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Diversity of Benthic Diatoms and Water Quality of the Ping River, Northern Thailand

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Abstract

A study on the diversity of benthic diatoms and water quality of the Ping River, Northern Thailand were carried out from December 2004-December 2005. Samples were collected from 15 sites covering the whole river. The water quality was based on specific physical and chemical factors indicated the water in the Ping River was moderately clean and classified in the mesotrophic status, except in the upstream area which was clean to moderate and of the oligo-mesotrophic status. Changing in water quality depended on the environmental status surrounding the sampling sites and seasonal changes. Two orders, forty genera and one hundred and twenty eight species of benthic diatoms were found and classified into the Division Bacillariophyta. Most of them (97%) were pennate diatoms in the Order Bacillariales. The remaining 3% were centric diatoms in the Order Biddulphiales. The relationship between water quality and dominant benthic diatoms in each sampling site and season were determined. It was found that *Nitzschia palea* (Kützing) W. smith, *Nitzschia* sp. 2 and *Synedra ulna* var. *aequalis* (Kützing) Hustedt were indicator species for moderate water quality whilst *Cymbella turgidula* Grunow, *Gomphonema lagenula* Kützing and *Navicula symmetrica* Patrick were indicator species of clean to moderate water quality.

***Keywords**:* biodiversity; water quality; benthic diatoms; Ping River; Thailand

1. Introduction

The study on diatom flora in South-East Asia is not as well-documented in terms of diversity, distribution pattern and related ecological data. Most of these studies focused on planktonic diatoms in stagnant water bodies with very rare reports of benthic diatoms in running water bodies.

Benthic diatoms play ecological roles in carbon dioxide reduction from the atmosphere and oxygen production, which helping in controlling global warming. These organisms act as producers in aquatic ecosystems, especially of food for heterotrophic benthic organisms (Lee, 1999). Owing to their ability to grow in different types of water quality, the utilization of benthic diatoms to monitor the water quality in running water has been used in some European countries for a long time.

In this research, the diversity of benthic diatoms and the physico-chemical properties of water including the relationships between dominant benthic diatoms species and their environments in the Ping River of Northern Thailand was investigated.

The Ping River is the major river in Northern Thailand. It runs through 5 provinces: Chiang Mai, Lamphun, Tak, Kamphaeng Phet and Nakorn Sawan and flows into the Chao Phraya River. Its estimated length is 750 km with catchment areas of around 34,885 km^2. The activities from people who live along this river not only affect physical and chemical properties of the water but also affect aquatic organisms. Benthic diatoms are useful in the biodiversity study because they could be found in many substrates in the water and could tolerate different environments. Fifteen study sites along the river from upstream to downstream were related to the study from 2004-2005. This research aims to fill the scientific gap in benthic diatoms data by investigating as many potential benthic diatom sites in the Ping River of northern Thailand as possible.

Table 1. Sampling sites and their topography.

Name of sites	Location			Latitude Longtitude	Altitudes (m)	Characters of each site
	Village	District	Province			
MP1	Muang Na	Chiang Dao	Chiang Mai	19°45”37’N 98°53”74’E	721	up stream
MP2	Tung Kaow Poung	Chiang Dao	Chiang Mai	19°33”47’N 98°57”19’E	455	agriculture
MP3	Wang Hi	Chiang Dao	Chiang Mai	19°23”69’N 98°59”13’E	390	agriculture
MP4	Mae Hor Phar	Mae Tang	Chiang Mai	19°00”60’N 98°57”61’E	348	agriculture, residential
MP5	Pa Dad	Muang	Chiang Mai	18°44”31’N 98°58”85’E	291	residential, junction of polluted canal
MP6	Pak Bor	Pa Sang	Lamphun	18°32”49’N 98°56”06’E	280	agriculture
MP7	Had Nak	Ban Hong	Lamphun	18°23”03’N 98°41”22’E	272	agriculture
MP8	Kong Hin	Lee	Lamphun	18°90”72’N 99°37”78’E	260	agriculture and residential
MP9	Jareon Pattana	Ban Tak	Tak	17°02”05’N 99°04”13’E	148	residential, behide Bhumibol Dam
MP10	Wang Chao	Muang	Tak	16°41”11’N 99°16”32’E	129	residential, behide Bhumibol Dam
MP11	Wang Yang	Muang	Kampeang Phet	16°26”73’N 99°31”39’E	80	residential
MP12	Koh Mou	Khlong Khlung	Kampeang Phet	16°14”47’N 99°42”84’E	61	residential
MP13	Chum Phae	Banphot Phisai	Nakorn Sawan	15°56”07’N 99°53”60’E	52	residential
MP14	Kao Liao	Kao Liao	Nakorn Sawan	15°50”90’N 100°04”30’E	34	residential
MP15	Pak Num Po	Muang	Nakorn Sawan	15°40”10’N 100°00”68’E	28	residential

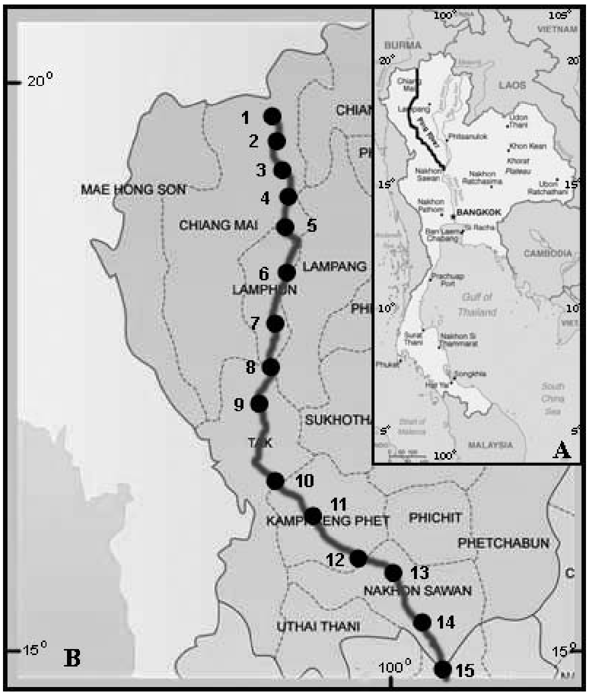

Figure 1. Map of Thailand and Ping watershed (A) and 15 sampling sites along the Ping River (B).

2. Material and Methods

Fifteen sampling sites along the length of the Ping River from upstream to downstream were selected. The details of each sampling site were shown in Table 1 and Fig. 1. The benthic diatoms and water samples were collected twice a season for 1 year from December 2004-December 2005 (the rainy season (June-September), the cool dry season (October-February) and the hot dry season (summer) (March-May)).

Water samples were collected in polyethylene bottles and kept in a cool box (5-7^{o}C). Measurement of some physico-chemical properties of water were done at each sampling site. Water temperature, conductivity and pH were measured in the field using portable meters. Dissolved oxygen (DO), BOD_5, alkalinity, ammonia- nitrogen, nitrate- nitrogen and soluble reactive phosphorus (SRP) were determined in the laboratory by azide modification, phenolpthalein methyl orange indicator, nesslerization, cadmium reduction and ascorbic acid methods, respectively (Greenberg *et al*., 2005).

The trophic status of water was evaluated from main parameters (conductivity, DO, BOD_5, alkalinity, ammonia- nitrogen, nitrate- nitrogen and soluble reactive phosphorus) according to Lorraine and Vollenweider (1981), Wetzel (2001) and Peerapornpisal *et al*. (2004).

The benthic diatoms samples were scraped from 5-10 stones (or other hard substrates) per site. The stones were brushed with a toothbrush. A plastic sheet with a hole area of 10 cm^2 cutout was placed on the upper surface of the selected stone, diatoms were brushed from the square hole and preserved with lugol's iodine solution. In the laboratory, the samples were cleaned by concentrated acid digestion method (Renberg, 1990; Kelly *et al.,* 1998). The benthic diatom samples were identified at a magnification of 400x and 1000x. Drawings were made with the help of a drawing tube (camera lucida). Photographs were taken by compound microscope and scanning electron microscope. Identification of benthic diatoms species was carried out according to Krammer and Lange-Bertalot (1986; 1988; 1991a; 1991b), Krammer (1992; 1997a; 1997b), Mettzeltin and Lange-Bertalot (1998; 2007), Rumrich *et al*. (2000) and Lange-Bertalot (2001).

Table 2. Minimum and maximum values of some physical, chemical and biological properties of water in Ping River during December 2004-December 2005.

Sampling sites	Water temp.(°C)	Velo. ($m.s^{-1}$)	pH	Alkali. ($mg.l^{-1}$ as $CaCO_3$)	TDS ($mg.l^{-1}$)	Coduc. ($\mu s.cm^{-1}$)	DO ($mg.l^{-1}$)	BOD_5 ($mg.l^{-1}$)	NO_3-N ($mg.l^{-1}$)	NH_3-N ($mg.l^{-1}$)	SRP ($mg.l^{-1}$)	Fecal coli. Bac. MPN.100 ml^{-1}	Total coli. Bac. MPN.100 ml^{-1}
MP1	15-27	0.16-1.35	6.65-7.33	24-25	22.6-43	38.8-80.7	6.8-8.4	0.1-2.2	0.02-1.8	0.06-0.95	0.15-0.54	210-460	210-640
MP2	18-26.5	0-1.05	7.37-8.38	121-167	131-191	236-360	6.4-9	0.4-5.8	0.1-0.8	0.24-0.88	0.12-1.61	110-2400	240-4600
MP3	18.7-27.5	0.4-1.11	6.96-8.05	140-200	159-229	270-430	5.8-8	0.3-4.4	0.2-1.4	0.1-1.02	0.12-0.94	240-4600	1100-4600
MP4	20.3-29	0.15-1.1	6.34-7.62	10-112	95-150	186-281	5.8-7.4	0.4-2.8	0.48-0.9	0.22-1.21	0.22-1.87	1100-11000	1100-11000
MP5	23-28.5	0-0.9	7-8.01	64-102	92-241	172-451	6-7.6	2.2-5.6	0.1-1.8	0.45-2.4	0.3-2.43	2100-11000	2400-11000
MP6	22-30	0-1.2	6.96-8	76-106	101-146	169-253	5.2-7.8	1.7-3	0.1-2.5	0.02-1.63	0.2-0.87	460-2400	1100-2400
MP7	23-31	0.43-0.9	7.13-8.2	78-101.5	80-139	168-235	5.2-7.6	0.8-3.2	0.1-2.1	0.31-1.32	0.28-1.95	1100-2400	1500-2400
MP8	23.5-33	0.15-0.9	6.71-8.3	64-91.5	80-124	149-196	5.2-8	1-2.6	0.1-3.2	0.32-1.01	0.24-1.31	110-2100	110-2100
MP9	23-29	0.32-0.95	6.32-8.1	70-89	35-122	167-216	5.2-8	0.4-2.4	0.3-2.6	0.12-0.35	0.02-0.23	110-390	110-750
MP10	24-30	0.26-0.86	6.77-8.2	72-91	22-140	185-235	5-7.6	0.4-2.8	0.1-1.3	0.11-0.44	0.05-0.46	110-1500	110-11000
MP11	25-30.5	0.34-0.86	6.03-7.9	58-93	83-163	157-216	4.6-6.6	0.3-2.4	0.6-2.3	0.07-1.29	0.2-1.97	110-2100	110-11000
MP12	26-31.5	0.18-1.1	6.93-8.23	70-95	104-133	180-233	5-8.2	0.1-3	0.6-3.3	0.1-1.02	0.18-1.61	110-2400	460-2400
MP13	26-33	0.21-0.9	6.7-8.34	62-91	100-140	168-240	5.4-8.6	0.2-3.4	0.4-4.6	0.08-5.7	0.08-0.94	10-11000	110-11000
MP14	26-33	0.19-0.8	7-8.14	61-93.5	98-164	168-308	5.6-8.6	0.2-3.6	0.3-2.5	0.11-1.14	0.23-1.04	750-4600	1100-4600
MP15	28-37	0.1-0.96	6.1-7.98	63-94.5	97-137	161-237	4.8-7.8	0.3-4	0.4-2.6	0.14-1.07	0.1-1.57	210-4600	640-4600

water temp. = water temperature, velo. = velocity, alkali. = alkalinity, TDS = total dissolved solid, conduc. = conductivity, SRP = soluble reactive phosphorus, Fecal coli. Bac. = Fecal coliform bacteria, Total coli. Bac. = Total coliform bacteria.

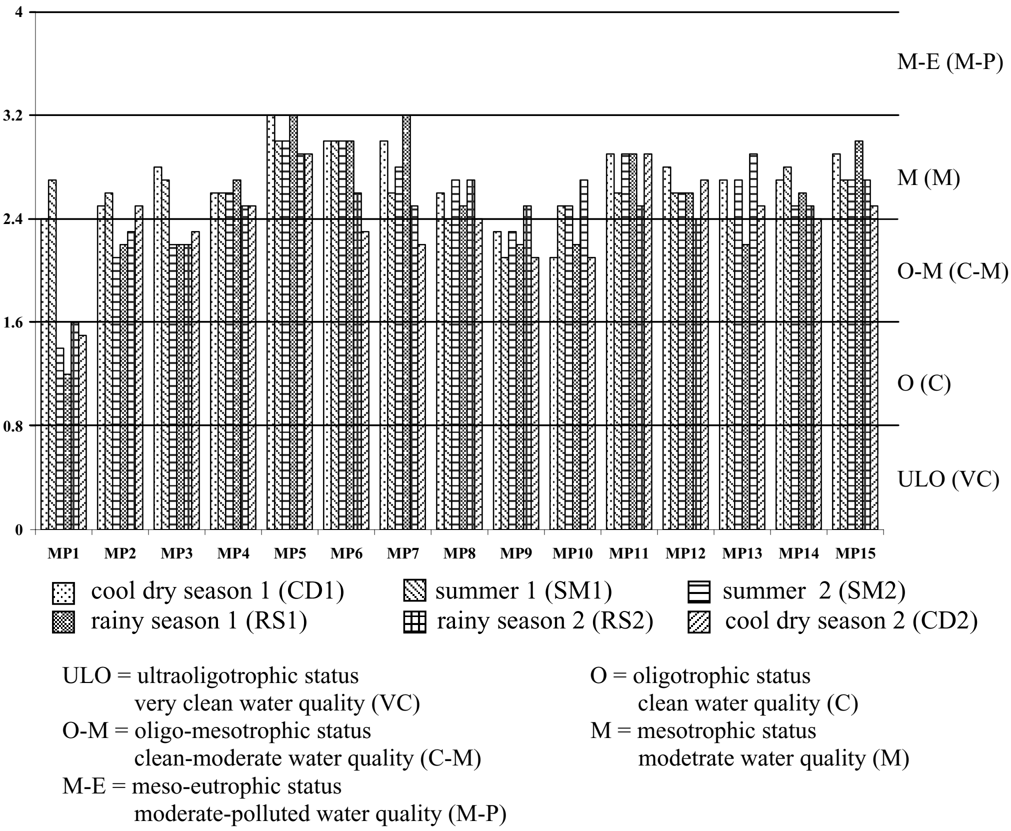

Figure 2. Water quality by trophic status and general water quality of each sampling site in each season of the Ping River from December 2004-December 2005.

3. Results and Discussions

Results of some physical, chemical and biological analysis of water in each sampling site were shown in Table 2. The trophic status and general water quality in each sampling site and each season were shown in Fig. 2 and Table 4.

In this investigation, the water quality of the Ping River was cleaner at the upstream area (MP1) with a low level of conductivity, BOD_5 and nutrients (ammonia- nitrogen, nitrate- nitrogen and soluble reactive phosphorus) (Table 2). This area was surrounded by deciduous forest so there was no contamination of the water bodies. MP2 and MP3 showed clean to moderate water quality with a high level of conductivity, TDS and alkalinity (Table 2) due to the calcium carbonate dissolved from the mountain to the water bodies. These areas were surrounded by forests but also orchards, so contamination was minimal. MP4-8 and MP11-15 showed moderate water quality with the highest level of trophic status in MP5 (Fig. 2). This was owing to the fact that the surrounded areas consisted of agriculture or residential areas and some small industrial factories. There was contamination from fertilizers, waste water from residential areas and some factories, especially at MP5. There was also the joining of the polluted canal (Mae Kha Canal) to the Ping River, so waste water from this canal was mixed with water bodies of the Ping River resulted in a high level of conductivity, BOD_5, ammonia- nitrogen and soluble reactive phosphorus (Table 2). In case of MP9 and MP10, the Ping River passed through the Bhumibol Dam, where the water were diluted, and the water quality showed a low level of nutrients (Table 2). The water quality in the Ping River in this research was similar to the report of Kunpradid and Peerapornpisal (2003) that showed moderate to polluted water quality in 2001-2002. However, MP5 showed polluted water quality but it displayed moderate water quality in this investigation. It was showed that the water from Mae Kha Canal was improved after the year 2003 from the management of Chiang Mai Municipality.

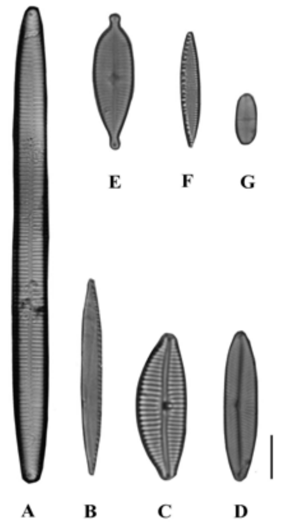

Figure 3. Dominant biomonitor benthic diatom species in Ping River during December 2004-December 2005 (Scale bar = 10 mm)
(A) *Synedra ulna* var. *aequalis*, (B) *Nitzschia palea*, (C) *Cymbella turgidula*, (D) *Navicula symmetrica*, (E) *Gomphonema lagenula*, (F) *Nitzschia* sp. 2, (G) *Achnanthidium minutissimum*

On the biodiversity of benthic diatoms, one hundred and twenty eight species of benthic diatoms were found (Table 3). This was higher than that of Kunpradid and Peerapornpisal's report (2005) which found only one hundred and three species along Ping River passed through Chiang Mai. The majority of benthic diatoms found in this study were pinnate diatoms (97%) while the remaining 3% were centric diatoms. This finding was in agreement with previous reports that pinnate diatoms were dominated in freshwater bodies whereas centric diatoms were more abundant in marine ecosystems (Round *et al*., 1990; Peerapornpisal, 2006).

Seven indicator species namely *Nitzschia palea*, *Achnanthidium minutissimum*, *Nitzschia* sp. 2, *Synedra ulna* var. *aequalis Cymbella turgidula, Gomphonema lagenula* and *Navicula symmetrica* were found (Fig. 3). The species of *Nitzschia palea* was dominate in the sites of moderate water quality and thus represented the highest rank to indicate biomonitor of moderate water quality (Table 5). Similarly, Palmer (1970), Gomez (1998), Jüttner *et al*. (2003) and Duong *et al*. (2007) reported the finding of *Nitzschia palea* in moderate to polluted water quality which indicated its tolerant to organic pollution. In this investigation, MP5 showed highest scores of near eutrophic polluted water quality (Fig. 2). In addition, *Achnanthidium minutissimum*, *Nitzschia* sp. 2 and *Synedra ulna* var. *aequalis* were found as dominant species 10, 6 and 2 times in moderate water quality and indicated as moderate water quality (Fig. 4). Monteiro *et al*. (1995) reported this species occurred only in moderate to polluted water quality. The dominant species of *Achnanthidium minutissimum*, *Cymbella turgidula, Gomphonema lagenula* and *Navicula symmetrica* were found 7, 4, 3 and 2 times in clean to moderate water quality, thus could be used to indicate clean to moderate water quality (Fig. 4). Passy and Bode (2004) found high abundant of *Achnanthidium minutissimum* in the non-impacted headwaters but nearly absent in the contaminated water. Krammer and Lange-Bertalot (1986) reported that *Cymbella turgidula* was found in rather clean to moderate water quality. In the case of *Gomphonema lagenula* and *Navicula symmetrica*, they indicated clean to moderate water quality which was similar to the report of Reichardt (1999) who found *Gomphonema lagenula* occurred in moderate water quality and Pruetiworanan *et al.* (2008) reported that *Navicula symmetric* was found in moderate water

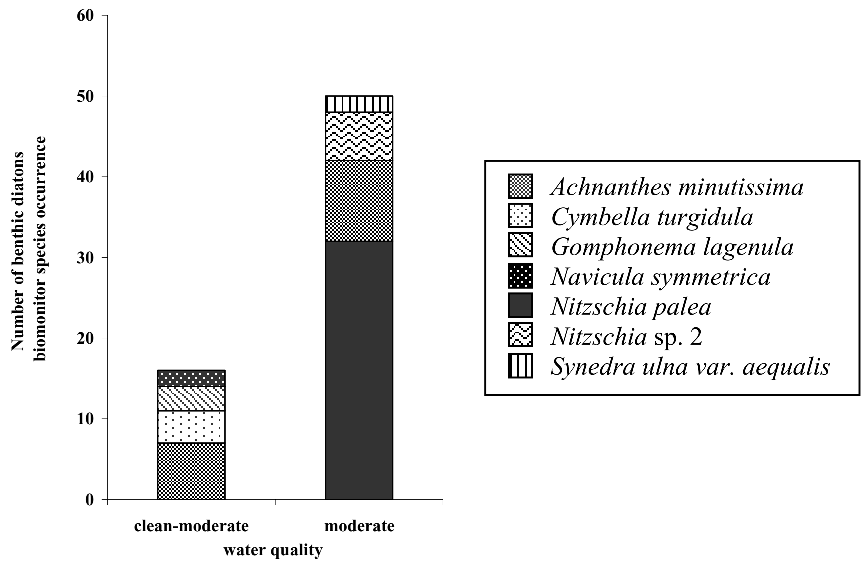

Figure 4. Water quality and biomonitor benthic diatoms species in Ping River during December 2004-December 2005.

quality. However, *Achnanthidium minutissimum* was the dominant species found in clean to moderate (7 times) and moderate (10 times) water qualities in this investigation. These findings indicate that this species could tolerate a wide range of water quality so it is not suitable for use as a biomonitor in the Ping River.

In conclusion, the water quality of the Ping River was moderately clean and the trophic status was oligo-mesotrophic. Upstream, the water quality was clean to moderate whilst downstream was moderate and the trophic status was mesotrophic depended on the environmental status around the sampling sites. The diversity of benthic diatoms changed seasonally and six indicator species were found for clean to moderate and moderate water quality.

Table 3. Benthic diatoms taxa in each sampling site of Ping River during December 2004-December 2005.

List of species	**sites**
Division Bacillariophyta	
Order Biddulphiales	
Family Biddulphiaceae	
Hydrosera triquetra G.C.Wall.	MP2, MP10
Family Melosiraceae	
Aulacoseira granulata Ehrenb.	MP2, MP4-15
Melosira varians C.Agardh	MP1-14
Family Thalassiosiraceae	
Cyclotella meneghiniana Kütz.	MP3-15
Discostella stelligera (Cleve & Grunow) Houk & Klee	MP3-4, MP6-7, MP9-15
Family Triceratiaceae	
Pleurosira laevis (Ehrenb.) Compere	MP3-4, MP10
Pleurosira sp.	MP3
Order Bacillariales	
Family Achnanthaceae	
Achnanthes crenulata Grunow	MP1, MP3, MP8-9, MP11
A. exigua var. *constricta* (Grunow) Hust.	MP1-15
A. lanceolata var. *rostrala* (Oestrup) Hust.	MP14-15
Achnanthidium biasolettianum (Grunow) L. Bukhtiyarova	MP15
A. brevipes var. *intermedia* (Kütz.) Cleve	MP11
A. inflatum (Kütz) Hutton	MP9-12
A. minutissimum (Kütz.) Czarnecki	MP1-15
Karayevia oblongella (Østrup) M. Aboal	MP3-7, MP9-12
Cocconeis placentula Ehrenb.	MP1-15
Diadesmis contenta (Grunow ex Van Heurck) D.G.Mann	MP1, MP7, MP9-12, MP14-15
D. gallica var. *perpusilla* (Grunow) Lange Bert.	MP5, MP9-12, MP14
Planothidium frequentissimum (Lange-Bert.) Lange-Bert.	MP1, MP3-4, MP6-15
P. lanceolatum (Bréb. ex Kütz.) Lange-Bert.	MP1-15
P. minutissimum (Krasske) Lange-Bert.	MP2-3, MP10-11, MP14
P. rostratum (Østrup) Lange-Bert.	MP1, MP3, MP5-15
Planothidium sp.	MP12, MP14-15
Family Naviculaceae	
Brachysira neoexilis Lange-Bert.	MP4, MP6, MP9-15
Caloneis sp.	MP1-2, MP4, MP11-12
Craticula ambigua (Ehrenb.) D.G.Mann	MP8
C. cuspidate (Ktz.) D.G.Mann	MP12

List of species	sites
Diploneis oblongella (Nägeli in Kütz.) Cleve-Euler	MP8
Diploneis subovalis Cleve	MP8
Diploneis sp.	MP2-3, MP10-11
Frustulia disjuncta Lange-Bert.	MP11
F. saxonica Rabenh.	MP1
F. spicula Amossé	MP1, MP7
F. undosa D. Metzeltin & Lange-Bert.	MP1
Frustulia sp.	MP7
Geissleria decussis (Østrup) Lange-Bert. & Metzeltin	MP1-15
Gomphonema acutiusculum (O.Mll.) Cleve	MP8, MP9
G. entolejum Østrup	MP1
G. gracile Ehrenb.	MP1, MP3-15
G. lagenula Kütz.	MP1-15
G. parvulum (Kütz.) Kütz.	MP1-10, MP12
G. pumilum (Grunow) Reichardt & Lange-Bert.	MP10
Gomphonema sp.	MP1-4, MP6-9, MP12, MP14-15
Gyrosigma scalproides (Rabenh.) Cleve	MP1-15
G. spencerii (W. Sm.) Griffith & Herfrey	MP1-15
Luticola goeppertiana (Bleisch) D.G. Mann	MP1, MP3-15
L. monita (Hust.) D.G. Mann	MP3-5, MP7-12, MP15
Mayamaea atomus (Kütz.) Lange-Bert.	MP1, MP3-10, MP12-15
Navicula capitatoradiata Germain	MP2-5, MP8, MP10
N. cryptocephala Kütz.	MP1, MP3, MP6, MP11, MP14
N. cryptotenella Lange-Bert.	MP1-9, MP11, MP14-15
N. novaesiberica Lange-Bert.	MP4-5, MP8-15
N. radiosa Kütz.	MP6
N. viridula (Kütz.) Kütz.	MP1-7, MP9-13
N. viridula var. *rostellata* (Kütz.) Cleve	MP1-15
N. viridula var. *germanii* (Wallace) Lange-Bert.	MP2-15
N. symmetrica Patrick	MP1-15
Navicula sp. 1	MP1-11, MP15
Navicula sp. 2	MP1-12, MP14-15
Navicula sp. 3	MP1-15
Neidium affine var. *humerus* Reimer	MP4, MP8, MP10-11, MP14
N. binodeforme Krammer	MP2-3, MP8
N. gracile Hust.	MP4-5, MP11
Neidium sp.	MP1, MP14
Pinnularia brauniana (Grunow) Mills	MP1
P. brebissonii (Kütz.) Rabenh.	MP5
P. divergens var. *linearis* Østrup	MP9, MP11
P. graciloides Hust.	MP10
P. mesolepta (Ehrenb.) W.Sm.	MP1, MP5, MP11, MP13-14
P.microstauron (Ehrenb.) Cleve	MP1, MP10
P. pseudogibba Krammer	MP11
P. subgibba Krammer	MP8
P. subinterrupta Krammer & Schroeter	MP7, MP10-11

List of species	sites
Placoneis clementis (Grunow) Cox	MP11, MP13
P. gastrum (Ehrenb.) Mereschkowsky	MP11-12
P. placentula (Ehrenb.) Heinzerling	MP11
Rhopalodia gibba (Ehrenb.) O.F. Müll.	MP14
R. gibberula (Ehrenb.) O.F. Müll.	MP10-11, MP14
Sellaphora gibbula D. Metzeltin & Lange-Bert.	MP4, MP10-11, MP13
S. pupula (Kütz.) Mereschkowsky	MP1-15
Stauroneis anceps Ehrenb.	MP1, MP3-4, MP8, MP11
S. smithii Grunow	MP8
S. legumen (Ehrenb.) Kütz.	MP1
Stauroneis sp.	MP8
Family Fragilariaceae	
Fragilaria capucina Desm.	MP3, MP6, MP8, MP11-14
F. crotonensis Kitton	MP6-7, MP10-11
F. tenera (W. Sm.) Lange-Bert.	MP7, MP9, MP10
Synedra ulna (Nitzsch) Ehrenb.	MP1-7, MP9-12, MP14
S. ulna var. *aequalis* (Kütz.) Hust.	MP1-3, MP6-10, MP12-15
Synedra sp.	MP1-5
Family Bacillariaaceae	
Bacillaria paradoxa J.F. Gmelin	MP2-7, MP9-15
Hantzschia amphioxys (Ehrenb.) Grunow	MP1-4, MP6-13, MP15
H. distinctepunctata Hust.	MP9-11, MP13
Nitzschia calida Grunow	MP9, MP14
N. clausii Hantzsch	MP5, MP7, MP9-10, MP15
N. coarctata Grunow	MP2-8, MP10-15
N. dissipata (Kütz.) Grunow	MP1, MP3-15
N. flexa Schum.	MP9
N. graciliformis Lange-Bert. & Simonsen	MP4, MP7, MP11, MP13-14
N. levidensis (W. Sm.) Grunow	MP3-15
N. littoralis Grunow	MP9, MP11-12
N. obtusa var. *scalpelliformis* Grunow	MP9, MP10, MP12
N. palea (Kütz.) W. Sm.	MP1-15
N. reversa W. Sm.	MP4, MP7, MP9-15
N. scalaris (Ehrenb.) W. Sm.	MP7
N. sigma (Kütz.) W. Sm.	MP1, MP4-11, MP15
N. subacicularis Hust.	MP1-2, MP4-15
N. umbonata (Ehrenb.) Lange-Bert.	MP4, MP10-11, MP15
Nitzschia sp. 1	MP1-5
Nitzschia sp. 2	MP1-15
Nitzschia sp. 3	MP2-15
Family Cymbellaceae	
Cymbella affinis Kütz.	MP11
C. cymbiformis C.Agardh	MP7, MP9
C. helvetica Kütz.	MP12
C. tumida (Bérb. in Kütz.) Van Heurck	MP1-12, MP15
C. turgidula Grunow	MP1-15
Cymbella sp.	MP8, MP10, MP13

List of species	sites
Encyoopsis leei var. *leei* Lange-Bert.	MP2
E. leei var. *sinensis* Metzeltin & Krammer	MP2-3, MP6, MP8
Family Epithemiaceae	
Epithemia adnata (Kütz.) Bérb.	MP11
Family Surirellaceae	
Cymatopleura solea (Bérb.) W. Sm.	MP2-3
Surirella angusta Kütz.	MP1, MP3
S. biseriata Bérb.	MP5
S. elegans Ehrenb.	MP10
S. roba Leclercq	MP1-9, MP11-12
S. rudis Hust.	MP2
S. splendida Kütz.	MP1-5, MP11-12, MP14
S. terricola Lange-Bert. & Alles	MP5

Table 4. Water quality and dominant benthic diatom species in each sampling site in Ping River during December 2004-December 2005.

Sampling sites	Season	Water quality	Dominant benthic diatom species
MP1	CD1	clean-moderate	*Achnanthes minutissima*
	SM1	moderate	*Gomphonema* sp.
	SM2	clean	*Cymbella tumida*
	RS1	clean	*Gomphonema parvulum*
	RS2	clean-moderate	*Gomphonema* sp.
	CD2	clean	*Navicula* sp. 1
MP2	CD1	moderate	*Achnanthes minutissima*
	SM1	moderate	*Cocconeis placentula*
	SM2	clean-moderate	*Cymbella turgidula*
	RS1	clean-moderate	*Cymbella turgidula*
	RS2	clean-moderate	*Cymbella turgidula*
	CD2	moderate	*Achnanthes minutissima*
MP3	CD1	moderate	*Synedra ulna var. aequalis*
	SM1	moderate	*Synedra ulna var. aequalis*
	SM2	clean-moderate	*Synedra ulna*
	RS1	clean-moderate	*Gomphonema lagenula*
	RS2	clean-moderate	*Navicula* sp. 2
	CD2	clean-moderate	*Gyrosigma spencerii*
MP4	CD1	moderate	*Nitzschia palea*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia* sp. 1
	RS1	moderate	*Nitzschia palea*
	RS2	moderate	*Nitzschia* sp. 2
	CD2	moderate	*Navicula viridula*
MP5	CD1	moderate	*Nitzschia palea*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	moderate	*Nitzschia palea*
	RS2	moderate	*Nitzschia palea*
	CD2	moderate	*Nitzschia palea*

Sampling sites	Season	Water quality	Dominant benthic diatom species
MP6	CD1	moderate	*Nitzschia palea*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	moderate	*Nitzschia palea*
	RS2	moderate	*Luticola goeppertiana*
	CD2	clean-moderate	*Navicula symmetrica*
MP7	CD1	moderate	*Nitzschia* sp. 2
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	moderate	*Gomphonema lagenula*
	RS2	moderate	*Nitzschia* sp. 3
	CD2	clean-moderate	*Gomphonema lagenula*
MP8	CD1	moderate	*Nitzschia palea*
	SM1	clean-moderate	*Gomphonema lagenula*
	SM2	moderate	less amount and unidentified
	RS1	moderate	*Sellaphora pupula*
	RS2	moderate	less amount and unidentified
MP9	CD2	clean-moderate	*Cymbella turgidula*
	CD1	clean-moderate	*Achnanthes minutissima*
	SM1	clean-moderate	*Achnanthes minutissima*
	SM2	clean-moderate	*Achnanthes minutissima*
	RS1	clean-moderate	*Achnanthes minutissima*
	RS2	moderate	*Diadesmis contenta*
MP10	CD2	clean-moderate	*Navicula symmetrica,*
	CD1	clean-moderate	*Achnanthes minutissima*
	SM1	moderate	*Nitzschia* sp. 2
	SM2	moderate	*Cymbella turgidula*
	RS1	clean-moderate	*Achnanthes minutissima*
	RS2	moderate	*Achnanthes minutissima*
MP11	CD2	clean-moderate	*Nitzschia* sp. 2
	CD1	moderate	*Achnanthes minutissima*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	moderate	*Achnanthes minutissima*
	RS2	moderate	*Nitzschia* sp. 2
MP12	CD2	moderate	*Cyclotella stelligera*
	CD1	moderate	*Achnanthes minutissima*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	moderate	*Achnanthes minutissima*
	RS2	moderate	*Diadesmis contenta*
MP13	CD2	moderate	*Nitzschia palea*
	CD1	moderate	*Achnanthes minutissima*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	clean-moderate	*Cyclotella stelligera*
	RS2	moderate	*Nitzschia* sp. 2

Sampling sites	Season	Water quality	Dominant benthic diatom species
MP14	CD2	moderate	*Nitzschia palea*
	CD1	moderate	*Achnanthes minutissima*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	clean-moderate	*Nitzschia palea*
	RS2	moderate	*Nitzschia* sp. 2
	CD2	moderate	*Nitzschia palea*
MP15	CD1	moderate	*Achnanthes minutissima*
	SM1	moderate	*Nitzschia palea*
	SM2	moderate	*Nitzschia palea*
	RS1	clean-moderate	*Nitzschia palea*
	RS2	moderate	*Nitzschia palea*
	CD2	moderate	*Nitzschia palea*

CD1= cool dry season 1, SM1=summer 1, SM2=summer 2,
RS=rainy season 1, RS2=rainy season 2, CD2=cool dry season 2

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