



New records of the marine pennate diatoms in Korea

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Abstract

A study on indigenous diatoms was carried out at 49 sites from November 2008 to December 2012 in the marine and brackish plankton and benthic ecosystem in Korea. The structure of small-sized pennate diatoms was examined by means of light and scanning electron microscopy. Twenty species of diatoms were newly identified and divided into five orders, 18 families, and nine genera in this study. The nomenclature, references, specimens examined, specimen descriptions, photographs, and distribution profiles are reported here. The newly reported pennate diatoms imply several reasons why these taxa have not been recorded previously in Korea and we present the strategy to understand the diversity of diatoms in Korea.

Key words: indigenous, Korea, new records, pennate diatoms

INTRODUCTION

Diatom classification can be made according to two groups based on morphology (Schütt 1896, Simonsen 1979), though recent insight on diatom classification has been debated (Williams and Kociolek 2011). Most planktonic diatoms in the marine environment consist of morphologically centric diatoms, which are classical concept following Simonsen (1979), such as *Actinocyclus* Ehrenberg, *Coscinodiscus* Ehrenberg, *Chaetoceros* Ehrenberg and *Thalassiosira* Cleve. The morphologically pennate diatoms have been mainly reported to live in diverse substrates such as plants, macroalgae, hard rock and sediments (Round et al. 1990, Joh 2013). Several planktonic pennate diatoms have been mainly reported from the nitzschoid diatoms such as *Bacillaria* Gmelin, *Fragilariopsis* Hustedt, and *Pseudo-nitzschia* Peragallo (Hasle and Syvertsen 1996); other planktonic diatoms have been overlooked due to the difficulty of their identification.

A master plan entitled "The Project on Survey and Excavation of Korean Indigenous Species" at the National

Institute of Biological Resources (NIBR), under the Ministry of Environment of Korea, was established in 2006. We conducted the survey and excavation of diatoms in brackish and marine waters of Korea from 2006 to the present. Lee et al. (2012) investigated the newly recorded diatoms in Korea in the first conclusive study of the species, reporting 60 species in 39 genera with illustrations based on light microscopy and scanning electron microscopy. This is the second serial study for newly recorded pennate diatoms in Korea during the investigation of "Survey and Excavation of Korean Indigenous Species". Twenty species of diatom are for the first time documented in this study.

MATERIALS AND METHODS

The specimens were collected from 46 sites from December 2008 to November 2012 from brackish and coastal waters of Korea (Table 1). All samples were collected by

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using 20- μ m mesh-sized phytoplankton nets with vertical and/or horizontal towing, and the collected net samples were immediately fixed with 4% neutralized formalin. To observe the fine structures and characteristics of each diatom, we removed the cell organelles and organic matter using concentrated HCl and saturated KMnO_4 (Hasle and

Fryxell 1970). Some acid-cleaned materials were affixed to permanent slides that were mounted in Pleurax. The permanent slides were observed by means of light microscopy (LM): Axioskop 40 (Zeiss, Jena, Germany) with an AxioCam MRc 5 (Zeiss) and Eclipse 80i (Nikon, Tokyo, Japan) with and DS-Fi1 (Nikon) digital camera. The remain-

Table 1. Sampling information in Korean coastal waters

Sites	Sampling date	Sampling location	Latitude (N)	Longitude (E)
1	Dec 27, 2008	Gwansado-ri, Jodo-myeon, Jindo-gun, Jeollanam-do	34°18'33"	125°58'42"
2	Jan 21, 2009	Daebo-ri, Homigot-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do	36°04'48"	129°33'36"
3	Jan 21, 2009	Guryongpo-ri, Guryongpo-eup, Nam-gu, Pohang-si, Gyeongsangbuk-do	35°59'05"	129°33'11"
4	Jan 22, 2009	Jangsa-ri, Namjeong-myeon, Yeongdeok-gun, Gyeongsangbuk-do	36°15'40"	129°22'30"
5	Jan 22, 2009	Gusan-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do	36°45'22"	129°28'10"
6	Jan 22, 2009	Mangyang-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do	36°51'09"	129°25'40"
7	Jan 22, 2009	Hujeong-ri, Jukbyeon-myeon, Uljin-gun, Gyeongsangbuk-do	37°01'58"	129°24'56"
8	Jan 22, 2009	Gungchon-ri, Geundeok-myeon, Samcheok-si, Gangwon-do	37°19'38"	129°16'07"
9	Jan 23, 2009	Daejin-dong, Donghae-si, Gangwon-do	37°34'55"	129°06'43"
10	Jan 23, 2009	Sacheonjin-ri, Sacheon-myeon, Gangneung-si, Gangwon-do	37°41'10"	129°02'34"
11	Feb 16, 2009	Gwangang-dong, Suyeong-gu, Busan	35°08'19"	129°06'52"
12	Feb 16, 2009	Ilgwang-myeon, Gijang-gun, Busan	35°21'19"	129°21'15"
13	Feb. 16, 2009	Daesong-ri, Seosaeng-myeon, Ulju-gun, Ulsan	35°21'19"	129°21'15"
14	Feb 16, 2009	Jeongja-dong, Buk-gu, Ulsan	35°41'35"	129°28'31"
15	Feb 16, 2009	Eupcheon-ri, Yangnam-myeon, Gyeongju-si, Gyeongsangbuk-do	35°41'29"	129°31'16"
16	Feb 16, 2009	Yangpo-ri, Janggi-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do	38°13'12"	128°35'24"
17	Jul 23, 2010	Chang-ri, Buseok-myeon, Seosan-si, Chungcheongnam-do	36°37'28"	126°22'00"
18	Jul 23, 2010	Sutong-ri, Buri-myeon, Geumsan-gun, Chungcheongnam-do	35°38'17"	126°27'46"
19	Jul 23, 2010	Anseong-ri, Dongjin-myeon, Buan-gun, Jeollabuk-do	35°47'15"	126°44'54"
20	Jul 24, 2010	Daehang-ri, Byeonsan-myeon, Buan-gun, Jeollabuk-do	35°41'17"	126°31'55"
21	Aug 28, 2010	Dogu-ri, Donghae-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do	35°59'48"	129°27'28"
22	Aug 29, 2010	Daetan-ri, Yeongdeok-eup, Yeongdeok-gun, Gyeongsangbuk-do	36°26'30"	129°26'00"
23	Aug 29, 2010	Chuksan-ri, Chuksan-myeon, Yeongdeok-gun, Gyeongsangbuk-do	36°30'28"	129°26'59"
24	Aug 29, 2010	Hupo-ri, Hupo-myeon, Uljin-gun, Gyeongsangbuk-do	36°40'36"	129°27'14"
25	Aug 29, 2010	Gusan-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do	36°45'37"	129°28'20"
26	Aug 29, 2010	Eumnam-ri, Uljin-eup, Uljin-gun, Gyeongsangbuk-do	36°59'05"	129°24'38"
27	Aug 29, 2010	Aninjin-ri, Gangdong-myeon, Gangneung-si, Gangwon-do	37°44'05"	128°59'13"
28	Aug 29, 2010	Sacheonjin-ri, Sacheon-myeon, Gangneung-si, Gangwon-do	37°50'16"	128°52'36"
29	Aug 30, 2010	Namae-ri, Hyeonnam-myeon, Yangyang-gun, Gangwon-do	37°56'39"	128°47'19"
30	Aug 30, 2010	Susan-ri, Sonyang-myeon, Yangyang-gun, Gangwon-do	38°04'38"	128°40'26"
31	Aug 30, 2010	Jucheong-ri, Ganghyeon-myeon, Yangyang-gun, Gangwon-do	38°07'23"	128°37'57"
32	Aug 30, 2010	Bongpo-ri, Toseong-myeon, Goseong-gun, Gangwon-do	38°15'03"	128°34'03"
33	Aug. 30, 2010	Oho-ri, Jugwang-myeon, Goseong-gun, Gangwon-do	38°19'28"	128°31'36"
34	Oct 15, 2010	Soryong-dong, Gunsan-si, Jeollabuk-do	35°58'11"	126°37'02"
35	Oct 15, 2010	Gyehwa-ri, Gyehwa-myeon, Buan-gun, Jeollabuk-do	35°47'38"	126°38'38"
36	Nov 15, 2010	Ogam-dong, Mokpo-si, Jeollanam-do	34°47'48"	126°26'06"
37	Nov 16, 2010	Sanam-myeon, Sacheon-si, Gyeongsangnam-do	35°04'08"	128°02'52"
38	Jun 9, 2011	Wondong-ri, Gunoe-myeon, Wando-gun, Jeollanam-do	34°23'35"	126°38'54"
39	Jun 9, 2011	Sin-gi-ri, Doam-myeon, Gangjin-gun, Jeollanam-do	34°31'41"	126°46'14"
40	Jun 9, 2011	Hoejin-ri, Hoejin-myeon, Jangheung-gun, Jeollanam-do	34°28'51"	126°56'28"
41	Jun 10, 2011	Hwagye-ri, Idong-myeon, Namhae-gun, Gyeongsangnam-do	34°46'38"	127°56'34"
42	Jun 11, 2011	Dadae-dong, Saha-gu, Busan	35°02'55"	128°58'16"
43	Jul 19, 2011	Changgi-ri, Anmyeon-eup, Taean-gun, Chungcheongnam-do	36°43'33"	126°08'00"
44	Mar 11, 2012	Aewol-ri, Aewol-eup, Jeju-si, Jeju-do	33°28'02"	126°19'18"
45	Mar 11, 2012	Hallim-ri, Hallim-eup, Jeju-si, Jeju-do	33°25'11"	126°15'37"
46	Oct 3, 2012	Janggok-ri, Gonam-myeon, Taean-gun, Chungcheongnam-do	36°24'34"	126°22'30"
47	Nov 2, 2012	Seopo-myeon, Sacheon-si, Gyeongsangnam-do	35°59'05"	129°33'11"
48	Nov 2, 2012	Chonam-ri, Gwangyang-eup, Gwangyang-si, Jeollanam-do	34°55'40"	127°36'18"
49	Nov 2, 2012	Daeseo-myeon, Goheung-gun, Jeollanam-do	34°44'52"	127°18'48"

ing cleaned materials were mounted on the aluminum stubs and coated with gold-palladium to examine the fine structures using scanning electron microscopy (SEM) (JSM-5600LV; Jeol, Tokyo, Japan). The dimensions of diatoms were measured from micrographs using ImageJ ver. 1.32 software. Diatom identifications were mainly based on the studies of Hendey (1964), Round et al. (1990), Hasle and Syvertsen (1996), Krammer and Lange-Bertalot (1997, 1999, 2004) and a number of references, including the original description for each taxon.

RESULTS

Order Achnanthes Silva Family Cocconeidaceae Kützing

Cocconeopsis wrightii (O'Meara) Witkowski 2000 (Fig. 1a-1d)

Basionym: *Cocconeis wrightii* O'Meara 1867.

Synonyms: *Cocconeis biflexa* Schmidt 1894; *Orthoneis wrightii* (O'Meara) Cleve 1895; *Navicula schonkenii* Hustedt 1955; *Navicula bijzexa* (Schmidt) Giffen 1970.

References: Riaux-Gobin and Compère 2004, p. 65, pl. III, figs 16–22, pl. IV, figs. d, e.

Specimen examined: NIBRDI0000130085.

Valves elliptical to almost rounded and slightly convex, length 12.8–22 µm, width 8.5–16 µm. Striae radiate, composed of rounded or slightly elongated areolae, 8–11 in 10 µm. One or two rows of areolae smaller near the margin. Raphe straight. End nodules rounded and distant from the valve apices, central endings pear-form and distant, central area transapically expanded and connected to an H-shaped area.

Korean distribution: *Cocconeopsis wrightii* was observed on October 29, 2010 at four sites in East Sea (Table 2).

Order Bacillariales Hendey Family Bacillariaceae Ehrenberg

Nitzschia improvisa Simonsen 1960 (Fig. 1e and 4a)

References: Lange-Bertalot and Krammer 1987, p. 44, 60; Krammer and Lange-Bertalot 1997, pl. 21.

Specimen examined: NIBRDI0000130087.

Valves linear with capitate pole. Length 117.5 µm, width 6.25 µm. Striae very clearly visible in LM and areolae resolvable, 24–25 in 10 µm. Raphe system fibulate, marginal. Fibulae square, regularly spaced, 8–10 in 10 µm. Raphe straight with distinct constriction in central area.

Korean distribution: *Nitzschia improvisa* was observed five times during this study (Table 2). Although *N. improvisa* has been reported from Yellow Sea, South Sea, and East Sea of Korea, this species mainly occurred in South Sea.

Nitzschia valdestriata Aleem & Hustedt 1951 (Figs. 1f-1h and 4b-4d)

References: Krammer and Lange-Bertalot 1997, p. 121, pl. 84, figs. 9-12.

Specimen examined: NIBRDI0000130092.

Valves bilaterally symmetrical, elliptical to linear-elliptical, with bluntly rounded poles. Length 6.1–12.1 µm, width 2.4–2.8 µm. Striae very clearly visible in LM, 15 in 10 µm, but areolae unresolvable. Raphe system fibulate, marginal. Fibulae square, regularly spaced. Central raphe endings absent. Raphes of the two valves lie at opposite sides.

Korean distribution: *Nitzschia valdestriata* was observed from four sites (Table 2): two times from South Sea and East Sea, respectively.

Order Naviculales Bessey Family Berkeleyaceae D.G. Mann

Parlibellus hamulifer (Grunow) Cox 1988 (Figs. 1i-1l and 4e-4f)

Basionym: *Navicula hamulifera* Grunow ex Cleve & Grunow 1880.

References: Hustedt 1961, p. 311, fig. 1430; Cox 1988, p. 24.

Specimen examined: NIBRDI0000130093.

Valves rhombic-lanceolate with sub-acute apices. Length 44.5–60.7 µm, width 11.2–15.7 µm. Striae poroidal, 19–21 in 10 µm, more or less parallel and throughout the length of the valve. Raphe straight and slightly curved in central area, extending almost to the apices, deflected to one side at the poles helictoglossae.

Korean distribution: *Parlibellus hamulifer* was observed ten times in this study (Table 2). This species mainly occurred from East Sea with *P. rhombicus*.

Parlibellus rhombicus (Gregory) Cox 1988 (Fig. 2c and 2d)

Basionym: *Navicula rhombica* Gregory 1855.

Synonyms: *Navicula libellus* Gregory 1857; *Navicula libellus* sensu Hustedt 1962.

References: Cox 1988, p. 25, figs 17, 33-38.

Specimen examined: NIBRDI0000130094.

Valves rhombic-lanceolate with acute apices. Length 34.6–48.0 µm, width 8.9–10.8 µm. Striae poroidal, 26–29 in

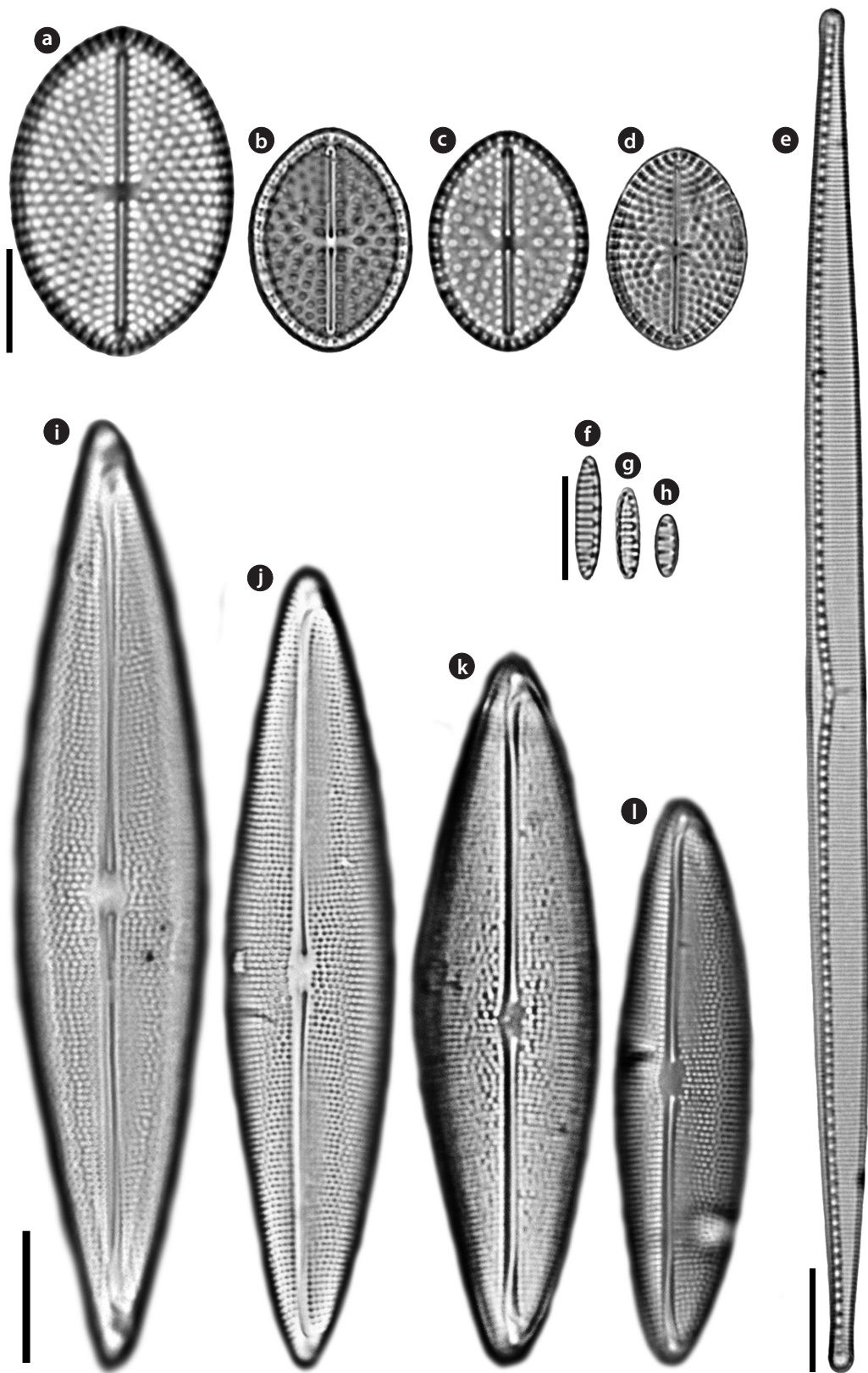


Fig. 1. Light microscopy (LM) microphotographs. (a-d) *Cocconeopsis wrightii*, (e) *Nitzschia improvisa*, (f-h) *Nitzschia valdestrata*, and (i-l) *Parlibellus hamulifer*. Scale bars, 10 μ m.

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Table 2. Check list of new recorded diatoms in this study

Species	Date	Sites	Location
<i>Cocconeopsis wrightii</i>	Aug 29, 2010	22	Daetan-ri, Yeongdeok-eup, Yeongdeok-gun, Gyeongsangbuk-do
		23	Chuksan-ri, Chuksan-myeon, Yeongdeok-gun, Gyeongsangbuk-do
		24	Hupo-ri, Hupo-myeon, Uljin-gun, Gyeongsangbuk-do
		27	Aninjin-ri, Gangdong-myeon, Gangneung-si, Gangwon-do
<i>Nitzschia improvisa</i>	Jan 22, 2009	4	Jangsa-ri, Namjeong-myeon, Yeongdeok-gun, Gyeongsangbuk-do
	Oct 15, 2010	35	Gyehwa-ri, Gyehwa-myeon, Buan-gun, Jeollabuk-do
	Nov 16, 2010	37	Sanam-myeon, Sacheon-si, Gyeongsangnam-do
	Jun 9, 2011	40	Hoejin-ri, Hoejin-myeon, Jangheung-gun, Jeollanam-do
	Nov 2, 2012	49	Daeseo-myeon, Goheung-gun, Jeollanam-do
<i>Nitzschia valdestrata</i>	Jan 22, 2009	8	Gungchon-ri, Geundeok-myeon, Samcheok-si, Gangwon-do
	Jan 23, 2009	10	Sacheonjin-ri, Sacheon-myeon, Gangneung-si, Gangwon-do
	Nov 15, 2010	36	Ogam-dong, Mokpo-si, Jeollanam-do
	Nov 2, 2012	48	Chonam-ri, Gwangyang-eup, Gwangyang-si, Jeollanam-do
<i>Navicula diabolica</i>	Nov 2, 2012	47	Seopo-myeon, Sacheon-si, Gyeongsangnam-do
<i>Navicula pavillardii</i>	Nov 2, 2012	49	Daeseo-myeon, Goheung-gun, Jeollanam-do
<i>Gyrosigma subtile</i>	Aug 29, 2010	28	Sacheonjin-ri, Sacheon-myeon, Gangneung-si, Gangwon-do
	Nov 2, 2012	47	Seopo-myeon, Sacheon-si, Gyeongsangnam-do
<i>Gyrosigma turgida</i>	Jul 23, 2010	19	Anseong-ri, Dongjin-myeon, Buan-gun, Jeollabuk-do
	Jun 9, 2011	38	Wondong-ri, Gunoe-myeon, Wando-gun, Jeollanam-do
	Dec 27, 2008	1	Gwansado-ri, Jodo-myeon, Jindo-gun, Jeollanam-do
<i>Pleurosigma inflatum</i>	Feb 16, 2009	14	Jeongja-dong, Buk-gu, Ulsan
		15	Eupcheon-ri, Yangnam-myeon, Gyeongju-si, Gyeongsangbuk-do
		16	Yangpo-ri, Janggi-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do
		5	Gusan-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do
		16	Yangpo-ri, Janggi-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do
		21	Dogu-ri, Donghae-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do
<i>Pleurosigma williamsii</i>	Jan 22, 2009	6	Mangyang-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do
		7	Hujeong-ri, Jukbyeon-myeon, Uljin-gun, Gyeongsangbuk-do
<i>Pleurosigma decorum</i>	Oct 3, 2012	46	Janggok-ri, Gonam-myeon, Taean-gun, Chungcheongnam-do
	Oct 15, 2010	34	Soryong-dong, Gunsan-si, Jeollabuk-do
	Jun 9, 2011	39	Sin-gi-ri, Doam-myeon, Gangjin-gun, Jeollanam-do
<i>Parlibellus hamulifer</i>	Jan 21, 2009	2	Daebo-ri, Homigot-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do
	Jan 23, 2009	9	Daejin-dong, Donghae-si, Gangwon-do
	Aug 29, 2010	24	Hupo-ri, Hupo-myeon, Uljin-gun, Gyeongsangbuk-do
		25	Gusan-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do
		28	Sacheonjin-ri, Sacheon-myeon, Gangneung-si, Gangwon-do
	Aug 30, 2010	29	Namae-ri, Hyeonnam-myeon, Yangyang-gun, Gangwon-do
		30	Susan-ri, Sonyang-myeon, Yangyang-gun, Gangwon-do
		31	Jucheong-ri, Ganghyeon-myeon, Yangyang-gun, Gangwon-do
		32	Bongpo-ri, Toseong-myeon, Goseong-gun, Gangwon-do
	Jun 11, 2011	42	Dadae-dong, Saha-gu, Busan
	Jan 21, 2009	3	Guryongpo-ri, Guryongpo-eup, Nam-gu, Pohang-si, Gyeongsangbuk-do
	Jan 22, 2009	5	Gusan-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do
<i>Parlibellus rhombicus</i>	Jan 16, 2009	6	Mangyang-ri, Giseong-myeon, Uljin-gun, Gyeongsangbuk-do
		11	Gwangan-dong, Suyeong-gu, Busan
		12	Ilgwang-myeon, Gijang-gun, Busan
		13	Daesong-ri, Seosaeng-myeon, Ulju-gun, Ulsan
		16	Yangpo-ri, Janggi-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do
		48	Chonam-ri, Gwangyang-eup, Gwangyang-si, Jeollanam-do
<i>Auricula complexa</i>	Nov 2, 2012	49	Daeseo-myeon, Goheung-gun, Jeollanam-do
		17	Chang-ri, Buseok-myeon, Seosan-si, Chungcheongnam-do
<i>Auricula flabelliformis</i>	Jul 23, 2010	20	Daehang-ri, Byeonsan-myeon, Buan-gun, Jeollabuk-do
	Jul 24, 2010	41	Hwagye-ri, Idong-myeon, Namhae-gun, Gyeongsangnam-do
	Jun 10, 2011	44	Aewol-ri, Aewol-eup, Jeju-si, Jeju-do
<i>Campylodiscus ambiguus</i>	Mar 11, 2012	12	Ilgwang-myeon, Gijang-gun, Busan
<i>Campylodiscus decorus</i>	Feb 16, 2009	26	Eumnam-ri, Uljin-eup, Uljin-gun, Gyeongsangbuk-do
<i>Campylodiscus samoensis</i>	Aug 29, 2010	16	Yangpo-ri, Janggi-myeon, Nam-gu, Pohang-si, Gyeongsangbuk-do
	Feb 16, 2009	18	Sutong-ri, Buri-myeon, Geumsan-gun, Chungcheongnam-do
	Jul 23, 2010	44	Aewol-ri, Aewol-eup, Jeju-si, Jeju-do
	Mar 11, 2012	45	Hallim-ri, Hallim-eup, Jeju-si, Jeju-do
		33	Oho-ri, Jugwang-myeon, Goseong-gun, Gangwon-do
<i>Catenula adhaerens</i>	Aug 30, 2010	43	Changgi-ri, Anmyeon-eup, Taean-gun, Chungcheongnam-do
	Jul 19, 2011		

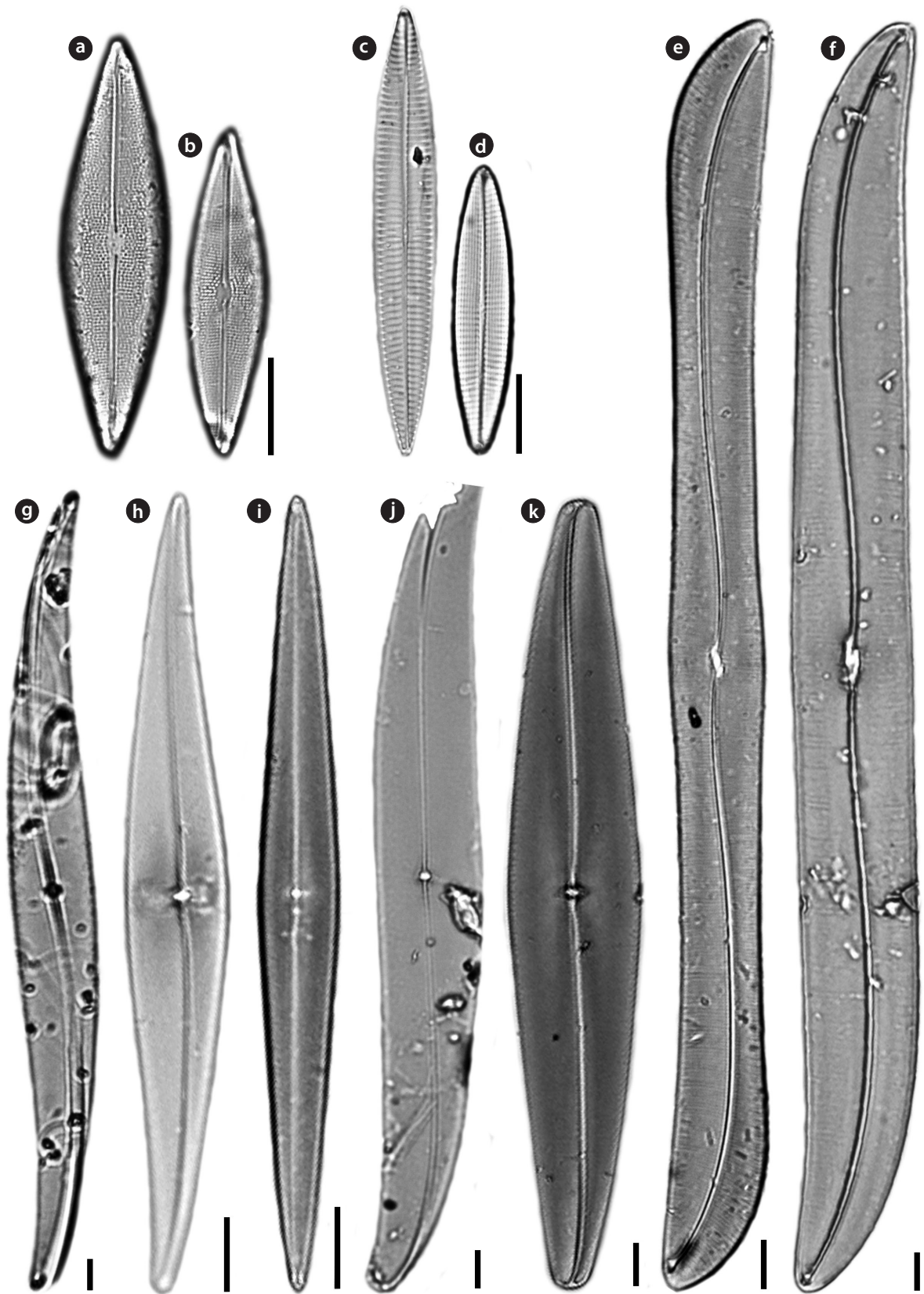


Fig. 2. Light microscopy (LM) microphotographs. (a, b) *Parlibellus rhombicus*, (c, d) *Navicula pavilladii*, (e) *Gyrosigma subtile*, (f) *Gyrosigma turgida*, (g) *Pleurosigma decorum*, (h) *Pleurosigma inflatum*, (i) *Pleurosigma patagonicum*, (j) *Pleurosigma speciosum*, and (k) *Pleurosigma williamsii*. Scale bars, 10 μ m.

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10 µm, radial in valve centre. Raphe straight and slightly curved in central area, extending almost to the apices, deflected to one side at the poles helictoglossae.

Korean distribution: *Parlibellus rhombicus* was observed seven times at the coasts of East Sea (Table 2).

Family Naviculaceae Kützing

Navicula diabolica Geissler & Gerloff 1963 (Fig. 4g)

References: Krammer and Lange-Bertalot 1999, p. 210, pl. 78, fig. 28.

Specimen examined: NIBRDI0000130095.

Valves linear-lanceolate to rhombic with bluntly rounded ends. Length 5–6 µm, width 2–2.5 µm. Raphe filiform, axial congruent with the media rib, very narrow, linear, central area and other structures in the LM not accurately differentiable. Striae parallel, 35 in 10 µm, Areolae fully developed, distributed only in the margin. Raphe straight, terminal end with a small helictoglossa internally.

Korean distribution: *Navicula diabolica* was only observed from Seopo-myeon, Sacheon-si, Gyeongsangnam-do on November 2, 2012 (Table 2).

Navicula pavillardii Hustedt 1939: 635 (Figs. 2e-2f and 4h)

References: Hendey 1964, p. 204; Krammer and Lange-Bertalot 1999, p. 118, pl. 39, figs 4, 5.

Specimen examined: NIBRDI0000130096.

Valves linear to lanceolate sometimes in the middle concave edges and wedge-shaped, lean, fairly acute to obtuse rounded ends. Length 36.9–57.7 µm, width 7.7–8.2 µm. Striae continuous radially around 12–14 in 10 µm, areolae fairly coarse to 28 in 10 µm. Raphe straight. Central raphe ending slightly expanded. Polar raphe fissure hooked to one side.

Korean distribution: *Navicula pavillardii* was only observed from Daeseo-myeon, Goheung-gun, Jeollanam-do, Korea on November 2, 2012 (Table 2).

Family Pleurosigmataceae Mereschowsky

Gyrosigma subtile (Brébisson) Reid 2003 (Figs. 2a and 5a-5b)

Basionym: *Navicula subtilis* Brébisson in Kützing 1849.

Synonym: *Scalprum subtile* (Brébisson) Kuntze 1891; *Pleurosigma subtile* (Brébisson) Ralfs in Pritchard 1861.

References: Kützing 1849, p. 87; Pritchard 1861, p. 917; Kuntze 1891, p. 919; Reid and Williams 2003, p. 139, figs 57–61.

Valve vaulted, linear, sigmoid, tapering to obtuse apices. Length 335–400 µm, width 30–40 µm. Transverse

striae 16–26 in 10 µm, longitudinal striae 14–16 in 10 µm. Raphe central, with double curvature. Central area transapically offset, with flattened central bars. Central hyaline area large. A row of pores, arranged in an arc, occurs above the helictoglossa.

Korean distribution: *Gyrosigma subtile* was observed at two sites in South Sea and East Sea, respectively (Table 2).

Gyrosigma turgida (Stidolph) Stidolph 1988 (Figs. 2b and 5c-5d)

Basionym: *Gyrosigma balticum* var. *turgidum* Stidolph 1980.

Synonym: *Gyrosigma perthense* John 1983.

References: Stidolph 1980, p. 385; John 1983, p. 115, pl. 48, figs. 1–3; Stidolph 1988, p. 380, figs. 6–10.

Specimen examined: NIBRDI0000130097.

Valves linear, sigmoid, oblong, gently inflated at the center. Length 148–256 µm, width 18–19 µm. Transverse striae 20–25 in 10 µm, longitudinal striae 19–20 in 10 µm. Raphe undulate, eccentric. Central area transapically offset, with smooth flattened central bars. No hyaline area at the apex. A series of minute pores surrounds the apex of the valve beyond the terminal raphe fissures and the helictoglossa.

Korean distribution: *Gyrosigma turgida* was observed two times in Yellow Sea and South Sea (Table 2).

Pleurosigma decorum Smith 1853 (Figs. 2g and 5e-5f)

Synonym: *Gyrosigma decorum* (W. Smith) Griffith & Henfrey 1856; *Scalprum decorum* (Smith) Kuntze 1891.

References: Smith 1853, 63, pl. 21, fig. 196; Griffith and Henfrey 1856, p. 302; pl. 11, fig. 26; Kuntze 1891, p. 919.

Specimen examined: NIBRDI0000130098.

Valves lanceolate, sigmoid, with sides between the middle and the end one convex and the opposite barely concave, vaulted and with sub-acute apices. Length 200–310 µm, width 20–28 µm. Transverse striae 18–20 in 10 µm, longitudinal striae 15–18 in 10 µm. Central area conspicuous, saddle-shaped, internally short and raised, with central bars surrounding the central nodule. Terminal endings finishing in helictoglossa turned by a siliceous ridge.

Korean distribution: *Pleurosigma decorum* was observed two times from Yellow Sea and South Sea (Table 2).

Pleurosigma inflatum Shadbolt 1854 (Figs. 2h and 5g-5h)

Synonym: *Pleurosigma naviculaceum* Brébisson 1854, *Pleurosigma transversal* (Griffith & Henfrey) Smith 1856.

References: Shadbolt 1854, p. 16, pl. 1, fig. 9; Brébisson 1854, p. 255, pl. 1, fig. 7; Smith 1856, p. 96.

Specimen examined: NIBRDI0000130099.

Valve only slightly sigmoid, broadly lanceolate, with acutely rounded and slightly rostrate apices. At valve center slightly vaulted, towards the apices more strongly vaulted. Length 148–150 µm, width 16–26 µm. Transverse striae 22–30 in 10 µm, longitudinal striae 22–30 in 10 µm. Central area slightly convex, with thin central bars. Central hyaline area large.

Korean distribution: *Pleurosigma inflatum* was observed at four sites in South Sea and East Sea (Table 2).

***Pleurosigma patagonicum* (Ferrario & Sar) Sterrenburg & Sar 2012 (Figs. 2i and 5i-5j)**

Synonym: *Pleurosigma chilensis* var. *patagonica* Ferrario & Sar 1990.

References: Ferrario and Sar 1990, p. 201, figs. 1–6; Sar et al. 2012, p. 248, figs. 59–76.

Specimen examined: NIBRDI0000130102.

Valves narrowly lanceolate to sub-rhomboidal, straight, tapering gradually towards the acute apices, slightly vaulted near the ends. Length 98–152 µm, width 10–17 µm. Transverse striae 20–25 in 10 µm, longitudinal striae 15–16 in 10 µm. Central area very small, orbicular, symmetric, funnel-shaped. Internal apices with one or two isolated pores in apical position and two rows of slits placed laterally at the last section of raphe-sternum towards the helictoglossa. No central hyaline area.

Korean distribution: *Pleurosigma patagonicum* was observed at two sites from East Sea (Table 2).

***Pleurosigma speciosum* Smith 1852 (Figs. 2j and 5k-5l)**

Synonym: *Gyrosigma speciosum* (Smith) Griffith & Henfrey 1856; *Scalprum speciosum* (Smith) Kuntze 1891.

References: Smith 1852, p. 6, pl. 1, fig. 3; Griffith and Henfrey 1856, p. 302, pl. 11, fig. 28; Kuntze 1891, p. 919.

Specimen examined: NIBRDI0000130103.

Valves linear and slightly attenuated at the apices, which are obtuse. Length 268–270 µm, width 28–33 µm. Transverse striae 16–17 in 10 µm, longitudinal striae 10–11 in 10 µm. Central bars smooth and slender and of approximately equal length. Central hyaline area adjacent to the central bars.

Korean distribution: *Pleurosigma speciosum* was observed two times in East Sea (Table 2).

***Pleurosigma williamsii* Reid 2002 (Figs. 2k and 5m-5n)**

References: Reid 2002, p. 80, figs. 9–17.

Specimen examined: NIBRDI0000130104.

Description: Valves lanceolate, barely sigmoid, gently curving to obtusely rounded ends. Length 136–192 µm,

width 22–34 µm. Transverse striae 18–20 in 10 µm, longitudinal striae 1213 in 10 µm. Central bars smooth and of approximately equal length. No central hyaline area next to the central bars. Extra siliceous thickening at the apices and valve margin, giving a hyaline area around the edge of the valve.

Korean distribution: *Pleurosigma williamsii* was observed three times in Yellow Sea and East Sea (Table 2).

**Order Surirellales D.G. Mann
Family Auriculaceae Hendey**

***Auricula complexa* (Gregory) Cleve 1894 (Fig. 3a)**

Basionym: *Amphiprora complexa* Gregory 1857.

References: Gomes et al. 1989, p. 6, fig. 1; Ruck and Kociolek 2004, pl. 2, fig. 2; Teanpisut and Patarajinda 2007, p. 122, pl. 2, fig. 31.

Specimen examined: NIBRDI0000130105.

Valve with ear-shaped outline. Length 60.0 µm, width 35.6 µm. Striae flabellate, radiating from ventral margin to dorsal raphe canal, 16–18 in 10 µm. Costae frequently bifurcated. Raphe canal is eccentric, present on slightly raised keel along the dorsal margin. Mantle well-developed on dorsal side only, becoming almost absent at the ventral margin.

Korean distribution: *Auricula complexa* was observed at two sites from South Sea (Table 2).

***Auricula flabelliformis* M.Voigt 1960 (Figs. 3b-3c and 4i)**

References: Ruck and Kociolek 2004, pl. 2, fig. 5, pl. 6, fig. 3.

Specimen examined: NIBRDI0000130106.

Valve with shellfish-shaped outline. Length 82–115.7 µm, width 56.7–75.7 µm. Striae flabellate, radiating from center of the ventral margin to dorsal raphe canal, 16–18 in 10 µm. Costae frequently bifurcated. Raphe canal surrounded valve margin, present on slightly raised keel along entire valve.

Korean distribution: *Auricula flabelliformis* was observed at three sites from Yellow Sea and East Sea (Table 2).

Family Surirellaceae Kützing

***Campylodiscus ambiguus* Greville 1860 (Fig. 3d and 3e)**

References: Schmidt 1875, pl. 18, figs. 23–26; Ruck and Kociolek 2004, p. 163, pl. 36, figs. 1–7, p. 165, pl. 37, figs. 8–12, p. 167, pl. 38, figs. 13–18.

Specimen examined: NIBRDI0000130107.

Valve circular to sub-circular, saddle-like, with barely

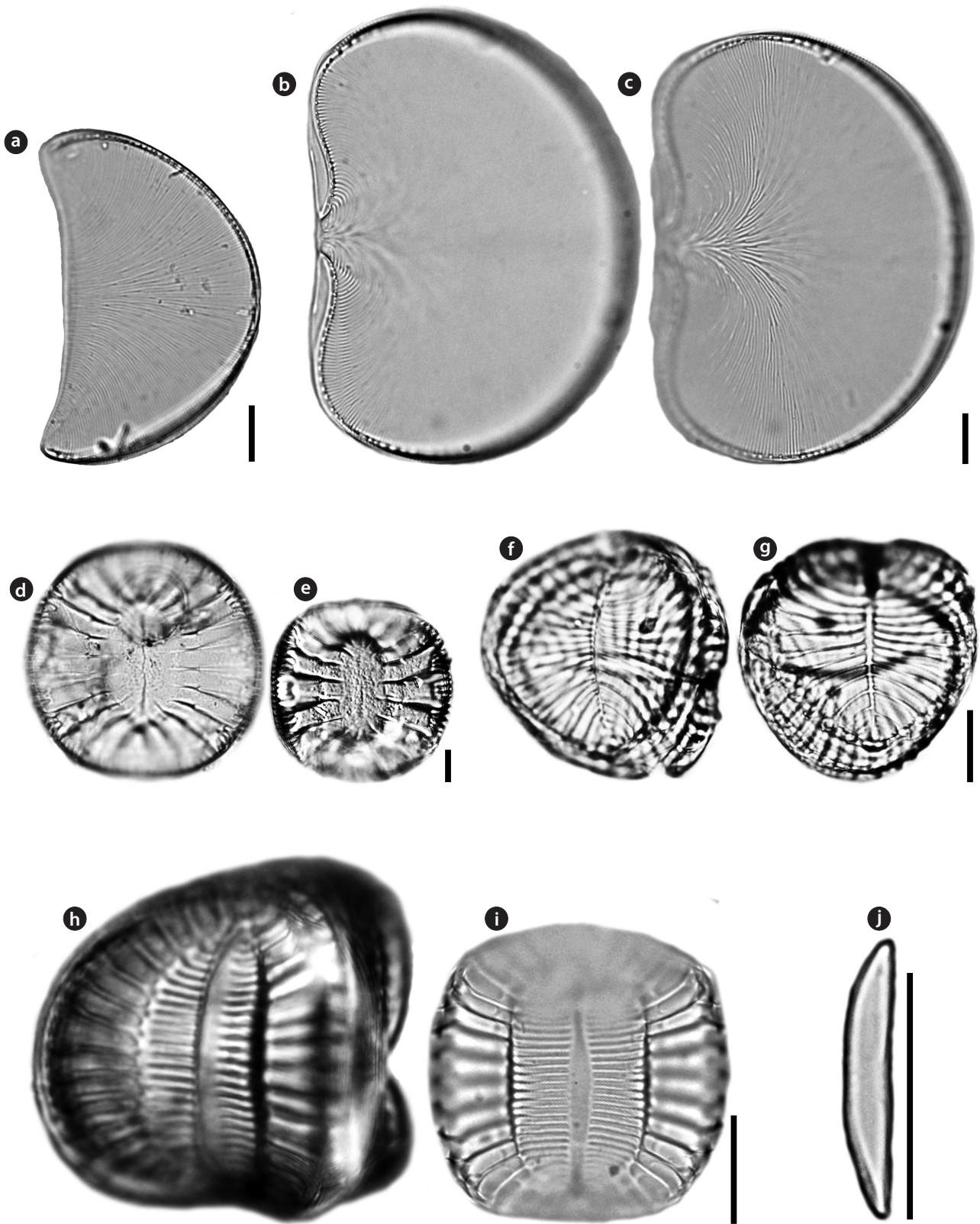


Fig. 3. Light microscopy (LM) microphotographs. (a) *Auricula complexa*, (b, c) *Auricula flabelliformis*, (d, e) *Campylodiscus ambiguus*, (f, g) *Campylodiscus decorus*, (h, i) *Campylodiscus samoensis*, and (j) *Catenula adhaerens*. Scale bars, 10 μm.

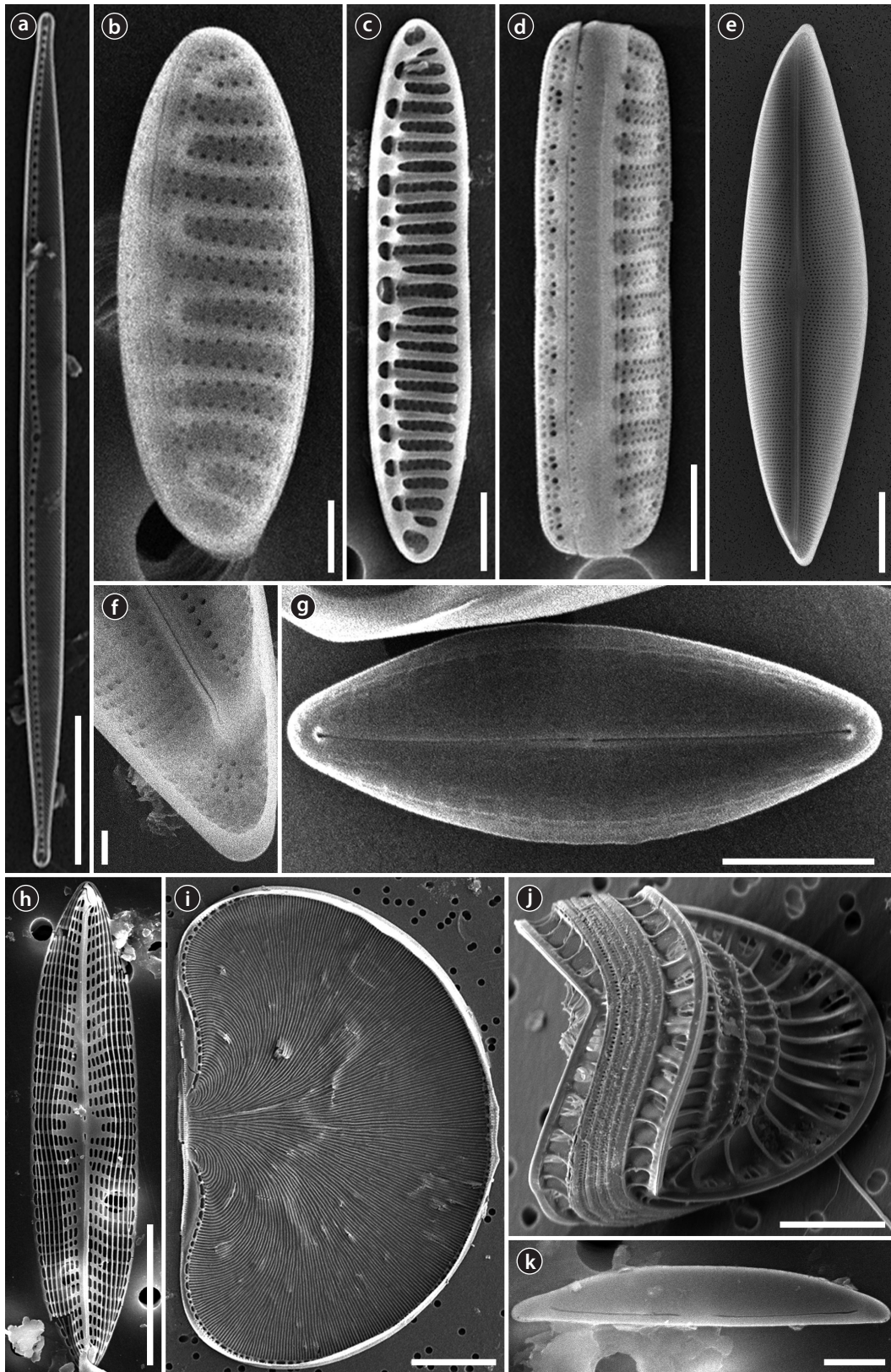


Fig. 4. Scanning electron microscopy (SEM) microphotographs. (a) *Nitzschia improvisa*, (b-e) *Nitzschia valdestriata*, (e, f) *Parlibellus hamulifer*, (g) *Parlibellus rhombicus*, (h) *Navicula pavilladii*, (i) *Auricula flabelliformis*, (j) *Campylodiscus samoensis*, and (k) *Catenula adhaerens*. Scale bars represent: 20 μm (a, i); 1 μm (b, f); 2 μm (c, d, g, k); 10 μm (e, h).

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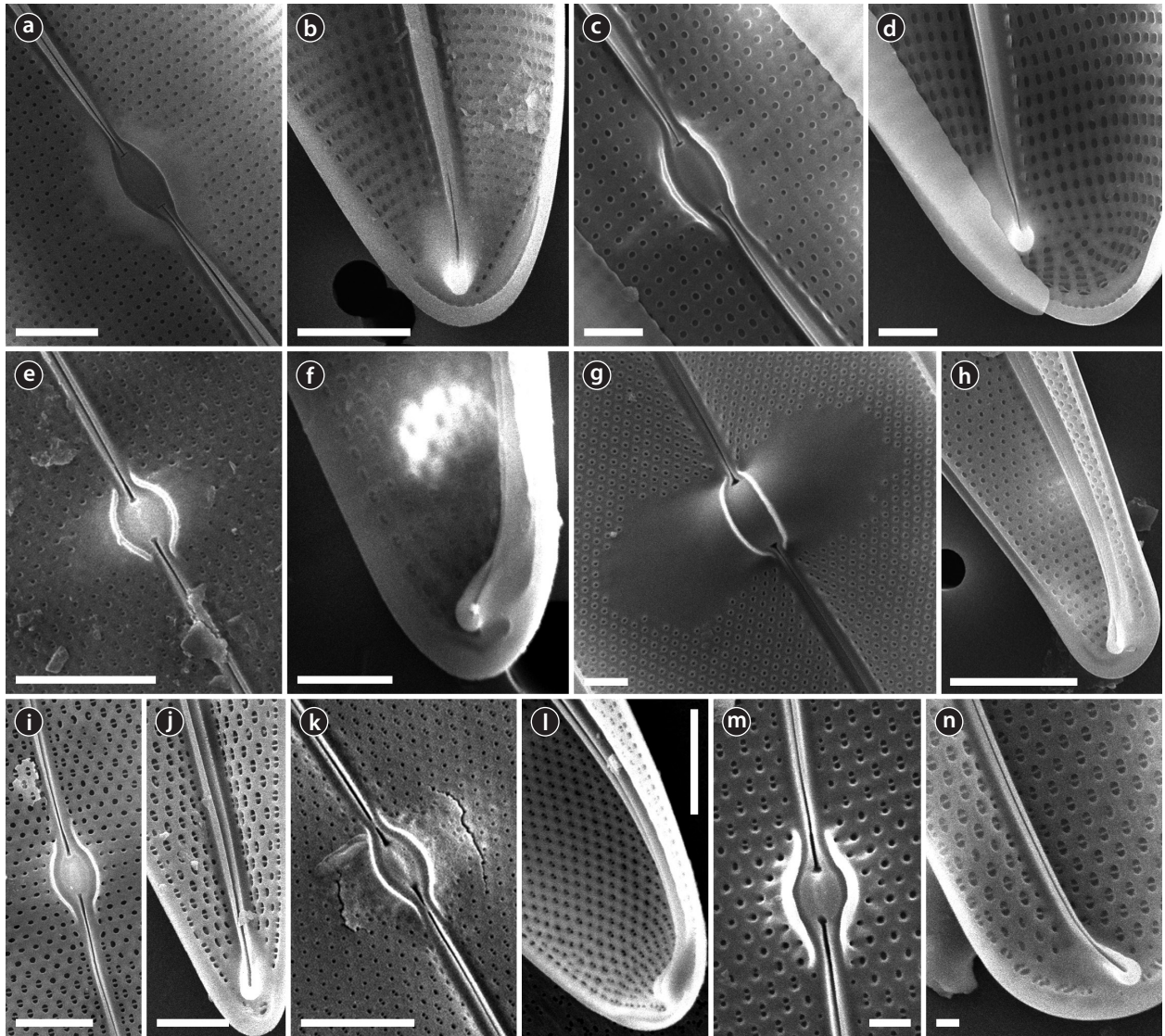


Fig. 5. Scanning electron microscopy (SEM) microphotographs. Internal central areas (a, c, e, g, i, k, m), raphe-sternum and helicoglossa (b, e, f, h, j, n) in *Gyrosigma* and *Pleurosigma*. (a, b) *Gyrosigma subtile*, (c, d) *Gyrosigma turgida*, (e, f) *Pleurosigma decorum*, (g, h) *Pleurosigma inflatum*, (i, j) *Pleurosigma patagonicum*, (k-l) *Pleurosigma speciosum*, and (m, n) *Pleurosigma williamsii*. Scale bars represent 5 μm (a, b, e, h, k, l), 2 μm (c, d, f, g, i, j), and 1 μm (m, n).

noticeable ribs, 45–107 μm in diameter. A circular and shallow navel in the middle of the valve depression. Central area marked by two ridges that expand the length of the axis. The central ridges and the area between them are hyaline without any striations.

Korean distribution: *Campylodiscus ambiguus* was only observed at Aewol-ri, Aewol-eup, Jeju-si, Jeju-do on March 11, 2012 (Table 2).

***Campylodiscus decorus* Brébisson 1854 (Fig. 3f-3g)**

References: Schmidt 1875, pl. 14, figs. 4–5; Stidolph 1980, p. 403, pl. 14, fig. 10; Lobban et al. 2012, p. 469, pl.

64, figs. 5–6.

Specimen examined: NIBRDI0000130108.

Valve circular to sub-circular, saddle-like, with barely noticeable ribs, 28 μm in diameter. Central area narrow and marginal ribs expand toward the center. Infundibula absent, single tubes connect the interior cell to the canal raphe. Fenestral openings have one or two fenestral bars each. Narrow ribs extending from keel to very narrow lanceolate. The pores in this species are resolvable in LM.

Korean distribution: *Campylodiscus decorus* was observed two times in East Sea (Table 2).

***Campylodiscus samoensis* Grunow in Schmidt 1875 (Figs. 3h-3i and 4j)**

References: Schmidt 1875, pl. 15, figs. 19–20; Schmidt 1897, pl. 207, fig. 14; Stidolph et al. 2012, pl. 21, fig. 16.

Specimen examined: NIBRDI0000130109.

Valve circular to sub-circular, saddle-like, with barely noticeable ribs. Infundibula visible around the margin of the valve. Central area marked by two ridges that extend the length of the apical axis. The central ridges and the area between them are transapically striated.

Korean distribution: *Campylodiscus samoensis* was observed at four sites from Yellow Sea and South Sea (Table 2).

**Order Thalassiophysales D.G. Mann
Family Catenulaceae Mereschkowsky**

***Catenula adhaerens* (Mereschkowsky) Mereschkowsky 1903 (Figs. 3j and 4k)**

Basionym: *Navicula adhaerens* Mereschkowsky 1901.

References: Sundbäck and Medlin 1986, p. 284, figs. 1–23.

Specimen examined: NIBRDI0000130110.

Valves bilaterally symmetrical, elliptical to linear-elliptical, with rounded apices. Apices slightly deflected to the ventral part. Length 7–21 µm, width 1.5–3.5 µm. Striae very fine, unresolvable. Raphe close to the ventral part, slightly deflected toward the dorsal part. Central raphe endings slightly expanded. Terminal raphe endings distant from the apices.

Korean distribution: *Catenula adhaerens* was observed twice in the Yellow Sea and East Sea (Table 2).

DISCUSSION

The number of diatoms has been estimated approximately 100,000 species in over 1,000 genera (Mann 1999, Fourtanier and Kociolek 1999, 2003). Despite of the high species diversity in the world, there have been approximately 1,000 diatom species in Korea (Lee et al. 1995, Lee 1995, Lee et al. 2012, Joh 2013). The diversity of diatoms in Korea is relatively low compared to the world record. In the present study, the new recorded pennate diatoms imply several reasons why the taxa have not been recorded in Korea. First, some genera such as *Navicula*, *Nitzschia*, *Gyrosigma*, *Pleurosigma*, and *Campylodiscus* have the high species diversity. These genera commonly include more than 100 species reported from worldwide.

It is difficult to identify the species positively through the comparison from widespread diverse literatures. In addition, many taxa have been corrected nomenclaturally and separated to the new genera (Round et al. 1990, Lange-Bertalot 2001). It is needed to confirm the validity of species from widespread literatures before the reporting of species newly in Korea, and to intensively study the highly diverse genera like *Thalassiosira* and *Chaetoceros* (Park and Lee 2010, Lee et al. 2014).

Second, some species is probably confused to the morphologically similar taxa. *Cocconeopsis wrightii* has been primarily described as *Cocconeis wrightii* (O'meara). The features of *C. wrightii* caused the confusion of positive identification: The frustule outline of *C. wrightii* is similar to the raphe-bearing valve of *Cocconeis*, but the species does not have the araphid valve like *Cocconeis*; the coarse and radial arrangement of areolae is similar to *Mastogloia bionata*, but the partectal ring of *Mastogloia* species lack in *C. wrightii* (Riaux-Gobin and Compère 2004). These confusions may be caused when the specimens were only observed under LM. Therefore, it is essential to examine specimens by using electron microscope for avoiding these confusions.

Third, several species only occurred from specific habitat. Most pennate diatoms have been mainly reported to live in diverse substrates such as plants, macroalgae, hard rock, and sediments (Round et al. 1990, Joh 2013). *Catenula adhaerens* has been reported from benthos and sand grains as the episammic diatom in worldwide (Sundbäck and Medlin 1986). In this study, *C. adhaerens* was also collected from the seaside (Table 2). The floristic studies on diatom from specific area such as seaside contribute to understand the diversity of Korean diatom. Beside above mentioned reasons concerning new recorded taxa in Korea, there are more various reasons such as nano-sized species, weakly silicified species, etc. To understand the diversity of diatom in Korea, it is mostly important to pay the consistent attention with continuous monitoring from diverse areas.

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