



Diatoms in Liyu Lake, Eastern Taiwan

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ABSTRACT: This study described the diatoms appeared in the sediments of Liyu Lake, a lowland natural lake situated at Hualen, eastern Taiwan. A total of 50 species was found in the sediments of this eutrophic lake. In them, 8 species were reported for the first time in Taiwan. They are: *Cymbella thienemannii*, *Navicula absoluta*, *Navicula bacillum*, *Frustulia rhomboides* var. *crassinervia*, *Gyrosigma procerum*, *Nitzschia paleacea*, *Epithemia smithii* and *Eunotia subarcuatioides*. The ultrastructures of each species were described on the basis of observations under a scanning electron microscope. The ecological implications of the occurrence of these diatom species in this lake were inferred.

KEY WORDS: Diatoms, Liyu Lake, lacustrine sediment, inland lake, Taiwan.

INTRODUCTION

Diatoms are one of algal groups with siliceous shell and thus can be preserved for a long time in the sediments of the aquatic environment. Usually, they are sensitive to changes in water quality and thus have been commonly used for the studies of lake environment and palaeolimnology (Wu et al., 1997; Chen and Wu, 1999; Wu, 1999; Wu and Kow, 2002; Wu and Chou, 2003; Chen et al., 2009). For this purpose, the information about floristic data of diatoms at the studied site should be established first.

In Taiwan, very few about the diatom flora in the natural lake has been reported in the past, except that for the Mystery Lake, a mountainous oligotrophic lake (Wu and Wang, 2002; Wang and Wu, 2005; Wu and Wang, 2009). In that lake, there were 76 diatom species in its sediments.

Liyu Lake (23°55'N, 121°30'E) is a lowland natural lake situated in a valley between Liyu Mountain and the Central Ridge of eastern Taiwan. It covers an area of ca. 106 hectares, with a maximum depth ca. 10 m. This lake is currently in eutrophic state due to input of nutrient-rich runoff from the forest and household discharges from the residents populated in the vicinity of this lake. However, this lake is unique for the study of paleolimnological environment, because its sediments have virtually undisturbed. In this study, we investigated first the diatom species preserved in lake sediments to provide basic data for further paleolimnological study. For identification, the fine structures of frustules observed under a scanning electron microscope (SEM) were used.

MATERIALS AND METHODS

A 280 cm piston core, LYHL-B was retrieved from the deepest part of Liyu lake in 2005 by the Asian Paleo-Environmental Changes (APEC) group. Sediment core was sub-sampled with an interval of 30 cm in the laboratory. For study, about 1 g of each sample was treated with saturated solution of KMnO₄ for 30 min at 100°C and subsequently with concentrated HCl to remove the organic matter on the frustules (Wang and Wang, 2008). The cleaned diatoms were dropped on an aluminum stub and were dried under room temperature in desiccators. The dried samples were coated with gold by a sputter coater (Hitachi E-1010) and viewed on a FEI Quanta 200 SEM.

RESULTS

Basing on the morphology observed under SEM, a total of 50 species were identified in the whole sediment core studied (Table 1). They belong to the orders of Aulacoseirales, Thalassiosirales, Fragilariales, Achnanthes, Cymbellales, Mastogloiales, Naviculales, Bacillariales, Rhopalodiales, and Eunotiales. The taxonomic designations of the genera were listed in Table 2.

TAXONOMIC TREATMENTS

Class Coscinodiscophyceae
Order Aulacoseirales
Family Aulacoseiraceae
Genus *Aulacoseira* Thwaites, 1848





Table 1. Checklist of diatom species found at the different depths of the sediments of Liyu Lake, Hualien.

Species (trophic indicator)	Depth (cm)	5	35	65	95	125	155	185	215	245	275
<i>Achnanthyrium exiguum</i>		*				*	*	*	*	*	*
<i>Ach. minutissimum</i>		*	*	*	*	*	*	*	*	*	*
<i>Aulacoseira ambigua</i> (e)		*		*							
<i>Aul. granulata</i> (e)		*	*	*	*	*	*	*	*	*	*
<i>Caloneis silicula</i> (m)										*	
<i>Cocconeis placentula</i> (m)				*						*	*
<i>Cyclotella meneghiniana</i> (e)										*	
<i>Cymbella affinis</i> (o-m)				*							
<i>Cym. cymbiformis</i> (o-m)							*	*			*
<i>Cym. hustedtii</i> (o)								*	*	*	*
<i>Cym. thienemannii</i>		*				*	*	*	*		
<i>Cym. tumida</i> (m-e)		*							*	*	*
<i>Discostella stelligera</i>		*	*	*	*	*	*	*	*	*	*
<i>Encyonema gracilis</i> (o)						*	*	*	*		*
<i>Enc. silesiacum</i>		*				*	*	*	*		*
<i>Epithemia adnata</i> (m)							*	*	*	*	*
<i>Epi. smithii</i> (o)						*	*	*	*		
<i>Eun. monodon</i> var. <i>bidens</i> (o)										*	
<i>Eun. pirla</i> (o)						*	*				*
<i>Eunotia subarcuatioides</i> (o)		*								*	
<i>Fragilaria capucina</i> var. <i>vaucheriae</i> (o-m)		*	*	*	*	*	*	*	*	*	*
<i>Fra. tenera</i> (o-m)		*		*		*	*	*	*	*	*
<i>Frustulia rhomboides</i> var. <i>crassinervia</i> (o)									*	*	*
<i>Gomphonema clevei</i> (o)									*		*
<i>Gom. gracile</i> (m)										*	*
<i>Gom. parvulum</i> (m)				*					*	*	*
<i>Gom. truncatum</i> (m)		*				*	*	*	*	*	*
<i>Gom. turris</i> (m-e)										*	
<i>Gyrosigma procerum</i>		*									
<i>Mastogloia elliptica</i> var. <i>dansei</i>											*
<i>Mas. smithii</i> (m)										*	*
<i>Navicula bacillum</i> (m-e)									*		
<i>Nav. cyptotenella</i> (m)				*	*	*	*	*	*	*	*
<i>Nav. minima</i> (e)		*		*		*			*		
<i>Nav. rhynchocephala</i> (e)						*					
<i>Nav. pupula</i> (m)				*				*			*
<i>Nav. absoluta</i>		*				*					*
<i>Neidium affine</i> (m-e)										*	
<i>Nitzschia frustulum</i> (m-e)								*	*	*	
<i>Nitzschia paleacea</i> (m-e)		*	*	*	*		*	*	*	*	*
<i>Pin. gibba</i> (o)									*		
<i>Pin. subcapitata</i> (o)				*							
<i>Pin. microstauron</i> (o)										*	
<i>Planothidium lanceolatum</i>						*	*	*	*	*	*
<i>Pla. lanceolatum</i> spp. <i>rostrata</i>						*			*		*
<i>Pseudostaurosira brevistriata</i>										*	
<i>Punctastriata linearis</i>											*
<i>Rhopalodia gibba</i> var. <i>ventricosa</i> (o)			*			*	*	*	*	*	*
<i>Staurosira construens</i> (m)		*			*	*	*	*	*	*	*
<i>Sta. pinnata</i>										*	*
Total species number		18	6	14	7	20	19	21	27	30	29

*presence of the diatom species. Trophic indicator: o: oligotrophy; m: mesotrophy; e: eutrophy.

Vegetative cells filamentous. Frustule cylinder, connected by the linking spines. Valves circular, thickenings between mantle and girdle. Row of areola obvious in girdle view.

Aulacoseira ambigua (Grunow) Simonsen, 1979. Watanabe et al. (2005), p. 20, pl. I-4, fig. 1-8; Kobayasi et al. (2006), p. 163, 165, pl. 8, 9, fig. 1-16. Fig. 1A

Melosira ambigua (Grunow) O. Müller; *Melosira crenulata* var. *ambigua* Grunow.

Vegetative cells filamentous. Frustule cylinder, connecting by the linking spines. Valves circular with sparse punctuate. Areola irregular ovule on the valve mantle, transverse and oblique. Linking spine short in one valve shoulder.

Dimension: 4-17×5-13 µm in girdle view, areola 14-22 in 10 µm.





Table 2. Summaries of the diatom taxa and their taxonomic positions described in the present article.

Class Coscinodiscophyceae Round <i>et</i> Crawford, 1990	<i>Encyonema</i> Kützinger 1833
Aulacoseirales Crawford 1990	Gomphonemataceae Kützinger 1844
Aulacoseiraceae Crawford 1990	<i>Gomphonema</i> Agardh 1824
<i>Aulacoseira</i> Thwaites 1848	Mastogloiales Mann 1990
Thalassiosirales Glezer <i>et</i> Makarova 1986	Mastogloiaaceae Mereschkowsky 1903
Stephanodiscaceae Ehrenberg 1846	<i>Mastogloia</i> Thwaites <i>ex</i> W. Smith 1856
<i>Cyclotella</i> (Kützinger) Brébisson 1838	Naviculales Bessey 1907
Thalassiosiraceae Lebour 1930	Naviculaceae Kützinger 1844
<i>Discostella</i> Houk <i>et</i> Klee 2004	<i>Navicula</i> Bory de Saint-Vincent 1822
	<i>Caloneis</i> Cleve 1894
Class Fragilariophyceae Round 1990	Amphipleuraceae Grunow 1862
Fragilariales Silva 1962	<i>Frustulia</i> Agardh 1824
Fragilariaceae Greville 1833	Neidiaceae Mereschkowsky 1903
<i>Fragilaria</i> Lyngbye 1819	<i>Neidium</i> Pfitzer 1871
<i>Pseudostaurosira</i> (Grunow) Williams <i>et</i> Round 1987	Pinnulariaceae Mann 1990
<i>Punctastriata</i> Williams <i>et</i> Round 1987	<i>Pinnularia</i> Ehrenberg 1843
<i>Staurosira</i> Ehrenberg 1843	Pleurosigmaaceae Mereschkowsky 1903
	<i>Gyrosigma</i> Hassall 1845
Class Bacillariophyceae Haeckel 1878	Bacillariales Hendey 1937
Achnanthes Silva 1962	Bacillariaceae Ehrenberg 1831
Achnanthesiaceae Mann 1990	<i>Nitzschia</i> Hassall 1845
<i>Achnanthes</i> Kützinger 1844	Rhopalodiales Mann 1990
<i>Planothidium</i> Round <i>et</i> L. Bukhtiyarova 1996	Rhopalodaceae (Karsten) Topachevskiy <i>et</i> Oksiyuk 1960
Cocconeidaceae Kützinger, 1844	<i>Rhopalodia</i> Müller 1895
<i>Cocconeis</i> Ehrenberg 1837	<i>Epithemia</i> Kützinger 1844
Cymbellales Mann 1990	Eunotiales Silva 1962
Cymbellaceae Greville 1833	Eunotiaceae Kützinger 1844
<i>Cymbella</i> Agardh 1830	<i>Eunotia</i> Ehrenberg 1837

Aulacoseira granulata (Ehrenberg) Simonsen, 1979.
Watanabe *et al.* (2005), p. 15, pl. 1-2, fig. 8-12;
Kobayasi *et al.* (2006), p. 169, 171, pl. 11, 12, fig.
1-11. Figs. 1B-D

Melosira granulata (Ehrenberg) Ralfs

Vegetative cells filamentous. Frustule cylinder.
Valves circular with sparse punctuate. Height/valve
diameter <10. Areola rectangular to elliptical on the
valve mantle, longitudinal parallel. Linking spine shorts
in one valve shoulder. Separation valve bearing
irregular long spines.

Dimension: 4-16 × 4.5-20 µm in girdle view, areola
7-12 in 10 µm.

Order Thalassiosirales

Family Stephanodiscaceae

Genus *Cyclotella* (Kützinger) Brébisson, 1838

Valves circular, ornamentation patterns distinctly
different in periphery and in center. Striae radiate in
periphery. Ornamentation pattern in center with strutted
processes, areola or row of areolae. Marginal strutted
process obvious in margin.

Cyclotella meneghiniana Kützinger, 1844. Watanabe *et al.*
(2005), p. 31, pl. 1-9, fig. 1-6; Kobayasi *et al.*
(2006), p. 241, pl. 47, fig. 1-11. Fig. 1E

Cyclotella kuetzingiana Thwaites, 1848; *C. laevis* Van
Goor; *C. meneghiniana* var. *rectangulata* Grunow; *C.*
meneghiniana var. *vogesiaca* Grunow; *C. meneghiniana* var.

binotata Grunow; *C. meneghiniana* var. *laevis* (Van
Goor) Husted; *C. rectangular* Brébisson.

Valves circular. Striae in radiate with spines in the
margin. One projection in the inner hyaline area.

Dimension: 5-43 µm in the diameter, striae 6-10 in
10 µm.

Family Thalassiosiraceae

Genus *Discostella* Houk *et* Klee, 2004

Valves circular, ornamentation patterns distinctly
different in periphery and in center. Striae radiate in
periphery, stellate in center

Discostella stelligera (Ehrenberg) Houk *et* Klee, 2004.
Watanabe *et al.* (2005), p. 34, pl. 1-10, fig. 17-21;
Kobayasi *et al.* (2006), p. 253, pl. 53, fig. 1-14.

Figs. 1F-H

Cyclotella stelligera Cleve *et* Grunow.

Valves circular. Striae marginal radiate about
1/2-1/3 valve radius. Inner striae short, stellate.

Dimension: 6-25.5 µm in the diameter, striae 12-18
in 10 µm.

Class Fragilariophyceae

Order Fragilariales

Family Fragilariaceae

Genus *Pseudostaurosira* (Grunow) Williams *et* Round,
1987

See Wu and Wang (2002), p. 86.



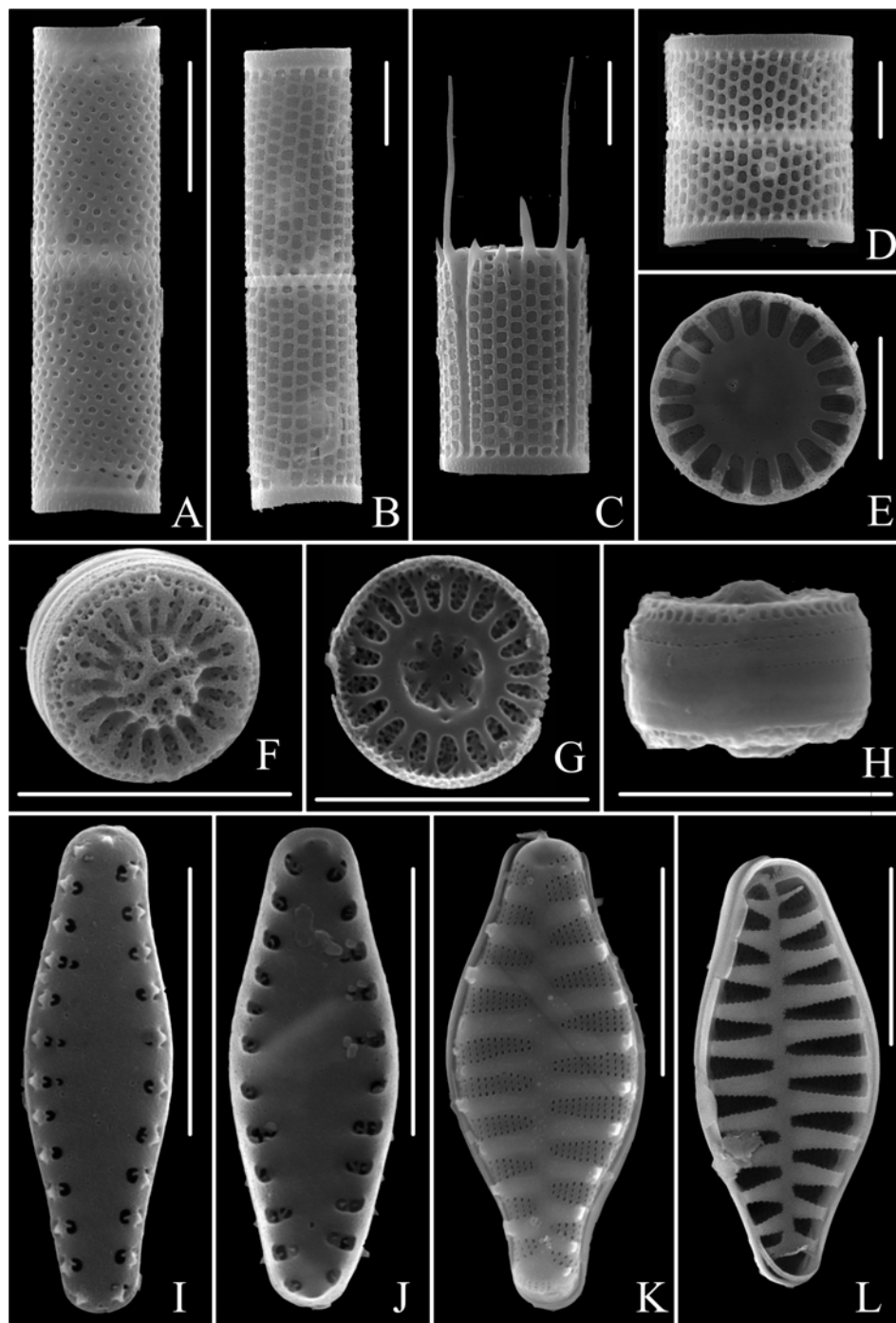


Fig. 1. A: *Aulacoseira ambigua*; B-D: *Aulacoseira granulata*; E: *Cyclotella meneghiniana*; F-H: *Discostella stelligera*; I & J: *Pseudostaurosira brevistriata*; K & L: *Punctastriata linearis*. Bar = 5μm.

Pseudostaurosira brevistriata (Grunow) Williams et Round, 1987. Figs. 1I & J
See Wu and Wang (2002), p. 86.

Genus *Punctastriata* Williams et Round, 1987
See Wu and Wang (2002), p. 86.

Punctastriata linearis Williams et Round, 1987. Figs. 1K & L
See Wu and Wang (2002), p. 88.

Genus *Staurosira* Ehrenberg, 1843
See Wu and Wang (2002), p. 88.



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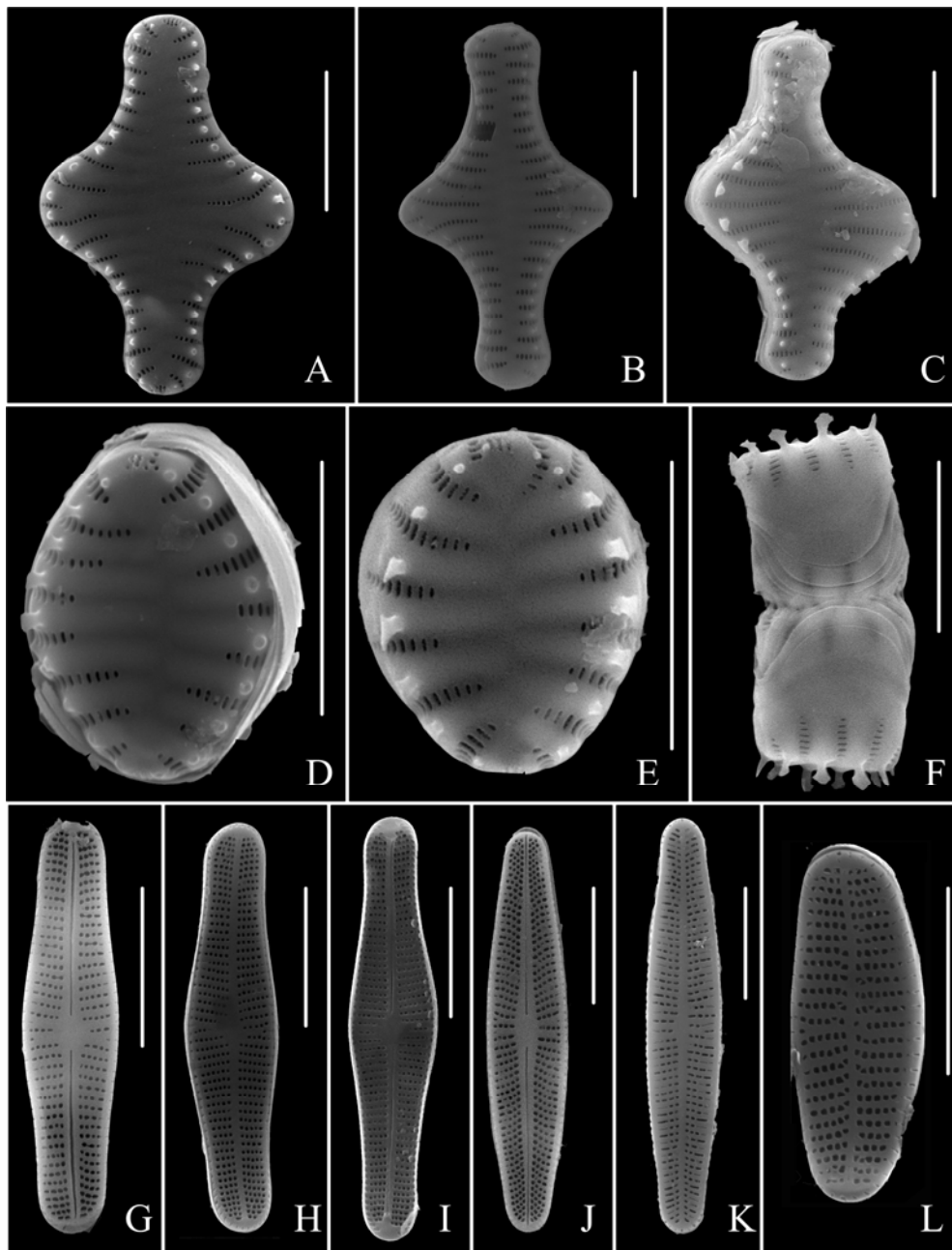


Fig. 2. A-C: *Staurosira construens*; D-F: *Staurosira pinnata*; G-L: *Achnantheidium minutissimum*. Bar = 5 µm.

Staurosira construens Ehrenberg, 1843. Figs. 2A-C
See Wu and Wang (2002), p. 88.

Staurosira pinnata (Ehrenberg) D.M. Williams &
Round, 1987. Kobayasi et al. (2006), p. 343, pl. 98,
fig. 1-14. Figs. 2D-F

Fragilaria pinnata Ehrenberg.

Valves elliptic, or lanceolate, expanded in the
central proportion, valves surface ribbed, ends broadly

round. Axial area narrow. Striae uniseriately punctuate,
slightly radiate. Linking spines situated interstriately on
the valve shoulder, branched in the end.

Dimension: 3-6 × 5-17 µm, striae 10-12 in 10 µm.

Class Bacillariophyceae

Order Achnanthes

Family Achnanthidiaceae

Genus *Achnantheidium* Kützing, 1844

See Wu and Wang (2002), p. 77.



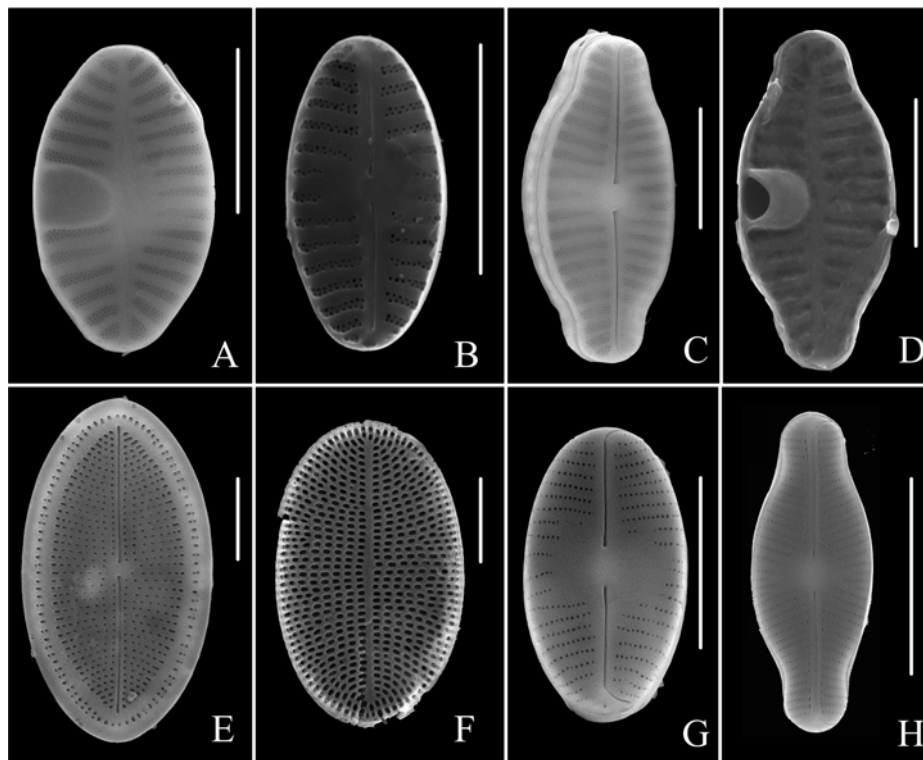


Fig. 3. A & B: *Planothidium lanceolatum*; C & D: *Planothidium lanceolatum* ssp. *rostrata*; E & F: *Cocconeis placentula*; G: *Navicula minima*; H: *Navicula absoluta*. Bar= 5 μ m.

Achnanthisdium minutissimum (Kützing) Czarnecki, 1994. Figs. 2G-L
See Wu and Wang (2002), p. 79.

Genus *Planothidium* Round et Bukhtiyarova, 1996

Valves elliptic, elliptic-lanceolate or lanceolate. Raphe valve: axial area narrow, linear. Central area rectangular or "butterfly"-shaped. Striae radiate. Pseudoraphe interrupted horseshoe-shaped thickening on one side. Striae multiserially punctuate, slightly radiate or parallel in the center.

Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot, 1999. Watanabe et al. (2005), p. 202, pl. IIB₂-8, fig. 12-21; Kobayasi et al. (2006), p. 481, pl. 167, fig. 1-14. Figs. 3A & B

Achnanthisdium lanceolatum Brébisson ex Kützing;
Achnanthes lanceolatum (Brébisson ex Kützing) Grunow.

Valves lanceolate, ends broadly round. Raphe valve: axial area narrow and linear; slightly widened towards the center of the valve. Central area wild, rectangular. Raphe filiform; proximal ends closed, rounded; distal ends hooking in the same direction. Striae multiserially punctate, slightly radiate or parallel. Pseudoraphe valve interrupted centrally on one

side by a horseshoe-shaped clear area. Striae multiserially punctate, almost parallel at the center, slightly radiate throughout the other part of the valve.

Dimension: 4.5-8 $\times$ 12-31 μ m, striae 11-14 in 10 μ m.

Planothidium lanceolatum ssp. *rostrata* (Østrup) Lange-Bertalot, 1991. Watanabe et al. (2005), p. 205, pl. IIB₂-9, fig. 9-20. Figs. 3C & D

Achnanthes rostrata Østrup; *A. piafica* Carter; *Planothidium rostratum* (Østrup) Round et Bukhtiyarova.

Valves wide lanceolate, ends subcapitate. Raphe valve: axial area narrow and linear; slightly widened towards the center of the valve. Central area wild, rectangular. Raphe filiform; proximal ends closed, rounded; distal ends hooking in the same direction. Striae multiserially punctate, slightly radiate or parallel. Pseudoraphe valve: interrupted centrally on one side by a horseshoe-shaped clear area. Striae multiserially punctate, almost parallel at the center, slightly radiate throughout the other part of the valve.

Dimension: 4-7 $\times$ 7-16 μ m, striae 11-14 in 10 μ m.

Family Cocconeidaceae

Genus *Cocconeis* Ehrenberg, 1837

See Wu and Wang (2002), p. 81.



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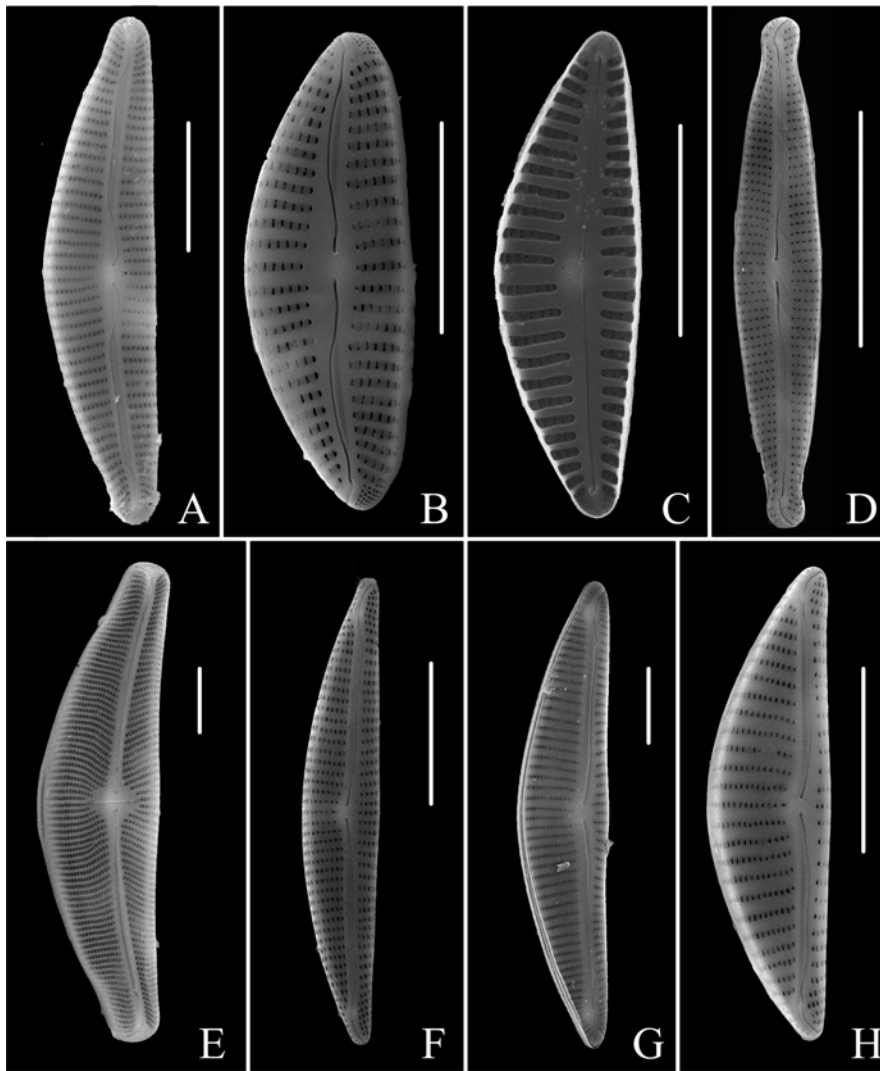


Fig. 4. A: *Cymbella affinis*; B & C: *Cymbella hustedtii*; D: *Cymbella thienemannii*; E: *Cymbella tumida*; F & G: *Encyonema gracilis*; H: *Encyonema silesiacum*. Bar = 10 μ m.

Cocconeis placentula Ehrenberg, 1838. Figs. 3E & F
See Wu and Wang (2002), p. 81.

Order Cymbellales

Family Cymbellaceae

Genus *Cymbella* Agardh 1830

See Wang and Wu (2005), p. 41.

Cymbella affinis Kützing, 1844. Watanabe et al. (2005), p. 432, pl. IIB₃-70, fig. 1-6. Fig. 4A

Cymbella excise Kützing; *Cocconema parvum* W. Smith;
Cymbella parva (W. Smith) Kirchner.

Valves lanceolate-lunate, dorsal margin convex, ventral margin slightly concave to straight, ends cuneate. Axial area arched, narrowing towards the ends.

Raphe arched; obviously sinuous towards the ventral margins in the center and the ends. Central area inconspicuous with one stigma in ventral. Striae uniseriately punctate, slightly radiate, radiate near the ends.

Dimension: 7-16 $\times$ 20-70 μ m, striae 7-12 in 10 μ m.

Cymbella hustedtii Krasske, 1923. Figs. 4B & C
See Wang and Wu (2005), p. 42.

Cymbella thienemannii Hustedt, 1938. Watanabe et al. (2005), p. 430, pl. IIB₃-69, fig. 25-34. Fig. 4D

Encyonopsis thienemannii (Hustedt) Krammer.

Valves lanceolate-lunate, ends capitate. Axial area narrow. Raphe filiform, proximal ends expanded.



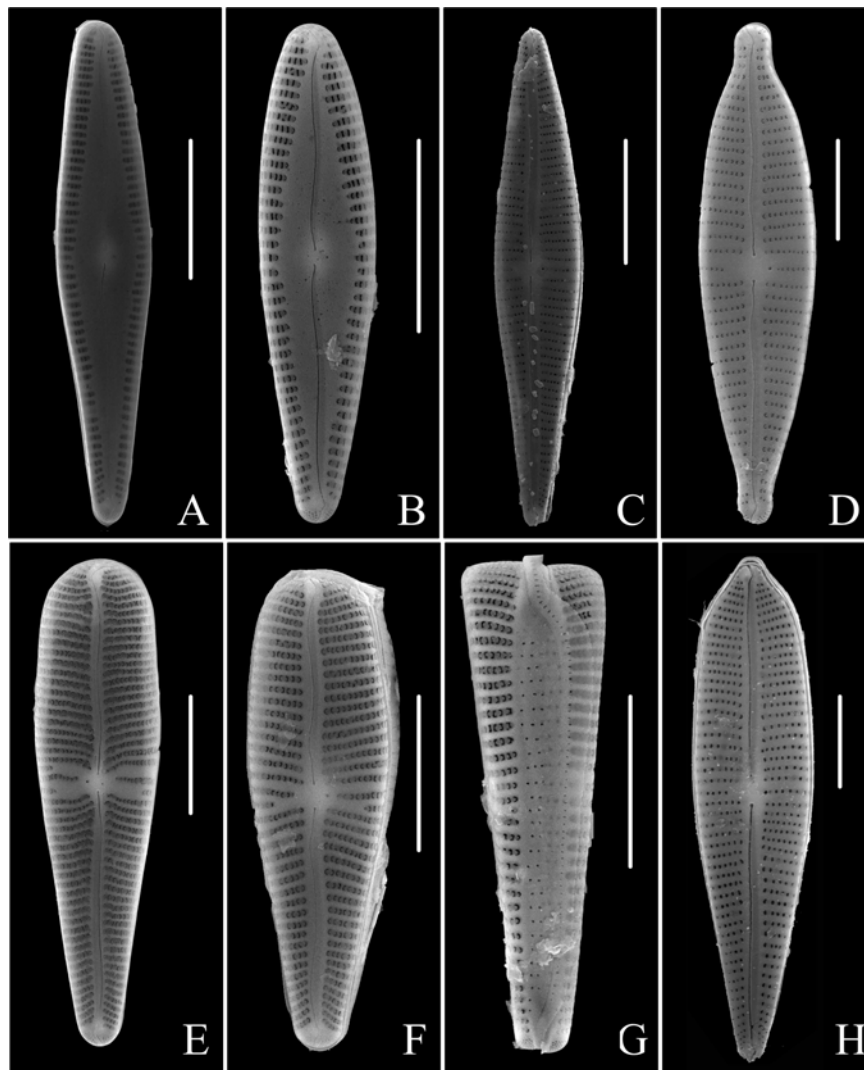


Fig. 5. A & B: *Gomphonema clevei*; C: *Gomphonema gracile*; D: *Gomphonema parvulum*; E-G: *Gomphonema truncatum*; H: *Gomphonema turris*. Bar = 10 μ m.

Central area inconspicuous. Striae uniseriately punctate, slightly radiate to parallel.

Dimension: 3-4.5 $\times$ 15-24 μ m, striae 22-25 in 10 μ m.

Cymbella tumida (Brébisson) van Heurck, 1880. Fig. 4E
See Wang and Wu (2005), p. 44.

Genus *Encyonema* Kützinger, 1833
See Wang and Wu (2005), p. 44.

Encyonema gracilis Ehrenberg, 1841. Figs. 4F & G
See Wang and Wu (2005), p. 44.

Encyonema silesiacum Mann, 1990. Fig. 4H
See Wang and Wu (2005), p. 45.

Family Gomphonemataceae
Genus *Gomphonema* Agardh, 1824
See Wang and Wu (2005), p. 45.

Gomphonema clevei Fricke, 1902. Figs. 5A & B
See Wang and Wu (2005), p. 48.

Gomphonema gracile Ehrenberg, 1838. Fig. 5C
See Wang and Wu (2005), p. 48.

Gomphonema parvulum (Kützinger) Kützinger, 1849. Fig. 5D
See Wang and Wu (2005), p. 50.

Gomphonema truncatum Ehrenberg, 1832. Figs. 5E-G
See Wang and Wu, 2005, p. 50.



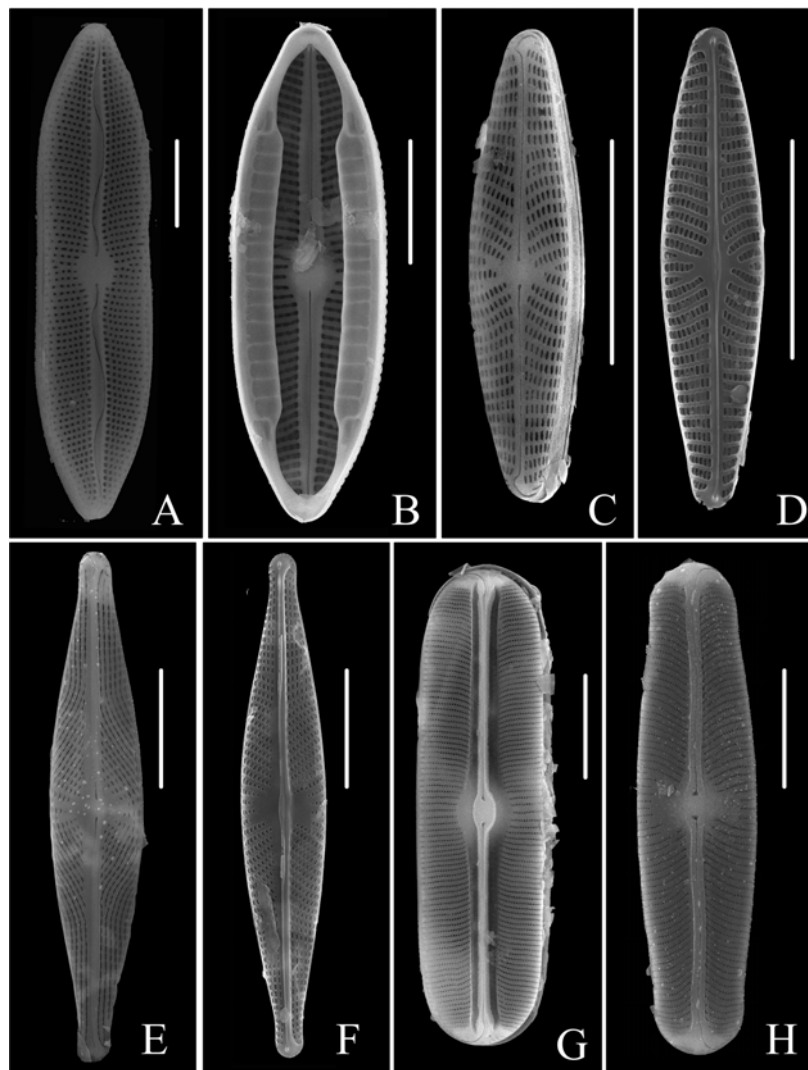


Fig. 6. A: *Mastogloia elliptica* var. *dansei*; B: *Mastogloia smithii*; C & D: *Navicula cryptotenella*; E & F: *Navicula rhynchocephala*; G: *Navicula bacillum*; H: *Navicula pupula*. Bar = 10 μ m.

Gomphonema turris Ehrenberg, 1843. Watanabe et al. (2005), p. 501, pl. IIB₃-93, figs. 1 & 2. Fig. 5H

Gomphonema augur var. *turris* (Ehrenberg) Lange-Bertalot.

Valves clavate, tapering with concave margins towards acutely rounded foot pole, with cuneate head pole. Axial area narrow. Raphe straight, proximal end round, distal ends hooked in the same direction. Central area elliptical, stigma unilateral, one shortened striae in opposite median. Striae uniseriately punctate, radiate.

Dimension: 13-18 $\times$ 50-100 μ m, striae 7-10 in 10 μ m.

Order Mastogloiales

Family Mastogloiaceae

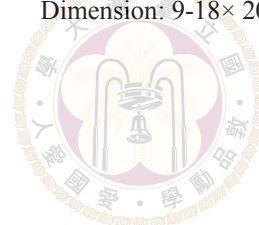
Genus *Mastogloia* Thwaites ex W. Smith, 1856

Valves linear-lanceolate to elliptical, ends slightly protracted, bluntly rounded. Raphe fissure undulate. Striae uniseriately punctate, radiate.

Mastogloia elliptica var. *dansei* (Twaites) Cleve, 1896. Krammer & Lange-Bertalot, 1986, p. 849, pl. 202, figs. 1 & 2. Fig. 6A

Valves narrow elliptic, ends cuneate. Axial area widening toward mid-valve. Raphe fissure strongly undulate, proximal ends close, distal ends curved in the same direction. Outer raphe fissure in the centre strongly turned outwards. Central area ovoid to elliptical. Pastectal rings rectangular in latterly margin. Striae uniseriately punctate, radiate.

Dimension: 9-18 $\times$ 20-80 μ m, striae 15-18 in 10 μ m.





Mastogloia smithii Thwaites, 1856. Watanabe et al. (2005), p. 227, pl. IIB₃-1, fig. 14-17. Fig. 6B

Valves narrow elliptic, ends cuneate. Axial area widening toward mid-valve. Raphe filiform, at most with the centre of the raphe somewhat curved. Central area ovoid to elliptical. Pastectal rings rectangular in latterly margin. Striae uniseriately punctate, radiate.

Dimension: 8-14 × 20-45 µm, striae 18-20 in 10 µm.

Order Naviculales

Family Naviculaceae

Genus *Navicula* Bory de Saint-Vincent, 1822

See Wu and Wang (2009), p. 231.

Navicula absoluta Hustedt, 1950. Watanabe et al. (2005), p. 307, pl. IIB₃-26, fig. 14-17. Fig. 3H

Navicula hustedtii var. *obtus* Hustedt; *N. hustedtii* f. *obtus*.

Valves lanceolate, ends rostrate. Axial area narrow. Raphe filiform, proximal ends expanded, distal ends hooking in the same direction. Central area small, ovoid to elliptical formed by 4-6 shortening median striae. Striae uniseriately punctate, radiate.

Dimension: 4-6 × 10-20 µm, striae 18-24 in 10 µm.

Navicula bacillum Ehrenberg, 1843. Watanabe et al. (2005), p. 300, pl. IIB₃-24, fig. 1-5. Fig. 6G

Valves lanceolate to narrow lanceolate, ends broadly round. Axial area linear, slightly widening toward the center. Raphe straight; proximal ends round, distal ends hooking in the same direction. Central area transversely elongated, elliptical. Striae uniseriately punctate, slightly radiate to parallel becoming slightly radiate at ends.

Dimension: 10-20 × 30-90 µm, striae 12-14 in 10 µm.

Navicula cryptotenella (Lange-Bertalot) Krammer et Lange-Bertalot, 1986. Figs. 6C & D

See Wu and Wang (2009), p. 232.

Navicula minima Grunow, 1986. Fig. 3K

See Wu and Wang (2009), p. 232.

Navicula rhynchocephala Kützinger, 1844. Watanabe et al. (2005), p. 345, pl. IIB₃-40, fig. 5, 6. Figs. 6E & F

Navicula rhynchocephala var. *constricta* Hustedt.

Valves lanceolate, ends cuneate. Axial area narrow, widening toward the center. Raphe straight, proximal ends rounded, close, distal ends hooking in the same direction. Central area transversely elongated, elliptical. Striae uniseriately punctate, strongly radiate.

Dimension: 8.5-10 × 40-60 µm, striae 9-12 in 10 µm.

Navicula pupula Kützinger, 1844. Watanabe et al. (2005), p. 303, pl. IIB₃-25, fig. 1-10. Fig. 6H

Valves narrow elliptic, ends broadly round. Axial area linear, slight widening toward the center. Raphe somewhat undulate in median, proximal ends rounded, distal ends hooking in the same direction. Central area transverse elongated, rectangular or "bow-tie" spaced hyaline area. Striae uniseriately punctate, strongly radiate becoming slightly radiate at ends.

Dimension: 7-11 × 13-17 µm, striae 9-12 in 10 µm.

Genus *Caloneis* Cleve, 1894

Valves linear to broadly lanceolate, ends cuneate, rounded, rostrate to sub-capitate. Axial area broad, slightly asymmetrical and transversally elongated in the center. Raphe straight, distal ends hooked in the same direction. Striae multiseriate, chambered.

Caloneis bacillum (Grunow) Cleve, 1894. Watanabe et al. (2005), p. 241, pl. IIB₃-5, figs. 2-7. Fig. 7A

Stauroneis bacillum Grunow; *Navicula fasciata* Lagerstedt; *Caloneis fasciata* (Lagerstedt) Cleve.

Valves narrow elliptic to narrow lanceolate, slightly swollen or biconstricted in the center, ends cuneate, broadly round or rostrate. Axial area narrow in the ends, slightly widening toward the central area. Raphe proximal ends expanded, rounded; distal ends curved in the same direction. Central area transversally elongated. Striae multiseriate, chambered, each chamber containing many rows of small rounded poroids, striae parallel.

Dimension: 4-9 × 15-48 µm, striae 20-30 in 10 µm.

Family Amphipleuraceae

Genus *Frustulia* Agardh, 1824

Valves rhomboidal to linear-lanceolate, ends bluntly rounded to subcapitate. Axial area linear. Raphe filiform, containing in a median rib extending throughout the valve. Striae areolate.

Frustulia rhomboides* var. *crassinervia (Brébisson ex W. Smith) Ross, 1947. Watanabe et al. (2005), p. 231, pl. IIB₃-2, figs. 7-10. Fig. 7B

Navicula crassinervia Brébisson ex W. Smith; *Vanheurckia crassinervia* (Brébisson ex W. Smith) Brébisson; *V. rhomboides* var. *crassinervia* (Brébisson) Van Heurck.

Valves lanceolate, ends capitate. Axial area linear. Raphe filiform. Striae areolate, transverse and longitudinal.



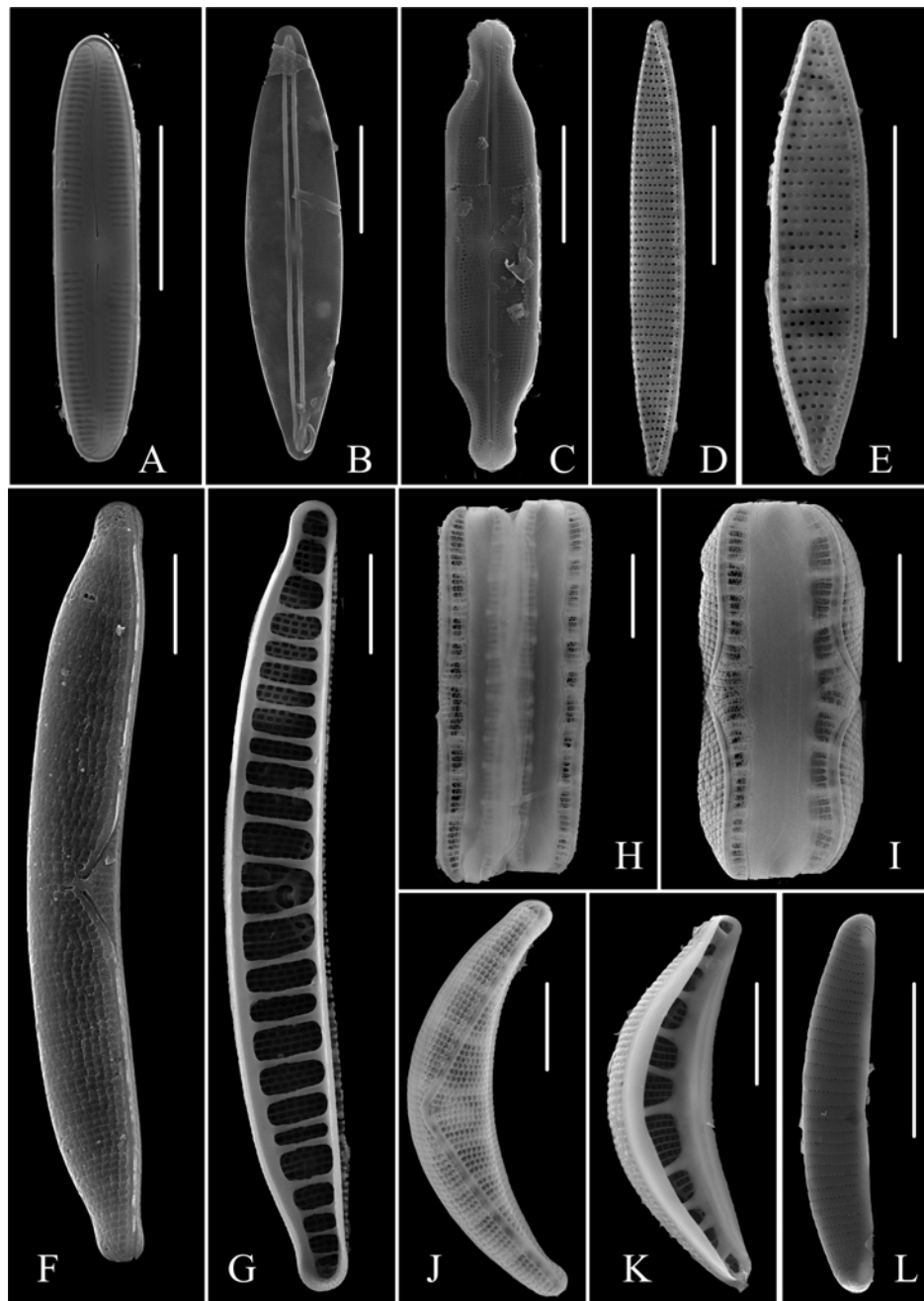


Fig. 7. A: *Caloneis bacillum*; B: *Frustulia rhomboides* var. *crassinervia*; C: *Neidium affine*; D: *Nitzschia frustulum*; E: *Nitzschia paleacea*; F-H: *Epithemia adnata*; I-K: *Epithemia smithii*; L: *Eunotia subarcuatioides*. Bar = 10 μ m.

Dimension: 10-15 $\times$ 30-50 μ m, striae 36-42 in 10 μ m.

Family Neidiaceae

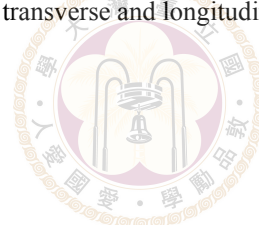
Genus *Neidium* Pfitzer, 1871

Valves linear to lanceolate, ends bluntly rounded, subrostrate or rostrate. Axial area narrow. Raphe straight, proximal ends forked. Striae areolate.

Neidium affine (Gregory) Cleve, 1894. Rewrite. Krammer & Lange-Bertalot, 1986, p. 655, pl. 106, figs. 8-10.

Fig. 7C

Valves lanceolate, ends rostrate. Axial area linear. Raphe straight, proximal ends hooking in the opposite directions, expanded, close, distal ends forked. Central area transverse elongated, elliptical. Striae areolate, transverse and longitudinal.



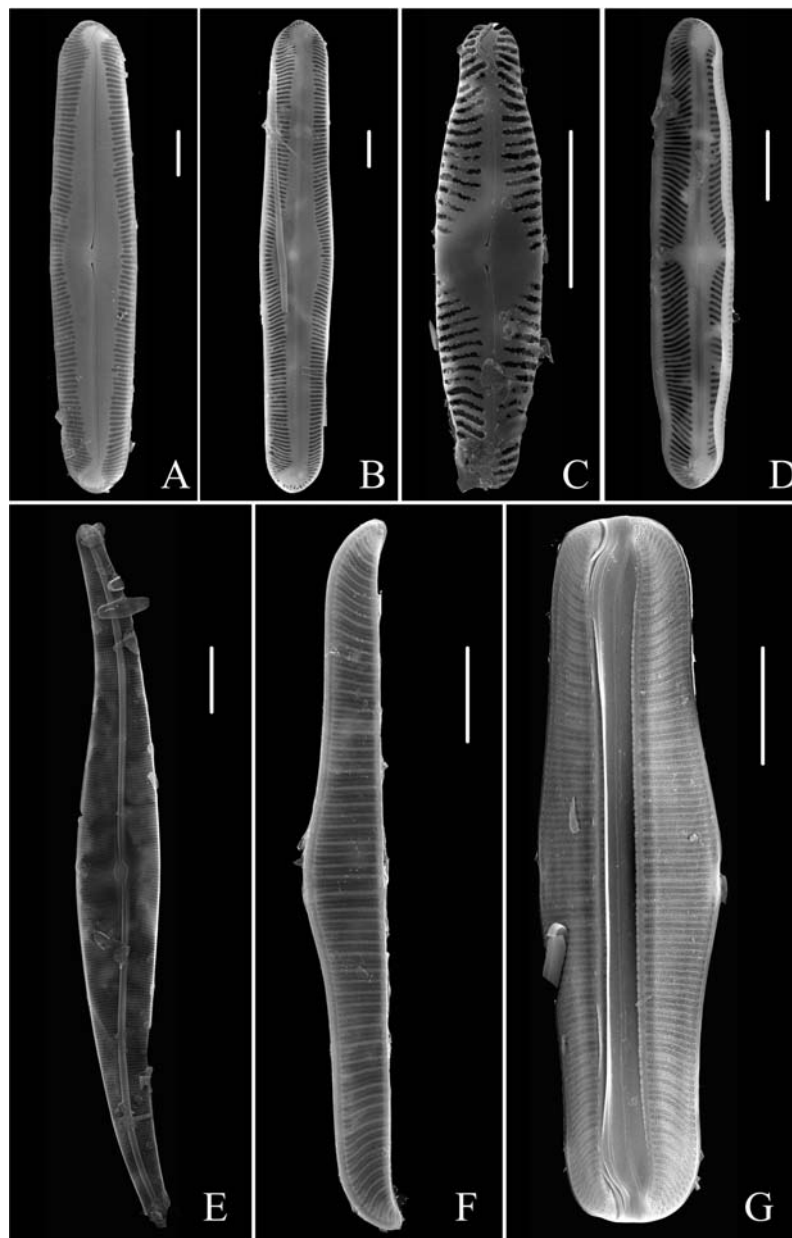


Fig. 8. A & B: *Pinnularia gibba*; C & D: *Pinnularia microstauron*; E: *Gyrosigma procerum*; F & G: *Rhopalodia gibba* var. *ventricosa*. Bar = 10 μ m.

Dimension: 6-17 $\times$ 20-80 μ m, striae 20-29 in 10 μ m.

Family Pinnulariaceae

Genus *Pinnularia* Ehrenberg, 1843

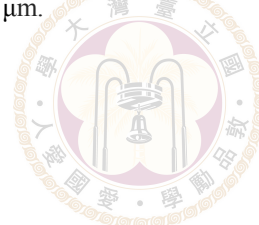
See Wu and Wang (2009), p. 232.

Pinnularia gibba Ehrenberg, 1843. Watanabe et al. (2005), p. 391, pl. IIB₃-56, figs. 1-3. Figs. 8A & B

Stauroptera gibba Ehrenberg; *Navicula stauroptera* Grunow; *N. abaujensis* Pantocsek.

Valves lanceolate, ends broadly round. Axial area broad, 1/2-2/3 valve width, widening toward the center. Raphe straight, proximal ends slightly curved in the same directions, rounded, rather close, distal ends hooking in the same direction. Central area transverse elongated, rhomboid, reaching the margin. Striae multiserially, chambered, strongly striae radiate at the center of the valve, convergent towards the ends.

Dimension: 10-13.5 $\times$ 60-110 μ m, striae 8-11 in 10 μ m.



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Pinnularia microstauron (Ehrenberg) Cleve, 1891.
Watanabe et al. (2005), p. 378, pl. IIB₃-50, fig. 1-5.
Figs. 8C & D

Pinnularia microstauron morphotype 1 sensu Krammer.

Valves lanceolate, ends rostrate or capitate. Axial area narrow. Raphe straight, proximal ends, rounded, rather close, distal ends hooking in the same direction. Central area transverse elongated, rhomboid, reaching the margin. Striae multiserially, chambered, striae parallel or somewhat radiate at the center of the valve, slightly convergent towards the ends.

Dimension: 7-13 × 30-100 µm, striae 9-11 in 10 µm.

Family Pleurosigmataceae

Genus *Gyrosigma* Hassall, 1845

Valves sigmoid, ends cuneate. Axial area narrow. Raphe sigmoid, proximal fissures hooking in opposite directions. Striae areolate, transverse and longitudinal.

Gyrosigma procerum Hustedt, 1956. Watanabe et al. (2005), p. 237, pl. IIB₃-4, fig. 1-3. Fig. 8E

Valves lanceolate- sigmoid, ends cuneate. Axial area narrow. Raphe sigmoid; proximal fissures strongly sinuous towards the opposite direction, proximal end expended, distal ends hooked in the opposite directions. Central area ovoid to longitudinally elliptical. Striae areolate, transverse and longitudinal.

Dimension: 13-18 × 70-130 µm, striae 19-21 in 10 µm.

Order Bacillariales

Family Bacillariaceae

Genus *Nitzschia* Hassall, 1845

See Wu and Wang (2009), p. 236.

Nitzschia frustulum (Kützinger) Grunow, 1880. Fig. 7D
See Wu and Wang (2009), p. 236.

Nitzschia paleacea (Grunow) Grunow, 1827. Watanabe et al. (2005), p. 590, pl. IIB₄-23, fig. 33; Krammer & Lange-Bertalot, 1988, p. 379, pl. 81, fig. 1-7.

Fig. 7E

Valves linear-lanceolate, ends produced apiculate. Keel puncta distinct. Striate uniseriately punctate, parallel.

Dimension: 1.5-4 × 8-55 µm, striae 27-32 in 10 µm, keel puncta 12-16 in 10 µm.

Order Rhopalodales

Family Rhopalodaceae

Genus *Rhopalodia* Müller, 1895

Valves lunate; dorsal margin strongly convex; ventral margin straight, ends produced apiculate, dorsally deflected. Raphe on the keel marginal. Striae trellisoid, chambered.

Rhopalodia gibba* var. *ventricosa (Kützinger) H. Peragallo et M. Peragallo, 1900. Watanabe et al. (2005), p. 535, pl. IIB₄-6, fig. 4. Figs. 8F & G

Epithemia ventricosa Kützinger; *E. gibba* var. *ventricosa* (Kützinger) Grunow; *Rhopalodia ventricosa* (Kützinger) O. Müller.

Valves lunate; dorsal margin strongly convex; ventral margin straight, ends produced apiculate, dorsally deflected. Raphe on the keel marginal, proximal ends hooked in the same direction. Striae trellisoid, chambered, each chamber containing many rows of small rounded poroids, striae parallel at the center of the valve, convergent towards the ends. Costa 5-8 in 10 µm.

Dimension: 7-10 × 25-100 µm, striae 11-14 in 10 µm.

Genus *Epithemia* Kützinger, 1844

See Wu and Wang (2002), p. 84.

Epithemia adnata (Kützinger) Brébisson, 1838. Figs. 7F-H
See Wu and Wang (2002), p. 84.

Epithemia smithii Carruthers, 1864. Watanabe et al. (2005), p. 526, pl. IIB₄-2, fig. 3; Krammer & Lange-Bertalot, 1988, p. 427, pl. 105, fig. 1-6.

Figs. 7I-K

Valves lunate; dorsal margin strongly convex; ventral margin straight, ends produced apiculate, dorsally deflected. Raphe strongly curved, central raphe ending closed to the dorsal margin. Septa not obvious. Alveoli radiated arrangement. Costa 2-4 in 10 µm.

Dimension: 9-18 × 30-73 µm, striae 8 in 10 µm.

Order Eunotiales

Family Eunotiaceae

Genus *Eunotia* Ehrenberg, 1837

Eunotia subarcuatioides Nörpel & Lange-Bertalot, 1991. Krammer & Lange-Bertalot, 1991, p. 537, pl. 138, fig. 1-9. Fig. 7L

Valves Lunate, ends capitate or produced rostrate. Ventral margins straight; dorsal margins convex. Striate parallel.

Dimension: 2.7-4.5 × 6-35 µm, striae 18-23 in 10 µm.





Changes of species throughout the sediment core

Throughout the sediment core, the diatom species altered with depth to some degrees. Table 1 showed a checklist of all species appeared in each sample. Of the diatom species found, there were some common species that appeared at the most of samples. They were: *Achnanthydium minutissimum*, *Aulacoseira granulata*, *Discostella stelligera*, *Fragilaria capucina* var. *vaucheriae*, *Frag. tenera*, *Navicula cryptotenella*, *Nitzschia amphibia* and *Staurosira construens*. In contrast to these, species of genera *Eunotia* and *Pinnularia* only appeared in one or two samples and were of rare species.

Some of species appeared in the lake sediments were of the indicator for oligotrophic status, such as species of genera *Encyonema*, *Eunotia*, *Frustulia*, *Neidium*, *Pinnularia*, *Rhopalodia*, and some of *Cymbella*, *Gomphonema*, and *Navicula* (Table 1). In contrast, those species of genera *Aulacoseira*, *Cocconeis*, and *Mastogloia* and some of *Gomphonema* and *Navicula* were either meso- or eutrophic indicator.

DISCUSSION

In the studied sediments, the number of diatom species at a given depth fluctuates to certain degrees throughout the core (cf. Table 1). However, it exhibits a tendency that there is higher species number in deeper segments (beneath 120 cm) than upper ones (i.e. above 95 cm). This suggests that the environmental conditions in earlier times are more favorable for maintaining higher diatom diversity than later and that there should have occurred some changes in the limnological environment. In this case, diatom data provide a good indicator which allows the inference of changes in the paleolimnological environment in this lake.

In the present study, there are 18 species which are in common with those found in the Mysterious Lake, and 8 species are new to the checklist recorded by Wang and Chen (2000). Comparing with the Mysterious Lake (cf. Wu and Wang, 2009), the diatom diversity in Liyu Lake is remarkably lower. The former is a mountainous oligotrophic lake located within a natural protection area, the Nan-ao Broadleaf Natural Preserve, and has been very little disturbed. On the contrary, Liyu Lake is an eutrophic lowland lake, being polluted by the household discharges coming from the vicinity of Liyu Lake. Apparently, this agrees well with the fact that the species richness is lower in eutrophic than in oligotrophic environment.

Diatoms can be used to indicate changes in water level in freshwater lakes (Wolin and Duthie, 1999). Some of diatoms found in Liyu Lake are of epiphytic species, such as *Cymbella* spp., *Encyonema* spp.,

Gomphonema spp., *Planothidium lanceolatum* and *Rhopalodia gibba* var. *ventricosa*. They were found mostly in deeper segments (between 125 and 275 cm). Other species, such as *Aulacoseira ambigua*, *Discostella stelligera*, *Pinnularia* spp., and *Neidium affine*, are of euplanktonic ones and are mostly found at the depth above 95 cm. It is assumed that such a difference is related to an alteration in the limnological environment over time, possibly a result of shift from riverine to lacustrine habitat. It is necessary to do a further study in order to ascertain this.

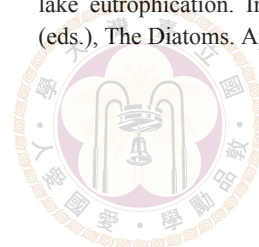
Diatoms are good indicators for lake eutrophication (Hall and Smol, 1999). Individual species of diatoms have specific preference to habitat and requirement for water chemistry (Patrick and Reimer, 1966; Round et al., 1990). In the present study, there appeared more epiphytic and oligotrophic species (such as *Cymbella* spp., *Gomphonema clevei*, *G. gracile* etc.) in deeper segments (i.e. corresponding to older times), while more euplanktonic and meso- or eutrophic species (such as *Achnanthydium pusillum*, *Aulacoseira ambigua* etc.) toward sediment surface. These implicate that the limnological environment should have altered over time. It is likely that there occurred changes in habitat, presumably from the riverine to lacustrine environment, and in trophic state, from oligotrophic to eutrophic one. In order to confirm these, a further study is necessary.

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摘要：本研究記述位於台灣東部低海拔區域的天然湖泊，花蓮鯉魚潭，其湖積物內的矽藻組成。在這優養化湖泊的沉積物內共有 50 種矽藻被紀錄。其中有 8 種是台灣新紀錄種，分別是 *Cymbella thienemannii*, *Navicula absoluta*, *Navicula bacillum*, *Frustulia rhomboides* var. *crassinervia*, *Gyrosigma procerum*, *Nitzschia paleacea* *Epithemia smithii* 與 *Eunotia subarcuatioides*。基於掃描式電子顯微鏡的觀察，我們描述了每一個種類的超微結構，並推論在本湖泊內矽藻種類其存在的生態意涵。

關鍵詞：矽藻、花蓮鯉魚潭、內陸湖、湖積物、臺灣。

