ISSN 1226-9999 (print)
ISSN 2287-7851 (online)

Korean J. Environ. Biol. 35(3) : 215~226 (2017) https://doi.org/10.11626/KJEB.2017.35.3.215

〈Original article〉

New Records of the Diatoms (Bacillariophyta) in the Brackish and Coastal Waters of Korea

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Abstract - A study on indigenous diatoms was carried out at 10 sites from May 2014 to December 2016 in marine and freshwater in Korea. Seventeen species of diatoms are new to Korea and they are divided into 3 classes, 4 subclasses, 10 orders, 14 families, and 16 genera. The nomenclatures, references, dimensions, specimens examined, local habitat, distribution in Korea, and photograph are reported here. Seventeen species found in marine, freshwater, and brackish water showed species-specific habitats.

Key words : Bacillariophyta, diatom flora, first record, indigenous species

INTRODUCTION

Diatoms are abundant in nearly every aquatic habitat such as oceans, lakes, streams, mosses, soils, and even the bark of trees. Diatoms are responsible for over 40 percent of photosynthesis in the world's oceans, and without them, the ocean would be unable to support the amount of life that it does. The number of diatoms are an estimated 20,000 to 200,000 species in the world. This range is large because specialists are still working to understand basic aspects about "what is a diatom species," and because new and diverse forms of diatom species are still being discovered and described in scientific publications.

Since the project, "Survey and Excavation of Korean Indigenous Species" started in 2006 under the National Institute of Biological Resources (NIBR), an organization of the Ministry of Environment of Korea, many diatom species have been newly reported to Korea and the species richness of the diatom gradually increases in the meantime. Lee and Joh (2015) arranged the publications on diatoms in Korea and complied the checklist of diatoms. They divided the Korean diatom species based on the habitat, namely freshwater and marine. The marine diatom was 520 species and freshwater was 1,495. Therefore, the total number of diatom species in Korea was 2,015 diatom species. Nevertheless, the effort for excavation for diatom species in Korea, many species are still unrevealed from Korean waters. This is the serial study as the fourth publication for the Korean diatoms follows Lee *et al*. (2012), Park *et al*. (2014), and Lee and Park (2015). Seventeen diatom species are newly reported with their distributional patterns.

MATERIALS AND METHODS

The materials were collected at 9 sites from May 2014 to December 2016, from marine and freshwater in Korea

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Table 1. The sampling sites on the newly reported diatoms species in Korea.

Sites	Date	Locality	Latitude (N)	Longitude (E)
1	Aug. 11, 2016	Oepo-ri, Naega-myeon, Ganghwa-gun, Incheon, Korea	37°42′00″	126°22′44″
2	Dec. 22, 2016	Mohang-ri, Sowon-myeon, Taean-gun, Chungcheongnam-do, Korea	36°46′37″	126°07′56″
3	May 24, 2014	Daehang-ri, Byeonsan-myeon, Buan-gun, Jeollabuk-do, Korea	35°40′37″	126°31′38″
4	Mar. 26, 2015	Chido-ri, Wido-myeon, Buan-gun, Jeollabuk-do, Korea	35°35′23″	126°16′11″
5	Jun. 24, 2014	Mara-ri, Daejeong-eup, Seogwipo-si, Jeju-do, Korea	33°07′20″	126°16′11″
6	Jun. 13, 2016	Seongsan-ri, Seongsan-eup, Seogwipo-si, Jeju-do, Korea	33°28′07″	126°55′34″
7	Sep. 2, 2014	Hadan-dong, Saha-gu, Busan, Korea	35°06′39″	128°56′21″
8	Sep. 2, 2014	Hyeonchang-ri, Ibang-myeon, Changnyeong-gun, Gyeongsangnam-do, Korea	35°30′30″	128°23′33″
9	Jul. 3, 2015	Gyeonso-dong, Gangneung-si, Gangwon-do, Korea	37°46′22″	128°57′05″

(Table 1). Phytoplankton were collected using 20-μm-mesh nets by vertical and/or horizontal towing. The collected materials were fixed with 4% neutralized formalin. The cell organelles and organic matters in the materials were removed to observe the fine structure and specific characters of diatoms (Hasle and Fryxell 1970). Some cleaned material was mounted in Pleurax and observed at ×400 to ×1,000 magnification, using a light microscope (Eclipse 80i; Nikon, Tokyo, Japan) with a digital camera (DS-Fi1; Nikon, Tokyo, Japan). The remaining material was filtered on 3.0 μm-pore-size polycarbonate membrane. The filtered membrane was dried in air and attached to an aluminum stub using carbon tape. The membrane on the stub was coated with gold-palladium and examined using a scanning electron microscope (JSM-5600LV; JEOL, Tokyo, Japan). Diatom identifications were mainly based on the specific references that provided with the species description.

RESULT AND DISCUSSION

Seventeen species of diatoms were newly recorded from marine and freshwater in Korea. As shown in the following, diatom taxa were composed of 3 classes, 3 subclasses, 9 orders, 13 families, and 15 genera based on the system of Round *et al*. (1990), Medlin and Kaczmarska (2004), and Medlin (2016). We described the taxonomic information of diatoms, illustrations, classifications, references, basionyms, synonyms, and distributions.

Phylum Bacillariophyta L.S. Dillon 1963
Class Coscinodiscophyceae Round & R.M. Crawford in Round *et al*. 1990
Subclass Coscinodiscophycidae Round & R.M. Crawford in Round *et al*. 1990
Order Coscinodiscales Round & R.M. Crawford in Round *et al*. 1990
Family Hemidiscaceae Hendey ex Hasle 1964
Genus *Azpeitia* M. Peragallo 1912
A. africana (Janisch ex A. Schmidt) G. Fryxell & T.P. Watkins 1986

Class Mediophyceae (Jousé & Proshkina-Lavrenko) Medlin & Kaczmarska 2004
Subclass Biddulphiophycidae Round & R.M. Crawford in Round *et al*. 1990
Order Biddulphiales Krieger 1954
Family Biddulphiaceae Kützing 1844
Genus *Lampriscus* A. Schmidt 1882
L. kittonii A. Schmidt 1882

Class Bacillariophyceae Haeckel 1878
Subclass Bacillariophycidae D.G. Mann in Round *et al*. 1990
Order Lyrellales D.G. Mann in Round *et al*. 1990
Family Lyrellaceae D.G. Mann in Round *et al*. 1990
Genus *Lyrella* Karajeva 1978
L. impercepta (Hustedt) J.L. Moreno in Moreno *et al*. 1996
L. majuscula (Hustedt) Witkowski in Moser *et al*. 1998

Order Mastogloiales D.G. Mann in Round *et al*. 1990
Family Mastogloiaceae Mereschkowsky 1903
Genus *Tetramphora* Mereschkowsky 1903
T. intermedia (Cleve) Stepanek & Kociolek 2016

Order Cymbellales D.G. Mann in Round *et al*. 1990

Family Gomphonemataceae Kützing 1844
Genus *Encyonema* Kützing 1834
E. appalachianum M. Potapova 2014
Genus *Gomphonema* Ehrenberg 1832
G. inaequilongum (H. Kobayasi) Kobayasi & Mayama in Mayama *et al*. 2002

Order Naviculales Bessey 1907
Family Diploneidaceae D.G. Mann in Round *et al*. 1990
Genus *Diploneis* Ehrenberg ex Cleve 1894
D. nitescens (Gregory) Cleve 1894

Family Naviculaceae Kützing 1844
Genus *Cymatoneis* Cleve 1894
C. sulcata (Greville) Cleve 1894
Genus *Seminavis* D.G. Mann in Round *et al*. 1990
S. latior (A. Schmidt) Danielidis & D.G. Mann 2003

Family Sellaphoraceae Mereschkowsky 1902
Genus *Sellaphora* Mereschkowsky 1902
S. saugerresii (Desmazières) Wetzel & D.G. Mann in Wetzel *et al*. 2015

Family Pinnulariaceae D.G. Mann in Round *et al*. 1990
Genus *Pinnularia* Ehrenberg 1843
P. rectangulata (Gregory) Rabenhorst 1864
P. trevelyana (Donkin) Rabenhorst 1864

Family Pleurosigmataceae Mereschowsky 1903
Genus *Pleurosigma* W. Smith 1852
P. rushdyensis G. Reid 2002

Order Thalassiophysales D.G. Mann in Round *et al*. 1990
Family Catenulaceae Mereschkowsky 1902
Genus *Amphora* Ehrenberg ex Kützing 1844
A. belgica Grunow 1882−1885

Order Bacillariales Hendey 1937
Family Bacillariaceae Ehrenberg 1831
Genus *Cymbellonitzschia* Hustedt 1924
C. szulczewskii Witkowski, Lange-Bertalot & Metzeltin 2000

Order Surirellales D.G. Mann in Round *et al*. 1990
Family Surireallaceae Kützing 1844
Genus *Surirella* Turpin 1828
S. taeniata Hustedt in Schmidt *et al*. 1925

***Azpeitia africana* (Janisch ex A. Schmidt) G. Fryxell & T.P. Watkins 1986 (Fig. 1)**

References: Schmidt 1874−1959, pl. 59, figs. 24, 25; Simonsen 1974, p. 13, pl. 9, fig. 1; Fryxell *et al*. 1986, p. 22, figs. XXII, XXIII, XXXII-1, 2; Hasle and Syvertsen 1996, p. 124, pl. 20.

Basionym: *Coscinodiscus africanus* Janisch ex A. Schmidt 1878

Specimen examined: NIBRDI0000136860

Valves circular, sometimes slightly elliptical, 30.2 μm in diameter. Areola rows radiating from the annulus and, in larger specimens, in spiraling rows, 9 in 10 μm. Annulus distinct, eccentric and consisted of larger areolae surrounded by small areolae. Central rimoportula on edge of an eccentric circle of linearly arranged areolae. Distinct external marginal slits leading into rimoportulae, 2.3−4.3 μm apart.

Distribution: *Azpeitia africana* has been found in warm water regions: the African, Indian, Arabian Sea, and the Persian Gulf (Simonsen 1974); Gulf stream warm core rings and the Central Pacific and Gulf of Mexico (Fryxell *et al*. 1986).

Distribution in Korea: This species was found at Jeju Island on Jun. 3. 2016 (Fig. 25i).

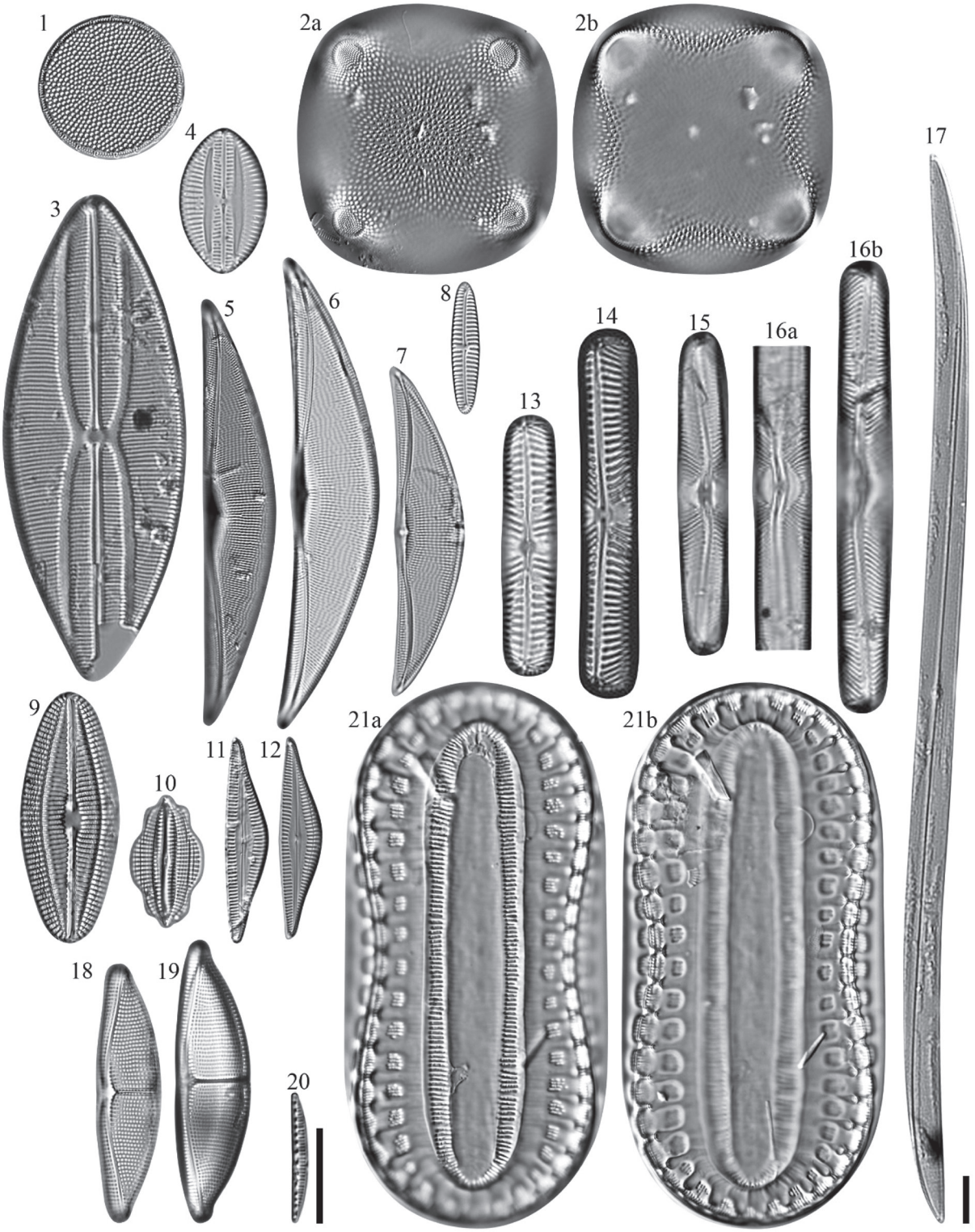
***Lampriscus kittonii* A. Schmidt in Schmidt *et al*. 1882 (Fig. 2a, b)**

Reference: Round *et al*. 1990 p. 222.

Specimen examined: NIBRDI0000137261

Valves quadrangular with distinct elevations in the valve corner, 73.4 μm in diameter. Striae radiate from valve center and continue without a break down the deep valve mantle. Areolae elliptical, occluded by rotae, occasional simple pores present, 5−6 in 10 μm in a striae row. Pseudocelli four, lying on slight elevations, are much smaller than the valve areolae and tend to form linear arrays both inside and outside the rim. The orientation of these arrays differs and the external rows have a line of discontinuity at the angle of the valve. One rimoportula located on valve center within central large annulus.

Distribution: *Lampriscus kittonii* has been found from



Figs. 1−21. Light micrographs of fifteen diatom species. Fig. 1. *Azpeitia africana*. Fig. 2. *Lampriscus kittonii*. Fig. 3. *Lyrella impercepta*. Fig. 4. *Lyrella majuscula*. Figs. 5−7. *Tetramphora intermedia*. Fig. 8. *Encyonema appalachianum*. Fig. 9. *Diploneis nitescens*. Fig. 10. *Cymatoneis sulcata*. Figs. 11, 12. *Seminavis latior*. Figs. 13, 14. *Pinnularia rectangulata*. Figs. 15, 16. *Pinnularia trevelyana*. Fig. 17. *Pleurosigma rushdyense*. Figs. 18, 19. *Amphora belgica*. Fig. 20. *Cymbellonitzschia szulczewskii*. Fig. 21. *Surirella taeniata*. Scale bar = 10 μm. The lower right corner of the scale bar applied all figures except for fig. 20.

warm water region: Europe, Italy, Adriatic Sea (Vilicic *et al*. 2002).

Distribution in Korea: This species was observed at Marado Island in Jun. 24, 2016 (Fig. 25h).

***Lyrella impercepta* (Hustedt) J.L. Moreno in Moreno, Licea & Santoyo 1996 (Fig. 3)**

Reference: Hustedt 1961−1966, p. 471, fig. 1530.

Basionym: *Navicula impercepta* Hustedt 1964

Specimen examined: NIBRDI0000137273

Valves broadly elliptical, with broadly rounded apices, 20−40 μm long, and 13−21 μm wide. Areolae 14−28 in 10 μm. Striae parallel in the middle parts and slightly convergent towards the ends, 7−9 rows in 10 μm. Raphe straight, external central endings moderately distant and large, axial area narrowly linear. The distal raphe fissures shortly hooked to the same side. Two axial area branches expanded, narrowly lanceolate, becoming narrower near the central pores and the terminal fissures. Central area almost rectangular, connected with broad lateral area, not geniculate in middle, tapering to a position distance from poles, curving weakly towards the axial area.

Distribution: *Lyrella impercepta* was reported in subtidal sediments and was found at Magdalena Bay, Baja, California Sur, Mexico (López-Fuerte *et al*. 2010); Laguna Guerrero Negro, Mexico (Siqueiros-Beltrones *et al*. 2017).

Distribution in Korea: This species was found at intertidal zone in the Byeonsan Peninsula, Yellow Sea in May 24, 2014 (Fig. 25f).

***Lyrella majuscula* (Hustedt) Witkowski in Moser *et al*. 1998 (Fig. 4)**

Reference: Nevrova *et al*. 2013, p. 23, figs. 86−95.

Basionym: *Navicula majuscula* Hustedt 1964

Specimen examined: NIBRDI0000137274

Valves linear to linear-elliptic, with broadly rounded apices, 92.8 μm long, and 31.4 μm wide. Areolae 18−26 in 10 μm. Striae radiate in the valve slightly, very finely punctate, 12−14 rows in 10 μm. Raphe strongly straight, external central endings somewhat distant. Axial area narrowly linear. Central area narrow and transversely rectangular shape, frequently developed at one side and connected to lateral areas. Lateral areas narrowly linear up to the margins of the apices, slightly constricted in the middle, encompassing 1/3−1/2 of the valve width.

Distribution: *Lyrella majuscula* is marine and brackish species, known from the tropical area of the Pacific Ocean (Witkowski *et al*. 2000); Black Sea, Crimean Peninsula.

Distribution in Korea: This species was found at Mohang coastal water in the Yellow Sea on Dec. 22, 2016 (Fig. 25b).

***Tetramphora intermedia* (Cleve) Stepanek & Kociolek 2016 (Figs. 5−7)**

References: Wachnicka and Gaiser 2007, p. 419, fig. 118, Stepanek and Kociolek 2016, p. 131, figs. 35−44.

Basionym: *Amphora rhombica* var. *intermedia* Cleve 1895

Specimen examined: NIBRDI0000137266

Valves asymmetrical, dorsal part convex, and ventral one nearly straight with acutely rounded and weakly ventrally deflected apcies. Apical axis 68.3−110.4 μm long and transapical axis 14.1−18.4 μm wide. Striae uniseriate, radiate throughout, 14−18 in 10 μm. Raphe biarcuate, and lying near the ventral margin. Proximal and distal raphe ends externally ambiguous due to the valve curvature. Axial area narrow throughtout.

Distribution: *Tetramphora intermedia* was found at Florida Bay, USA (Wachnicka and Gaiser 2007; Stepanek and Kociolek 2016).

Distribution in Korea: This species was observed at the lagoon of Jeju Isalnd on Jun. 13, 2016 (Fig. 25k).

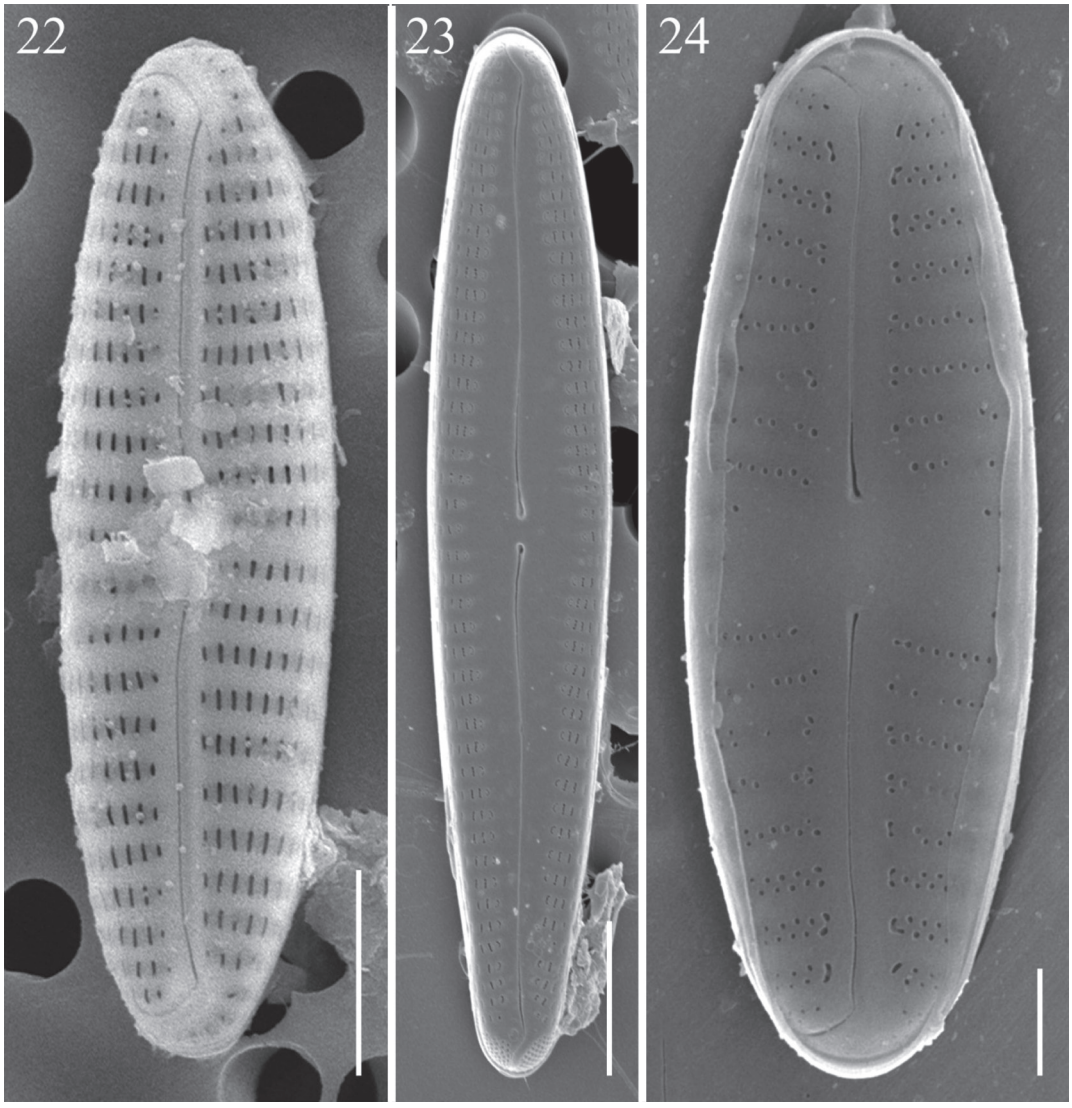
***Encyonema appalachianum* M. Potapova 2014 (Figs. 8, 22)**

Reference: Potapova 2014, p. 116, figs. 1−12.

Specimen examined: NIBRDI0000137264

Valves linear-lanceolate, very slightly dorsiventral with rounded and slightly protracted ends. Apical axis 24.8−37.3 μm long, transapical axis 7−8 μm wide. Areolae apically elongated, approximately 24−27 in 10 μm. Striae parallel, 9−10 in 10 μm, mostly uniseriate, occasionally biseriate. Striae continue uninterrupted around valve apices. Raphe lateral with sharply bent terminal fissures. Axial area narrow linear. Central area formed by considerably shortened stria on ventral side and very slightly shortened stria on dorsal side.

Distribution: *Encyonema appalachianum* was firstly described at Youghiogheny River in Pennsylvania, USA on May 4, 2013 (Potapova 2014).



Figs. 22–24. Scanning electron micrographs of three raphid diatoms species. Fig. 22. *Encyonema appalachianum*. Fig. 23. *Gomphonema inaequilongum*. Fig. 24. *Sellaphora saugerresii*. Scale bars = 5 μm (Figs. 22, 23), 1 μm (Fig. 24).

Distribution in Korea: This species was observed at Ganghwa Island where shown a high disturbance by tidal range and freshwater input in Aug. 11, 2016 (Fig. 25a).

Remarks: Potapova (2014) mentioned several possibilities why *E. appalachianum* has never been detected before: *E. appalachianum* is endemic species of the Western Pennsylvania. Its abundance is expanding and increasing rather than the past. With the presence from Korean water. *E. appalachianum* is not an endemic species of Western Pennsylvania. Potapova (2014) compared *E. appalachianum* with three *Encyonema* species, *E. lacustre* (Agardh) D.G. Mann, *E. rumrichae* Krammer, and *E. aueri* (Krasske) Krammer, but did not with *E. leei* (Krammer) Ohtsuk, Hanada & Nakamura which is very close to *E. appalichianum* (Ohtsuka *et al*. 2004). Once we identified the Korean specimen as *E. appalachianum* based on the valve width and striae density, this species should be considered the taxonomic relationship with *E. leei*.

***Gomphonema inaequilongum* (H. Kobayasi) Kobayasi & Mayama in Mayama *et al*. 2002 (Fig. 23)**

Reference: Kobayasi 2006, p. 101, pl. 124, figs. 1–11.

Basionym: *Gomphonema clevei* var. *inaequilongum* H. Kobayasi 1964

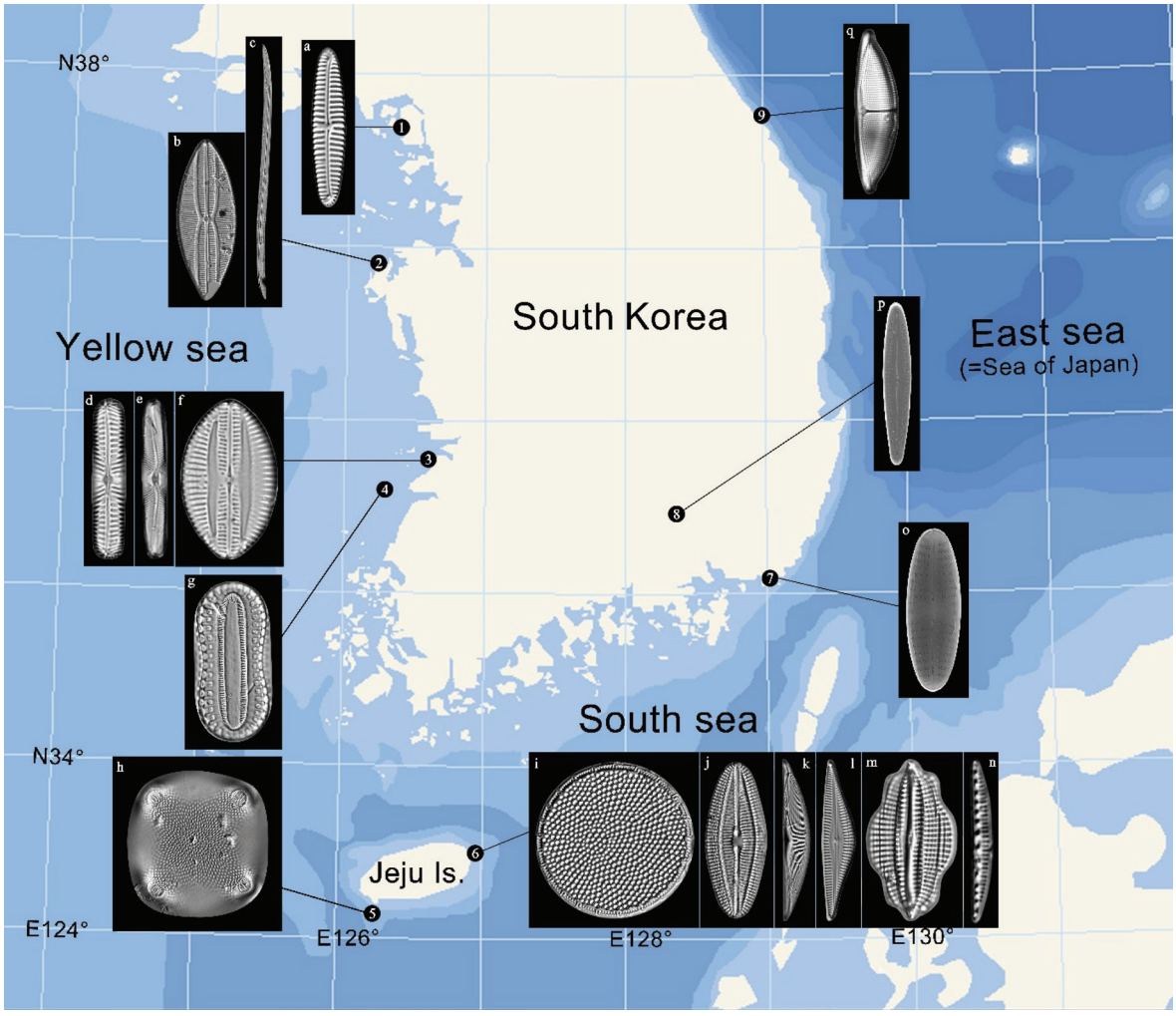


Fig. 25. The distribution of new-recorded diatoms in Korea. a. *Encyonema appalachianum*. b. *Lyrella majuscula*. c. *Pleurosigma rushdyense*. d. *Pinnularia rectangulata*. e. *Pinnularia trevelyana*. f. *Lyrella impercepta*. g. *Surirella taeniata*. h. *Lampriscus kittonii*. i. *Azpeitia africana*. j. *Diploneis nitescens*. k. *Tetramphora intermedia*. l. *Seminavis latior*. m. *Cymatoneis sulcata*. n. *Cymbellonitzschia szulczewskii*. o. *Sellaphora saugerresii*. p. *Gomphonema inaequilongum*. q. *Amphora belgica*.

Specimen examined: photo

Valves clavate with round headpole and narrow round footpole, 33.5 μm long and 5.9 μm width. Areolae apically elongated, 48 in 10 μm. Striae nearly parallel mid-valve, becoming radiate at the apices, 14 in 10 μm. Raphe slightly sinuous. Proximal raphe ends externally dilated and deflected to the primary valve side. Distal raphe ends externally bent to the secondary side. Axial area wide, lanceolate and tapered near the apices. Central area symmetric and transapically expanded. A distinct porefield present at the footpole.

Distribution: *Gomphonema inaequilongum* reported at Hagure River, Saitama in Japan (Kobayasi 2006). Despite of *G. inaequilongum* has been preliminary reported from freshwater, the co-occurrence from Korean and Japanese waters indicate *G. inaequilongum* might be a brackish water to marine species. An additional report or laboratory experiment of *G. inaequilongum* is needed to confirm its distribution.

Distribution in Korea: This species was observed in the middle part of Nakdong River on Sep. 2, 2014 (Fig. 25p).

***Diploneis nitescens* (W. Gregory) Cleve 1894 (Fig. 9)**

Reference: Schmidt 1874−1959, pl. 7, figs. 37−41.

Basionym: *Navicula smithii* var. *nitescens* W. Gregory 1857

Synonym: *Navicula nitescens* (Gregory) Ralfs in Pritchard 1861
Navicula smithii var. *nitescens* W. Gregory 1857
Navicula nitescens (Gregory) Gregory 1857
Schizonema nitescens (Gregory) Kuntze 1898
Specimen examined: NIBRDI0000137267

Valves rhomboic with broadly rounded apices, 52.6 μm long, and 20.1 μm wide. Striae radiate interrupted by longitudinal costae, 10 in 10 μm. Raphe straight enclosed in narrow siliceous ribs. Central area is apically elliptical.

Distribution: *Diploneis nitescens* has been found from warm water region: Asia, Thailand, gulf of Thailand (Kokociński *et al*. 2009).

Distribution in Korea: This species was found at the lagoon of Jeju Island on Jun. 13, 2016 (Fig. 25j).

***Cymatoneis sulcata* (Greville) Cleve 1894 (Fig. 10)**

Reference: Round *et al*. 1990, p. 578.
Basionym: *Navicula sulcata* Greville 1865
Specimen examined: NIBRDI0000137268

Valves linear-lanceolate, with apiculate apices, 27.8 μm long, 15.41 μm wide. Valve face thrown into a series of folds and bearing one or more prominent ridges parallel to apical axis. Striae uniseriate, containing apically elongate poroids, 13 in 10 μm. Raphe slightly sigmoid and eccentric. Raphe-sternum very narrow. Proximal raphe ends externally expanded and internally formed a small beak-like double helictoglossa. Distal raphe ends externally and is sometimes bordered by ridges without terminal fissures. Central area is very small and apically elliptic.

Distribution: *Cymatoneis sulcata* was frequently reported in subtropical or tropical seas, in sandy sediments (Round *et al*. 1990). This species was found at Yap Island, USA (Navarro and Lobban 2009).

Distribution in Korea: This species was found at the lagoon of Jeju Island on Jun. 13, 2016 (Fig. 25m).

***Seminavis latior* (A. Schmidt) Danielidis & D.G. Mann 2003 (Figs. 11, 12)**

Reference: Danielidis and Mann 2003, p. 34, figs. 35–41.
Basionym: *Amphora cymbelloides* var. *latior* A. Schmidt in Schmidt 1875
Synonym: *Amphora angusta* var. *latior* (Grunow) F.W. Mills 1933
Specimen examined: NIBRDI0000137269

Valves semi-lanceolate to semi-rhombic, with convex dorsal and ventral margins and slightly protracted apices, 42.0–47.3 μm long, 9.0–10.0 μm wide. Striae dorsally radiate throughout, 12–13 in 10 μm and ventrally distinctly radiate at the centre but less so at the apices, 13–14 in 10 μm. A fine longitudinal line runs across the dorsal striae, parallel to the junction of the dorsal striae, and the raphe sternum. Raphe straight and placed closer to the ventral side of the valve. Proximal raphe ends are deflected ventrally and distal raphe ends dorsally hooked at the apices. The axial area is wider on the dorsal side and has a slight central expansion on the ventral side.

Distribution: *Seminavis latior* was found at Java Island, Indonesia (Danielidis and Mann 2003).

Distribution in Korea: This species was found at the lagoon of Jeju Island on Jun. 13, 2016 (Fig. 25l).

***Sellaphora saugerresii* (Desmazières) Wetzel & D.G. Mann in Wetzel *et al*. 2015 (Fig. 24)**

Reference: Wetzel *et al*. 2015, p. 209, figs. 112–127, 251–261.
Basionym: *Navicula saugerresii* Desmazières 1858
Synonym: *Navicula minima* Grunow in Van Heurck 1880
Navicula seminulum Grunow sensu Krammer & Lange-Bertalot 1986
Sellaphora seminulum (Grunow) D.G. Mann sensu Hofmann *et al*. 2011
Sellaphora styxii P.M. Novis, J. Braidwood & C. Kilroy 2012
Specimen examined: photo

Valves linear-elliptic to linear-lanceolate with rounded apices, 9.9 μm long and 3.3 μm wide. Areolae unresolvable under light microscopy, 88 in 10 μm. Striae slightly radiate near the central area, becoming parallel toward the apices, 25 in 10 μm. Striae generally uniseriate but becoming biseriate towards the mantle. Raphe slightly curved. The proximal raphe ends externally tear-drop-shaped and the distal raphe ends smoothly curved toward the same side of the valve. Polar bars are absent. Axial area narrow and straight. Central area wide, symmetric, and bow-tie shaped with two or three shorter, uneven striae.

Distribution: *Sellaphora saugerresii* was found at Piraquara river, Paraná state, Brazil (Marra *et al*. 2016).

Distribution in Korea: This species was found at the estuary of Nakdong River in the South Sea of Korea on Sep. 2, 2014 (Fig. 25o).

***Pinnularia rectangulata* (Gregory) Rabenhorst 1864 (Figs. 13, 14)**

Reference: Hendey 1964, p. 233, pl. 34, fig. 10.

Basionym: *Navicula rectangulata* Gregory 1857

Specimen examined: NIBRDI0000137271

Valves linear in outline and the margins of the valve parallel, sometimes slightly convex or tri-undulate margins, central and ends of the valve slightly convex, with broadly rounded ends. Apical axis 64–79 μm long and transapical axis 12.5 μm in wide. Striae 5–7 rows in 10 μm, strongly radiate in the middle and convergent towards the ends. Longitudinal lines are absent across the striae. Raphe broadly lateral, the outer fissures of the raphe slightly undulate the central ends of the raphe expanded and bend in one direction. The central pores large and round, terminal ends of the raphe shaped like sickle. Axial area broadly linear, and central area widening up to the valve margins.

Distribution: *Pinnularia rectangulata* was reported in subtropica or tropical seas, in sandy sediments (Dawson 2007). This species was found at Chesapeake Bay, USA (Marshall *et al*. 2005); Sissano coastal water, Papua New Guinea (Dawson 2007).

Distribution in Korea: This species was found at Byeonsan coastal water in the Yellow Sea on May 24, 2014 (Fig. 25d).

***Pinnularia trevelyana* (Donkin) Rabenhorst 1864 (Figs. 15, 16a, b)**

References: Hendey 1964, p. 232, pl. 34, fig. 11; Witkowski *et al*. 2000, p. 337, pl. 156, fig. 5.

Basionym: *Navicula trevelyana* Donkin 1861

Specimen examined: NIBRDI0000137272

Valves linear-oblong in outline and the margins of the valve parallel, central of the valve slightly convex, isopolar valves with rounded ends. Apical axis 67.5–91.5 μm long and transapical axis 12 μm wide. Striae 8–10 rows in 10 μm, strongly radiate in the middle and convergent towards the ends. Longitudinal lines absent across the striae. Raphe is broadly lateral. The outer fissures of the raphe slightly undulate the central ends of the raphe expanded and bent in one direction. The central pores large and round and the terminal ends of the raphe shaped like question marks. Axial area is broadly linear and central area nearly rounded up to the margins of the valve.

Distribution: *Pinnularia trevelyana* was found at Chesapeake Bay, USA (Marshall 2005).

Distribution in Korea: This species was found at Byeonsan coastal water in the Yellow Sea on May 24, 2014 (Fig. 25e).

***Pleurosigma rushdyensis* G. Reid 2002 (Fig. 17)**

Reference: Reid 2002, p. 90, figs. 59–66.

Specimen examined: NIBRDI0000137276

Valves linear-lanceolate, slightly sigmoid shape, middle part almost parallel-sided, commonly bluntly rounded ends. Apical axis 220 μm long and transapical axis 8.6 μm wide. Striae 12 in 10 μm. The large apical pore present at the poles. Raphe sternum double curvature, very narrow. Raphe sigmoid, eccentric, just visible in axial area, presenting along the edge of the valve. External central raphe fissures very close in central area. Internal areola openings with a bar across them. Central area small, shaped like saddle, with central bars of approximately equal length.

Distribution: *Pleurosigma rushdyensis* was found at Rushdy, Egypt (Reid 2002).

Distribution in Korea: This species was found at Mohang-ri coastal water in the Yellow Sea on Dec. 22, 2016 (Fig. 25c).

Remark: *Pleurosigma rushdyensis* is close to *P. formosum*.

Reid (2002) distinguished both species by the central area and striae density: the central area of *P. formosum* have a larger hyaline area than *P. rushdyensis*. The oblique striae density of *P. formosum* have higher than *P. rushdyensis*. Based on the criteria by Reid (2002), we identified the extremely long and thin *Pleurosigma* as *P. rushdyensis*.

***Amphora belgica* Grunow 1882–1885 (Figs. 18, 19)**

Reference: Van Heurck 1885, p. 56.

Synonym: *Amphora ostreaira* subvar. *belgica* Grunow in Van Heurck 1885

Specimen examined: NIBRDI0000137265

Valves asymmetrical, dorsal part convex and ventral one slightly curved with protracted apcies. Apical axis 54.0–78.5 μm long and transapical axis 12.3–16.1 μm wide.

Areolae occluded by hymens, 14–17 in 10 μm. Striae uniseriate, parallel rows in transapical axis, 12–13 in 10 μm. Raphe system eccentric, lying nearer the ventral margin, curved along ventral margin. External central raphe endings deflected towards ventral margin. Terminal fissures usually present, short, diverse in form.

Distribution: *Amphora belgica* was firstly described from the beach of Blankenberge in Belgium (Kützing 1844). There was no report from the other region, the Korean reported was the second report since the first report. During the diatom study in Korea, *A. belgica* was frequently present at the beach of East Sea in Korea. The occurrence of *A. belgica* is related to the sandy habitat.

Distribution in Korea: This species was frequently observed from the East Sea in Jul. 2015 (Fig. 25q).

***Cymbellonitzschia szulczewskii* Witkowski, Lange-Bertalot & Metzeltin 2000 (Fig. 20)**

Reference: Stepanek *et al*. 2016, p. 30, figs. 23–39.

Specimen examined: NIBRDI0000137271

Valves asymmetry, a smoothly arched dorsal margin and a straight ventral margin, with protracted and acutely rounded apices. Apical axis 13.8 μm long and transapical axis 1.6 μm wide. Striae very fine, numbering 28 in 10 μm. Canal raphe runs along the ventral margin. Fibulae somewhat irregularly spaced, 11 in 10 μm.

Distribution: *Cymbellonitzschia szulczewskii* was reported in sandy sediments and was found at Tokyo Bay, Japan (Stepanek *et al*. 2016).

Distribution in Korea: This species was found at the lagoon of Jeju Island on Jun. 13, 2016 (Fig. 25n).

***Surirella taeniata* Hustedt in Schmidt *et al*. 1925 (Fig. 21a, 21b)**

References: Schmidt 1874–1959, pl. 359, figs. 8, 9; Simonsen 1987, p. 96, pl. 140, figs. 1–2, pl. 141, figs. 1–2.

Specimen examined: NIBRDI0000137270

Valves isopolar, elliptical with broadly rounded apices. Apical axis 113.4 μm long and transapical axis 55.4 μm wide. Raphe canal circumferential, located atop a well-developed keel. Valve may appear constricted in the middle depending on level of focus. Mantle edge and raphe canal parallel around most of the valve, except in the middle portion, where the raphe canal and top of the keel are gently drawn inward, while the position of the mantle edges stays constant, creating a sloped mantle in this region. Infundibula are visible around the margin of the valve. The central area is marked and surrounded by elevated elliptic ridges on valve face.

Distribution: *Surirella taeniata* was reported from Port Townsend, Washington, USA (Schmidt 1874–1959).

Distribution in Korea: This species was found at Wido Island in the Yellow Sea on Mar. 26, 2015 (Fig. 25g).

CONCLUSION

Seventeen new recorded species were found in the Yellow Sea, Jeju Island, East Sea, Nakdong River (Fig. 25). According to the Seas, seven species, *Encyonema appalachianum*, *Lyrella impercepta*, *L. majuscula*, *Pinnularia rectangulata*, *P. trevelyana*, *Pleurosigma rushdyense*, *Surirella taeniata* were found in the Yellow Sea, and seven species, *Azpeitia africana, Tetramphora intermedia, Diploneis nitescens, Cymatoneis sulcata, Seminavis latior, Cymbellonitzschia szulczewskii* from the Jeju Island, one species, *Amphora belgica* from the East Sea, and two species, *Gomphonema inaequilongum* and *Sellaphora saugerresii* from the middle part and estuary of Nakdong River, respectively. The diatom assemblages well reflect the features of the seas and habitats. The species from the Yellow Sea are composed of benthic genera such as *Lyrella*, *Pleurosigma*, and *Surirella*. Although the benthic diatom species were observed from phytoplankton samples in the Yellow Sea, most of them are tychopelagic by vertical mixing. The species from Jeju Island are known to the subtropical to tropical species and have never been observed in Korean peninsula. The subtropical microalgal species, particularly dinoflagellates, has steadily been reported from the coastal water of Jeju Island (e.g. Kim *et al*. 2008; Shah *et al*. 2013), but the study on the subtropical diatom in Jeju Island have been little known. The study on the diatom in Nakdong River were investigated by Joh (2013, 2014). The study mainly focused on the diatom genera such as *Hantzschia* (Joh 2014) and Naviculoids (Joh 2013). However, the *Gomphonema* and *Sellaphora* species have been less studied than the other diatom genera. Most of the records on Korean diatoms have focused on the plankton. The new recorded diatom species were collected

from the less studied habitats such as tidal flat, estuaries, lagoon, and beach. There were so many unrecorded Korean diatom species in the present study and the species diversity of Korean diatoms might be much higher than our knowledge.

ACKNOWLEDGEMENT

This work was supported by a grant from the National Institute of Biological Resources (NIBR), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIBR201701204).

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Received: 24 August 2017
Revised: 11 September 2017
Revision accepted: 11 September 2017