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

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ABSTRACT

Mae Teang District is home to many tributaries of the Ping River. Each tributary is associated with different geographical characteristics and uses. This study is the first report on benthic diatom diversity in the designated water bodies and the first comparison of benthic diatom distribution in the Ping River and its tributaries, including the Mae Hao and Mae Luang Streams in Mae Taeng District of Chiang Mai Province, Thailand. The benthic diatom distribution and physico-chemical properties were 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). 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*, *Diadesmis contenta*, *Karayevia oblongella* and *Achnanthes brevipes*. Additionally, *Amphipleura lindheimeri* Grunow was identified as a newly recorded species for Thailand. This study revealed that the Ping River and Mae Hao Stream are 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. In conclusion, the areas of utilization were found to have affected the distribution of benthic diatoms in these water bodies, along with the water quality of the Ping River and its tributaries.

Keywords: *Amphipleura lindheimeri*, cluster analysis, diversity index, water quality

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 (Smol & Stoermer 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 Mea 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 Teang 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 aims of the study were as follows: (i) to determine the diversity of benthic diatoms and the physico-chemical properties in the Ping River and its tributaries in Mae Taeng District of Chiang Mai

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Province, Thailand; and (ii) to compare the benthic diatoms and physico-chemical properties in each water body.

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 and 2.

Table 1 Sampling sites and their topography

Sampling site	GPS (Lat-Long)	Altitude (m asl)	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 19º06’06.18” E 98º85’56.06”	360	Paddy field and village
Mae Hao stream 2	N 19º04’15.43” E 98º86’94.56”	357	Paddy field and village
Mae Hao stream 3	N 19º03’01.07” E 98º87’40.23”	350	Paddy field and village
Pa Pae sub-district			
Mae Luang stream 1	N 19º11’84.08” E 98º70’59.97”	849	Forest and hill tribe village
Mae Luang stream 2	N 19º10’68.65” E 98º71’31.38”	835	Forest and village
Mae Luang stream 3	N 19º11’17.44” E 98º70’77.41”	822	Forest and village

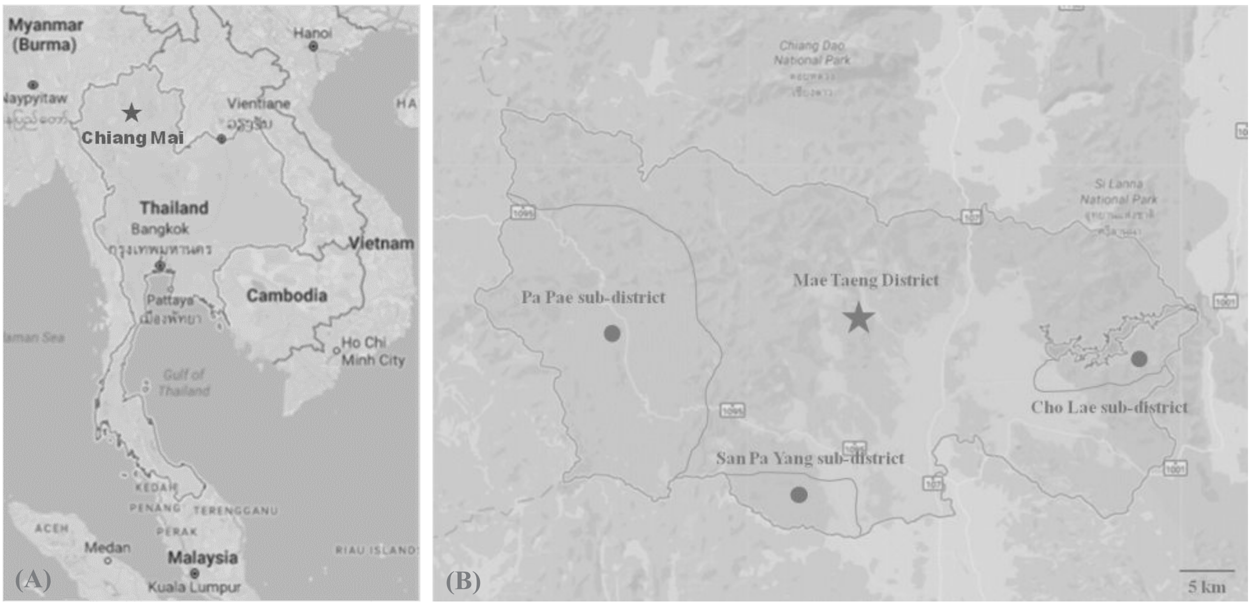

Figure 1 Map showing location of Chiang Mai Province and the Cho Lae, San Pa Yang and Pa Pae sub-districts in Mae Taeng district

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

Benthic Diatoms Study

Benthic diatoms were studied following the methods of Renberg (1990), Vilbaste (1994), Kelly *et al.* (1998) 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 HNO_3 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 and Lange-Bertalot (1986, 1988, 1991a, 1991b), Lange-Bertalot (2001), Kelly and Haworth (2002), and Guiry and Guiry (2017). The relative abundance of the benthic diatoms was then indicated according to the following system; + = present, - = absent and * = dominant according to Leelahakrieng and 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), BOD_5, nitrate nitrogen (NO_3), ammonium nitrogen (NH_4^+) 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).

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 lindheimeri* 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 November 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, Achnanthidium 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 November 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 November 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 *Achnanthidium 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 was 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 (Schneck *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
Aulacoseira granulate (Ehrenberg) Simonsen	-,+,-/+,-,-	+,-,+/-,-,+	-
Melosira varians C. Agardh	-	-,-,-/-,+,-	-
Cyclotella atomus Hustedt	-,-,+/+,-,-	-	-,-,-/-,+,-
Cyclotella meneghiniana Kützing	-,-,-/+,-,+	-,-,-/-,-,+	-
Cyclotella pseudostelligera Hustedt	-,+,+/+,+,+	-	-
Thalassiosira weissflogii (Grunow) G. Fryxell & Hasle	-,-,+/-,-,+	+,-,+/-,+,-	-
Karayevia oblongella (Østrup) Aboal	-,+,+/+,+,+	+,-,+/+,+,+	+,*,*/+,*,*
Achnanthes brevipes C. Agardh	-	-	+,+,+/*,*,+
Achnanthes brevipes var. *intermedia* (Kützing) Cleve	-,+,+/+,+,+	-,-,-/-,-,+	-
Achnanthes inflata (Kützing) Grunow	-,-,-/+,-,-	-,-,+/-,+,-	-,-,-/-,-,+
Achnanthes crenulata Grunow	-	+,-,+/+,-,-	-
Achnanthes sp.	-	-	-,-,-/-,+,-
Aneumastus stroesei (Østrup) D.G. Mann	-	+,-,+/-,-,-	+,+,+/-,-,-
Achnanthidium exiguum (Grunow) Czarnecki	-,+,*/+,+,+	+,-,+/+,+,+	+,+,+/+,-,+
Achnanthidium jackii Rabenhorst	-,+,+/-,-,-	+,-,-/-,-,-	-
Achnanthidium minutissimum (Kützing) Czarnecki	-,+,+/+,+,+	+,-,+/-,-,-	+,-,-/*,-,-
Achnanthidium sp.	-	-	+,+,+/+,+,+
Lemnicola hungarica (Grunow) Round & Basson	-,+,-/-,-,-	-	-
Rossithidium pusillum (Grunow) Round & Bukhtiyarova	-,+,+/+,-,+	+,-,+/+,-,+	-
Planothidium biporomum (M.H. Hohn & Hellerman) Lange-Bertalot	-,+,+/+,+,+	-,-,+/-,-,+	-
Planothidium lanceolatum (Brébisson ex Kützing) L.Bukhtiyarova	-,*,+/*,*,+	+,-,+/+,+,+	-
Planothidium rostratum (Østrup) Lange-Bertalot	-,+,+/+,+,+	+,-,+/+,+,-	-
Cocconeis placentula Ehrenberg	-,*,+/*,*,+	+,-,+/+,+,+	-,-,+/+,-,+
Cocconeis sp.	-	-,-,-/-,-,+	-
Cymbella affinis Kützing	-,+,+/+,+,+	-	-
Cymbella helvetica Kützing	-,+,+/+,+,+	-	-
Cymbella neoleptoceros Krammer	-,-,-/+,-,-	-	-
Cymbella tumida (Brébisson) Van Heurck	-,+,-/+,+,+	-,-,-/+,+,-	-,-,-/+,-,-
Cymbella turgidula Grunow	-,+,+/+,+,*	+,-,+/+,+,+	-,-,-/+,-,+
Cymbopleura amphicephala (Nägeli) Krammer	-	-,-,-/+,-,-	-
Encyonema gracile Kirchner	-	-,-,-/+,+,-	-
Encyonema mesianum (Cholnoky) D.G.Mann	-,-,-/-,+,+	-	-,-,-/+,-,-
Encyonema minutum (Hilse) D.G. Mann	-,+,+/+,+,+	+,-,+/+,+,+	+,+,+/+,+,+
Encyonopsis leei Krammer	-,-,-/+,+,+	-	-
Geissleria decussis (Østrup) Lange-Bertalot & Metzeltin	-,+,+/+,+,+	+,-,+/+,-,+	-,+,+/+,+,+
Gomphonema augur Ehrenberg	-,+,-/-,-,+	-	-
Gomphonema clavatum Ehrenberg	-,+,+/+,+,+	-,-,-/+,+,+	-,-,-/+,-,-
Gomphonema clevei Fricke	-,+,+/+,+,+	-,-,+/+,+,+	*,+,*/*,*,+
Gomphonema gracile Ehrenberg	-,+,+/+,+,+	-	-,+,-/+,-,-
Gomphonema hebridense W.Gregory	-,+,-/+,-,-	-	-
Gomphonema lagenula Kützing	-,+,+/+,+,+	+,-,+/+,-,+	+,+,+/+,+,+
Gomphonema minutum (C. Agardh) C. Agardh	-,+,-/-,-,-	-	-
Gomphonema parvulum (Kützing) Kützing	-,+,+/+,+,+	-	+,+,+/+,+,+
Gomphonema pumilum (Grunow) E. Reichardt & Lange-Bertalot	-,+,+/+,+,+	-,-,-/+,+,+	-
Gomphonema turris Ehrenberg	-	+,-,+/+,+,-	-
Gomphonema vibrio Ehrenberg	-,+,-/-,-,-	-	-
Placoneis dicephala (Ehrenberg) Mereschkowsky	-,+,-/-,-,-	+,-,+/+,+,*	+,+,+/+,-,+
Placoneis elginensis (W. Gregory) E.J. Cox	-,+,+/+,+,+	-	-
Placoneis gastrum (Ehrenberg) Mereschkowsky	-,+,+/+,+,-	-	-
Placoneis placentula (Ehrenberg) Mereschkowsky	-,-,-/+,-,-	-	-
Placoneis sp. 1	-,+,+/-,-,-	+,-,+/+,+,+	-,+,-/+,-,-
Placoneis sp. 2	-	-,-,-/+,+,+	-,-,-/+,+,+
Adlafia sp.	-,+,-/+,-,+	-	-
Amphipleura lindheimeri Grunow	-	-	+,-,-/-,-,-
Amphora aequalis Krammer	-	+,-,+/-,+,+	+,-,-/-,-,-
Amphora libyca Ehrenberg	-,+,+/+,+,+	+,-,-/+,*,+	+,+,+/-,-,+
Caloneis bacillum (Grunow) Cleve	-,-,-/+,+,-	-,-,+/+,+,+	-

Caloneis silicula (Ehrenberg) Cleve	-,+,+/+,+,-	-,-,+/+,+,+	-
Gyrosigma scalproides (Rabenhorst) Cleve	-,+,+/+,+,+	+,-,+/+,+,+	+,+,+/+,+,+
Gyrosigma acuminatum (Kützing) Rabenhorst	-,+,+/+,+,+	-,-,+/*,+,+	+,+,+/+,-,-
Navicula angusta Grunow	-,-,+/-,-,-	+,-,+/+,-,-	+,+,+/+,+,+
Navicula capitatoradiata H.Germain	-,+,+/+,+,+	+,-,-/+,-,-	-
Navicula cinctaeformis Hustedt	-,+,+/+,-,-	-	-,-,-/+,-,-
Navicula cryptocephala Kützing	-,+,+/+,+,+	-,-,+/+,-,+	+,+,+/+,+,+
Navicula cryptocephaloides Hustedt	-,+,+/+,+,+	+,-,+/+,+,+	-
Navicula cryptotenella Lange-Bertalot in Krammer & Lange-Bertalot	-,+,+/*,*,*	+,-,+/+,*,+	*,*,*/*,*,+
Navicula erifuga Lange-Bertalot in Krammer & Lange-Bertalot	-,+,+/+,+,+	+,-,-/+,+,+	+,+,+/+,+,+
Navicula germainii J.H. Wallace	-,+,+/+,+,*	-,-,-/-,-,+	-
Navicula menisculus Schumann	-,+,+/-,-,-	+,-,+/+,+,+	+,+,-/+,-,-
Naviculadicta nanogomphonema Lange-Bertalot & U. Rumrich	-,-,-/+,-,-	-	-
Navicula phyllepta Kützing	-,+,+/+,+,+	+,-,+/+,+,+	+,+,*/+,+,+
Navicula radiosa Kützing	-	+,-,+/-,-,+	-,-,-/+,-,-
Navicula radiosafallax Lange-Bertalot	-,+,+/+,+,+	+,-,-/-,+,-	-
Navicula recens (Lange-Bertalot) Lange-Bertalot in Krammer & Lange-Bertalot	-,+,+/-,-,-	-	-
Navicula rhynchocephala Kützing	-,+,+/-,-,-	-,-,-/-,-,+	-
Navicula rostellata Kützing	-,+,+/+,+,+	+,-,+/+,+,+	+,+,+/+,+,+
Navicula schroeteri F. Meister	-	-,-,-/-,-,+	+,*,+/+,-,+
Navicula symmetrica R.M. Patrick	-,+,+/+,+,+	+,-,+/+,+,+	*,*,+/*,*,*
Navicula viridula (Kützing) Ehrenberg	-,+,+/+,+,+	+,-,+/+,+,+	-,-,+/+,+,+
Navicula sp. 1	-,-,-/-,+,-	-	-
Navicula sp. 2	-	-	*,+,+/*,*,+
Seminavis strigosa (Hustedt) Danieledis & Economou-Amilli in Danielidis & D.G.Mann	-,+,*/*,*,*	-,-,-/*,*,+	-
Eolimna minima (Grunow) Lange-Bertalot	-,+,+/+,-,-	+,-,+/+,+,-	-,-,+/-,-,-
Eolimna subminuscula (Manguin) Gerd Moser, Lange-Bertalot & Metzeltin	-,+,-/+,+,+	-,-,-/+,+,+	-
Craticula accomoda (Hustedt) D.G.Mann	-	-	-,-,+/-,-,-
Craticula cuspidata (Kutzing) D.G.Mann	-,+,-/-,-,-	+,-,+/+,+,+	-
Craticula riparia (Hustedt) Lange-Bertalot	-	-,-,-/-,+,-	-
Stauroneis anceps Ehrenberg	-	-,-,+/+,-,-	-
Stauroneis kriegeri R.M. Patrick	-,-,-/+,-,-	+,-,+/-,+,+	+,+,+/+,+,+
Stauroneis smithii Grunow	-,-,-/-,-,+	+,-,+/+,-,-	-,+,+/+,+,+
Stauroneis schimanskii Krammer	-,-,-/+,+,+	-	-
Halamphora montana (Krasske) Levkov	-,+,+/+,+,+	-	-
Halamphora normanii (Rabenhorst) Levkov	-,+,+/+,-,+	-,-,-/+,-,-	-,+,-/-,-,-
Frustulia rhomboides (Ehrenberg) De Toni	-,+,-/-,+,-	-,-,-/-,-,+	+,-,+/+,+,+
Frustulia vulgaris (Thwaites) De Toni	-	-,-,-/-,-,+	-
Frustulia weinholdii Hustedt	-	+,-,+/-,-,-	-,-,-/+,-,-
Brachysira neoexilis Lange-Bertalot in Lange-Bertalot & Moser	-,+,+/+,+,+	+,-,+/+,-,-	-
Brachysira vitrea (Grunow) R. Ross in Hartley, Ross & Williams	-,-,+/-,-,-	+,-,+/+,-,+	-,-,-/-,-,+
Diadesmis brekkaensis (J.B.Petersen) D.G.Mann	-,+,-/-,-,-	-	-
Diadesmis confervacea Kützing	-,-,-/+,+,-	-,-,-/-,-,+	-
Diadesmis contenta (Grunow) D.G.Mann	-,+,+/+,+,+	+,-,+/-,+,+	+,*,+/+,+,+
Luticola cohnii (Hilse) D.G. Mann	-,-,+/-,+,-	-,-,-/-,+,-	+,+,+/+,-,+
Luticola goeppertiana (Bleisch) D.G. Mann ex J. Rarick, S. Wu, S.S. Lee & Edlund	-,+,+/+,+,+	+,-,-/-,-,+	-,+,-/-,-,-
Luticola permuticoides Metzeltin & Lange-Bertalot	-,-,+/+,+,-	+,-,+/+,+,+	+,+,+/+,-,+
Luticola mitigata (Hustedt) D.G. Mann	-,-,-/-,+,+	+,-,+/+,+,+	+,+,+/-,-,+
Luticola mutica (Kützing) D.G. Mann	-,+,+/+,+,+	-,-,-/-,+,+	+,+,+/+,+,+
Diploneis elliptica (Kützing) Cleve	-,+,+/+,+,+	+,-,+/+,+,-	+,+,+/+,-,+
Fallacia insociabilis (Krasske) D.G. Mann	-,+,+/-,+,+	-	+,-,-/-,-,-
Fallacia pygmaea (Kützing) Stickle & D.G. Mann	-,-,-/+,+,+	-,-,-/+,-,-	-,-,-/+,-,-
Neidium ampliatum (Ehrenberg) Krammer	-,-,+/+,+,+	+,-,+/+,+,+	-,-,-/+,-,-
Neidium binodeforme Krammer	-,-,-/+,+,+	+,-,-/+,-,-	-
Neidium dubium (Ehenberg) Cleve	-,-,-/+,+,+	-,-,+/+,+,+	-
Neidium ladogense (Cleve) Foged	-	-	-,-,-/-,-,+

Neidium sp.1	-,-,+/-,+,-	-,-,-/+,+,+	-,-,-/+,-,-
Neidium sp.2	-	-,-,-/+,-,+	-
Pinnularia acrosphaeria W. Smith	-	-,-,+/+,+,+	-
Pinnularia braunii Cleve	-	+,-,+/+,+,+	-
Pinnularia brebissonii (Kützing) Rabenhorst	-	-,-,-/-,-,+	-
Pinnularia borealis Ehrenberg	-,-,-/-,-,+	-	-
Pinnularia cruciformis (Donkin) Cleve	-	+,-,+/+,+,+	*,+,+/+,+,+
Pinnularia divergens W. Smith	-,+,+/+,+,+	+,-,-/+,+,+	+,-,+/+,+,+
Pinnularia episcopalis Cleve	-	-,-,+/-,+,+	-,-,-/-,-,+
Pinnularia interrupta W. Smith	-	+,-,+/+,+,+	+,+,+/+,-,+
Pinnularia legumen Ehrenberg	-	-,-,+/+,-,-	+,-,-/+,-,+
Pinnularia macilenta Ehrenberg	-	-	-,-,-/+,-,+
Pinnularia mesolepta (Ehrenberg) W. Smith	-,+,+/+,-,-	+,-,+/+,-,-	-,-,+/-,-,-
Pinnularia microstauron (Ehrenberg) Cleve	-,-,-/+,-,-	+,-,+/+,+,+	-,+,-/-,-,-
Pinnularia nobilis (Ehrenberg) Ehrenberg	-,-,+/-,-,-	-	-
Pinnularia subcapitata W. Gregory	-,+,+/+,+,+	-,-,+/+,-,+	-,+,-/-,-,+
Pinnularia subgibba Krammer	-	+,-,+/-,-,-	-
Pinnularia rupestris Hantzsch	-	+,-,-/-,-,-	-
Pinnularia sp.1	-,+,-/+,-,-	+,-,+/+,+,+	-,-,-/+,+,+
Pinnularia sp.2	-	-,-,-/-,-,+	-
Pinnularia sp.3	-	-,-,-/-,-,+	-
Diadesmis contenta (Grunow) D.G. Mann	-,+,+/+,+,+	+,-,+/-,+,+	+,*,+/+,+,+
Luticola cohnii (Hilse) D.G. Mann	-,-,+/-,+,-	-,-,-/-,+,-	+,+,+/+,-,+
Sellaphora bacillum (Ehrenberg) D.G. Mann	-,+,+/+,+,-	-,-,-/+,+,+	-
Sellaphora garciarodriguezii Metzeltin & Lange-Bertalot		+,-,+/+,+,+	-
Sellaphora japonica (Kobayasi) Kobayasi	-,+,+/+,+,+	-	-
Sellaphora pupula (Kützing) Mereschkovsky	-,+,+/+,+,+	*,-,*/+,+,*	+,+,+/+,+,+
Bacillaria paxillifera (O.F. Müller) T. Marsson	-,+,+/+,-,+	+,-,+/+,+,+	-
Hantzschia amphioxys (Ehrenberg) Grunow	-,+,+/-,-,-	+,-,+/+,+,+	-,-,+/+,-,+
Hantzschia distinctepunctata Hustedt	-,+,-/-,-,-	-	-
Nitzschia acicularis (Kützing) W. Smith	-,-,-/-,-,+	-	-
Nitzschia amphibia Grunow	-,-,+/+,+,+	+,-,+/+,+,+	-
Nitzschia brevissima Grunow	-,+,+/+,+,+	+,-,+/+,-,-	-
Nitzschia clausii Hantzsch	-,+,+/+,+,-	+,-,+/+,-,+	-
Nitzschia compressa (Bailey) C.S. Boyer	-,+,-/+,-,-	-,-,-/+,-,-	-
Nitzschia constricta (Kützing) Ralfs	-,-,+/+,+,+	-	-
Nitzschia draveillensis Coste & Ricard	-,+,+/+,-,+	+,-,+/+,+,+	-
Nitzschia dissipata (Kützing) Rabenhorst	-,+,+/+,+,+	+,-,+/*,+,+	+,+,+/+,+,+
Nitzschia dubia W. Smith	-,-,-/-,+,-	-	-
Nitzschia fonticola (Grunow) Grunow	-	+,-,+/+,-,-	-,-,+/-,-,-
Nitzschia fossilis (Grunow) Grunow	-	+,-,+/-,-,-	-,-,+/-,-,-
Nitzschia frustulum (Kützing) Grunow	-	+,-,+/+,+,-	-,+,+/+,-,+
Nitzschia graciliformis Lange-Bertalot & Simonsen	-,-,-/+,-,+	-	-
Nitzschia heufleriana Grunow	-,-,-/-,+,-	-	-
Nitzschia intermedia Hantzsch in Cleve & Grunow	-,+,+/+,-,-	+,-,+/+,+,+	-,-,-/-,-,+
Nitzschia lacuum Lange-Bertalot	-,+,-/-,-,-	-	-
Nitzschia lorenziana Grunow		-,-,-/+,-,+	-
Nitzschia palea (Kützing) W. Smith	-,*,*/+,+,+	*,-,*/*,+,+	-,+,+/-,-,-
Nitzschia philippinarum Hustedt	-	+,-,+/+,+,-	-
Nitzschia pumila Hustedt	-,+,+/-,-,-	-	-
Nitzschia sigma (Kützing) W. Smith	-,+,+/+,+,+	-	-
Nitzschia sigmoidea (Nitzsch) W. Smith	-,+,-/-,-,-	+,-,+/+,-,+	-
Nitzschia subcohaerens (Grunow) Van Heurck	-,-,+/+,+,+	-,-,+/+,-,-	-
Nitzschia sp.1	-,-,-/+,+,-	-,-,-/+,-,-	-
Nitzschia sp.2	-	-	+,+,+/+,+,+
Grunowia tabellaria (Grunow) Rabenhorst	-,+,+/-,-,-	-	-
Tryblionella coarctata (Grunow) D.G. Mann	-	+,-,+/+,+,-	-
Tryblionella levidensis W.Smith	-,+,+/+,+,+	+,-,+/+,+,+	-,+,-/-,-,-
Epithemia adnata (Kützing) Brébisson	-,-,-/-,+,+	-	-
Rhopalodia gibba (Ehrenberg) Otto Müller	-,-,+/-,-,+	-,-,-/+,-,-	-
Rhopalodia gibberula (Ehrenberg) Otto Müller	-,+,+/+,-,+	+,-,+/+,+,+	-
Eunotia bilunaris (Ehrenberg) Schaarschmidt	-,+,+/+,+,+	+,-,+/+,+,+	+,+,+/+,+,+

Eunotia soleirolii (Kützing) Rabenhorst	-,-,-/-,+,-	-,-,-/-,+,-	-
Fragilaria capucina Desmazières	-,+,+/+,+,+	-,-,-/+,-,-	-
Fragilaria capucina var. *vaucheriae* (Kützing) Lange-Bertalot	-,+,-/-,-,-	-	-
Fragilaria crotonensis Kitton	-,-,+/+,-,-	-,-,-/+,-,-	-
Fragilaria acus (Kützing) Lange-Bertalot	-,+,-/+,-,+	-	+,+,-/+,-,+
Ulnaria ulna (Nitzsch) Compère	-,+,+/+,+,+	+,-,+/+,+,-	-
Ulnaria ulna var. *aequalis* (Kützing) Aboal	-,+,+/+,+,+	-	-
Surirella amphioxys W. Smith	-	-	+,+,+/+,-,+
Surirella angusta Kützing	-,-,-/+,+,+	-	+,+,+/+,+,+
Surirella biseriata Brébisson	-	-	-,-,-/+,-,-
Surirella brebissonii Krammer & Lange-Bertalot	-,-,-/-,-,+	-	-
Surirella ovalis Brébisson	-	-,-,-/-,+,+	-
Surirella splendida (Ehrenberg) Kützing	-,-,-/+,+,+	+,-,+/+,+,*	-,-,+/-,-,-
Surirella terricola Lange-Bertalot & E. Alles	-	-,-,-/+,+,+	+,+,+/+,+,+
Surirella sp. 1	-,+,-/+,+,+	-	-,-,-/-,-,+
Surirella sp. 2	-,-,+/+,+,+	-	-,-,-/-,-,+
Surirella sp. 3	-,-,-/-,+,-	-	-

Note: + = present; - = absent, * = dominant (Site 1, Site 2, Site 3 in August / Site 1, Site 2, Site 3 in November)

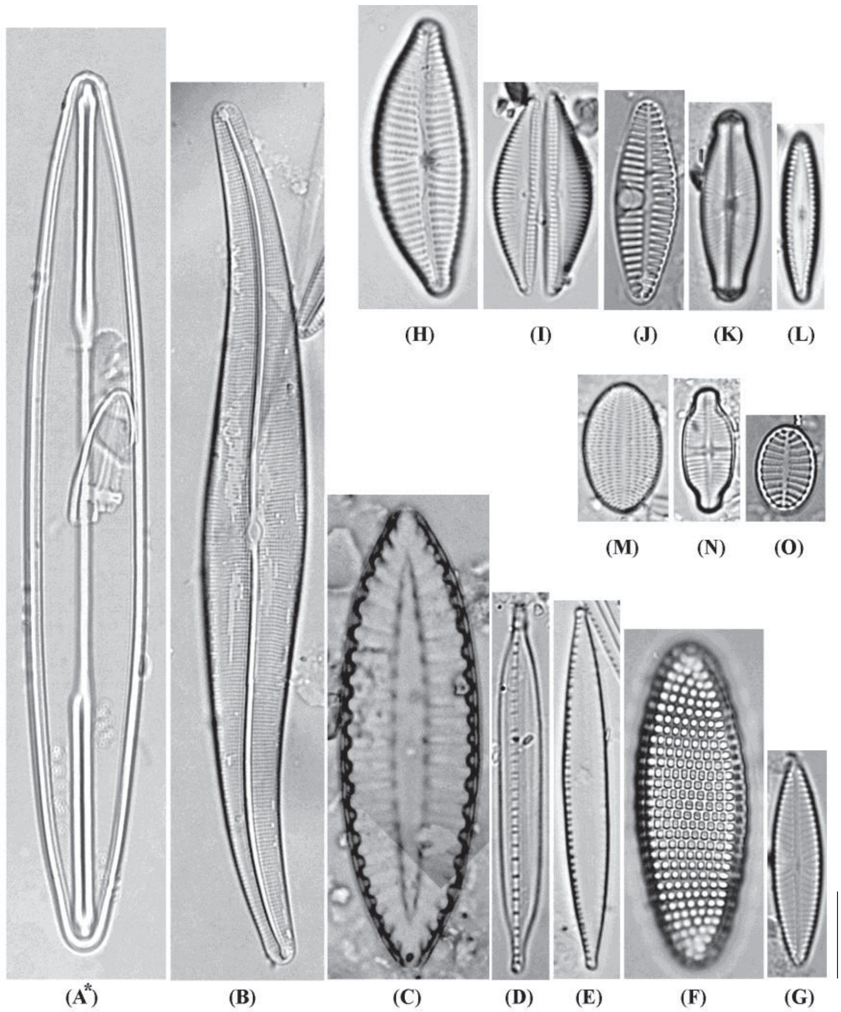

Figure 3 Light micrographs of dominant benthic diatoms in Ping river, Mae Hao and Mae Luang streams and new-recorded benthic diatom of Thailand (A*). (scale bar = 10 μm)

Note: (A*) *Amphipleura lindheimeri*, (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) *Planothidium lanceolatum,* (K) *Sellaphora pupula*, (L) *Gomphonema clevei,* (M) *Cocconeis placentula*, (N) *Achnanthidium exiguum*, (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 Nov-15	3.14	0.225	103
Ping2 Nov -15	3.03	0.235	88
Ping3 Nov -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 Nov -15	3.21	0.260	95
Mae Hao2 Nov -15	3.08	0.272	80
Mae Hao3 Nov -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 Nov -15	2.87	0.275	64
Mae Luang2 Nov -15	2.56	0.371	35
Mae Luang3 Nov -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.

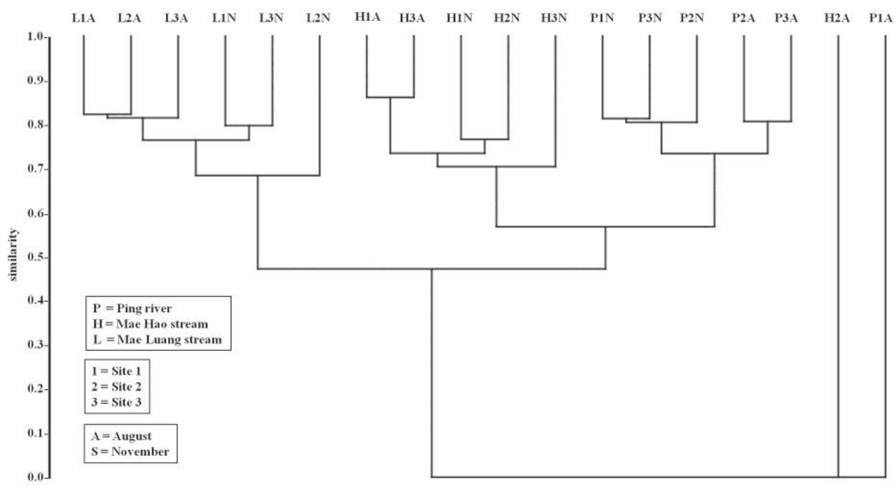

Figure 4 Cluster analysis of benthic diatoms diversity grouping by Dice's similarity coefficient

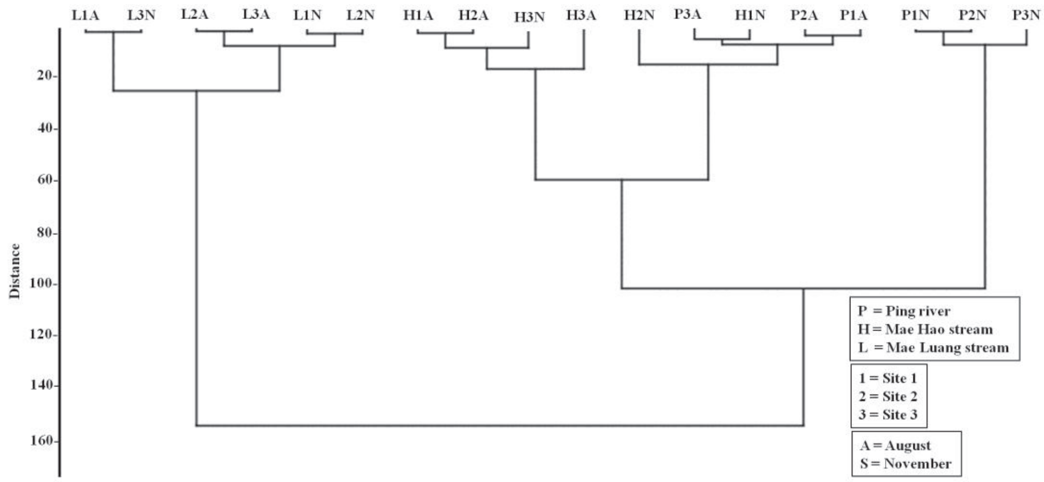

Figure 5 Cluster analysis of physical and chemical water quality grouping by Ward's method with squared Euclidean distances

Table 4 Physico-chemical factors of Ping river, Mae Hao and Mae Luang streams (n=3)

Sampling sites	pH	Conductivity (μs/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}
P1Nov	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}
P2Nov	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}
P3Nov	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^{e}	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}
MH1Nov	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}
MH2Nov	7.97±0.07^{fg}	198.1±0.99^{h}	7.00±0.00^{c}	2.33±0.11^{e}	0.79±0.01^{ef}	0.00±0.00^{a}	0.08±0.01^{ab}
MH3Nov	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^{e}	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}
ML1Nov	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}
ML2Nov	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}
ML3Nov	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}

Note: 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

CONCLUSION

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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