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 $KMnO_4$ 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, Achnanthales, 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
Achnanthidium exiguum	*				*	*	*	*	*	*
Ach. minutissimum	*	*	*	*	*	*	*	*	*	*
Aulacoseira ambigua (e)	*		*							
Aul. granulata (e)	*	*	*	*	*	*	*	*	*	*
Caloneis silicula (m)									*	
Cocconeis placentula (m)			*						*	*
Cyclotella meneghiniana (e)									*	
Cymbella affinis (o-m)			*							
Cym. cymbiformis (o-m)						*	*			*
Cym. hustedtii (o)							*	*	*	*
Cym. thienemannii	*				*	*	*	*		
Cym. tumida (m-e)	*							*	*	*
Discostella stelligera	*	*	*	*	*	*	*	*	*	
Encyonema gracilis (o)					*	*	*	*		*
Enc. silesiacum	*				*	*	*	*		*
Epithemia adnata (m)						*	*	*	*	*
Epi. smithii (o)					*	*	*	*		
Eun. monodon var. *bidens* (o)									*	
Eun. pirla (o)					*	*				*
Eunotia subarcuatioides (o)	*								*	
Fragilaria capucina var. *vaucheriae* (o-m)	*	*	*	*	*	*	*	*	*	*
Fra. tenera (o-m)	*		*		*	*	*	*	*	*
Frustulia rhomboides var. *crassinervia* (o)								*	*	*
Gomphonema clevei (o)								*		*
Gom. gracile (m)									*	*
Gom. parvulum (m)			*					*	*	
Gom. truncatum (m)	*				*	*	*	*	*	*
Gom. turris (m-e)									*	
Gyrosigma procerum	*									
Mastogloia elliptica var. *dansei*										*
Mas. smithii (m)									*	*
Navicula bacillum (m-e)								*		
Nav. cyptotenella (m)			*	*	*	*	*	*	*	*
Nav. minima (e)	*		*		*			*		
Nav. rhynchocephala (e)					*					
Nav. pupula (m)			*				*			*
Nav. absoluta	*				*					*
Neidium affine (m-e)									*	
Nitzschia frustulum (m-e)							*	*	*	
Nitzschia paleacea (m-e)	*	*	*	*		*	*	*	*	*
Pin. gibba (o)								*		
Pin. subcapitata (o)			*							
Pin. microstauron (o)									*	
Planothidium lanceolatum					*	*	*	*	*	*
Pla. lanceolatum spp. *rostrata*					*			*		*
Pseudostaurosira brevistriata									*	
Punctastriata linearis										*
Rhopalodia gibba var. *ventricosa* (o)		*			*	*	*	*	*	*
Staurosira construens (m)	*			*	*	*	*	*	*	*
Sta. pinnata									*	*
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. Raw 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 ambigula (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 *et* Crawford, 1990	*Encyonema* Kützig 1833
Aulacoseirales Crawford 1990	Gomphonemataceae Kützing 1844
Aulacoseiraceae Crawford 1990	*Gomphonema* Agardh 1824
Aulacoseira Thwaites 1848	Mastogloiales Mann 1990
Thalassiosirales Glezer *et* Makarova 1986	Mastogloiaceae Mereschkowsky 1903
Stephanodiscaceae Ehrenberg 1846	*Mastogloia* Thwaites ex W. Smith 1856
Cyclotella (Kützing) Brébisson 1838	Naviculales Bessey 1907
Thalassiosiraceae Lebour 1930	Naviculaceae Kützing 1844
Discostella Houk et Klee 2004	*Navicula* Bory de Saint-Vince 1822
	Caloneis Cleve 1894
Class Fragilariophyceae Round 1990	Amphipleuraceae Grunow 1862
Fragilariales Silva 1962	*Frustulia* Agardh 1824
Fragilariaceae Greville 1833	Neidiaceae Mereschkowsky 1903
Fragilaria Lyngbye 1819	*Neidium* Pfitzer 1871
Pseudostaurosira (Grunow) Williams *et* Round 1987	Pinnulariaceae Mann 1990
Punctastriata Williams *et* Round 1987	*Pinnularia* Ehrenberg 1843
Staurosira Ehrenberg 1843	Pleurosigmataceae Mereschkowsky 1903
	Gyrosigma Hassall 1845
Class Bacillariophyceae Haekel 1878	Bacillariales Hendey 1937
Achnanthales Silva 1962	Bacillariaceae Ehrenberg 1831
Achnanthidiaceae Mann 1990	*Nitzschia* Hassall 1845
Achnanthidium Kützing 1844	Rhopalodiales Mann 1990
Planothidium Round *et* L.Bukhtiyarova 1996	Rhopalodaceae (Karsten) Topachevs'kyj *et* Oksiyuk 1960
Cocconeidaceae Kützing, 1844	*Rhopalodia* Müller 1895
Cocconeis Ehrenberg 1837	*Epithemia* Kützig 1844
Cymbellales Mann 1990	Eunotiales Silva 1962
Cymbellaceae Greville 1833	Eunotiaceae Kützig 1844
Cymbella Agardh 1830	*Eunotia* Ehrenberg 1837

Aulacoseira granulata (Ehrenberg) Simonsen, 1979. Watanabe et al. (2005), p. 15, pl. I-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* (Kützing) 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 Kützing, 1844. Watanabe et al. (2005), p. 31, pl. I-9, fig. 1-6; Kobayasi et al. (2006), p. 241, pl. 47, fig. 1-11. Fig. 1E

Cyclotella kuetzingiana Thwaites, 1848; C. laevissima Van Goor; *C. meneghiniana* var. *rectangulata* Grunow; *C. meneghiniana* var. *vogesiaca* Grunow; *C. meneghiniana* var. *binotata* Grunow; *C. meneghiniana* var. *laevissima* (Van Goor) Hustedt; *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. I-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.

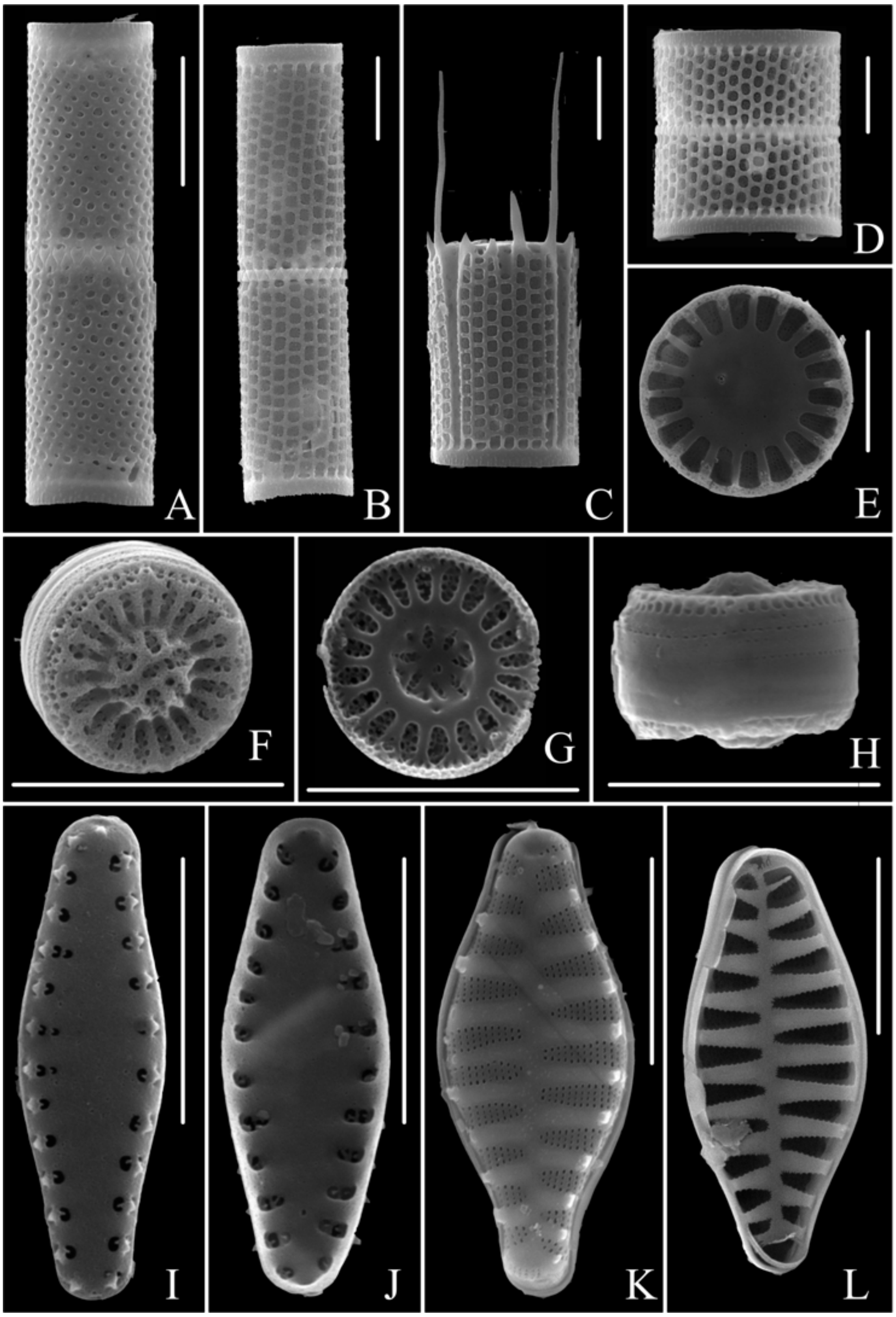

Fig. 1. A: *Aulacoseira ambigua*; B-D: *Aulacoseira granulata*; E: *Cyclotella meneghiniana*; F-H: *Discostella stelligera*; I & J: *Pseudostaurosira brevistriata*; K & L: *Punctastriata linearis*. Bar = 5μm.

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.

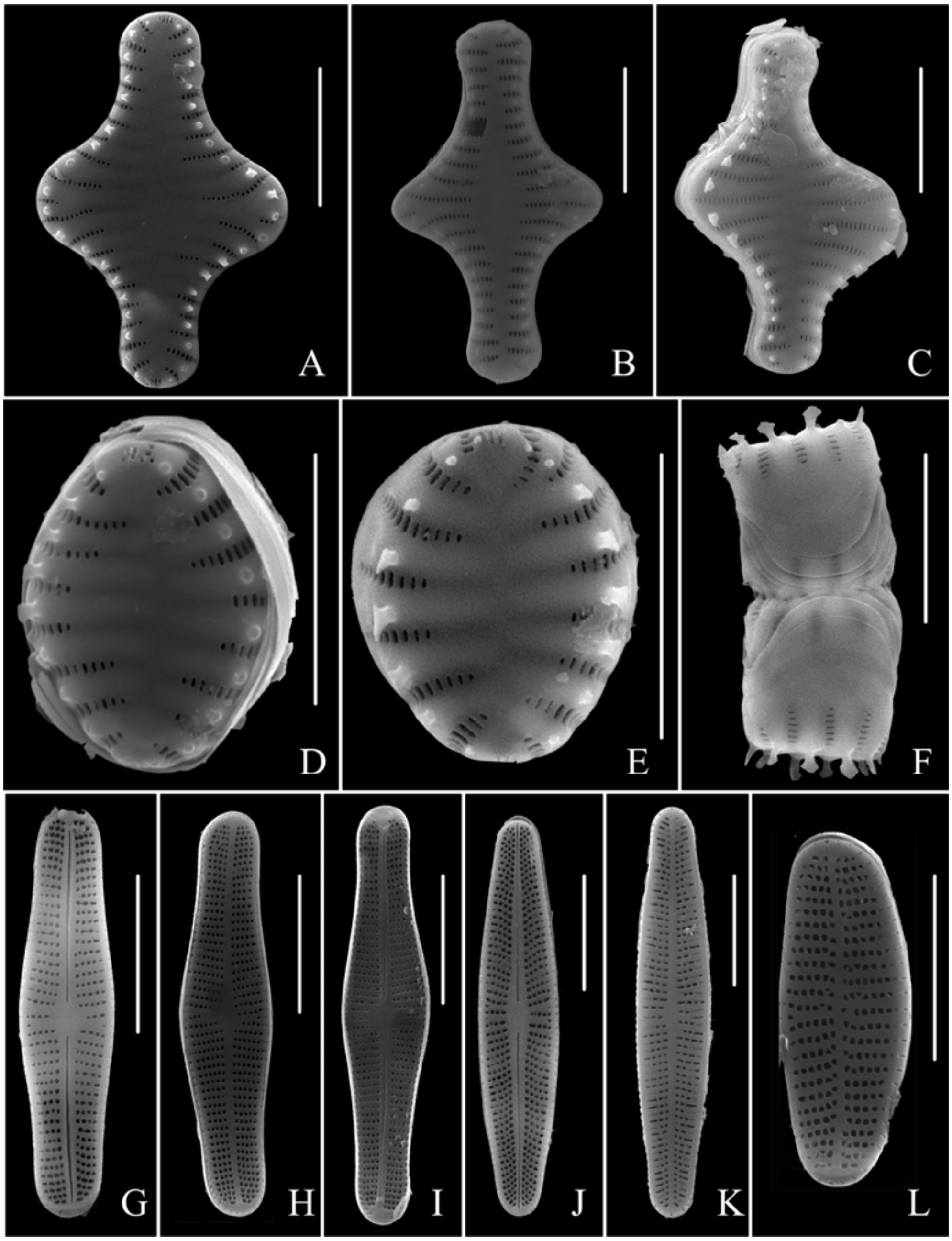

Fig. 2. A-C: *Staurosira construens*; D-F: *Staurosira pinnata*; G-L: *Achnanthidium minutissimum*. Bar = 5 μm.

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 Achnanthales
Family Achnanthidiaceae
Genus *Achnanthidium* Kützing, 1844
See Wu and Wang (2002), p. 77.

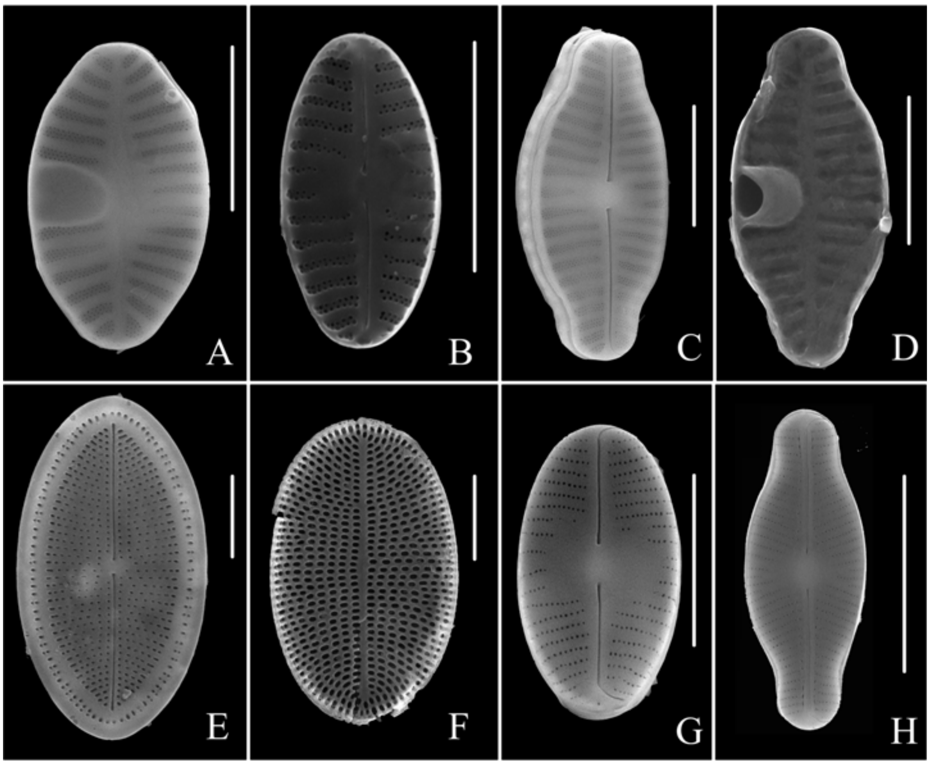

Fig. 3. A & B: *Planothidium lanceolatum*; C & D: *Planothidium lanceolatum* ssp. *rostrata*; E & F:*Cocconeis placentula* ; G: *Navicula minima*; H: *Navicula absoluta*. Bar= 5 μm.

Achnanthidium 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 multiseriately punctuate, slightly radiate or parallel in the center.

Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot, 1999. Watanabe et al. (2005), p. 202, pl. IIB_2-8, fig. 12-21; Kobayasi et al. (2006), p. 481, pl. 167, fig. 1-14. Figs. 3A & B

Achnanthidium 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 multiseriately punctate, slightly radiate or parallel. Pseudoraphe valve interrupted centrally on one side by a horseshoe-shaped clear area. Striae multiseriately punctate, almost parallel at the center, slightly radiate throughout the other part of the valve.

Dimension: 4.5-8 × 12-31 μm, striae 11-14 in 10 μm.

Planothidium lanceolatum* ssp. *rostrata (Østrup) Lange-Bertalot, 1991. Watanabe et al. (2005), p. 205, pl. IIB_2-9, fig. 9-20. Figs. 3C & D

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

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 multiseriately punctate, slightly radiate or parallel. Pseudoraphe valve: interrupted centrally on one side by a horseshoe-shaped clear area. Striae multiseriately punctate, almost parallel at the center, slightly radiate throughout the other part of the valve.

Dimension: 4-7 × 7-16 μm, striae 11-14 in 10 μm.

Family Cocconeidaceae

Genus *Cocconeis* Ehrenberg, 1837

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

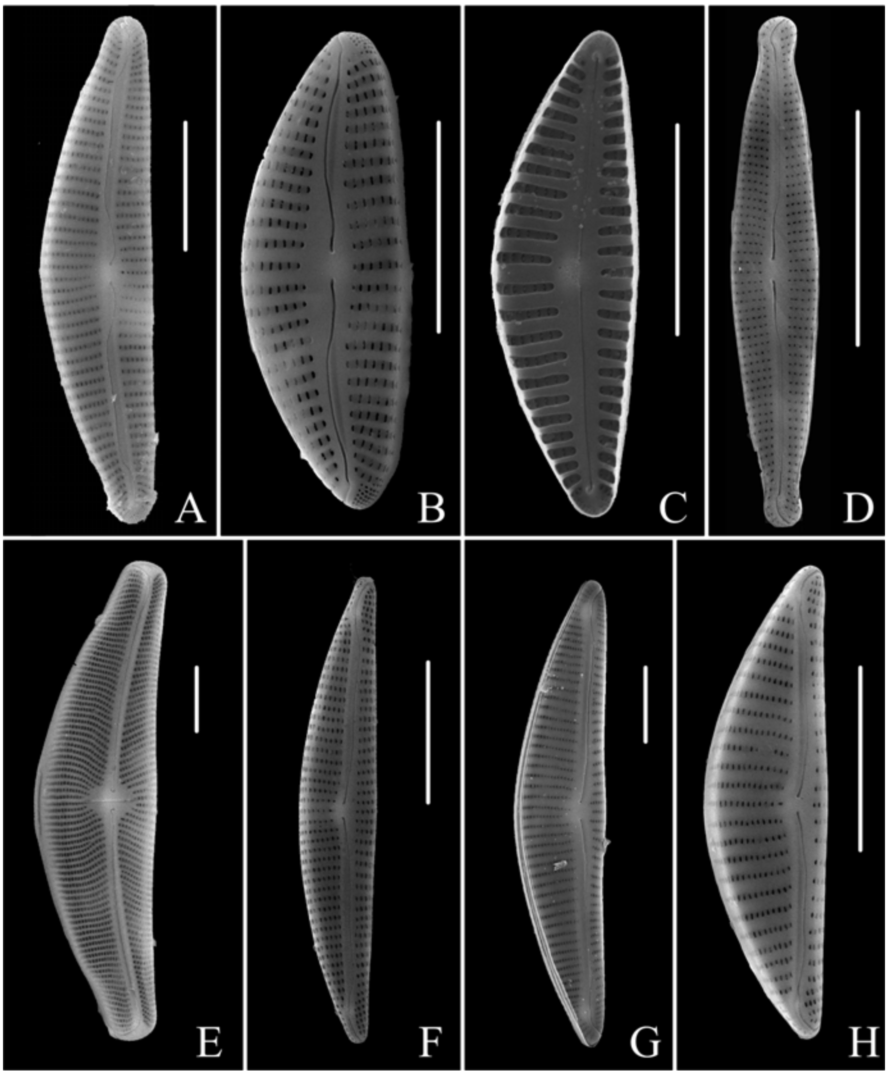

Fig. 4. A: *Cymbella affinis*; B & C: *Cymbella hustedtii*; D: *Cymbella thienemannii*; E: *Cymbella tumida*; F & G: *Encyonema gracilis*; H: *Encyonema silesiacum*. Bar = 10 μm.

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. IIB_3-70, 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 × 20-70 μm, striae 7-12 in 10 μm.

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. IIB_3-69, fig. 25-34. Fig. 4D

Encyonopsis thienemannii (Hustedt) Krammer.

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

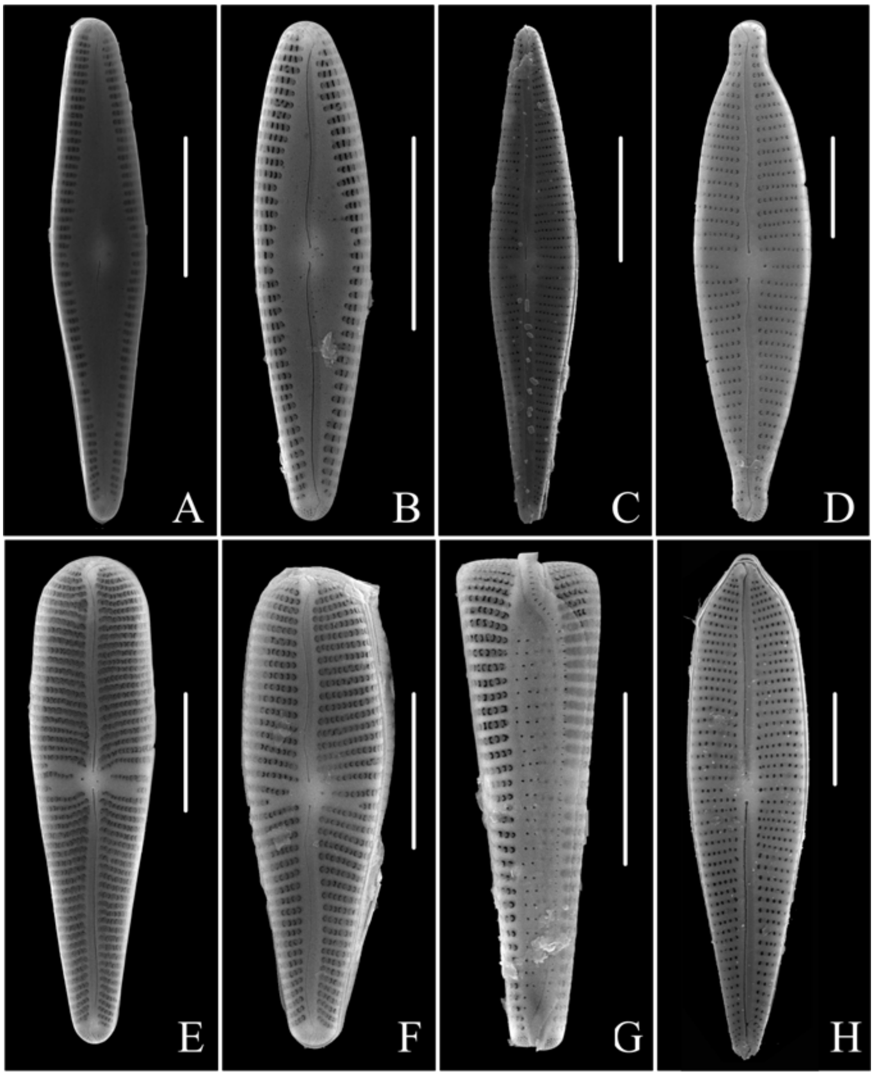

Fig. 5. A & B: *Gomphonema clevei*; C: *Gomphonema gracile*; D: *Gomphonema parvulum*; E-G: *Gomphonema truncatum*; H: *Gomphonema turris*. Bar = 10 μm.

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

Dimension: 3-4.5 × 15-24 μm, striae 22-25 in 10 μm.

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

Genus *Encyonema* Kützig, 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 (Kützing) Kützing, 1849. Fig. 5D
See Wang and Wu (2005), p. 50.

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

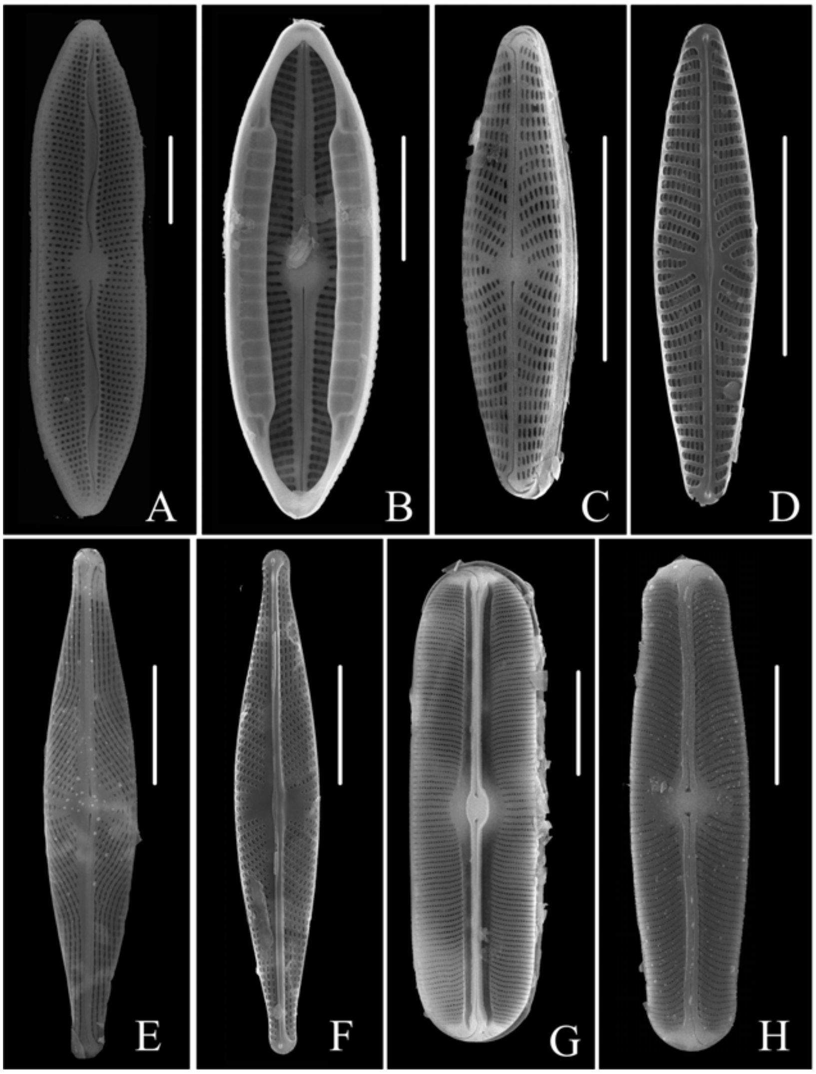

Fig. 6. A: *Mastogloia elliptica* var. *dansei*; B: *Mastogloia smithii*; C & D: *Navicula cryptotenella*; E & F: *Navicula rhynchocephala*; G: *Navicula bacillum*; H: *Navicula pupula*. Bar = 10 µm.

Gomphonema turris Ehrenberg, 1843. Watanabe et al. (2005), p. 501, pl. IIB$_3$-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 × 50-100 µm, striae 7-10 in 10 µm.

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× 20-80 µm, striae 15-18 in 10 µm.

Mastogloia smithii Thwaites, 1856. Watanabe et al. (2005), p. 227, pl. IIB_3-1, fig. 14-17. Fig. 6B

Valves narrow elliptic, ends cuneate. Axial area widening toward mid-valve. Raphe filifrom, 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-Vince, 1822
See Wu and Wang (2009), p. 231.

Navicula absoluta Hustedt, 1950. Watanabe et al. (2005), p. 307, pl. IIB_3-26, fig. 14-17. Fig. 3H

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

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

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

Navicula bacillum Ehrenberg, 1843. Watanabe et al. (2005), p. 300, pl. IIB_3-24, 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 punctuate, 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 Kützing, 1844. Watanabe et al. (2005), p. 345, pl. IIB_3-40, 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 punctuate, strongly radiate.

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

Navicula pupula Kützing, 1844. Watanabe et al. (2005), p. 303, pl. IIB_3-25, 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 punctuate, strongly radiate becoming slightly radiate at ends.

Dimension: 7-11 × 13-17μm, 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. IIB_3-5, 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. IIB_3-2, figs. 7-10. Fig. 7B

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

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

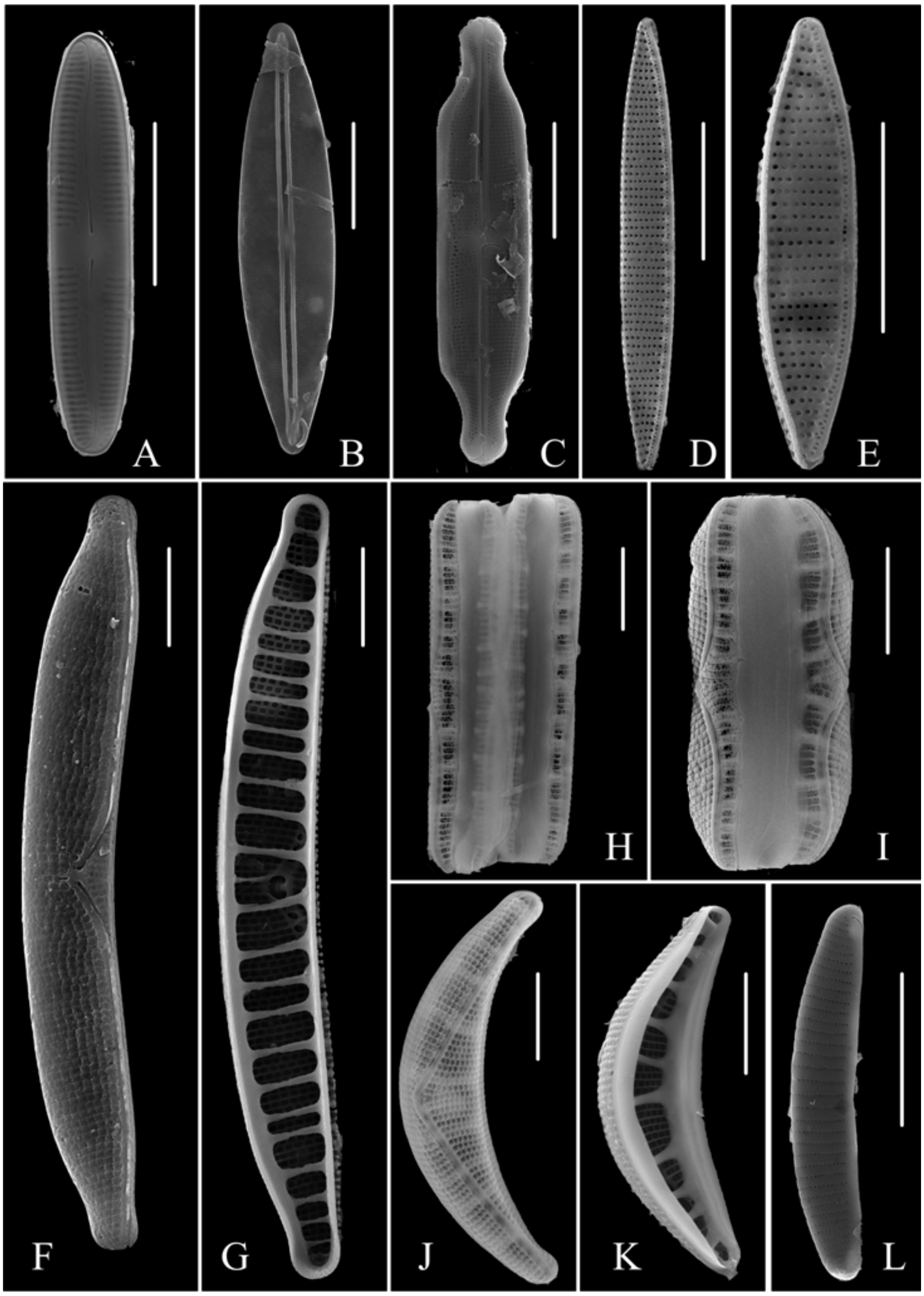

Fig. 7. A: *Caloneis bacillum*; B: *Frustulia rhomboides* var. *crassinervia*; C: *Neidium affine*; D: *Nitzschia frustulum*; E: *Nitzschia* paleacea; F-H: *Epithemia adnata*; I-K: *Epithemia smithii*; L: *Eunotia subarcuatioides*. Bar = 10 μm.

Dimension: 10-15 × 30-50 μm, striae 36-42 in 10 μm.

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, expended, close, distal ends forked. Central area transverse elongated, elliptical. Striae areolate, transverse and longitudinal.

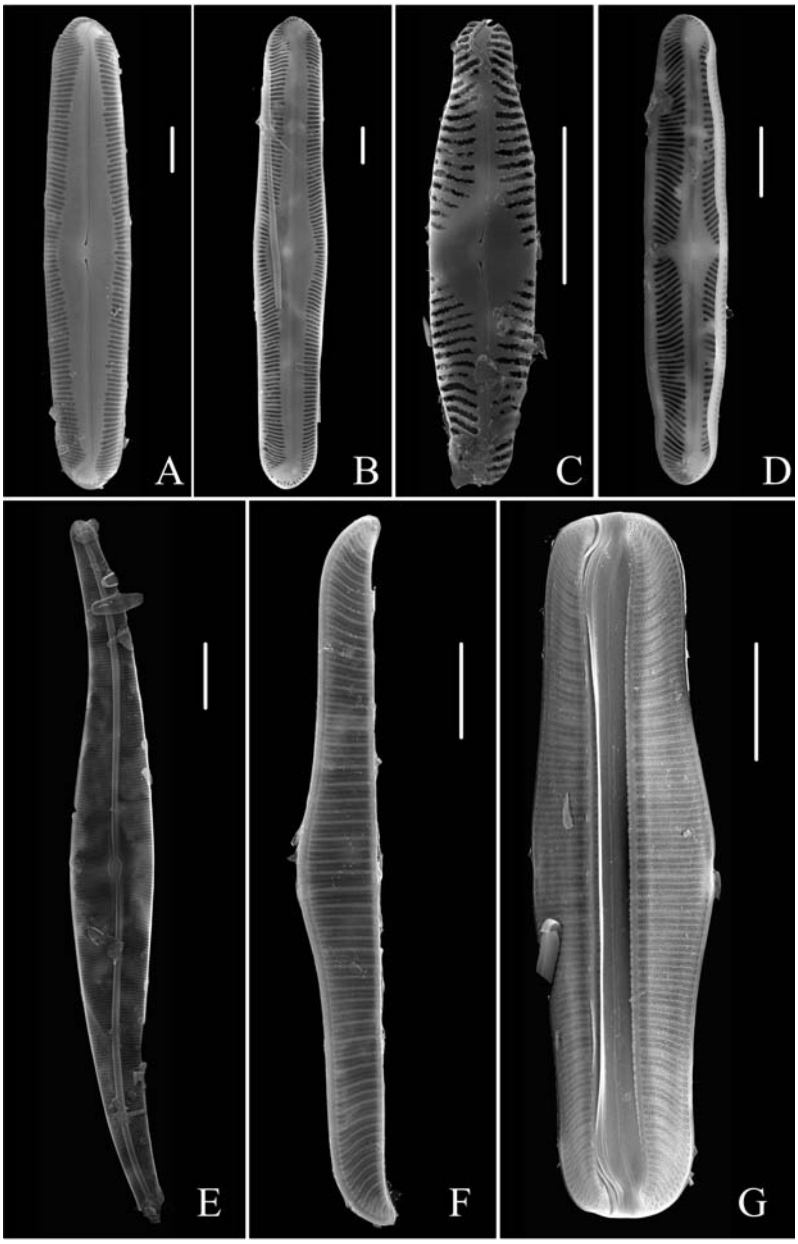

Fig. 8. A & B: *Pinnularia gibba*; C & D: *Pinnularia microstauron*; E: *Gyrosigma procerum*; F & G: *Rhopalodia gibba* var. *ventricosa*. Bar = 10 μm.

Dimension: 6-17 × 20-80 μm, striae 20-29 in 10 μm.

Family Pinnulariaceae
Genus *Pinnularia* Ehrenberg, 1843
See Wu and Wang (2009), p. 232.

Pinnularia gibba Ehrenberg, 1843. Watanabe et al. (2005), p. 391, pl. IIB_3-56, 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 multiseriately, chambered, strongly striae radiate at the center of the valve, convergent towards the ends.

Dimension: 10-13.5 × 60-110 μm, striae 8-11 in 10 μm.

Pinnularia microstauron (Ehrenberg) Cleve, 1891. Watanabe et al. (2005), p. 378, pl. IIB_3-50, fig. 1-5. Figs. 8C & D

Pinnularia microstauron morphotype 1 sensu Krammer.

Valves lanceolate, ends rostrate or capitates. 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 multiseriately, 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. IIB_3-4, 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 (Kützing) Grunow, 1880. Fig. 7D

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

Nitzschia paleacea (Grunow) Grunow, 1827. Watanabe et al. (2005), p. 590, pl. IIB_4-23, 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 (Kützing) H. Peragallo *et* M. Peragallo, 1900. Watanabe et al. (2005), p. 535, pl. IIB_4-6, fig. 4. Figs. 8F & G

Epithemia ventricosa Kützing; *E. gibba* var. *ventricosa* (Kützing) Grunow; *Rhopalodia ventricosa* (Kützing) 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* Kützig, 1844

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

Epithemia adnata (Kützig) Brébisson, 1838. Figs. 7F-H

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

Epithemia smithii Carruthers, 1864. Watanabe et al. (2005), p. 526, pl. IIB_4-2, 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 capitates 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: *Achnanthidium 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 *Achnanthidium 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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東臺灣鯉魚潭之矽藻

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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。