TAENG DISTRICT, CHIANG MAI PROVINCE, THAILAND

PONGPAN LEELAHAKRIENGKRAI* and TATPORN KUNPRADID

Department of Biology, Faculty of Science and Technology, Chiang Mai Rajabhat University, Chiang Mai 50300, Thailand

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ABSTRACT

A comparison of benthic diatoms in the Ping River and its tributaries, including the Mae Hao and Mae Luang Streams in Mae Taeng District of Chiang Mai Province, Thailand was investigated in August and November 2015 at three locations in each water body. The highest abundance of benthic diatoms was found in the Ping River (143 species), followed by Mae Hao (132 species) and Mae Luang Streams (90 species), respectively. The most abundant species found in the Ping River were *Planothidium lanceolatum*, *Nitzschia palea*, *Navicula cryptotenella* and *Seminavis strigosa*. The most abundant species found in the Mae Hao Stream were *Nitzschia palea*, *Seminavis strigosa*, *Surirella splendida* and *Sellaphora pupula*. The most abundant species found in the Mae Luang Stream were *Navicula cryptotenella*, *Diadmesmis contenta*, *Karayevia oblongella* and *Achnanthes brevipes*. Additionally, *Amphipleura lindheimeri* Grunow was identified as a newly recorded species for Thailand. This study determined that the Ping River and Mae Hao Stream were similar bodies of water when compared with the Mae Luang Stream in terms of benthic diatom diversity and water quality. In addition, indicator species of tolerance and sensitivity to organic pollution were found.

Keywords: Diversity index, Water quality, Cluster analysis, *Amphipleura lindheimeri*

INTRODUCTION

Benthic diatoms are unicellular and eukaryotic microorganisms and have been classified in the Division Bacillariophyta. They are the most common group of algae that are found in lotic ecosystems (Stoermer & Smol 2010). In the northern part of Thailand, only a few studies have focused on the benthic diatom diversity of water bodies of this area and these include; Ping River (Leelahakriengkrai & Peerapornpisal 2011), Yom River (Yana *et al.* 2013), and Wang River (Nakkaew *et al.* 2015). In Chiang Mai, only two studies have focused on these tributaries. The first one focused on the Mae Sa Stream at Mae Rim District and was conducted by Peerapornpisal *et al.* (2000), and the second study focused on the Mae Lu and Tong Ta Streams in Chiang Dao District and was conducted by Leelahakriengkrai (2013). There

have been no other reports accordingly on benthic diatom diversity in areas of Mae Taeng District. This district is the 5th largest district in Chiang Mai Province, which is located in the north of Thailand. This area is comprised of a variety of geographical characteristics and has an altitude of between 330-1200 meters above sea-level. The area has many tributaries that result in a broad diversity of organisms. Mae Hao and Mae Luang Streams are two of the major tributaries in Mae Taeng District and run through San Pa Yang and Pa Pae Sub-districts, respectively. With regard to this location, differences were identified in terms of the geographical characteristics and utilization purposes of the sampling areas. The results of this study are the first report on benthic diatom diversity and the first comparison of benthic diatom distribution in the Ping River and its tributaries in Mae Taeng District of Chiang Mai Province, Thailand. Additionally, certain relevant physico-chemical properties of the water have been presented.

* Corresponding author: bank_2525@hotmail.com

MATERIALS AND METHODS

Study areas

The study areas were located in the Cho Lae, San Pa Yang and Pa Pae Sub-districts, which were located in Mae Taeng District of Chiang Mai Province. Samples were collected from Mae Luang and Mae Hao Streams, as well as the Ping River, and were representational of the different characteristics of each stream in terms of size, geographic location, altitude and utilization purposes of the sampling areas. Samples were collected in August and November of 2015 from three sampling sites per stream. The details of each sampling site are shown in Table 1 and Fig. 1-2.

Benthic diatoms study

Benthic diatoms were studied following the methods of Renberg (1990), Vilbaste (1994) and Kelly *et al.* (1998). The benthic diatom samples were collected from areas comprised of loose pebbles to cobbles or from hard substrates such as bamboo sticks, aquatic plants and artificial substrates in order to produce 5 replicates at each sampling site. The centrifugation of the samples

was done at 2,500 rpm for 15 minutes to isolate diatom cells from the gravel and sand. Samples were cleaned by the concentrated acid digestion method in boiling HNO₃ and peroxide. The cleaned samples were mounted in Naphrax® and photographed at a magnification of 1000X under an Olympus Normaski light microscope. The samples were identified and counted according to the keys of Krammer & Lange-Bertalot (1986, 1988, 1991a, 1991b), Lange-Bertalot (2001), Kelly & Haworth (2002) and Guiry & Guiry (2016). The relative abundance of the benthic diatoms was then indicated according to the following system; + = present, - = absent and * = dominant according to Leelahakrieng & Peerapornpisal (2011).

Water quality study

Water samples were collected for field and laboratory measurements in terms of the following values: pH, conductivity, dissolved oxygen (DO), BOD₅, nitrate nitrogen (NO₃), ammonium nitrogen (NH₄⁺) and soluble reactive phosphorus (SRP). All of these measurements were measured according to the standard methods for the examination of water and wastewater (Eaton *et al.* 2005).

Table 1 Sampling sites and their topography

Sampling site	GPS (Lat-Long)	Altitude (m)	Utilization
Cho Lae sub-district			
Ping river 1	N 19°09'08.82" E 99°10'36.03"	342	Mix agricultural and city
Ping river 2	N 19°07'44.74" E 99°00'26.64"	339	Mix agricultural and city
Ping river 3	N 19°07'49.19" E 99°00'25.33"	338	Mix agricultural and city
San Pa Yang sub-district			
Mae Hao stream 1	N 19°06'06.18" E 98°85'56.06"	360	Paddy field and village
Mae Hao stream 2	N 19°04'15.43" E 98°86'94.56"	357	Paddy field and village
Mae Hao stream 3	N 19°03'01.07" E 98°87'40.23"	350	Paddy field and village
Pa Pae sub-district			
Mae Luang stream 1	N 19 11'84.08" E 98 70'59.97"	849	Forest and hill tribe village
Mae Luang stream 2	N 19 10'68.65" E 98 71'31.38"	835	Forest and village
Mae Luang stream 3	N 19 11'17.44" E 98 70'77.41"	822	Forest and village

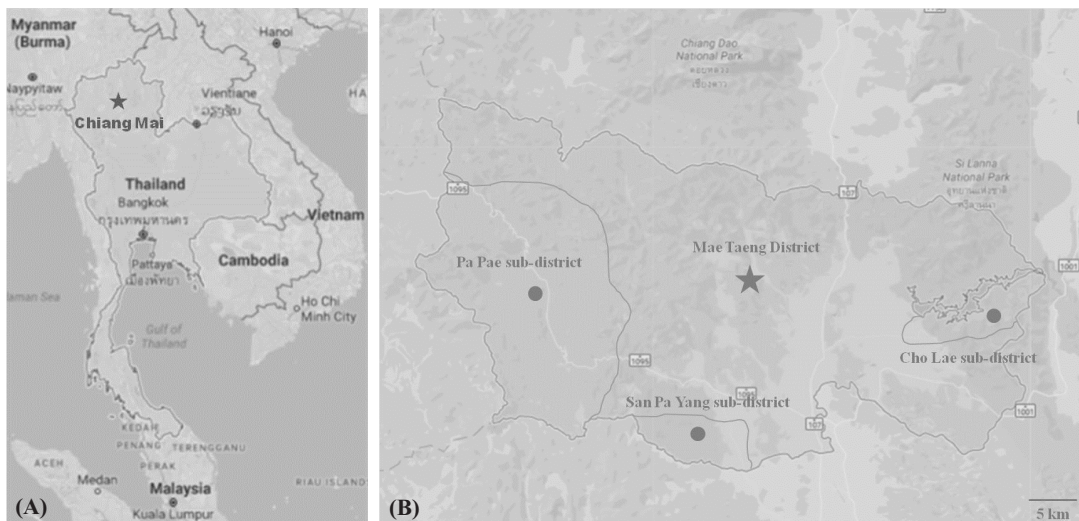


Figure 1 Map showing location of Chiang Mai Province and the Cho Lae, San Pa Yang and Pa Pae sub-districts in Mae Taeng district.

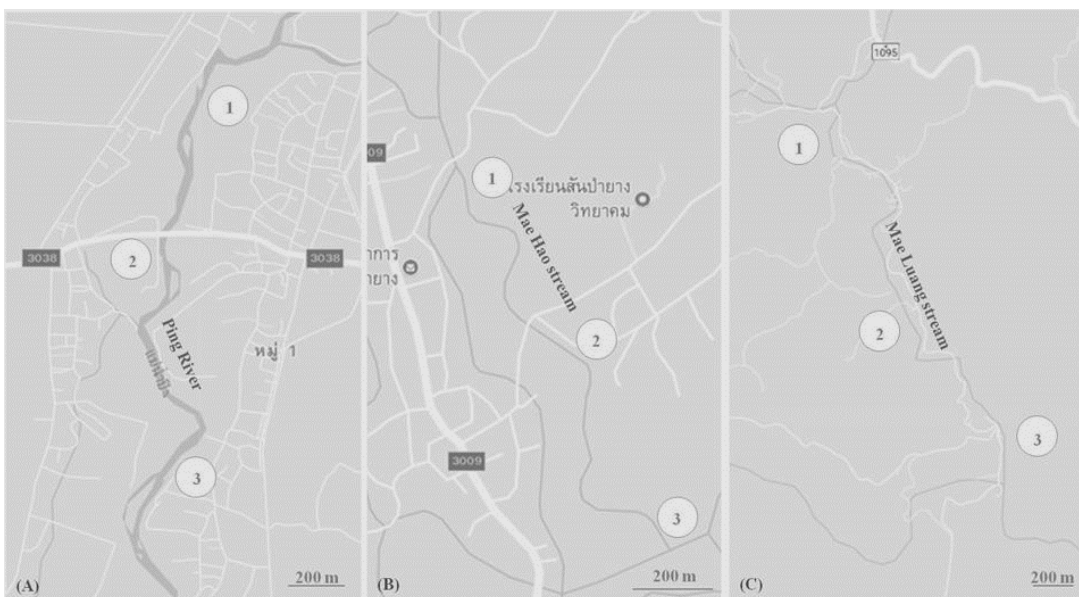


Figure 2 Map showing location of the three sampling sites in Ping river (A), Mae Hao stream (B) and Mae Luang stream (C).

Statistical study

Cluster analysis of benthic diatoms and water quality grouping were done by similarity coefficient (Hammer *et al.* 2001). Physical and chemical water quality values are expressed as the Mean±Standard Deviation (SD). The data was analyzed using one-way analysis of variance (ANOVA) following Duncan's Multiple Range Test (DMRT) at a 5% level of significance. In addition, the species diversity index (H') and (E) of the benthic diatoms were determined and calculated following the Shannon Diversity Index (Odum & Barrett, 2004).

RESULTS AND DISCUSSION

A total of one hundred and ninety-two species of benthic diatoms were found from Mae Hao and Mae Luang Streams and the Ping River in Mae Taeng District of Chiang Mai Province (Table 2). Most of the benthic diatom species found in this study were acknowledged as a common species that could be found in lotic ecosystems throughout Thailand; however, *Amphipleura lindheimeri* Grunow (Fig. 3) was found to be a newly recorded species for Thailand when compared with the relevant published records of

Thailand (Lewmanomont *et al.* 1995; Pekthong & Peerapornpisal 2001; Suphan & Peerapornpisal 2010; Leelahakriengkrai & Peerapornpisal 2011; Yana *et al.* 2013; Nakkaew *et al.* 2015). In addition, the newly recorded species was identified only once in the upstream area of Mae Luang Stream, which was a high altitude location and had a low level of conductivity. This was similar to the findings that were reported in the studies conducted in Brazil by Lobo *et al.* (2004) and Peresin *et al.* (2014), who found *Amphipleura lindbeimeri* in streams with low levels of nutrients and which could be characterized as being indicated by species that display a medium level of tolerance to eutrophication.

A total of one hundred and forty-two species of benthic diatoms were found in the Ping River. The highest abundance was found during the month of September 2015 (121 species), followed by the month of August 2015 (114 species). The most abundant species found in the Ping River were *Nitzschia palea*, *Planothidium lanceolatum*, *Navicula cryptotenella*, *Cocconeis placentula*, *Achnantheidium exiguum*, *Seminavis strigosa*, *Cymbella turgidula* and *Navicula germainii*. A total of one hundred and thirty-two species of benthic diatoms were found in the Mae Hao Stream. The highest abundance was found in the month of September 2015 (125 species), followed by the month of August 2015 (94 species). The most abundant species found in the Mae Hao Stream were *Nitzschia palea*, *Sellaphora pupula*, *Seminavis strigosa*, *Gyrosigma acuminatum*, *Nitzschia dissipata*, *Navicula cryptotenella*, *Surirella splendida* and *Placoneis dicephala*. A total of ninety species of benthic

diatoms were found in the Mae Luang Stream. The highest abundance was found in the month of September 2015 (76 species), followed by the month of August 2015 (68 species). The most abundant species found in the Mae Luang Stream were *Navicula cryptotenella*, *Navicula symmetrica*, *Pinnularia cruciformis*, *Diadesmis contenta*, *Navicula schroeteri*, *Achnanthes oblongella*, *Gomphonema clevei*, *Navicula phyllepta*, *Achnanthes brevipes* and *Achnantheidium minutissimum*. Some of the dominant diatom species found in this study are shown in Fig. 3. In addition, some dominant diatom species of the Ping River and Mae Hao Stream were considered to be potential indicator species displaying tolerance to organic pollution, while some dominant diatom species of the Mae Luang Stream were considered to be potential indicator species displaying sensitivity to organic pollution (Van Dam *et al.* 1994; Rott *et al.* 1997; Potapova & Charles 2007; Almeida *et al.* 2010; Segura-García *et al.* 2012; Leelahakriengkrai & Peerapornpisal 2014; Noga *et al.* 2014; Lobo *et al.* 2015). The results of Shannon's diversity index along with values of evenness and the numbers of benthic diatoms are shown in Table 3. The sampling sites of the Mae Luang Stream were located at a high altitude, where a low level of nutrients were found displaying low values in terms of the diversity index and species richness. This finding was similar to the findings of studies conducted in Southern Brazil (Chneck *et al.* 2007) and Northern Thailand (Leelahakriengkrai 2013), which found low values in terms of the diversity index and species richness at the upstream sites.

Table 2 Species list and distribution of benthic diatoms in Ping river, Mae Hao and Mae Luang streams.

Species list	Ping	Mae Hao	Mae Luang
<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen	-,+,-/+,-,-	+,-,+/-,-,+	-
<i>Melosira varians</i> C.Agardh	-	-,-,-/+,-,-	-
<i>Cyclotella atomus</i> Hustedt	-,-,+/+,-,-	-	-,-,-/+,-,-
<i>Cyclotella meneghiniana</i> Kützing	-,-,-/+,-,+	-,-,-/-,-,+	-
<i>Cyclotella pseudostelligera</i> Hustedt	-,+,+/+,-,+	-	-
<i>Thalassiosira weissflogii</i> (Grunow) G.Fryxell & Hasle	-,-,+/-,-,+	+,-,+/-,-,+	-
<i>Karayevia oblongella</i> (Østrup) Aboal	-,+,+/+,-,+	+,-,+/+,-,+	+,*,-/+,*,-
<i>Achnanthes brevipes</i> C.Agardh	-	-	+,-,+/*,-,*,-
<i>Achnanthes brevipes</i> var. <i>intermedia</i> (Kützing) Cleve	-,+,+/+,-,+	-,-,-/-,-,+	-
<i>Achnanthes inflata</i> (Kützing) Grunow	-,-,-/+,-,-	-,-,+/-,-,+	-,-,-/-,-,+
<i>Achnanthes crenulata</i> Grunow	-	+,-,+/+,-,-	-
<i>Achnanthes</i> sp.	-	-	-,-,-/-,-,+
<i>Aneumastus stroesei</i> (Østrup) D.G.Mann	-	+,-,+/-,-,-	+,-,+/-,-,-
<i>Achnantheidium exiguum</i> (Grunow) Czarnecki	-,+,*/+,-,+	+,-,+/+,-,+	+,-,+/+,-,+
<i>Achnantheidium jackii</i> Rabenhorst	-,+,-/+,-,-	+,-,-/-,-,-	-

Table 2 Continued

Species list	Ping	Mae Hao	Mae Luang
<i>Acnanthidium minutissimum</i> (Kützing) Czarnecki	-,+,+ / +,+,+	+,-,+ / -,-,-	+,-,- / *,-,-
<i>Acnanthidium</i> sp.	-	-	+ ,+ ,+ / + ,+ ,+
<i>Lemnicola hungarica</i> (Grunow) Round & Basson	-,+,- / -,-,-	-	-
<i>Rosithidium pusillum</i> (Grunow) Round & Bukhtiyarova	-,+,+ / +,-,+	+,-,+ / +,-,+	-
<i>Planothidium biporumum</i> (M.H.Hohn & Helleman) Lange-Bertalot	-,+,+ / +,+,+	-,+,- / -,-,+	-
<i>Planothidium lanceolatum</i> (Brébisson ex Kützing) L.Bukhtiyarova	-,*,+ / * ,* ,+	+,-,+ / +,+,+	-
<i>Planothidium rostratum</i> (Østrup) Lange-Bertalot	-,+,+ / +,+,+	+,-,+ / +,+,-	-
<i>Cocconeis placentula</i> Ehrenberg	-,*,+ / * ,* ,+	+,-,+ / +,+,+	-,-,+ / +,-,+
<i>Cocconeis</i> sp.	-	-,-,- / -,-,+	-
<i>Cymbella affinis</i> Kützing	-,+,+ / +,+,+	-	-
<i>Cymbella helvetica</i> Kützing	-,+,+ / +,+,+	-	-
<i>Cymbella neoleptoceros</i> Krammer	-,-,- / +,-,-	-	-
<i>Cymbella tumida</i> (Brébisson) Van Heurck	-,+,- / +,+,+	-,-,- / +,+,-	-,-,- / +,-,-
<i>Cymbella turgidula</i> Grunow	-,+,+ / +,+,*	+,-,+ / +,+,+	-,-,- / +,-,+
<i>Cymbopleura amphicephala</i> (Nägeli) Krammer	-	-,-,- / +,-,-	-
<i>Encyonema gracile</i> Kirchner	-	-,-,- / +,+,-	-
<i>Encyonema mesianum</i> (Cholnoky) D.G.Mann	-,-,- / -,+,+	-	-,-,- / +,-,-
<i>Encyonema minutum</i> (Hilse) D.G.Mann	-,+,+ / +,+,+	+,-,+ / +,+,+	+ ,+ ,+ / + ,+ ,+
<i>Encyonopsis lei</i> Krammer	-,-,- / +,+,+	-	-
<i>Geissleria decussis</i> (Østrup) Lange-Bertalot & Metzeltin	-,+,+ / +,+,+	+,-,+ / +,-,+	-,+,+ / +,+,+
<i>Gomphonema angur</i> Ehrenberg	-,+,- / -,-,+	-	-
<i>Gomphonema clavatum</i> Ehrenberg	-,+,+ / +,+,+	-,-,- / +,+,+	-,-,- / +,-,-
<i>Gomphonema clevei</i> Fricke	-,+,+ / +,+,+	-,-,+ / +,+,+	* ,+ ,* / * ,* ,+
<i>Gomphonema gracile</i> Ehrenberg	-,+,+ / +,+,+	-	-,+,- / +,-,-
<i>Gomphonema bebridense</i> W.Gregory	-,+,- / +,-,-	-	-
<i>Gomphonema lagenula</i> Kützing	-,+,+ / +,+,+	+,-,+ / +,-,+	+ ,+ ,+ / + ,+ ,+
<i>Gomphonema minutum</i> (C.Agardh) C.Agardh	-,+,- / -,-,-	-	-
<i>Gomphonema parvulum</i> (Kützing) Kützing	-,+,+ / +,+,+	-	+ ,+ ,+ / + ,+ ,+
<i>Gomphonema pumilum</i> (Grunow) E.Reichardt & Lange-Bertalot	-,+,+ / +,+,+	-,-,- / +,+,+	-
<i>Gomphonema turris</i> Ehrenberg	-	+,-,+ / +,+,-	-
<i>Gomphonema vibrio</i> Ehrenberg	-,+,- / -,-,-	-	-
<i>Placoneis dicephala</i> (Ehrenberg) Mereschkowsky	-,+,- / -,-,-	+,-,+ / +,+,*	+ ,+ ,+ / + ,+ ,+
<i>Placoneis elginensis</i> (W.Gregory) E.J.Cox	-,+,+ / +,+,+	-	-
<i>Placoneis gastrum</i> (Ehrenberg) Mereschkowsky	-,+,+ / +,+,-	-	-
<i>Placoneis placentula</i> (Ehrenberg) Mereschkowsky	-,-,- / +,-,-	-	-
<i>Placoneis</i> sp. 1	-,+,+ / -,-,-	+,-,+ / +,+,+	-,+,- / +,-,-
<i>Placoneis</i> sp. 2	-	-,-,- / +,+,+	-,-,- / +,+,+
<i>Adlafia</i> sp.	-,+,- / +,-,+	-	-
<i>Amphipleura lindbeimeri</i> Grunow	-	-	+,-,- / -,-,-
<i>Amphora aequalis</i> Krammer	-	+,-,+ / -,+,+	+,-,- / -,-,-
<i>Amphora libyca</i> Ehrenberg	-,+,+ / +,+,+	+,-,- / +,* ,+	+ ,+ ,+ / -,-,+
<i>Caloneis bacillum</i> (Grunow) Cleve	-,-,- / +,+,-	-,-,+ / +,+,+	-
<i>Caloneis silicula</i> (Ehrenberg) Cleve	-,+,+ / +,+,-	-,-,+ / +,+,+	-
<i>Gyrosigma scalproides</i> (Rabenhorst) Cleve	-,+,+ / +,+,+	+,-,+ / +,+,+	+ ,+ ,+ / + ,+ ,+
<i>Gyrosigma acuminatum</i> (Kützing) Rabenhorst	-,+,+ / +,+,+	-,-,+ / * ,+ ,+	+ ,+ ,+ / +,-,-
<i>Navicula angusta</i> Grunow	-,-,- / +,-,-	+,-,+ / +,-,-	+ ,+ ,+ / + ,+ ,+
<i>Navicula capitatoradiata</i> H.Germain	-,+,+ / +,+,+	+,-,- / +,-,-	-
<i>Navicula cinctaeformis</i> Hustedt	-,+,+ / +,-,-	-	-,-,- / +,-,-
<i>Navicula cryptocephala</i> Kützing	-,+,+ / +,+,+	-,-,+ / +,-,+	+ ,+ ,+ / + ,+ ,+
<i>Navicula cryptocephaloides</i> Hustedt	-,+,+ / +,+,+	+,-,+ / +,+,+	-
<i>Navicula cryptotenella</i> Lange-Bertalot in Krammer & Lange-Bertalot	-,+,+ / * ,* ,*	+,-,+ / +,* ,+	* ,* ,* / * ,* ,+
<i>Navicula erifuga</i> Lange-Bertalot in Krammer & Lange-Bertalot	-,+,+ / +,+,+	+,-,- / +,+,+	+ ,+ ,+ / + ,+ ,+
<i>Navicula germainii</i> J.H.Wallace	-,+,+ / +,+,*	-,-,- / -,-,+	-
<i>Navicula menisculus</i> Schumann	-,+,+ / -,-,-	+,-,+ / +,+,+	+ ,+ ,+ / +,-,-
<i>Naviculadicta nanogomphonema</i> Lange-Bertalot & U.Rumrich	-,-,- / +,-,-	-	-

Table 2 Continued

Species list	Ping	Mae Hao	Mae Luang
<i>Navicula phyllepta</i> Kützing	-3,+ +/+3,+ +	+3,- +/+3,+ +	+3,+*/+3,+ +
<i>Navicula radiosa</i> Kützing	-	+3,- +/-3,- +	-3,- +/+3,- -
<i>Navicula radiosafalla</i> x Lange-Bertalot	-3,+ +/+3,+ +	+3,- -/-3,+ -	-
<i>Navicula recens</i> (Lange-Bertalot) Lange-Bertalot in Krammer & Lange-Bertalot	-3,+ +/-3,- -	-	-
<i>Navicula rhynchocephala</i> Kützing	-3,+ +/-3,- -	-3,- -/-3,- +	-
<i>Navicula rostellata</i> Kützing	-3,+ +/+3,+ +	+3,- +/+3,+ +	+3,+ +/+3,+ +
<i>Navicula schroeteri</i> F.Meister	-	-3,- -/-3,- +	+3,* +/+3,- +
<i>Navicula symmetrica</i> R.M.Patrick	-3,+ +/+3,+ +	+3,- +/+3,+ +	*3,* +/*3,* *
<i>Navicula viridula</i> (Kützing) Ehrenberg	-3,+ +/+3,+ +	+3,- +/+3,+ +	-3,- +/+3,+ +
<i>Navicula</i> sp. 1	-3,- -/-3,+ -	-	-
<i>Navicula</i> sp. 2	-	-	*3,+ +/*3,* +
<i>Seminavis strigosa</i> (Hustedt) Danieleadis & Economou-Amilli in Danielidis & D.G.Mann	-3,+ +/*3,* *	-3,- -/*3,* +	-
<i>Eolimna minima</i> (Grunow) Lange-Bertalot	-3,+ +/+3,- -	+3,- +/+3,+ -	-3,- +/-3,- -
<i>Eolimna subminuscula</i> (Manguin) Gerd Moser, Lange-Bertalot & Metzeltin	-3,+ -/+3,+ +	-3,- -/+3,+ +	-
<i>Craticula accomoda</i> (Hustedt) D.G.Mann	-	-	-3,- +/-3,- -
<i>Craticula cuspidata</i> (Kützing) D.G.Mann	-3,+ +/-3,- -	+3,- +/+3,+ +	-
<i>Craticula riparia</i> (Hustedt) Lange-Bertalot	-	-3,- -/-3,+ -	-
<i>Stauroneis anceps</i> Ehrenberg	-	-3,- +/+3,- -	-
<i>Stauroneis kriegei</i> R.M.Patrick	-3,- -/+3,- -	+3,- +/+3,+ +	+3,+ +/+3,+ +
<i>Stauroneis smithii</i> Grunow	-3,- -/-3,- +	+3,- +/+3,- -	-3,+ +/+3,+ +
<i>Stauroneis schimanskii</i> Krammer	-3,- -/+3,+ +	-	-
<i>Halambhora montana</i> (Krasske) Levkov	-3,+ +/+3,+ +	-	-
<i>Halambhora normanii</i> (Rabenhorst) Levkov	-3,+ +/+3,- +	-3,- -/+3,- -	-3,+ -/-3,- -
<i>Frustulia rhomboides</i> (Ehrenberg) De Toni	-3,+ -/-3,+ -	-3,- -/-3,- +	+3,- +/+3,+ +
<i>Frustulia vulgaris</i> (Thwaites) De Toni	-	-3,- -/-3,- +	-
<i>Frustulia weinboldii</i> Hustedt	-	+3,- +/-3,- -	-3,- -/+3,- -
<i>Brachysira neoexilis</i> Lange-Bertalot in Lange-Bertalot & Moser	-3,+ +/+3,+ +	+3,- +/+3,- -	-
<i>Brachysira vitrea</i> (Grunow) R.Ross in Hartley, Ross & Williams	-3,- +/-3,- -	+3,- +/+3,- +	-3,- -/-3,- +
<i>Diadesmis brekekaensis</i> (J.B.Petersen) D.G.Mann	-3,+ -/-3,- -	-	-
<i>Diadesmis confervacea</i> Kützing	-3,- -/+3,+ -	-3,- -/-3,- +	-
<i>Diadesmis contenta</i> (Grunow) D.G.Mann	-3,+ +/+3,+ +	+3,- +/+3,+ +	+3,* +/+3,+ +
<i>Luticola cobnii</i> (Hilse) D.G.Mann	-3,+ +/+3,+ -	-3,- -/-3,+ -	+3,+ +/+3,+ +
<i>Luticola goeppertiana</i> (Bleisch) D.G.Mann ex J.Rarick, S.Wu, S.S.Lee & Edlund	-3,+ +/+3,+ +	+3,- -/-3,- +	-3,+ -/-3,- -
<i>Luticola permuticoides</i> Metzeltin & Lange-Bertalot	-3,- +/+3,+ -	+3,- +/+3,+ +	+3,+ +/+3,- +
<i>Luticola mitigata</i> (Hustedt) D.G.Mann	-3,- -/-3,+ +	+3,- +/+3,+ +	+3,+ +/+3,- +
<i>Luticola mutica</i> (Kützing) D.G.Mann	-3,+ +/+3,+ +	-3,- -/-3,+ +	+3,+ +/+3,+ +
<i>Diploneis elliptica</i> (Kützing) Cleve	-3,+ +/+3,+ +	+3,- +/+3,+ -	+3,+ +/+3,+ +
<i>Fallacia insociabilis</i> (Krasske) D.G.Mann	-3,+ +/+3,+ +	-	+3,- -/-3,- -
<i>Fallacia pygmaea</i> (Kützing) Stickle & D.G.Mann	-3,- -/+3,+ +	-3,- -/+3,- -	-3,- -/+3,- -
<i>Neidium ampliatum</i> (Ehrenberg) Krammer	-3,- +/+3,+ +	+3,- +/+3,+ +	-3,- -/+3,- -
<i>Neidium binodeforme</i> Krammer	-3,- -/+3,+ +	+3,- -/+3,- -	-
<i>Neidium dubium</i> (Ehrenberg) Cleve	-3,- -/+3,+ +	-3,- +/+3,+ +	-
<i>Neidium ladogensense</i> (Cleve) Foged	-	-	-3,- -/-3,- +
<i>Neidium</i> sp.1	-3,- +/+3,+ -	-3,- -/+3,+ +	-3,- -/+3,- -
<i>Neidium</i> sp.2	-	-3,- -/+3,+ +	-
<i>Pinnularia acrosphaeria</i> W.Smith	-	-3,- +/+3,+ +	-
<i>Pinnularia braunii</i> Cleve	-	+3,- +/+3,+ +	-
<i>Pinnularia brebissonii</i> (Kützing) Rabenhorst	-	-3,- -/-3,- +	-
<i>Pinnularia borealis</i> Ehrenberg	-3,- -/-3,- +	-	-
<i>Pinnularia cruciformis</i> (Donkin) Cleve	-	+3,- +/+3,+ +	*3,+ +/+3,+ +
<i>Pinnularia divergens</i> W.Smith	-3,+ +/+3,+ +	+3,- -/+3,+ +	+3,- +/+3,+ +
<i>Pinnularia episcopalis</i> Cleve	-	-3,- +/+3,+ +	-3,- -/-3,- +
<i>Pinnularia interrupta</i> W.Smith	-	+3,- +/+3,+ +	+3,+ +/+3,+ +
<i>Pinnularia legumen</i> Ehrenberg	-	-3,- +/+3,- -	+3,- -/+3,- +
<i>Pinnularia macilenta</i> Ehrenberg	-	-	-3,- -/+3,- +

Table 2 Continued

Species list	Ping	Mae Hao	Mae Luang
<i>Pinnularia mesolepta</i> (Ehrenberg) W.Smith	-,+,+/-,+,-	+,-,+/-,+,-	-,+,-/-,+,-
<i>Pinnularia microstauron</i> (Ehrenberg) Cleve	-,-,+/-,+,-	+,-,+/-,+,-	-,+,-/-,+,-
<i>Pinnularia nobilis</i> (Ehrenberg) Ehrenberg	-,-,+/-,+,-	-	-
<i>Pinnularia subcapitata</i> W.Gregory	-,+,+/-,+,-	-,+,+/-,+,-	-,+,-/-,+,-
<i>Pinnularia subgibba</i> Krammer	-	+,-,+/-,+,-	-
<i>Pinnularia rupestris</i> Hantzsch	-	+,-,+/-,+,-	-
<i>Pinnularia</i> sp.1	-,+,-/+,-,-	+,-,+/-,+,-	-,-,+/-,+,-
<i>Pinnularia</i> sp.2	-	-,-,+/-,+,-	-
<i>Pinnularia</i> sp.3	-	-,-,+/-,+,-	-
<i>Diadesmis contenta</i> (Grunow) D.G.Mann	-,+,+/-,+,-	+,-,+/-,+,-	+,*,+/-,+,-
<i>Luticola cobnii</i> (Hilse) D.G.Mann	-,+,-/+,-,-	-,-,+/-,+,-	+,-,+/-,+,-
<i>Sellaphora bacillum</i> (Ehrenberg) D.G.Mann	-,+,-/+,-,-	-,-,+/-,+,-	-
<i>Sellaphora garciarodriguezii</i> Metzeltin & Lange-Bertalot	-	+,-,+/-,+,-	-
<i>Sellaphora japonica</i> (Kobayasi) Kobayasi	-,+,+/-,+,-	-	-
<i>Sellaphora pupula</i> (Kützing) Mereschkovsky	-,+,+/-,+,-	*,-,*/+,-,-	+,-,+/-,+,-
<i>Bacillaria paxillifera</i> (O.F.Müller) T.Marsson	-,+,-/+,-,-	+,-,+/-,+,-	-
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow	-,+,-/+,-,-	+,-,+/-,+,-	-,+,-/+,-,-
<i>Hantzschia distinctepunctata</i> Hustedt	-,+,-/+,-,-	-	-
<i>Nitzschia acicularis</i> (Kützing) W.Smith	-,-,+/-,+,-	-	-
<i>Nitzschia amphibia</i> Grunow	-,-,+/-,+,-	+,-,+/-,+,-	-
<i>Nitzschia brevissima</i> Grunow	-,+,-/+,-,-	+,-,+/-,+,-	-
<i>Nitzschia clausii</i> Hantzsch	-,+,-/+,-,-	+,-,+/-,+,-	-
<i>Nitzschia compressa</i> (Bailey) C.S.Boyer	-,+,-/+,-,-	-,-,+/-,+,-	-
<i>Nitzschia constricta</i> (Kützing) Ralfs	-,-,+/-,+,-	-	-
<i>Nitzschia draveillensis</i> Coste & Ricard	-,+,-/+,-,-	+,-,+/-,+,-	-
<i>Nitzschia dissipata</i> (Kützing) Rabenhorst	-,+,-/+,-,-	+,-,+/*,+,-	+,-,+/-,+,-
<i>Nitzschia dubia</i> W.Smith	-,-,+/-,+,-	-	-
<i>Nitzschia fonticola</i> (Grunow) Grunow	-	+,-,+/-,+,-	-,-,+/-,+,-
<i>Nitzschia fossilis</i> (Grunow) Grunow	-	+,-,+/-,+,-	-,-,+/-,+,-
<i>Nitzschia frustulum</i> (Kützing) Grunow	-	+,-,+/-,+,-	-,+,-/+,-,-
<i>Nitzschia graciliformis</i> Lange-Bertalot & Simonsen	-,-,+/-,+,-	-	-
<i>Nitzschia heufliera</i> Grunow	-,-,+/-,+,-	-	-
<i>Nitzschia intermedia</i> Hantzsch in Cleve & Grunow	-,+,-/+,-,-	+,-,+/-,+,-	-,-,+/-,+,-
<i>Nitzschia lacuum</i> Lange-Bertalot	-,+,-/+,-,-	-	-
<i>Nitzschia lorenziana</i> Grunow	-	-,-,+/-,+,-	-
<i>Nitzschia palea</i> (Kützing) W.Smith	-,*,+/-,+,-	*,-,*/+,-,-	-,+,-/+,-,-
<i>Nitzschia philippinarum</i> Hustedt	-	+,-,+/-,+,-	-
<i>Nitzschia pumila</i> Hustedt	-,+,-/+,-,-	-	-
<i>Nitzschia sigma</i> (Kützing) W.Smith	-,+,-/+,-,-	-	-
<i>Nitzschia sigmoidea</i> (Nitzsch) W.Smith	-,+,-/+,-,-	+,-,+/-,+,-	-
<i>Nitzschia subcobaerens</i> (Grunow) Van Heurck	-,-,+/-,+,-	-,+,-/+,-,-	-
<i>Nitzschia</i> sp.1	-,-,+/-,+,-	-,-,+/-,+,-	-
<i>Nitzschia</i> sp.2	-	-	+,-,+/-,+,-
<i>Grunowia tabellaria</i> (Grunow) Rabenhorst	-,+,-/+,-,-	-	-
<i>Tryblionella coarctata</i> (Grunow) D.G.Mann	-	+,-,+/-,+,-	-
<i>Tryblionella levidensis</i> W.Smith	-,+,-/+,-,-	+,-,+/-,+,-	-,+,-/+,-,-
<i>Epithemia adnata</i> (Kützing) Brébisson	-,-,+/-,+,-	-	-
<i>Rhopalodia gibba</i> (Ehrenberg) Otto Müller	-,-,+/-,+,-	-,-,+/-,+,-	-
<i>Rhopalodia gibberula</i> (Ehrenberg) Otto Müller	-,+,-/+,-,-	+,-,+/-,+,-	-
<i>Eunotia bilunaris</i> (Ehrenberg) Schaarschmidt	-,+,-/+,-,-	+,-,+/-,+,-	+,-,+/-,+,-
<i>Eunotia soleirolii</i> (Kützing) Rabenhorst	-,-,+/-,+,-	-,-,+/-,+,-	-
<i>Fragilaria capucina</i> Desmazières	-,+,-/+,-,-	-,-,+/-,+,-	-
<i>Fragilaria capucina</i> var. <i>vaucheriae</i> (Kützing) Lange-Bertalot	-,+,-/+,-,-	-	-
<i>Fragilaria crotonensis</i> Kitting	-,-,+/-,+,-	-,-,+/-,+,-	-
<i>Fragilaria acus</i> (Kützing) Lange-Bertalot	-,+,-/+,-,-	-	+,-,+/-,+,-
<i>Ulnaria ulna</i> (Nitzsch) Compère	-,+,-/+,-,-	+,-,+/-,+,-	-
<i>Ulnaria ulna</i> var. <i>aequalis</i> (Kützing) Aboal	-,+,-/+,-,-	-	-
<i>Surirella amphioxys</i> W.Smith	-	-	+,-,+/-,+,-
<i>Surirella angusta</i> Kützing	-,-,+/-,+,-	-	+,-,+/-,+,-

Table 2 Continued

Species list	Ping	Mae Hao	Mae Luang
<i>Surirella biseriata</i> Brébisson	-	-	-,-,+/-,-,-
<i>Surirella brebissonii</i> Krammer & Lange-Bertalot	-,-,-/-,-,+	-	-
<i>Surirella ovalis</i> Brébisson	-	-,-,-/-,+,,+	-
<i>Surirella splendida</i> (Ehrenberg) Kützing	-,-,-/+,,+,+	+,-,+/-,+,,+*	-,-,+/-,-,-
<i>Surirella terricola</i> Lange-Bertalot & E.Alles	-	-,-,-/+,,+,+	+,,+/-,+,,+,+
<i>Surirella</i> sp. 1	-,+,-/+,,+,+	-	-,-,-/-,-,+
<i>Surirella</i> sp. 2	-,-,+/-,+,,+,+	-	-,-,-/-,-,+
<i>Surirella</i> sp. 3	-,-,-/-,-,+,-	-	-

Notes: + = present; - = absent, * = dominant (Site1, Site 2 Site 3 in August / Site1, Site 2 Site 3 in November)

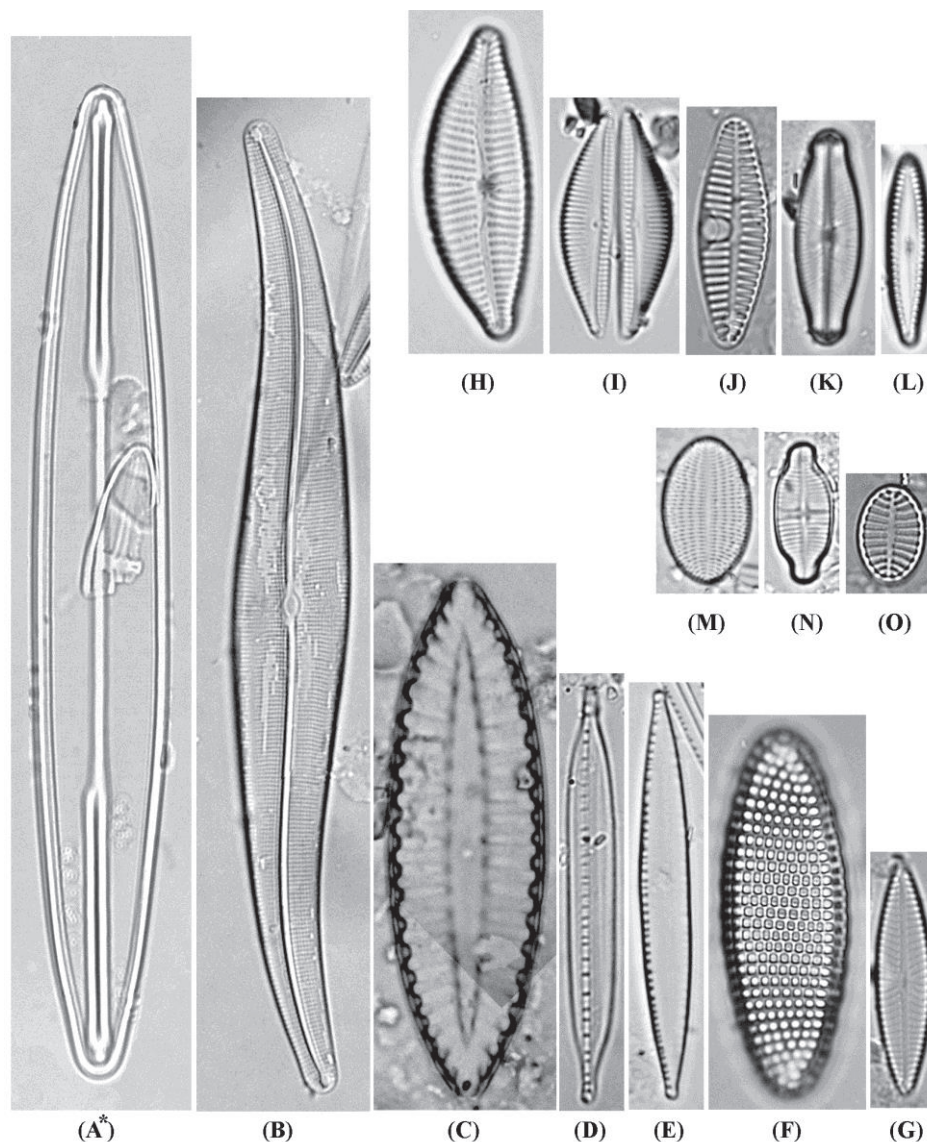


Figure 3 Light micrographs of dominant benthic diatoms in Ping river, Mae Hao and Mae Luang streams and new record benthic diatoms of Thailand (A*). (scale bar = 10 μ m)

(A*) *Amphibleura lindbeimeri*, (B) *Gyrosigma acuminatum*, (C) *Surirella splendida*, (D) *Nitzschia dissipata*, (E) *Nitzschia palea*, (F) *Achnanthes brevipes*, (G) *Navicula cryptotenella*, (H) *Cymbella turgidula*, (I) *Seminavis strigosa*, (J) *Planorbidium lanceolatum*, (K) *Sellaphora pupula*, (L) *Gomphonema clevei*, (M) *Cocconeis placentula*, (N) *Achnantheidium exciguum*, (O) *Karayevia oblongella*

Table 3 Shannon's diversity index and evenness of benthic diatoms in the Ping river, Mae Hao and Mae Luang streams

Sampling	Diversity index	Evenness	Species number
Ping1 Aug-15	-	-	-
Ping2 Aug-15	3.34	0.289	98
Ping3 Aug-15	3.13	0.245	93
Ping1 Sep-15	3.14	0.225	103
Ping2 Sep-15	3.03	0.235	88
Ping3 Sep-15	3.00	0.227	89
Mae Hao1 Aug-15	2.87	0.221	80
Mae Hao2 Aug-15	-	-	-
Mae Hao3 Aug-15	2.95	0.225	85
Mae Hao1 Sep-15	3.21	0.260	95
Mae Hao2 Sep-15	3.08	0.272	80
Mae Hao3 Sep-15	3.45	0.353	89
Mae Luang1 Aug-15	2.90	0.379	48
Mae Luang2 Aug-15	2.89	0.350	52
Mae Luang3 Aug-15	2.30	0.184	54
Mae Luang1 Sep-15	2.87	0.275	64
Mae Luang2 Sep-15	2.56	0.371	35
Mae Luang3 Sep-15	2.38	0.187	58

The cluster analysis of benthic diatom diversity grouping was completed using Dice's similarity coefficient and is presented in Fig. 4. The dendrogram clearly shows that all sampling sites were grouped into two main clusters at 50% similarity. All sampling sites of the Ping River and Mae Hao Stream were in Group 1 and all sampling sites of Mae Luang Stream were in Group 2. The cluster analysis of water quality grouping by Ward's method with squared Euclidean distances

(Fig. 5) presented similar results in terms of the benthic diatom diversity clusters, which clearly showed that benthic diatom diversity was correlated with the water quality factors. Additionally, the correlation of water quality by ANOVA proved to be significantly different at the different sampling sites (Table 4), particularly with regard to the measurements of conductivity of Mae Luang Stream where low levels were recorded at all of the sampling sites..

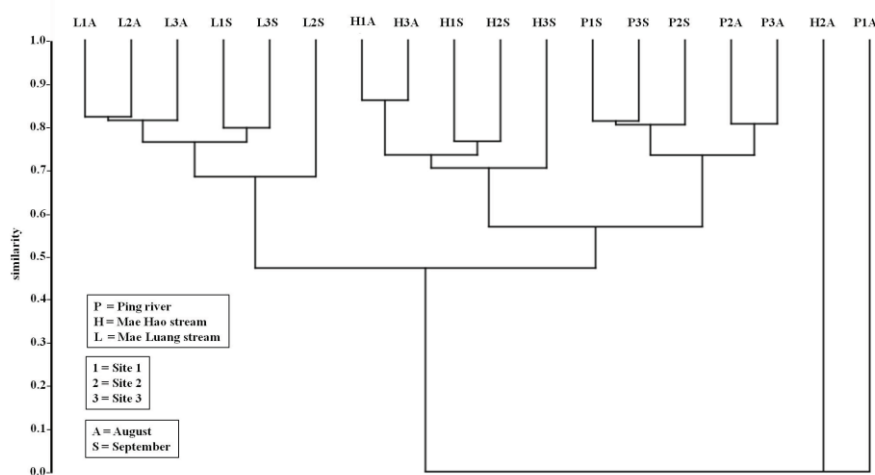


Figure 4 Cluster analysis of benthic diatoms diversity grouping by Dice's similarity coefficient.

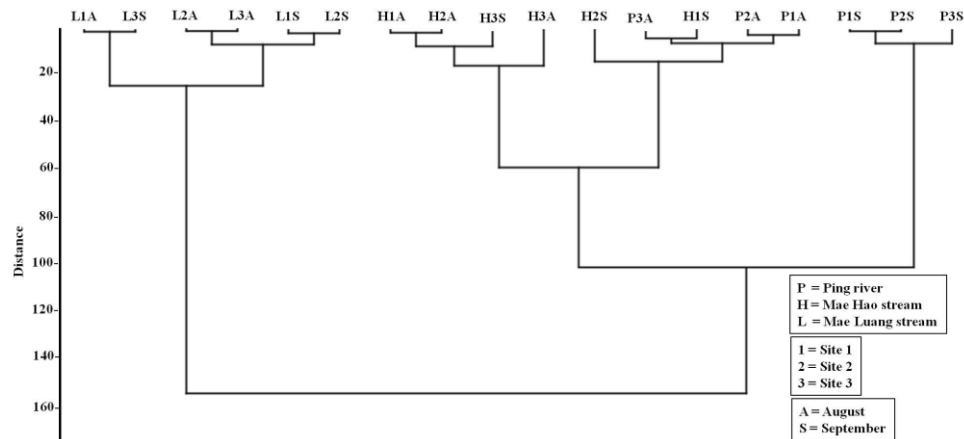


Figure 5 Cluster analysis of physical and chemical water quality grouping by Ward's method with squared Euclidean distances.

Sampling sites	pH	Conductivity ($\mu\text{s}/\text{cm}^{-1}$)	DO (mg/l)	BOD ₅ (mg/l)	NO ₃ (mg/l)	NH ₄ ⁺ (mg/l)	SRP (mg/l)
P1Aug	7.35±0.05 ^d	216.1±0.25 ^k	6.40±0.00 ^b	1.07±0.12 ^{cd}	0.70±0.10 ^{de}	0.41±0.02 ^d	0.73±0.02 ^h
P2Aug	6.83±0.05 ^{ab}	213.4±0.46 ^j	6.40±0.00 ^b	1.07±0.12 ^{cd}	0.50±0.10 ^{bc}	0.56±0.02 ^{ef}	0.36±0.04 ^g
P3Aug	7.01±0.05 ^c	208.7±0.4 ⁱ	5.60±0.00 ^a	0.27±0.12 ^a	0.00±0.00 ^a	0.54±0.05 ^e	1.83±0.08 ⁱ
P1Sep	7.89±0.04 ^{efg}	281.3±1.8 ^l	7.00±0.00 ^c	0.40±0.00 ^{ab}	1.70±0.10 ^g	0.05±0.09 ^{ab}	0.10±0.01 ^{ab}
P2Sep	7.77±0.02 ^e	281.8±0.4 ^l	6.50±0.50 ^b	0.40±0.00 ^{ab}	0.80±0.10 ^{ef}	0.21±0.02 ^c	0.15±0.02 ^{bcd}
P3Sep	7.95±0.14 ^{fg}	287.8±0.21 ^m	7.00±0.00 ^c	0.40±0.00 ^{ab}	0.60±0.10 ^{cd}	0.00±0.00 ^a	0.11±0.02 ^{ab}
MH1Aug	6.74±0.05 ^a	149.6±1.20 ^f	5.87±0.11 ^a	0.33±0.11 ^a	0.70±0.08 ^{de}	0.34±0.04 ^d	0.25±0.03 ^{ef}
MH2Aug	6.71±0.03 ^a	148.5±0.50 ^f	6.87±0.11 ^c	1.33±0.09 ^d	0.40±0.01 ^b	0.50±0.00 ^c	0.40±0.01 ^f
MH3Aug	6.91±0.06 ^{bc}	162.4±0.45 ^g	6.47±0.09 ^b	1.00±0.17 ^c	0.38±0.01 ^b	0.42±0.03 ^d	0.39±0.02 ^f
MH1Sep	7.81±0.05 ^{ef}	209.3±0.86 ⁱ	7.07±0.09 ^c	3.53±0.11 ^g	0.70±0.00 ^{de}	0.00±0.00 ^a	0.08±0.01 ^{ab}
MH2Sep	7.97±0.07 ^{fg}	198.1±0.99 ^h	7.00±0.00 ^c	2.33±0.11 ^c	0.79±0.01 ^{ef}	0.00±0.00 ^a	0.08±0.01 ^{ab}
MH3Sep	8.22±0.09 ^h	142.1±0.40 ^e	7.60±0.00 ^d	2.60±0.17 ^f	0.93±0.05 ^f	0.07±0.01 ^{ab}	0.06±0.01 ^a
ML1Aug	7.05±0.02 ^c	38.5±0.25 ^a	7.60±0.00 ^d	1.13±0.09 ^{cd}	0.10±0.00 ^a	0.40±0.02 ^d	0.20±0.01 ^{cde}
ML2Aug	7.05±0.03 ^c	65.7±0.05 ^d	7.67±0.11 ^d	0.43±0.05 ^{ab}	0.10±0.00 ^a	0.63±0.05 ^f	0.30±0.01 ^f
ML3Aug	7.76±0.03 ^c	66.3±0.48 ^d	7.20±0.00 ^c	0.67±0.11 ^b	0.10±0.00 ^a	0.33±0.03 ^d	0.14±0.01 ^{abc}
ML1Sep	8.24±0.06 ^h	60.4±0.09 ^c	7.67±0.09 ^d	0.57±0.05 ^{ab}	0.63±0.04 ^{cde}	0.00±0.00 ^a	0.14±0.01 ^{bc}
ML2Sep	8.03±0.04 ^g	58.4±0.20 ^b	7.73±0.11 ^d	0.57±0.05 ^{ab}	0.67±0.05 ^{cde}	0.10±0.01 ^b	0.14±0.03 ^{abc}
ML3Sep	7.42±0.06 ^d	38.7±0.18 ^a	6.87±0.11 ^c	0.33±0.09 ^a	0.73±0.05 ^{de}	0.05±0.03 ^{ab}	0.21±0.02 ^{de}

Notes: Values expressing the Mean±SD followed by similar letters in a column do not differ significantly at $p < 0.05$, P = Ping River, MH = Mae Hao, ML = Mae Luang

CONCLUSIONS

Our findings showed that the Ping River and its tributaries were found to be significantly different in terms of benthic diatom diversity and water quality. This was especially true in Mae Luang Stream, which was found to have low values in terms of the diversity index and richness. *Amphipleura lindheimeri* were found to be a newly recorded species for Thailand in this stream. The Ping River and Mae Hao Stream were similar in terms of benthic diatom diversity and water quality. Furthermore, this study identified the potential indicator species in the Ping River and Mae Hao Stream that displayed tolerance to

organic pollution, while potential indicator species in terms of sensitivity to organic pollution were identified in Mae Luang Stream.

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