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Distribution of the genus *Cocconeis* (Bacillariophyceae) along the Seogwipo coast of Jeju Island, South Korea

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Abstract

Cocconeis Ehrenberg species (Bacillariophyceae) are documented from benthic samples collected along the Seogwipo coast of Jeju Island, the southernmost region of Korea. The 25 taxa were identified from seaweeds, sand, and sediments, their morphological features are described, and the distributions of the taxa are summarized. Three groups of *Cocconeis* e.g., *Cocconeis dirupta* var. *flexella*, *C. pseudomarginata* var. *intermedia*, *Cocconeis scutellum*, and their similar taxa were dominant in this area. Many other *Cocconeis* that grows mainly along the coasts of warmer oceans were also identified. The floristic study reveals the existence of rare or retrieved species that were not well known until recently, and expands some of their geographical distributions; *Cocconeis* cf. *callosa*, *C. conspicua*, *C. cyclophora* var. *decora*, *C. cyclophora* var. *meisteri*, *C. delicata*, *C. schmidtii*, *C. shikinensis*, *C. suzukii*, *C. voigtii*. In this floristic study, 14 *Cocconeis* taxa are new records in South Korea.

Keywords: *Cocconeis*, epiphytic, epipelic, intertidal zone, new to South Korea

Introduction

Diatoms exist as water-borne planktons or as periphytons that adhere to various objects in the water. In coastal areas, a variety of substrates (e.g., sand bottoms, stones or rocks, seaweeds, zoobenthos, etc.) can act as media for the attachment of diatoms (Round 1984). Diatoms can attach to seaweeds and seagrasses by various mechanisms that reflect the complex structures of the plants (Totti *et al.* 2009, Tiffany 2011). The coast is subject to strong physical disturbances, but *Cocconeis* species overcome this by securely attaching their raphe valves to the substrate surface; this allows such species to be more abundant and more diverse than other taxa of the marine coasts (Ferreira & Seeliger 1985). *Cocconeis* species account for a high proportion of the periphytons in a given region, especially in intertidal zones of coastal areas (Round 1984). Many of these taxa were reported from seaweeds (Tanaka 1986, Suzuki *et al.* 1999, Totti *et al.* 2009, Da Silva-Costa *et al.* 2016), seagrasses (Majewska *et al.* 2013), hard substrates (Poulin *et al.* 1984, Sullivan 2019), and intertidal surficial sediments to *Cocconeis* (Riaux-Gobin 1991). The surface of seaweeds is substrates perfectly suited for colonization by diatoms, particularly *Cocconeis*.

Cocconeis species are representative microbe that attaches to the shells of zoobenthos as well as marine macrophytes (Totti *et al.* 2010), and they can also cause fouling by overgrowth (Pelletier *et al.* 2009). It has been reported that a lot of taxa among the genus *Cocconeis* colonized the shell of various marine biota: on mollusk of genus *Mytilus* in the Sea of Japan and the Black Sea (Ryabushko & Ryabushko 2000), on gastropods and planktonic crustaceans (D'alelio *et al.* 2010), even on the skin of cetaceans (Holmes 1985). In particular, *Cocconeis* taxa reported by Meister (1937) on a marine snail (probably *Haliothis*) are of great interest from diatom taxonomists (Riaux-Gobin *et al.* 2017). *Cocconeis* diatoms were also detected in large quantities and with high diversity in the diets of juvenile abalone collected on coasts (León-Cisneros *et al.* 2017).

The genus *Cocconeis* was created in 1837 by C.G. Ehrenberg; it has long been considered to be the single genus, due to its characteristic morphology as a monoraphid taxon. The members of genus *Cocconeis* have been regarded as complex diatoms because of their heterovalvy, complex shape, and often elaborate girdle bands (De Stefano & Oscar 2005, De Stefano *et al.* 2008, Jüttner *et al.* 2010). Since the 2000s, increasingly intensive taxonomic accounts of *Cocconeis* species have eliminated much of the confusion and taxonomic ambiguity; at the same time, however, many

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new species have continued to be identified (Romero 1996, Romero & Navarro 1999, De Stefano & Marino 2001, De Stefano *et al.* 2008, Suzuki *et al.* 2008, Riaux-Gobin *et al.* 2014a, 2014b, 2016).

Some floristic studies of *Cocconeis* have been locally undertaken, such as the Lawrence Estuary, Eastern Canada (Poulin *et al.* 1984), in North Brittany, France (Riaux-Gobin 1991), Patagonia, Argentina (Sar *et al.* 2003), and the Mediterranean Sea (Majewska *et al.* 2013).

The purpose of this study is to report the occurrence and distribution of the genus *Cocconeis* along the Seogwipo coast of Jeju Island, which represents the southernmost region of South Korea, and to describe their morphological characteristics.

Materials and methods

Diatom samplings

The survey was conducted on the coast of Seogwipo, east of Jeju Island in South Korea, and 34 km (33° 18' N to 33° 27' N; 126° 49' E to 126° 55' E) away along the coast (Fig. 1). This coast is a rocky area with a lot of volcanic rocks, and sandy coasts are developed in several places. In this intertidal zone, there is a fairly large lagoon (St. 3) and a lake-type wetland (St. 4) known as a settlement for migratory birds. The nearby coast, including the sampling site 1, is largely surrounded by rocks and is like a small lagoon at low tide (herein called 'pseudo-lagoon'). Seaweeds grow abundantly in the shallows. In St. 2, small tidal pools remain on and among the rocks at low tide (herein called 'rock pools'), seaweeds don't grow naturally in the pools, but seaweeds are swept away during high tides.

To search for diatoms, seaweeds and bottom sand were collected at St. 1 and St. 3, seaweeds at rock pools (St. 2), and bottom sediment at the wetland site (St. 4), respectively. The seaweeds were placed in a large vessel, shaken thoroughly, sieved, and the remaining liquid was collected. After sedimentation for a day, the supernatant was discarded. To obtain the sand/sediment on the bottom, a small tube (3.0 cm in diameter) was brought to the wet surface and gently pushed aside. Topsoil piled up on one side of the inner side of the tube can be taken. All samples were fixed at a final concentration of 3.5% by adding phosphate-buffered formalin, and kept in 100 ml bottles. Sample materials were collected five times from 2017 to 2019, and 110 samples were collected: May 2017, March, April, and August 2018, January 2019. However, sample materials abundant in *Cocconeis* species were targeted, and, in particular, specimens with unusual morphology or rare values were intensively examined, although poor in their abundance. In this way, there were 28 in total, 16 and 3 samples in St 1 and St 2, and 6 and 3 samples for St 3 and St 4, respectively.

Sample preparation and examinations

Before cleaning the samples, subsamples were washed four times with distilled water to remove salt and fixative from the sample. On a sand bath filled with sand thinly on a hot plate, samples were boiling with nitric acid and a small amount of potassium dichromate was added while gently boiling (APHA 1995). The sample was then allowed to settle overnight and washed with distilled water 9 times. Permanent slides were made by mounting diatoms in Pleurax resin branded Mountmedia (Wako Pure Chemical Industries, Ltd., Osaka, Japan). Diatoms were identified and photographed in light microscopy (LM) (Axioplan, Carl Zeiss, Oberkochen, Germany) equipped with an Infinity 1 digital camera (Lumenera Scientific, Ottawa, Canada). For scanning electron microscopy (SEM), cleaned diatom frustules were dried on small glass, which was attached to aluminium stubs and coated with a deionized gold sputter coater. SEM two Hitachi models, SU-70 and S-4800 (Hitachi, Tokyo, Japan), at 5 to 10 kV, were used for SEM examination.

Cocconeis taxa were identified mainly by referring to the following works of literatures: Hustedt (1933), Romero (1996), Romero and Navarro (1999), Witkowski *et al.* (2000), De Stefano *et al.* (2000, 2006), De Stefano and Marino (2001), Suzuki *et al.* (2001a, 2001b, 2001c, 2008)), Sar *et al.* (2003) and Riaux-Gobin *et al.* (2014a, 2014b, 2014c, 2016, 2017).

The abundance of all taxa was divided into four qualitative categories considering the abundance as well as the frequency of species in the microscopy. When examining diatoms under microscopy, 'common' was assigned when the species was abundant or observed in a large number of samples, 'frequent' when not always regular but frequent encounters, and 'rare' when present in a small number of specimens, and 'very rare' when the frequency of appearance is very low.

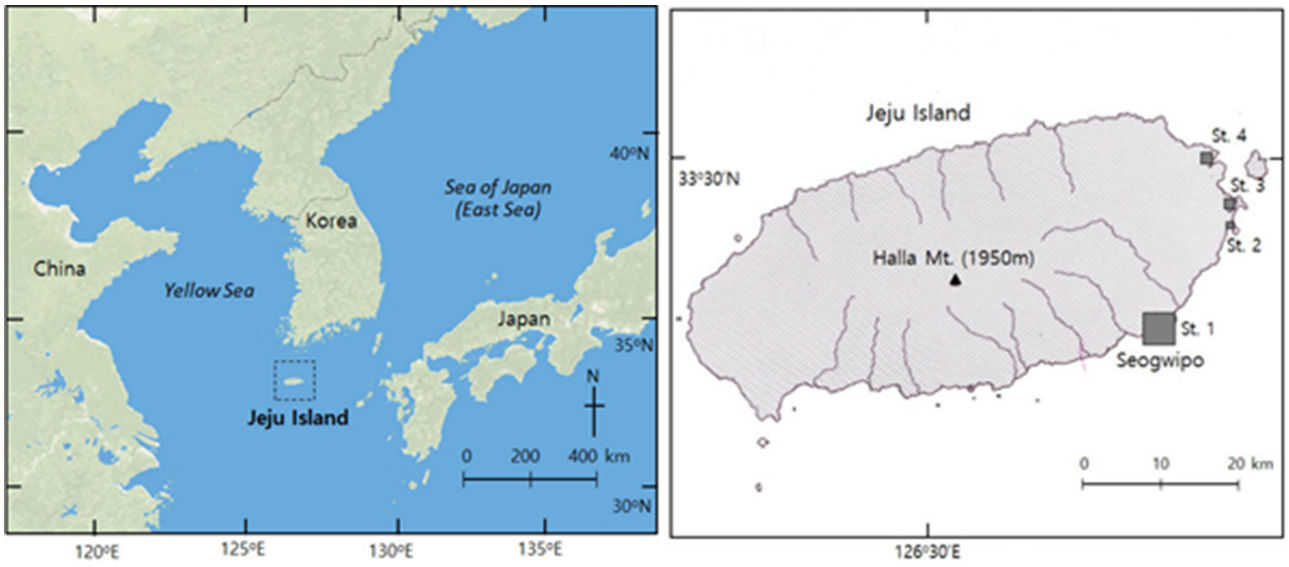


FIGURE 1. Map of Jeju Island (dotted square), the southernmost regions of Korea (left), the four localities for diatom samplings in Seogwipo coast of Jeju Island (right). St. 1: A partly closed water body surrounded by volcanic rocks in the coast, a kind of shallow pseudo-lagoon with a lot of seaweeds (a representative point, 33°18'N 126°49'E). St. 2: As a rocky coast, there are small pools on rocks after high tide (33°25'N 126°55'E). St. 3: A large open lagoon where seawater moves at low and high tide through one entrance (33°27'N 126°55'E). St. 4: A lake in coast, a field of reeds in the mouth area, where many migratory birds flock (33°30'N 126°53'E).

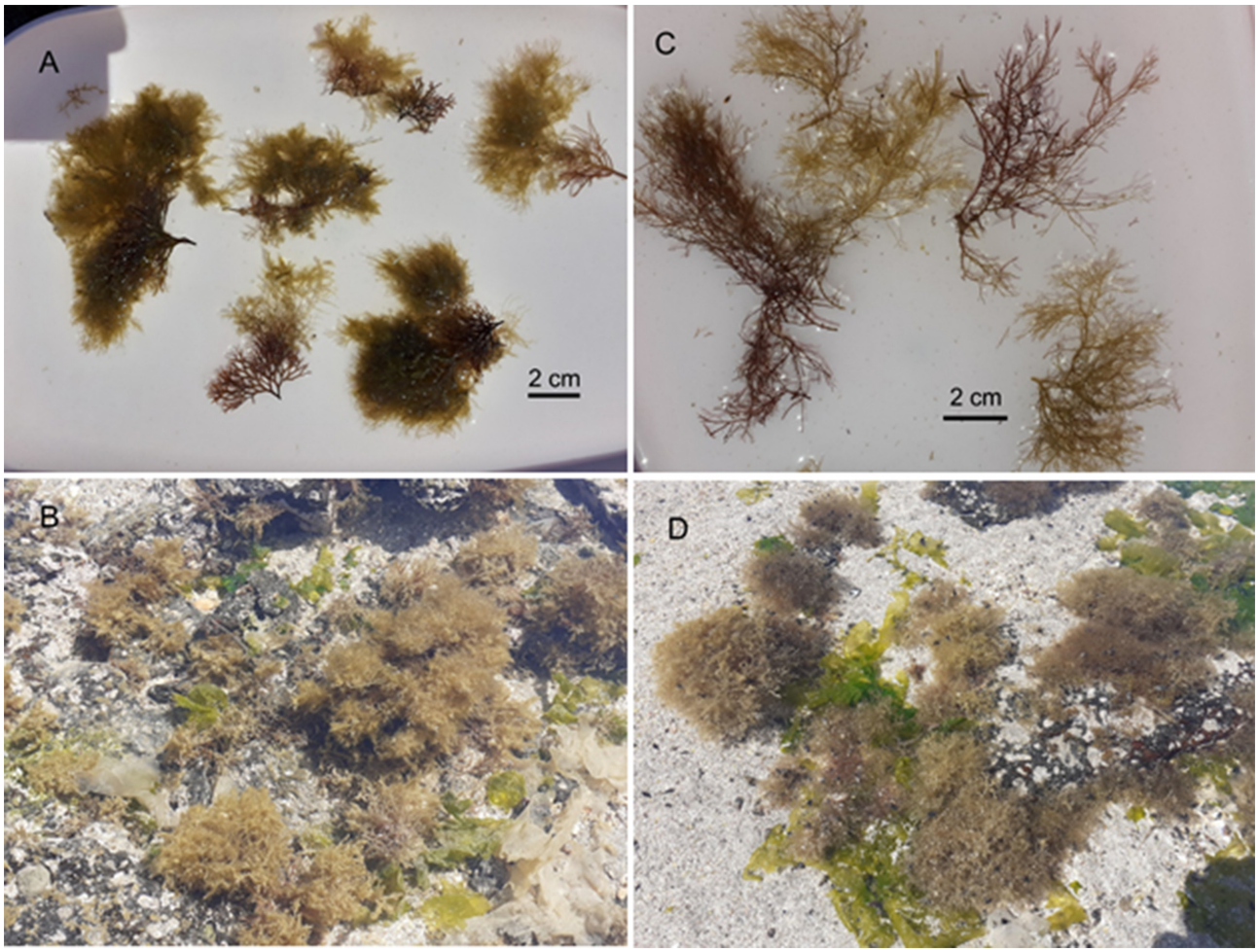


FIGURE 2. Field images of two seaweeds, *Melanothamnus harlandii* (A, B) and *Gelidium elegans* (C, D), which are representative ones among host plants and were collected in St. 1.

Results

Diatoms were collected from various epiphytic and epipelic substrates of the intertidal zone, including seaweeds, bottom sand, and sediments. More than 250 diatom species were encountered in the course of this study, and the most abundant taxa were *Cocconeis* Ehrenberg and *Achnanthes* Bory. Many species belonging to the genus *Cocconeis* were observed, but the infraspecific taxa of *Cocconeis scutellum* and its neighboring taxa were most common, and *Achannhthes angustata* Greville was the representative among the genus *Achnanthes*.

There were many differences in the abundance of epiphytic diatoms according to the three divisions of seaweed (Chlorophyta, Phaeophyta, Rhodophyta). Diatoms were more abundant and the species composition was more diverse in the small Rhodophyta, which grows in tufts than the broad-bladed *Ulva* or Phaeophyta with fleshly branches. The largest number of diatoms were observed in seaweeds with dense branches like threads, such as *Melanothamnus harlandii* (Harvey) Díaz-Tapia & Maggs, and *Gelidium elegans* Kützing (Fig. 2). Epiphytic diatom assemblages varied significantly in correspondence with Rhodophyta species on which they thrive and host-epiphyte specificity was not apparent, although differences at division level are also evident. Epiphytic diatoms are mainly influenced by the complexity of the host plants despite their overall sizes.

Epipelic or epipsammic diatom assemblages on sediments where seaweeds grow are influenced under the epiphytic diatom flora through suspension by tidal currents and wave action. On the other hand, at the sediments of the intertidal zone without seaweed, small naviculoid taxa represented by *Navicula* Bory and *Fallacia* Stickle & D.G. Mann were the most common, and the species of small-sized *Cocconeis* were also observed. However, most of the tiny *Cocconeis* observed on the bottom were left undetermined to the species level.

A total of 25 taxa of *Cocconeis* were identified in the local area. The descriptions of each taxon are based on the valve outlines and morphometrics of the sternum (SV) and raphe valve (RV), and then the morphological characteristics of valves are described secondarily. In this floristic study, 14 taxa are new records in South Korea.

Order: Achnanthales P.C. Silva
Family: Achnanthaceae Kützing
Genus *Cocconeis* Ehrenberg

1. *Cocconeis* cf. *callosa* Meister (Figs 79–83)

Basionym: Meister 1937, p. 266, pl. 8, fig. 11.
Reference: Riaux-Gobin *et al.* 2017, p. 57, figs 9, 44–51.

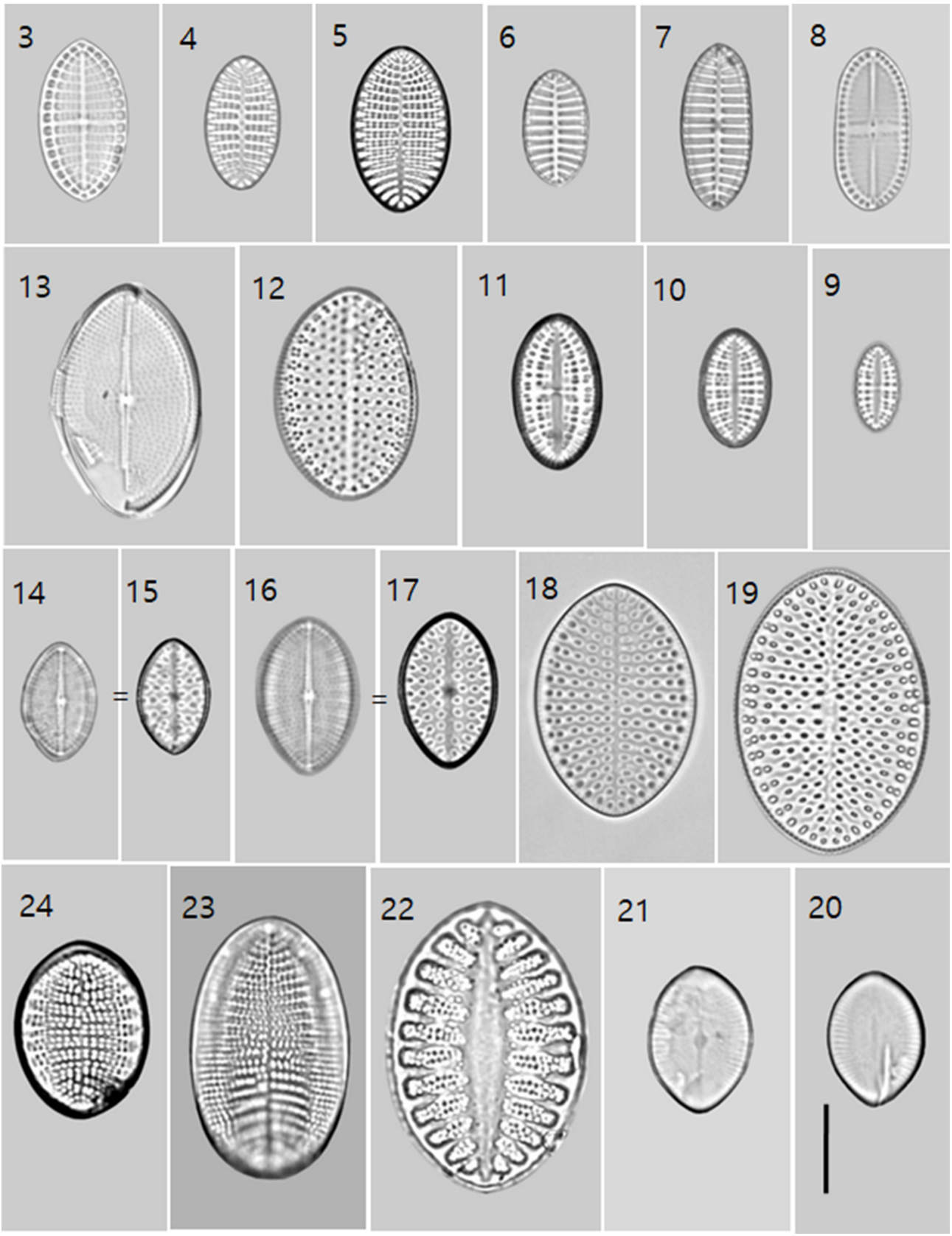
Description: Valves rather circular, 27–54 μm long, 21–49 μm wide. SV: sternum narrow and bent in opposite directions at the apices, forming a distinct sigmoid curvature. Central area not developed, but only a few areolae missing in the middle to form a small hyaline space. Transapical striae radiate in the middle and strongly radiate towards the apices, 13–15 in 10 μm, formed by coarse areolae, with 10–11 areolae in 10 μm of stria. RV: raphe and sternum strongly sigmoid, with opposite curvatures of the terminal ends, both ends of raphe and sternum distant from the apices. Central area extended transversely in a narrow hyaline area not reaching the margins. Transapical striae, 13–14 in 10 μm distinctly areolae, with 12–16 in 10 μm of stria.

Remarks: Although there was no type specimen of the species, and the morphology of RV was not even described in the original statement, Riaux-Gobin *et al.* (2017) searched the Meister's collections, and erected *Cocconeis* cf. *callosa* as a legitimate taxon. This species has only been reported from the type locality, Nagasaki in Japan. In the Seogwipo coast of Jeju Island, very rare as epiphytes from a small rock pool (St. 2), representing a new record for South Korea.

2. *Cocconeis capensis* (Cholnoky) Witkowski (Figs 9–11)

References: Cholnoky 1963, p. 42, figs 6, 7; Witkowski *et al.* 2000, p. 103, pl. 40, figs 9, 10; Riaux-Gobin *et al.* 2017, p. 58, figs 20–23.

Description: Valves elliptical, 10–17 μm long, 5–10 μm wide. SV: sternum linear, and central area not developed. Transapical striae coarse, composed of elongated areolae, 20–22 in 10 μm, crossed by a hyaline longitudinal line, and radiate towards the apices. Striae as bundle of 1–3 rows of areolae. One row of dense areolae on the margins of valve. A complete frustule is observed (Fig. 12).



FIGURES 3–24. LM micrographs of *Cocconeis* species (1). Figs 3–5. *Cocconeis stauroneiformis*, RV (Fig. 3) and SVs (Figs 4, 5). Figs 6–8. *C. costata*, SVs (Figs 6, 7) and RV (Fig. 8). Figs 9–11. *C. capensis*, SVs. Figs 12–19. *C. distans*, SVs (Figs 12, 15, 17–19) and RVs (Figs 13, 14, 16) (Figs 14 and 15, 16 and 17, complete valve). Figs 20, 21. *C. pelta*, SV (Fig. 20) and RV (Fig. 21). Fig. 22. *C.* cf. *pinnata*, SV. Figs 23, 24. *C. clandestina*, SVs. Scale bar = 10 μm (Figs 3–24).

Remarks: This species was previously reported as *Cocconeis clandestina* var. *capensis* Cholnoky from the type locality of the Steanbras River of South Africa (Cholnoky 1963), and from Saldanha Bay of South Africa (Giffen 1976). It occurred in the Azores of Portugal (Stidolph *et al.* 2012), and in Nagasaki of Japan (Riaux-Gobin *et al.* 2017). In the Seogwipo coast of Jeju Island, rare in a single sample on seaweeds collected from a small rock pool; it is herein newly described for South Korea.

3. *Cocconeis clandestina* A. Schmidt (Figs 23, 24)

Basionym: Schmidt *et al.* 1894a, pl. 192, figs 28, 29.

References: Hustedt 1933, p. 331, fig. 784; Witkowski *et al.* 2000, p. 103, pl. 41, figs 20–25. **Description:** Valves elliptical to nearly circular, 18–29 μm long, 14–18 μm wide. SV: sternum narrow and linear. Transapical striae biseriate and radiate towards the apices, 5–6 in 10 μm, with 10–12 areolae in 10 μm of stria. No RV observed.

Remarks: This taxon is widespread along the coast of northern Europe (Hustedt 1933, Witkowski *et al.* 2000) and common in the Baltic Sea (Witkowski *et al.* 2000). In the Seogwipo coast, very rare from small rock pools; it is herein newly described for South Korea.

4. *Cocconeis conspicua* A. Schmidt (Figs 87, 105)

Basionym: Schmidt *et al.* 1894b, pl. 196, figs 27–30.

Description: Valves broadly elliptical, but slightly oblique along apical axis, 31–38 μm long, 24–30 μm wide. SV: sternum broadly elliptical and sigmoid. Longitudinal hyaline area bisecting twice striae between sternum and valve margins, a row of very large puncta on the outer hyaline area, the largest punctum in the area 1.5 μm in diameter. A longitudinal line crossing striae between the sternum and inner hyaline area. Transapical striae radiate towards the apices, 26–27 in 10 μm, striae composed of elongated areolae. RV: No RV observed, only trace of sigmoid raphe could be seen.

Remarks: This taxon is characterized by a marginal axial hyaline area on each part of the SV and the presence of large round structures in these hyaline areas. There are no descriptions of this taxon except for the illustrations at the times of the naming. From the original valve drawings (Fig. 92) of Schmidt *et al.* (1894b), valves are 27–38 μm long and 18–29 μm wide. At that times, it was found in Kings Mill Islands (now Gilbert Islands) and Samoa in the Pacific Ocean, in Bissex of Barbados in the West Indies, and in Singapore (Schmidt *et al.* 1894b). However, it is placed on the checklist of marine diatoms in the Caribbean Sea (Navarro and Hernández-Becerril, 1997). Based on the localities found to date, it is a typical tropical taxon. Very rare in a few samples as epiphytes on seaweed in rock pools (St. 2) of Seogwipo coast; it is herein newly described for South Korea.

5. *Cocconeis convexa* Giffen (Figs 42–44, 100–102)

Basionym: Giffen 1967, p. 257, figs 26–28.

References: Witkowski *et al.* 2000, p. 104, pl. 37, figs 5, 6, pl. 41, figs 1–4; Suzuki 2001, p. 60, figs 1–35; Riaux-Gobin *et al.* 2011, p. 22, pl. 3, figs 1–5, pl. 32, figs 1–7.

Description: Valves broadly elliptical to almost rhombic, 16–25 μm long, 12–18 μm wide. SV: sternum narrow and linear, and central area not developed. Transapical striae parallel at middle, strongly radiate towards the apices, and interrupted by many slightly undulate hyaline lines, 37–41 in 10 μm. RV: raphe straight, the central ends of raphe slightly curved to the opposite directions, the terminal ends of the raphe distant from the apices without areolation and sternum narrow. Central area expanded transversely to less than half the hemivalve, and central nodule between the central raphe ends thickened. Under the LM, only the thickened central nodule highlighted, making the central area more narrow than it really is. Transapical striae parallel in the middle, strongly radiate towards the apices, 26–31 in 10 μm of stria, often 1–2 striae in the middle of one side of the valve particularly short.

Remarks: *Cocconeis convexa* is pantropical, and described from the Pacific and Indian Oceans (Witkowski *et al.* 2000), Guam in the western Pacific Ocean (Navarro & Lobban 2009), Réunion and Rodrigues in the western Indian Ocean (Riaux-Gobin *et al.* 2011), and Tahiti and Tuamotu Archipelago of the southern Pacific Ocean (Riaux-Gobin *et al.* 2015). The species has been reported from the coasts of Japan (Suzuki 2001), Argentina (Sar *et al.* 2003), Mexico

(Siqueiros-Beltrones & Argumedo-Hernández 2015). In South Korea, it was already reported in the coast of Jeju Island (Kim *et al.* 2017), and in this survey, was found frequently as epiphytes on seaweeds along the Seogwipo coast.

6. *Cocconeis costata* Gregory (Figs 6–8)

Basionym: Gregory 1855, p. 39, pl. 4, fig. 10.
References: Hustedt 1933, p. 332, fig. 785; Romero & Rivera 1996, p. 321, figs 2–16; Witkowski *et al.* 2000, p. 104, pl. 38, figs 36–38.

Description: Valves elliptical to linear-elliptical, 8–19 μm long, 5–8 μm wide. SV: sternum narrow and linear. Central area not developed. Transapical striae parallel in the middle, radiate towards the apices, biseriate to triseriate, 9–10 in 10 μm, but pluriseriae on a stria unresolvable in LM. RV: raphe straight, the central ends of raphe expanded externally, but slightly deflected in opposite directions internally; sternum very narrow. Central area transversely expanded as hyaline fascia up to the margins. Transapical striae biseriate, parallel in the middle, radiate towards the apices, 14–15 in 10 μm.

Remarks: This is ubiquitous or cosmopolitan taxon, occurring on the coasts from the Mediterranean to the northern Arctic Ocean (Hustedt 1933), occurred frequently near Cape Town coast of South Africa (Giffen 1970) and in the Kerguelen Islands of the southern Indian Ocean (Riaux-Gobin 1994), along the Pacific Ocean coasts of Chile, including parts of the Subarctic and Arctic (Romero & Rivera 1996), and in western Baltic Sea (Witkowski *et al.* 2000). Along the Seogwipo coast of Jeju Island, it was rarely found as epiphytes on seaweeds of some samples; it is herein newly described for South Korea.

7. *Cocconeis cyclophora* var. *decora* A. Schmidt (Fig. 64)

Basionym: Schmidt *et al.* 1895, pl. 198, figs 1–3.
References: Wu *et al.* 2012, p. 771, pl. 1, fig. e; Riaux-Gobin *et al.* 2017, p. 58, figs 19, 52–54.

Description: Valves elliptical, 33–40 μm long, 20–22 μm wide. SV: sternum sigmoid and enlarged between the middle and ends of the valve. A large ocellus in the middle on one side of valve. Transapical striae coarse and radiate towards the apices, 22–26 in 10 μm, with 17–18 areolae in 10 μm of stria. Three elliptical hyaline areas lacking areolae on each side of the sternum, the hyaline area in the middle connected to the sternum. No RV observed.

Remarks: The variety was reported from the type locality, Yokohama of Japan (Schmidt *et al.* 1895). It was found in sediments collected from the 1,071m deep bottom surface of the South China Sea (Wu *et al.* 2012), and in marine benthic materials from Nagasaki of Japan through F. Meister's collections (Riaux-Gobin *et al.* 2017). During the survey at Seogwipo coast of Jeju Island, this taxon was encountered twice as epiphytes in small rock pools (St. 2); it is herein newly described for South Korea.

8. *Cocconeis cyclophora* var. *meisteri* Riaux-Gobin (Figs 62, 63)

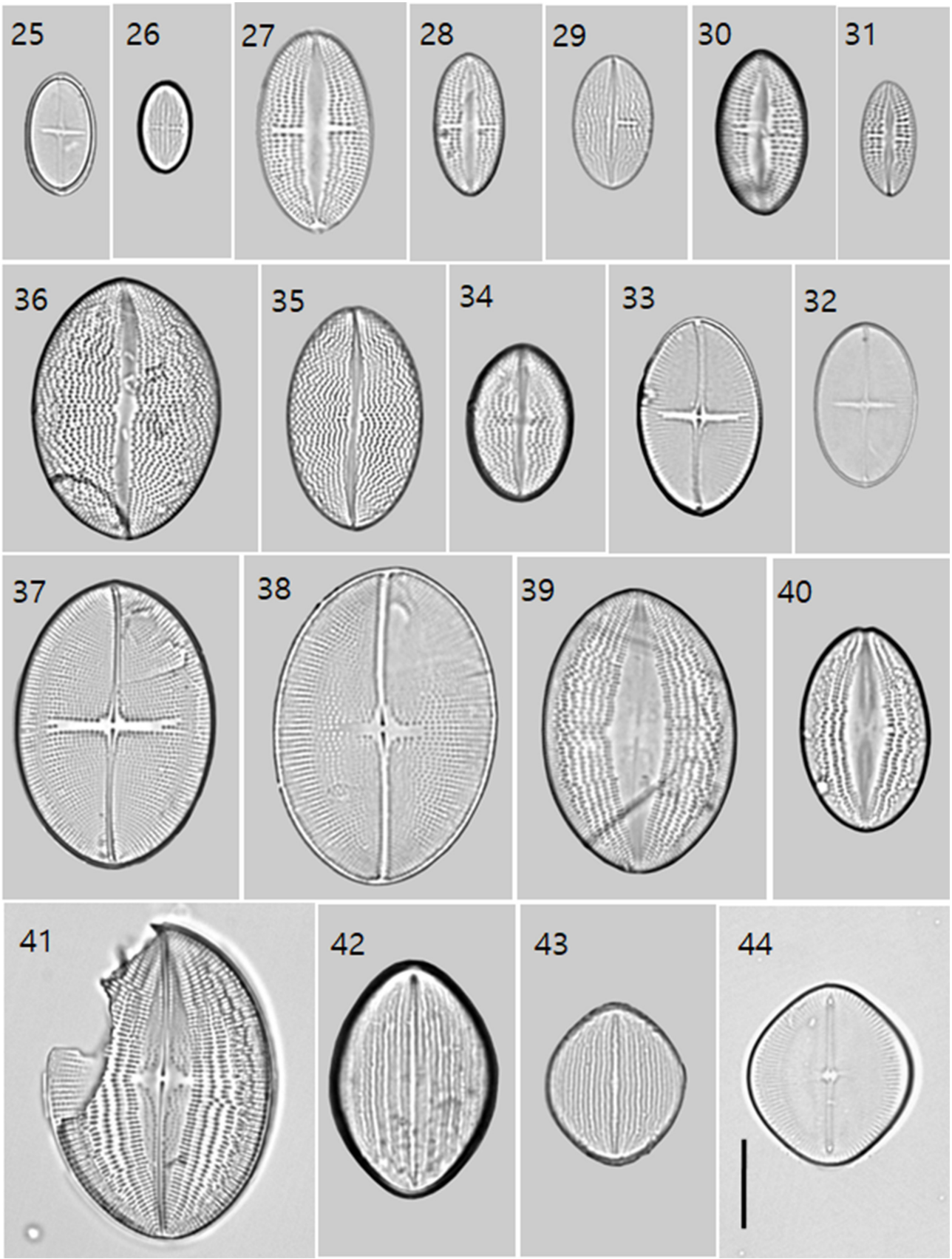
Basionym: Riaux-Gobin *et al.* 2017, p. 58, figs 55–58.

Description: Valves elliptical to linear-elliptical, 22–24 μm long, 12–13 μm wide. SV: sternum broad, slightly sigmoid and enlarged between the center and ends of valve. A large ocellus in the middle on one side of the valve. Transapical striae radiate towards the apices, 24 in 10 μm, with 23 areolae in 10 μm of stria, a few small hyaline areas lacking areolae on each side of the sternum near the margins, a large hyaline area in the middle connected to the sternum. RV: a complete frustule observed with sigmoid raphe.

Remarks: This taxon was reported from the type locality, Nagasaki of Japan (Riaux-Gobin *et al.* 2017). Along the Seogwipo coast of Jeju Island, it was encountered a few times in seaweeds collected from small rock pools; it is herein newly described for South Korea.

9. *Cocconeis delicata* A. Schmidt (Figs 38–41)

Basionym: Schmidt *et al.* 1894b, pl. 196, fig. 24.
References: Suzuki *et al.* 2007, p. 38, figs 15, 16; Riaux-Gobin *et al.* 2017, p. 52, figs 8, 34–38.



FIGURES 25–44. LM micrographs of *Cocconeis* species (2). Figs 25, 26. *Cocconeis* cf. *diruptoides*, RV (Fig. 25) and SV (Fig. 26). Figs 27–32. *C. dirupta* var. *dirupta*, SVs (Figs 27–31) and RV (Fig. 32). Figs 33–37. *C. dirupta* var. *flexella*, SVs (Figs 34–36) and RVs (Figs 33, 37). Figs 38–41. *C. delicata*, RVs (Figs 38) and SVs (Figs 39, 40, 41). Figs 42–44. *C. convexa*, SVs (Figs 42, 43) and RV (Fig. 44). Scale bar = 10 µm (Figs 25–44).

Description: Valves elliptical, 21–35 μm long, 14–25 μm wide. SV: sternum elliptical, central area not developed. Transapical striae radiate towards the apices, crossed by hyaline and zigzag longitudinal rows, 18–22 in 10 μm, areolae on a stria transversely elongated, 9–11 in 10 μm. RV: raphe weakly sigmoid, sternum very narrow. Central area transversely hyaline, occupying the short width of the middle field. Transapical striae radiate towards the apices, 18–22, with 16–23 areolae in 10 μm of stria.

Remarks: This species was originally identified from Yokohama materials by Schmidt *et al.* (1894b), but very few examples have been reported since. Meister (1935) and Suzuki *et al.* (2007) reported this species on the coast of Japan, and Riaux-Gobin *et al.* (2017) described the species in detail, using materials obtained from Nagasaki, Japan. The species was rarely encountered along the Seogwipo coast of Jeju Island. It is herein newly described for South Korea.

10. *Cocconeis dirupta* var. *dirupta* Gregory (Figs 27–32, 95)

Basionym: Gregory 1857, p. 491(19), pl. IX(1), fig. 25.

References: Hustedt 1933, p. 354, figs 809a–c; Kobayasi & Nagumo 1985, p. 99, pl. 2. figs 16–27; Witkowski *et al.* 2000, p. 105, pl. 39, figs 1–5; Riaux-Gobin *et al.* 2011, p. 26, pl. 3, figs 9–11, pl. 41, figs 1–6; Lobban *et al.* 2012, p. 286, pl. 40, figs 1–3; Riaux-Gobin *et al.* 2016, p. 11, figs 4, 35–38

Description: Valves broadly elliptical, 9–23 μm long, 5–14 μm wide. SV: sternum narrow to broadly lanceolate, fusiform, sometimes slightly retracted in the middle. Transapical striae radiate, crossed by hyaline and longitudinal rows, 15–22 in 10 μm, one median stria often shorter on one or both side of the central area. RV: raphe slightly sigmoid. Sternum narrow and straight. Central area not developed or extended as transversely narrrow fascia, not reaching to the margins. Transapical striae radiate, 24–28 in 10 μm.

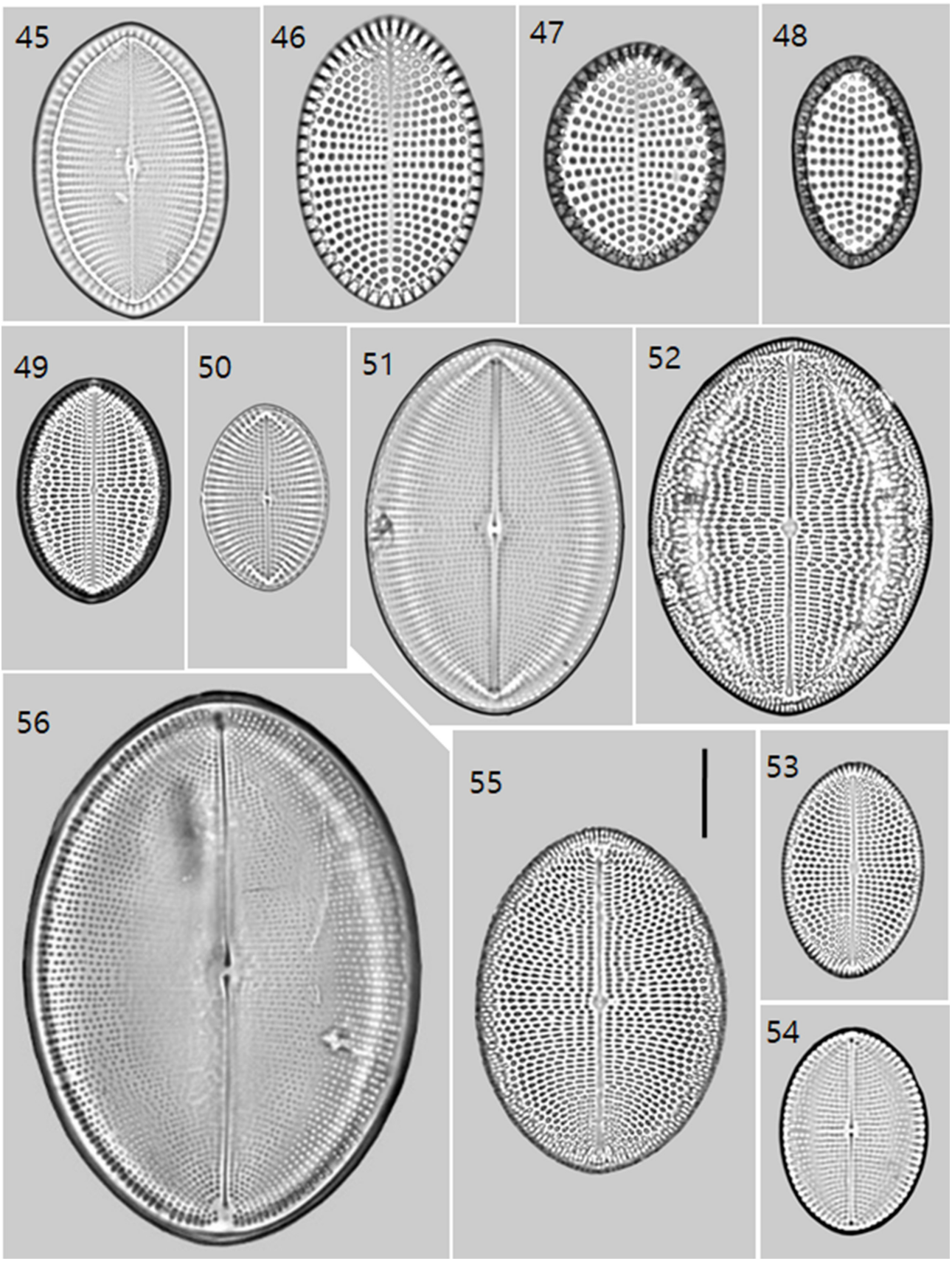
Remarks: The specimens described herein have valve outlines that are more elliptical rather than round-elliptical to discoid, as described for the lectotype designated by Riaux-Gobin *et al.* (2016). *C. dirupta* is distinguished from *C. dirupta* var. *flexella* by the straight axial area in the SV. In the literature, *Cocconeis dirupta* corresponds to two forms: one having large valves with a wide sternum (Kobayasi & Nagumo 1985, Riaux-Gobin *et al.* 2016) and the other having valves with a strong retraction in the middle of the sternum (Witkowski *et al.* 2000, Lobban *et al.* 2012). This species has a wide range in length and width dimensions, and both forms were found in the present study. The identifications were conducted according to the large forms designated by Hustedt (1933), and the small retracted forms by Lobban *et al.* (2012). The retracted forms collected in local areas have smaller dimensions, 9–17 μm long and 5–9 μm wide. In the smaller forms, transapical striae are abruptly denser at apices.
This taxon was reportedly common along oceanic coasts (Witkowski *et al.* 2000), and in tropical coasts (Riaux-Gobin *et al.* 2011, Lobban *et al.* 2012). Here, frequent on seaweeds of the Seogwipo coast of South Korea.

11. *Cocconeis dirupta* var. *flexella* (Janisch & Rabenhorst) Grunow (Figs 33–37, 90)

Basionym: Janisch & Rabenhorst 1863, p. 7, pl. 1, fig. 11.
References: Hustedt 1933, p. 355, figs 809d–i; Witkowski *et al.* 2000. p. 105, pl. 39, figs 6, 7, pl. 51, figs 3–8; De Stefano & Marino 2001, p. 304; Lobban *et al.* 2012, p. 287, pl. 40, figs 4, 5; Stidolph *et al.* 2012, pl. 22, figs 25, 30.

Description: Valves broadly elliptical to almost circular, 16–31 μm long and 10–21 μm wide. SV: sternum moderately broad and sigmoid. Central area not developed, or often a short fascia with missing of a stria in either side of valve. Transapical striae radiate towards apices, crossed by hyaline and longitudinal rows, 20–23 in 10 μm. RV: striae slightly sigmoid, sternum very narrow. Central area transversely narrow fascia, not reaching to the margins. Transapical striae radiate, 20–21 in 10 μm.

Remarks: The collected variants are distinguished from the nominate variety by the sigmoid sternum of SV (Hustedt 1933). This taxon has been reported from the Mediterranean, some islands of the Pacific and western Indian Oceans (Riaux-Robin *et al.* 2011, Lobban *et al.* 2012, Stidolph *et al.* 2012), Namibia of western Atlantic Ocean (Witkowski *et al.* 2000), and Mexico (Siqueiros-Beltrones & Romero 2004). This taxon is distributed in warmer coasts and the Mediterranean. Here, it was frequently encountered as epiphytes on seaweeds and the benthic of the sandy bottom of the Seogwipo coast, South Korea.



FIGURES 45–56. LM micrographs of *Cocconeis* species (3). Figs 45–48. *Cocconeis scutellum*, RV (Fig. 45) and SVs (Figs 46–48). Figs 49–52. *C. shikinensis*, SVs (Figs 49, 52) and RVs (Figs 50, 51). Figs 53–56. *C. schmidtii*, RVs (Figs 54, 56) and SVs (Figs 53, 55). Scale bar = 10 μm (Figs 45–56).

12. *Cocconeis* cf. *diruptoides* Hustedt (Figs 25, 26, 91–94)

Basionym: Hustedt 1933, p. 356, fig. 810.

References: Simonsen 1987, p. 133, pl. 219, figs 5–10, 13, 14; De Stefano & Marino 2001, p. 303, figs 15–27; Car *et al.* 2012, p. 445, figs S18–21.

Description: Valves oblong-elliptical to elliptical, 9–23 μm long and 5–13 μm wide. SV: sternum narrow and slightly sigmoid. Central area forming with lacking one striae, expanding into a short hyaline fascia on the one side of valve. Transapical striae slightly radiate towards apices, 25–37 in 10 μm, areolae on striae transapically elongated, 18–26 in 10 μm, forming wavy longitudinal lines, a few striae bifurcated in the margins of valve. RV: raphe slightly sigmoid, sternum very narrow. Central area as transversely narrow and hyaline fascia, not reaching up to the margins. Transapical striae slightly radiate, 28–35 in 10 μm, with 29–35 areolae in 10 μm of stria. Narrow hyaline area around the margins of valve.

Remarks: The local specimens match the description of De Stefano *et al.* (2000), based on Hustedt's type specimen, characterized by the presence of hemifascia on SV and strial dichotomy in the margins. However, since the hemifascia is not found in Hustedt's illustration and the exact type specimens are controversial on the other hand (Riaux-Gobin *et al.* 2018), the local specimens are recorded as *Cocconeis* cf. *diruptoides*.

Specimens collected in the current study were often less than 18 μm long; some were as short as 9 μm. The species is similar to *Cocconeis dirupta* var. *flexella* in its valve morphology, but the latter is distinguished by a sigmoid raphe and sternum of the valve, a low density of transapical striae (De Stefano & Marino 2001), and sparse strial areolae in the SV.

In the present survey, this is one of the most commonly observed *Cocconeis*. The valves are very variable in size and range from 9 μm to 23 μm long. In the assemblage, individuals commonly exhibited weakly sigmoidal raphe of valves, but widely differed in the density of striae for both valves.

This taxon is distributed in the Mediterranean (Hustedt 1933), has been collected from the northern Adriatic Sea between Rovinj and Vis (De Stefano & Mario 2001), and is widely distributed at temperate and warm coasts (Car *et al*. 2012). Along the Seogwipo coast, it was found frequently as epiphytes on seaweeds; it is herein newly described for South Korea.

13. *Cocconeis distans* Gregory (Figs 12–19)

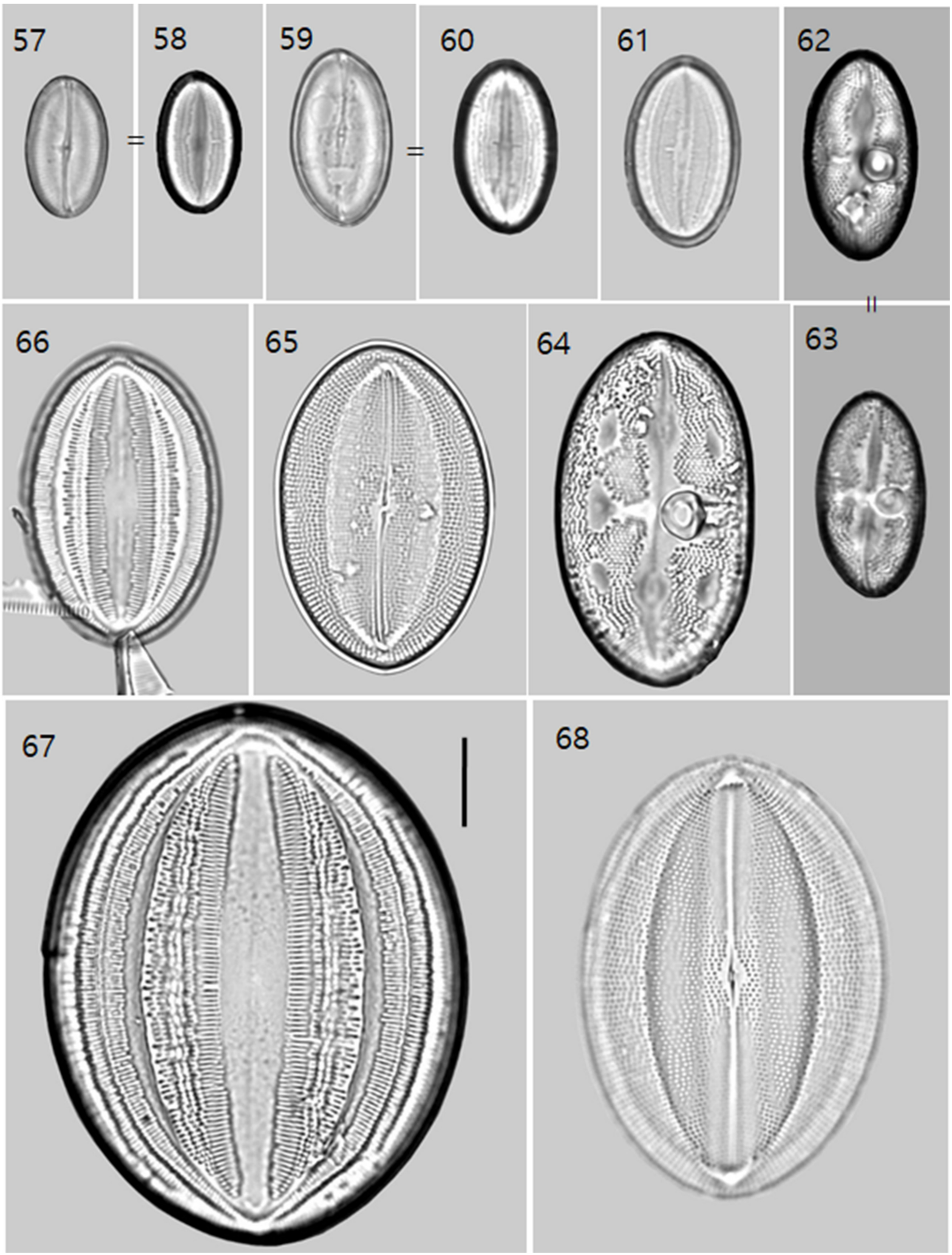
Basionym: Gregory 1855, p. 39, pl. 4, fig. 9 (incorrect); Gregory 1857, p. 490, pl. 9, fig. 23 (correct) (De Stefano *et al.* 2006).

References: Sar *et al.* 2003, p. 86, figs 16–21, as *Cocconeis guttata* Hustedt & Aleem; De Stefano *et al.* 2006, p. 440, figs 1–7, 15–32.

Description: Valves elliptical, often rhombic in large forms, 13–31 μm long, 8–23 μm wide. SV: sternum linear, central area not developed. Transapical striae radiate towards the apices, 6–9 in 10 μm, areolae on striae, coarsely round to subquadrangular and included inflated costae around each areola, 5–9 in 10 μm of stria. A row of areolae distinct around the margins of valve, on the other hand, among some large forms, two or three small areoale regularly arranged at the terminal ends of each stria in the valve margins (Fig. 13). RV: raphe straight, sternum narrow. Central area not developed. A narrow, hyaline area in the margin borders between valve and mantle. Transapical striae radiate towards the apices, 15–20 in 10 μm, with 12–19 areolae in 10 μm of stria.

Remarks: *Cocconeis distans* and *C. guttata* are occasionally confused due to their similar morphology of valves, and until recently, taxonomic confusion still exists. A close examination of the literature describing the two species found that, before comparing the two taxa, there were two morphotypes in the *C. distans*, small form and very large form in terms of dimensions of valves. As a result of referring to the literature describing small forms (Gregory 1855, Sar *et al.* 2003, De Stephano et a. 2006, Riaux-Gobin *et al.* 2011) and large forms (Cleve 1895, Peragallo and Peragallo 1897-1908, Hustedt 1933, Hendey 1964, Riaux-Gobin *et al.* 2014a), these two morphotypes are clearly distinguished in valve length (18–31 : 28–60 μm) and valve width (10–20 : 17–40 μm), density of stria (7–11 : 4–5 rows in 10 μm), and density of areolae on a stria (4–8 : 12–14 in 10 μm of SV). Some morphological differences in length or stria densities may be due to the presence of morphological variations. Genetic analyses will precise if it is the same species or varieties.

Meanwhile, Hustedt (1933) described *C. granulifera* Greville as a synonym for *C. distans* while describing *C. distans*, and until recently the two species are still considered as a heterotypic synonym. However, the synonym of *C. granulifera* seems to correspond to the large *C. distans*.



FIGURES 57–68. LM micrographs of *Cocconeis* species (4). Figs 57–61. *Cocconeis suzukii*, RVs (Figs 57, 59) and SVs (Figs 58, 60, 61) (Figs 57 and 58, 59 and 60, complete valves) Figs 62, 63. *C. cyclophora* var. *meisteri*, SV. Fig. 64. *C. cyclophora* var. *decora*, SV. Figs 65–68. *C. voigtii*, RVs (Figs 65, 68) and SVs (Figs 66, 67). Scale bar = 10 µm (Figs 57–68).

On the other hand, both large and small form of *C. distans* are clearly distinguished by the difference in the density of the striae on the valve and areolae on the stria. Local taxonomic identity and dimensions of the species are adopted from three references, Sar *et al.* (2003), De Stefano *et al.* (2006), and Riaux-Gobin *et al.* (2011).

This taxon is reported from the Patagonian coast of Argentina (Sar *et al.* 2003) and is distributed throughout the Mediterranean Sea (De Stefano *et al.* 2006), and common in coral sediments of Réunion and Rodrigues in the western Indian Ocean (Riaux-Gobin *et al.* 2011). It occurred infrequently as benthic diatoms in sand bottoms and salt marshes along the Seogwipo coast of Jeju Island. Local assemblages of the species can be divided into two categories, short and long, based on 23 μm in length.

14. *Cocconeis heteroidea* Hantzsch (Figs 77, 78)

Basionym: Rabenhorst 1863, p. 21, pl. 6 A, fig. 10.

References: Hustedt 1933, p. 256, fig. 811; Suzuki *et al.* 2001a, p. 131, figs 1–28; Lobban *et al.* 2012, p. 287, pl. 40, figs 6, 7, pl. 41, figs 1–3.

Description: Valves broadly elliptical to almost circular, 36–55 μm long, 30–47 μm wide. SV: sternum broadly linear in outline, but distinctly sigmoid. Transapical striae radiate towards the apices, 30, interrupted by a broad longitudinal furrow, and four longitudinal hyaline lines between sternum and the margins, appearing like some longitudinal folds, areolae in a stria transapically elongated. RV: raphe strongly sigmoid, and sternum narrow. Central area small and circular. Valve deeply buried to apical direction between the raphe and the margins, the apical central parts looking prominent in the sigmoid ridge. Transapical striae radiate towards the apices, 23 in 10 μm.

Remarks: This taxon is common in the Mediterranean Sea (Hustedt 1933, Witkowski *et al.* 2000, Majewska *et al.* 2013), and was reported for the East Sea of Russia (Orlova *et al.* 2009) as well as for islands of the Pacific Ocean, Bahamas, and Caribbean Sea (Lobban *et al.* 2012). It is widely distributed along warmer coasts. In South Korea, it was recorded as plankton off the coast of Jeju Island (Lee *et al.* 1990), as epiphytes on *Zostera* in the coast of Geoje Island (Chung & Lee 2008), and in this survey, occurred rarely as epiphytes on seaweeds from small rock pools in Seogwipo coast (St. 2).

15. *Cocconeis pellucida* Grunow (Figs 84–86)

Basionym: Rabenhorst 1863, p. 21, pl. 6, fig. 11.

References: Hustedt 1933, p. 357, fig. 812; Kobayasi & Nagumo 1985, p. 102, pl. 3, figs 28–40; Witkowski *et al.* 2000, p. 111, pl. 34, figs 1–3.

Description: Valves broadly elliptical to almost orbicular, 47–104 μm long, 40–95 μm wide. SV: sternum broadly linear and widened in the middle. Central area not developed. Transapical striae radiate towards the apices, 30–34 in 10 μm, but regularly interrupted by several longitudinal hyaline lines appearing to form many longitudinal folds, areolae in a stria transapically elongated. RV: both raphe and sternum slightly sigmoid, sternum narrow, the terminal ends of sternum expanded to crescent hyaline area and distant from the apices. Central area small and rhombic. Valves between the raphe and the margins slightly depressed. Transapical striae radiate, 18–24 in 10 μm.

Remarks: This species is common in warmer oceans and in the Mediterranean, and has rarely been reported from Europe (Hustedt 1933, Witkowski *et al.* 2000). It occurred in the coasts of Japan (Takano 1962, Kobayasi & Nagumo 1985), South Africa (Giffen 1970), Brazil (Procopiak *et al.* 2006), the New Hebrides (now Vanuatu) (Stidolph *et al.* 2012), and Mexico (López-Fuerte & Siqueiros-Beltrones 2016). In South Korea, this taxon was reported as pelagic planktons from Korea Strait (Skvortzow 1932), as plankton and periphytes off the coast of Jeju Island (Lee *et al.* 1990, 1991), and in this survey, occurred rarely as epiphytes on seaweeds collected from St. 2 in the Seogwipo coast.

16. *Cocconeis pelta* A. Schmidt (Figs 20, 21)

Basionym: Schmidt 1874, p. 93, pl. 3, fig. 17.

References: Hustedt 1933, p. 361, fig. 815; Witkowski *et al.* 2000, p. 111, pl. 41, figs 7–10; Sar *et al.* 2003, p. 91, fig. 33.

Description: Valves elliptical, 15–16 μm long, 11–12 μm wide. SV: sternum slightly very broadly lanceolate to elliptical, depressed making a distinct marginal rim, irregularly punctate. Central area not developed. Transapical striae

developed in the margins, radiate towards the apices, 17–18 in 10 μm. RV: raphe straight, sternum broadly elliptical like the SV. Transapical striae in the margins radiate towards the apices.

Remarks: The local specimens are smaller than the dimensions reported in referred literatures. Though the fine morphology of the three taxa seen with SEM differs, *Cocconeis pelta* is similar to *C. peltoides* Hustedt and *C. fluminensis* H. Peragallo & M. Peragallo in the morphology of SV under LM. Commonly, the three species have longitudinal costae in the median area of the SV, but the first species is distinguished from the second and the third taxon in that there is no striae in the inside of the longitudinal costae (Sar *et al.* 2003). The first species has a similar stria density with the second, while it is distinguished from the higher density than the third.

This species has been reported from the western Baltic Sea (Witkowski *et al.* 2000), European coasts in the North Atlantic and the Patagonian coasts of Argentina (Sar *et al.* 2003). In South Korea, this taxon was reported firstly as the epipsammic from the Nakdong River estuary (Joh 2012), and in this survey, very rare in small rock pools (St. 2) and salt marshes (St. 4) of the Seogwipo coast.

17. *Cocconeis* cf. *pinnata* W. Gregory ex Greville (Fig. 22)

Basionym: Greville 1859, p. 79, pl. 6, fig. 1.

References: Hustedt 1933, p. 330, fig. 783; Witkowski *et al.* 2000, p. 112, pl. 37, figs 14, pl. 39, fig. 10; Riaux-Gobin *et al.* 2014c, p. 85, figs 7–43.

Description: Valve elliptical to ovoid, 28–31 μm long, 20–21 μm wide. SV: sternum broadly lanceolate, central area not differentiated. Transapical striae robust, raised, biseriate, but uniseriate towards the inner, and radiate towards the apices, 3–4 in 10 μm. Marginal area of valve lacking areolae to make a hyaline band. No RV observed.

Remarks: Striae on valves are biseriate with large puncta, but uniseriate towards the margins of valve. These characteristics of striae are consistent with those of Hustedt (1933) and Witkowski *et al.* (2000), but the width of sternum of SV is different each other. However, according to the inspection of the type specimens, the striae are uniseraite on valve and biseriate towards the margins (Riaux-Gobin *et al.* 2014c). For this reason, this taxon collected in the local area is named *C.* cf. *pinnata*.

This species is distributed along the coasts of Europe, from the Mediterranean to the northern Arctic (Hustedt 1933); it has also been reported for the west Iberian coast of North Portugal (Resende *et al.* 2007), King George Island, Antarctica (Al-Handal & Wulff 2008), and elsewhere, in the Mediterranean (Majewska *et al.* 2013). In the Seogwipo coast, it occurred very rarely as epiphytes on seaweed from small rock pools (St. 2); it is herein newly described for South Korea.

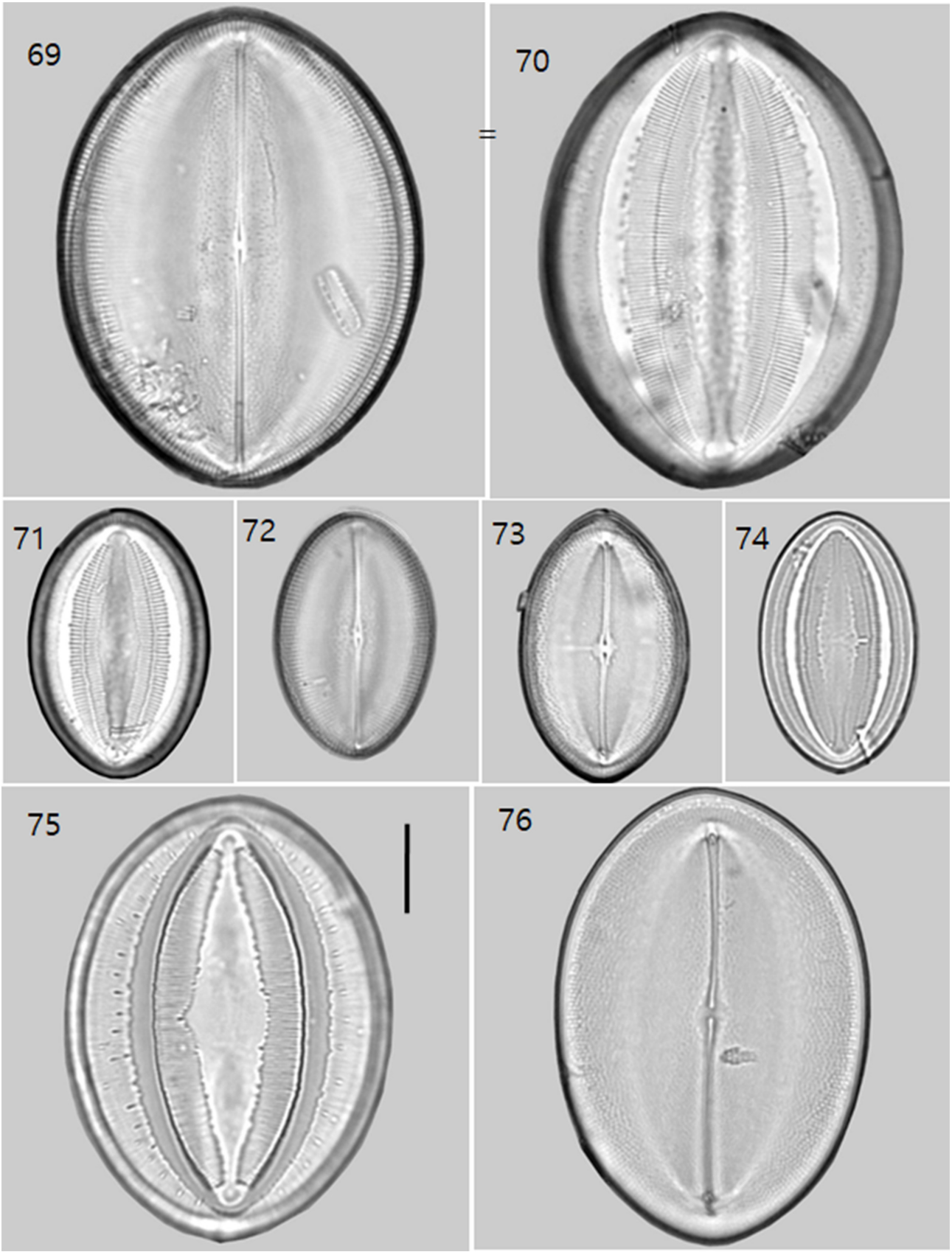
18. *Cocconeis pseudomarginata* Gregory (Figs 69–72)

Basionym: Gregory 1857, p. 492, pl. 9, fig. 27.

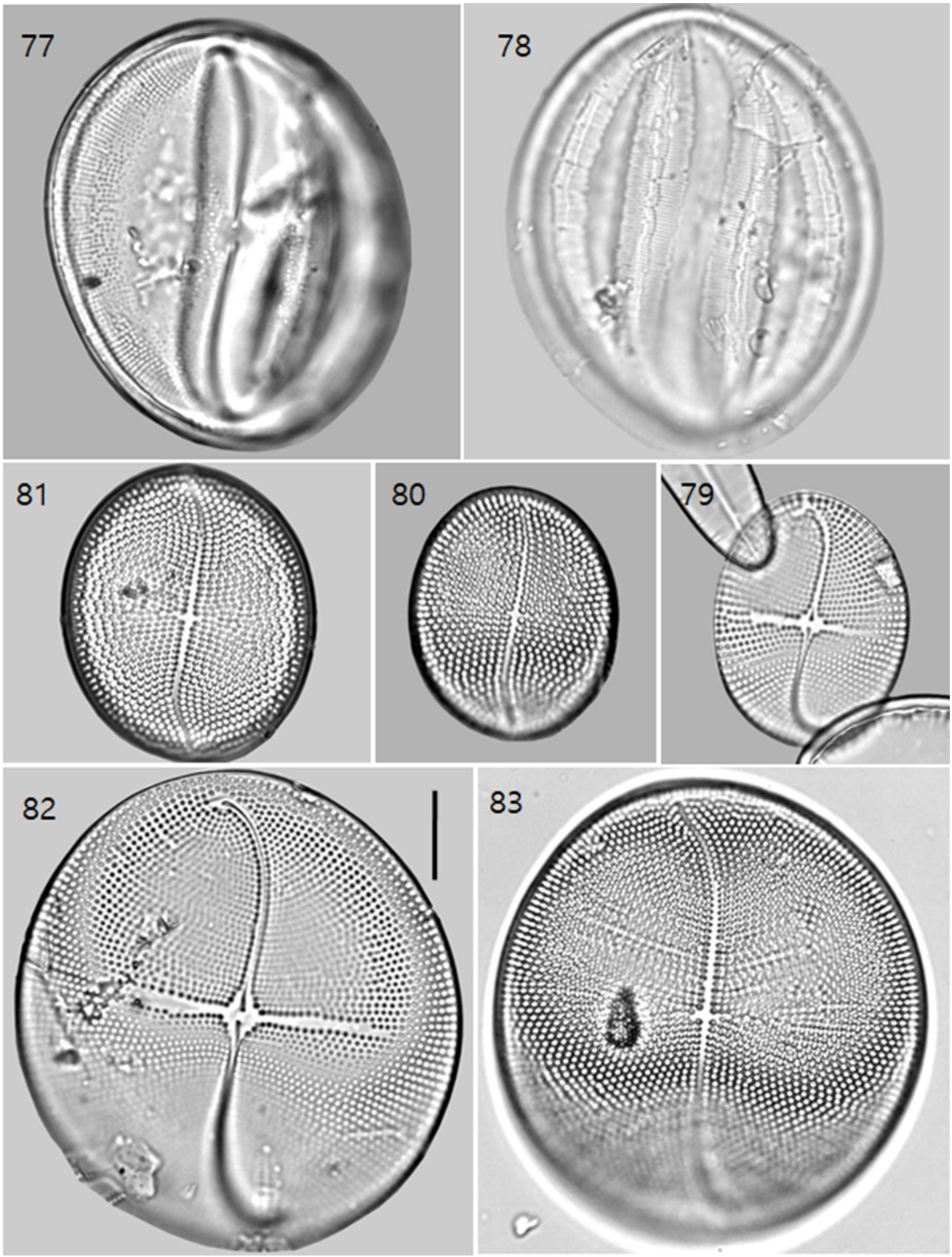
References: Hustedt 1933, p. 359, figs 813a–c; Romero & Navarro 1999, figs 1–6, 13–15, 20–31; Riaux-Gobin *et al.* 2014a, p. 176, f, 33, 34.

Description: Valves broadly elliptical to ovoid, 19–54 μm long, 10–41 μm wide. SV: sternum wide lanceolate, the terminal ends of sternum enlarged and pear-shaped, extending to submarginal hyaline line, and a longitudinal row of areolae between sternum and the submarginal hyaline lines. Transapical striae in inner parts of valve radiate towards the apices, 22–29 in 10 μm, areolae on a stria transapically elongated. RV: raphe straight and linear, sternum very narrow, crescent-shaped hyaline area at the terminal ends of sternum, resulting the ends of raphe distant from the apices. Central area small lanceolate or circular. The valve depressed between the raphe and valve margins. Transapical striae radiate towards the apices, 21–30 in 10 μm in the inner parts of valve.

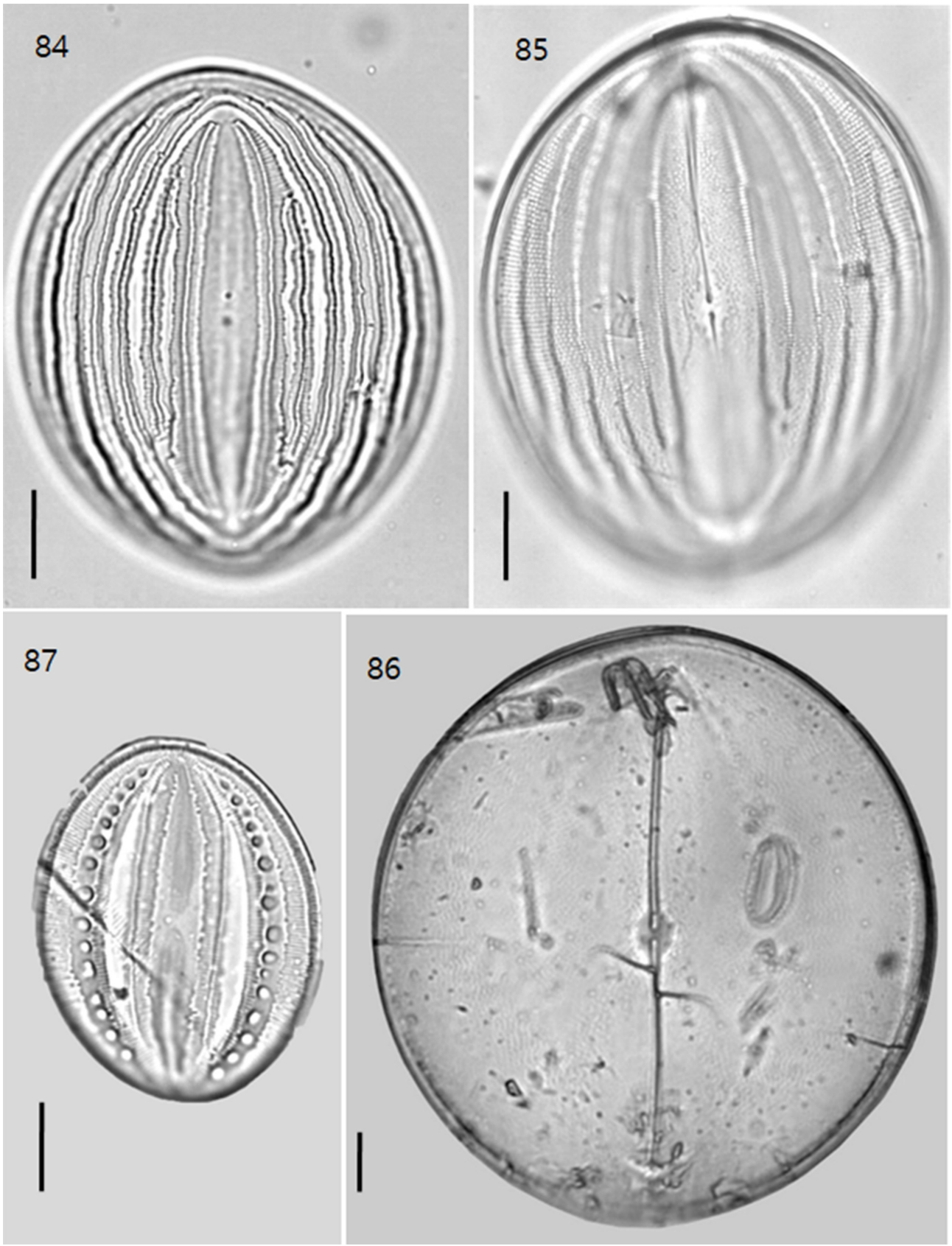
Remarks: This species is similar to *Cocconeis multiperforata* De Stefano, Mario & Mazzella and the two may be confused in the image of light microscopy. However, the comprehensive comparison of relevant reports and data of SEM (Romero & Navarro 1999, De Stefano *et al.* 2000, Mori *et al.* 2002, Riaux-Gobin *et al.* 2014a) allowed to identify the following differences: the former has uniseriate striae in the SV, a crescent shape of the hyaline area at the terminal ends of the raphe, and more than 22 of striae in the SV, while these parameters of the latter are biseriate, pear-shaped, and less than 20, respectively.



FIGURES 69–76. LM micrographs of *Cocconeis* species (5). Figs 69–72. *Cocconeis pseudomarginata*, RVs (Figs 69, 72) and SVs (Figs 70, 71) (Figs 69 and 70, a complete valve). Figs 73–76. *C. pseudomarginata* var. *intermedia*, RVs (73, 76) and SVs (Figs 74, 75). Scale bar = 10 μm (Figs 69–76).



FIGURES 77–83. LM micrographs of *Cocconeis* species (6). Figs 77, 78. *Cocconeis heteroidea*, RV (Fig. 77) and SV (Fig. 78). Figs 79–83. *C.* cf. *callosa*, RVs (Figs 79, 82) and SVs (Figs 80, 81, 83). Scale bar = 10 μm (Figs 77–83).



FIGURES 84–87. LM micrographs of *Cocconeis* species (7). Figs 84–86. *Cocconeis pellucida*, SVs (Figs 84, 85) and RVs (Figs 85, 86), internal view (Fig. 84) and external view of SV (Fig. 86). Fig. 87. *C. conspicua*, SV. Scale bars = 10 µm (Figs 84–87).

This taxon is widespread along marine coasts worldwide (Hustedt 1933); it has been collected in many places, ranging from Puerto Rico to Scotland (Romero & Navarro 1999). It was reported near Cape Town of South Africa (Giffen 1970), in the southeastern Pacific Ocean and the Caribbean Sea (Romero & Navarro 1999), common in Kattegat of Baltic Sea (Witkowski *et al.* 2000), and in Japan (Mori *et al.* 2002). In South Korea, this species was reported as planktons and periphytes off the coast of Jeju Island (Lee *et al.* 1990, 1991), and in this survey, occurred infrequently as epiphytes in the Seogwipo coast.

19. *Cocconeis pseudomarginata* var. *intermedia* Grunow (Figs 73–76, 88, 89)

Basionym: Grunow 1867, p. 13, pl. 1, fig. 6.
References: Suzuki *et al.* 2001c, p. 94, figs 1–26; Suzuki *et al.* 2008, p. 277.

Description: Valves elliptical, 26–68 μm long, 14–51 μm wide. SV: sternum broadly lanceolate, the ends of sternum enlarged and pear-shaped, connected to the submarginal hyaline area, a longitudinal line bisecting striae between sternum and valve margins. The outer surface of sternum longitudinally depressed. Transapical striae radiate towards the apices, 25–30 in 10 μm, striae composed of elongated areolae. RV: raphe weakly sigmoid, sternum very narrow, the terminal ends of the sternum expanded with a crescent-shaped hyaline area, resulting the raphe distant from the apices. Longitudinal depression between the raphe and valve margins. Central area small rhombic. Transapical striae radiate towards the apices, 23–28 in 10 μm in the inner parts of valve.

Remarks: This taxon differs from the nominate variety, *Cocconeis pseudomarginata*, in that the raphe is slightly sigmoid and transapical striae of SV are dense.

The distribution area of the species is quite limited, compared with the nominate variety, but prefer warmer marine coasts in view of localities, Cape of Good Hope, Nicobar Islands, Luzon, Manilla, and Tahiti (Fourtanier & Kociolek 2011). More recently, it has frequently been found in Japan (Suzuki *et al.* 2001c). In the present study, it was frequently encountered as epiphytes on seaweeds along the Seogwipo coast of South Korea.

20. *Cocconeis schmidtii* Heiden (Figs 53–56, 106, 107)

Basionym: Heiden and Kolbe 1928, p. 587.
Reference: Simonsen 1992, p. 33, pl. 33, figs 1–5, pl. 34, figs 1–3.

Description: Valves broadly elliptical, 17–61 μm long, 11–44 μm wide. SV: sternum narrow. Central area very small and circular, but indistinct in small-sized valves. Transapical striae parallel in the middle, strongly radiate towards the apices, 15–20 in 10 μm, interrupted by zig-zag longitudinal hyaline lines, areolae in a stria transversely elongated, 7–12 in 10 μm. RV: valve surface slightly depressed concentrically in the submarginal area. Raphe straight and linear, the terminal ends of the raphe distant from apices without any areolation, sternum narrow. Central area small and circular. Transapical striae parallel in the middle, strongly radiate towards the apices, 13–17 in 10 μm, with 13–23 circular areolae in 10 μm of stria.

Remarks: The species is very similar to *Cocconeis shikinensis* in morphology. If one addition is made to the differences between the two species, the transapical striae of the former are strongly radiate towards the ends of valve, which is distinct from the latter.

Occurring in the type locality, Kerguelen Island, in the Antarctica of the Indian Ocean. This taxon has been described from the type locality of Kerguelen Island in the Subantarctic of the Indian Ocean (Simonsen 1992), in coastal areas of King George Island, and the western Antarctic Peninsula (Lange *et al.* 2018). This taxon was encountered frequently as epiphytes along the Seogwipo coast; it is herein newly described for South Korea.

21. *Cocconeis scutellum* Ehrenberg (Figs 45–48)

Basionym: Ehrenberg 1838, p. 194, pl. 14, fig. 8.
References: Poulin *et al.* 1984, p. 56, figs 43–48; Mizuno 1987, p. 592, figs 1–5, 6A–F; De Stefano *et al.* 2008, p. 508, figs 19–35.

Description: Valves elliptic-lanceolate to broadly elliptical, 13–31 μm long, 12–24 μm wide. SV: sternum narrow and linear, and central area not developed Transapical striae coarsely punctate, radiate towards the apices, 9–10 in 10 μm, uniseriate entirely, but bi- and tri-seriate near the mantle, areolae in striae coarsely circular, 9–12 in 10 μm of stria.

RV: A narrow hyaline band in the submarginal area along the valve margin. Striae radiate, 10–13 in 10 μm, uniseriate, becoming biseriate on the mantle, areolae circular, 16–19 in 10 μm. Valvocopulae closed, having short fimbriae.

Remarks: *Cocconeis scutellum* is the most commonly reported in taxonomical and ecological research among the genus *Cocconeis*, but its morphological features have been neglected for a long time in the past. However, with the increase of SEM morphology, *C. scutellum* was recognized as a complex composed of many heterogeneous taxa rather than a single one (De Stephano *et al.* 2008). In the meantime, a lot of new taxa have been recently described as new species, and many specimens that have been reported as *C. scutellum* have been separated as new species (Riaux-Gobin *et al.* 2013). Therefore, the morphological boundary of the *C. scutellum* var. *scutellum* became very important, and it is not easy to identify the nominate variety.

The important feature of circumscribing *C. scutellum* from neighboring species is the poroid areolae on striae of SV, becoming biseriate or triseriate towards the mantle (Mizuno 1987, De Stefano *et al.* 2008). Loculiferous bands in the margins of the RV, which is fimbriate valvocopulae, is visible.

Many frustules of the *C. scutellum* were also found in the Seogwipo coast, and the morphology of valves was very diverse and there were too many complex morphology and similarities, making it difficult to identify them. Although many images of light and electron microscopy were obtained, accurate identification was difficult. Only two species of *C. scutellum* and *C. speciosa* were extracted, and the rest were all set aside for later work.

This taxon is widespread and cosmopolitan along the coasts of marine and brackish waters, and has even been found in Antarctic regions (Witkowski *et al.* 2000, De Stefano *et al.* 2008). In South Korea, it was reported frequently as planktons and periphytic off the coast (Lee 1995), as epiphytes on *Zostera* in Geoje Island (Chung & Lee 2008), and as the epipsammic on the sand flat of the Nakdong River estuary (Joh 2012). In this survey, common as epiphytes on seaweeds along the Seogwipo coast, particularly abundant in the lagoon (St. 3).

22. *Cocconeis shikinensis* Suzuki (Figs 49–52, 96–98)

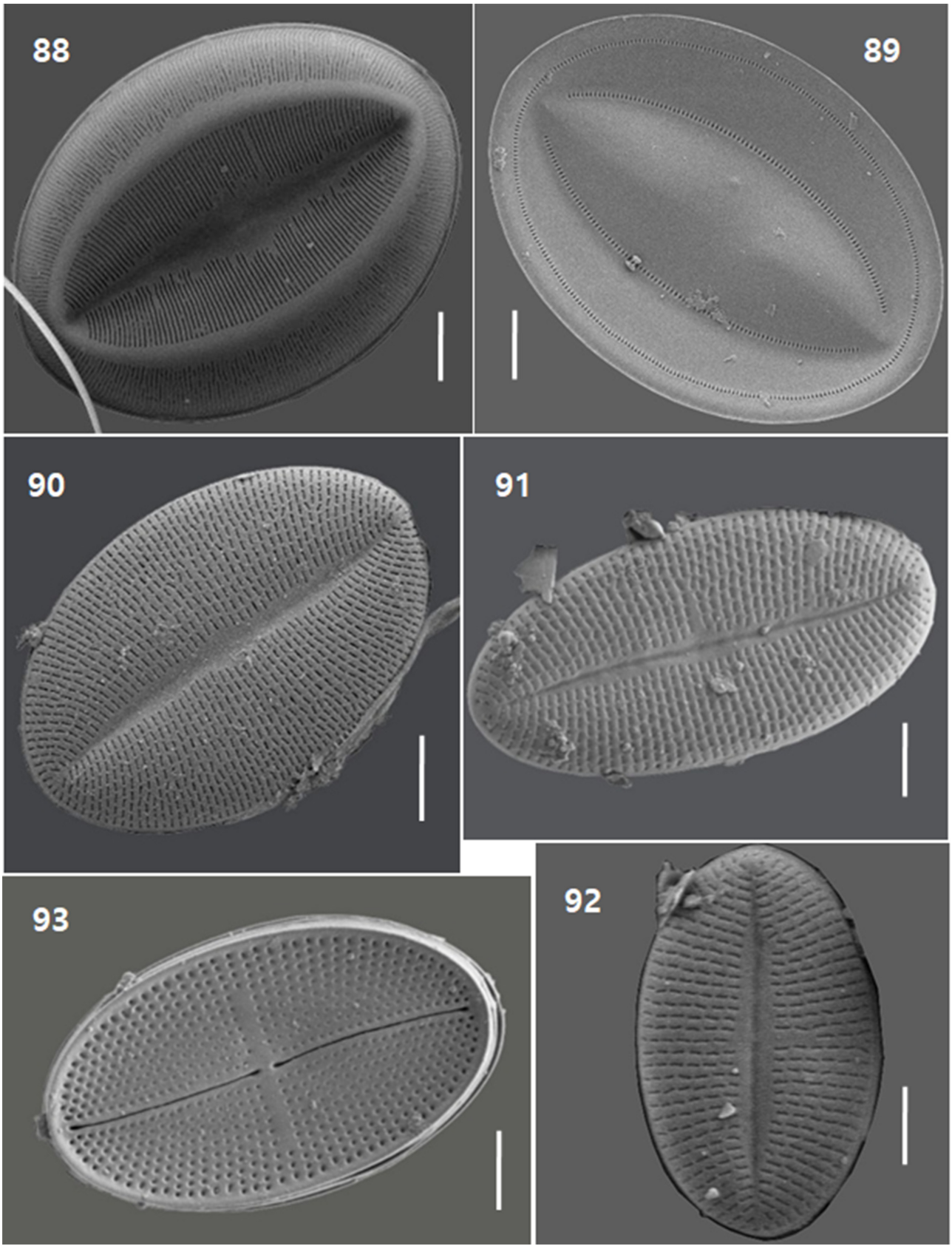
Basionym: Suzuki *et al.* 2001b, p. 138, figs 1–31.

Description: Valves elliptical, 19–50 μm long, 12–36 μm wide, the valve surface overall convex, but two-thirds of inner parts on valve face slightly concave. SV: sternum narrow and linear. Central area not developed, but very small circular in large specimens. Transapical striae transversely elongated, radiate towards the apices, 13–17 in 10 μm, crossed by several hyaline and zigzag longitudinal lines, elongated areolae in striae, alveolus, with 8–10 in 10 μm of stria. In some valves, often areolae arranged sparsely in the submarginal area. At the marginal area of the valve, one short striae arranged every 1–3 transapical striae, so the striae at the margins more dense than the middle.

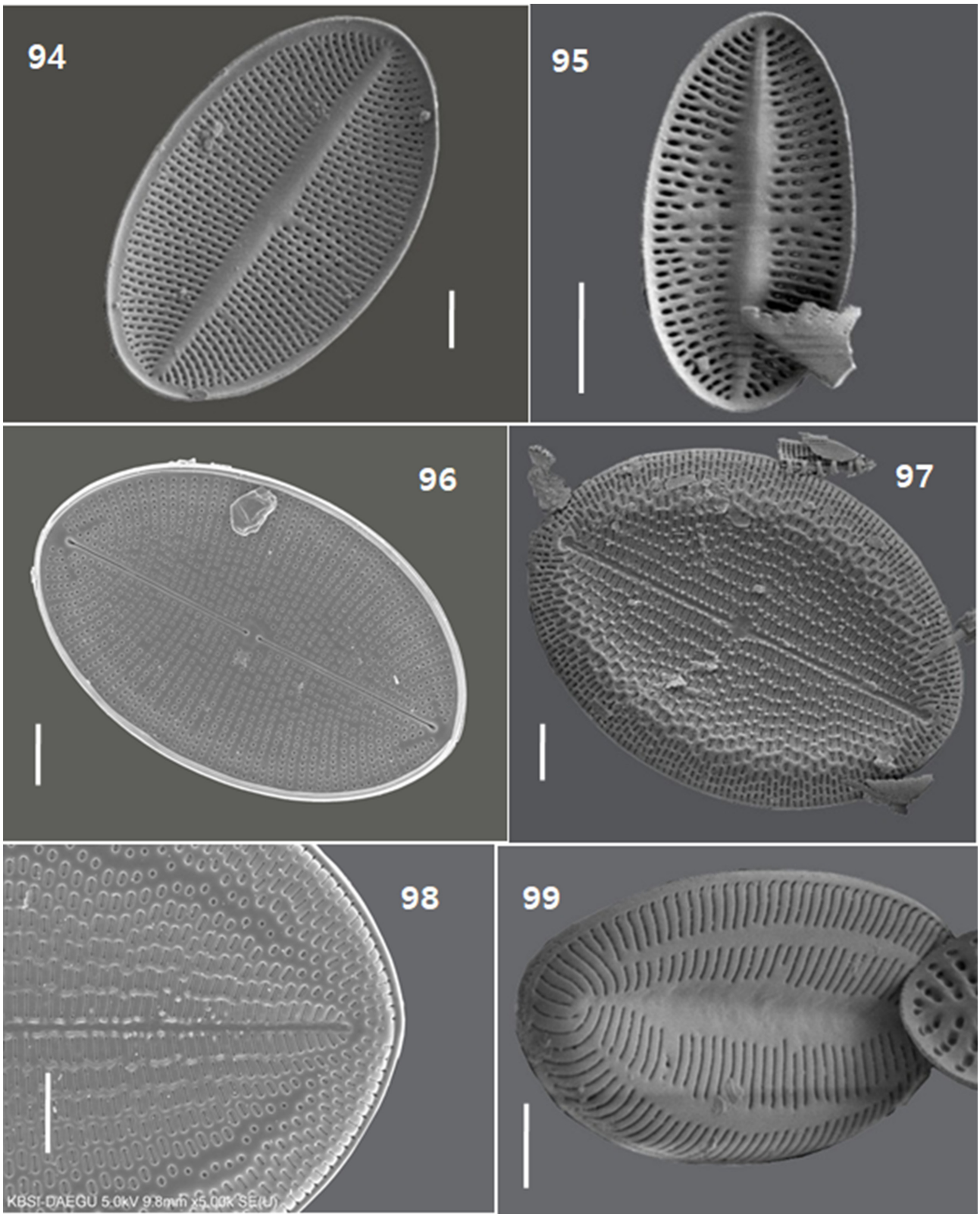
RV: raphe straight. Sternum narrow, but the terminal ends of the sternum expanded with crescent-shaped hyaline area, resulting the raphe ends distant from the apices. Central area small and circular. Transapical striae radiate, 14–21 in 10 μm, areolae in striae circular-shaped, with 16–20 areolae in 10 μm of stria. Valve face between raphe and valve margins depressed concentrically.

Remarks: This species is similar to *Cocconeis schmidtii* Heiden in its valve morphology, but differs in having a crescent hyaline area on the terminal ends of the RV, in lacking a round central hyaline area, and in having a lower density of areolae on both valves (Suzuki *et al.* 2001b). It was reported as important epiphytes on *Caulerpa* sp. (Chlorophyta) in Japan (Suzuki 2001b). In the present study, it was mainly found in Rhodophyta, such as *Plocamium* sp. This species has morphological features that may cause confusion with *C. placentula* Ehrenberg and its allied taxa. The RV is not so, but the SV is similar to that of *C. placentula*; thus, judging by the SV alone can be misleading. Prior to the naming of this species, the taxon attached to a carapace in Japan was recorded as *C. placentula* (Takano 1962). The two species, *Cocconeis shikinensis* and *C. placentula*, are sometimes found in the marine coasts. In the present study, the valve length of *C. shikinensis* ranges from 19 μm to 50 μm, while that of *C. placentula* does from 11 μm to 36 μm (Lange-Bertalot *et al.* 2017).

Previously, these taxa had been reported strictly from Japanese coasts, including the type locality, Izu Islands of Tokyo (Suzuki *et al.* 2001b, 2007). This taxon was encountered infrequently as epiphytes on seaweeds of the Seogwipo coast; it is herein newly described for South Korea.



FIGURES 88–93. SEM micrographs of *Cocconeis* species (8). Figs 88, 89. *C. pseudomarginata* var. *intermedia*, the external view (Fig. 88) and internal view of SVs (Fig. 89). Fig. 90. *C. dirupta* var. *flexella*, the external valve of SV. Figs 91–93. *C.* cf. *diruptoides*, the external view of SVs (Figs 91, 92), and the internal view of RV (Fig. 93). Scale bars = 5 μm (Figs 88, 89), 2 μm (Figs 90, 92), 1 μm (Fig. 93).



FIGURES 94–99. SEM micrographs of *Cocconeis* species (9). Fig. 94. *Cocconeis* cf. *diruptoides*, the internal view of SV. Fig. 95. *C. dirupta* var. *dirupta*, the internal view of SV. Figs 96–98. *C. shikinensis*, the external view of SV (Figs 97, 98), the internal view of RV (Fig. 96). Fig. 99. *C. suzukii*, the external view of SV. Scale bars = 1 μm (Figs 94, 98, 99), 2 μm (Figs 95–97).

23. *Cocconeis stauroneiformis* (Rabenhorst) Okuno (Figs 3–5, 103, 104)

Basionym: Rabenhorst 1864, p. 101.

References: Romero 1996, p. 371, figs 25–54; De Stefano *et al.* 2000, p. 237, figs 87–92; Witkowski *et al.* 2000, p. 116, pl. 36, figs 8, 9, pl. 54, figs 1–3; Sar *et al.* 2003, p. 95, figs 51–57.

Description: Valves elliptic-lanceolate to elliptical, 15–20 μm long, 8–12 μm wide. SV: sternum moderately linear to lanceolate, and central area not developed. Transapical striae broad, uniseriate, slightly radiate towards the apices, 8–11 in 10 μm, with 15–16 areolae in 10 μm of stria. RV: raphe straight, the central ends of raphe close each other, and sternum narrow. Central area transversely expanded into a hyaline fascia, up to the margins. Transapical striae slightly radiate towards the apices, 11 in 10 μm, with 16–17 areolae in 10 μm of stria. A hyaline rim in the submarginal area of valve.

Remarks: As epiphytic and benthic diatoms, *Cocconeis stauroneiformis* is distributed widely from the Pacific Ocean to the Antarctica (Romero 1996), and cosmopolitan from marine to brackish waters (Witkowski *et al.* 2000). It occurred in Gulf of Naples of Italy (De Stefano *et al.* 2000), and in Patagonian coast of Argentina (Sar *et al.* 2003). In South Korea, this taxon was reported firstly as the epipsammic from the Nakdong River estuary (Joh 2012), and in this survey, infrequent as the epiphytes on seaweeds along the Seogwipo coast.

24. *Cocconeis suzukii* Riaux-Gobin, Compère, Coste, Straub & Taxböck (Figs 57–61, 99)

Basionym: Riaux-Gobin *et al.* 2014b, p. 213, figs 24–28.

Description: Valves elliptical, 13–20 μm long, 9–11 μm wide. SV: sternum large, elliptical and slightly sigmoid, not constricted in the middle. Transapical striae delicate and radiate towards the apices, 29–32 in 10 μm, but interrupted by a hyaline longitudinal line, one stria shorter in the middle of one side of valve. RV: both raphe and sternum sigmoid, sternum very narrow, the central ends of raphe close each other, but the terminal ends of raphe relatively far from the apices. Central area not developed. Transapical striae radiate towards the apices, 24–28 in 10 μm.

Remarks: This species was designated from F. Meister's slide specimens, collected from Nagasaki of Japan (Riaux-Gobin *et al.* 2014b). It does not appear to have been reported anywhere other than Nagasaki. Along Seogwipo coast, the species was encountered less frequently as epiphyte from small rock pools (St. 2); it is herein newly described for South Korea.

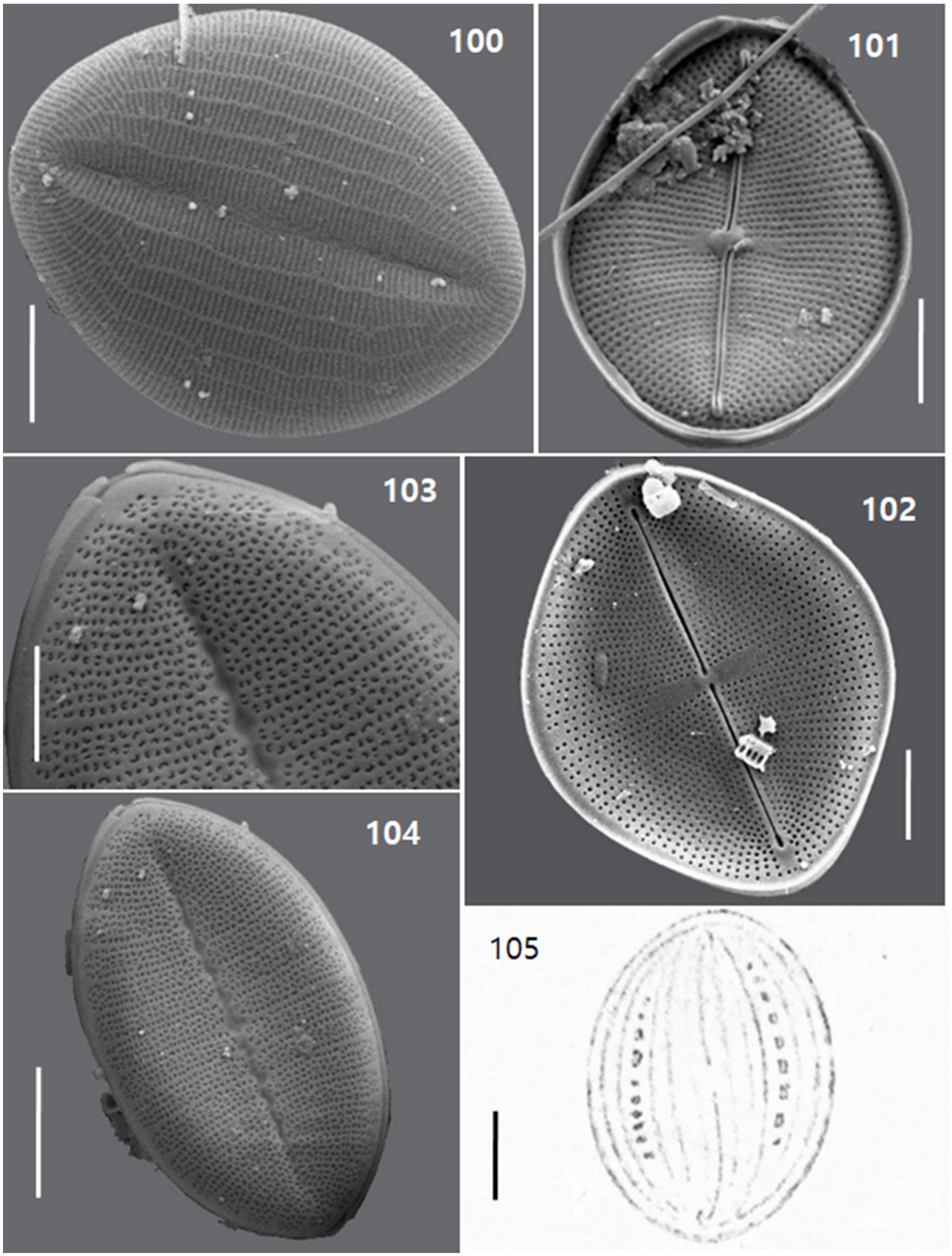
25. *Cocconeis voigtii* Meister 1937 (Figs 65–68)

Basionym: Meister 1937, p. 266, pl. 10, fig. 5.

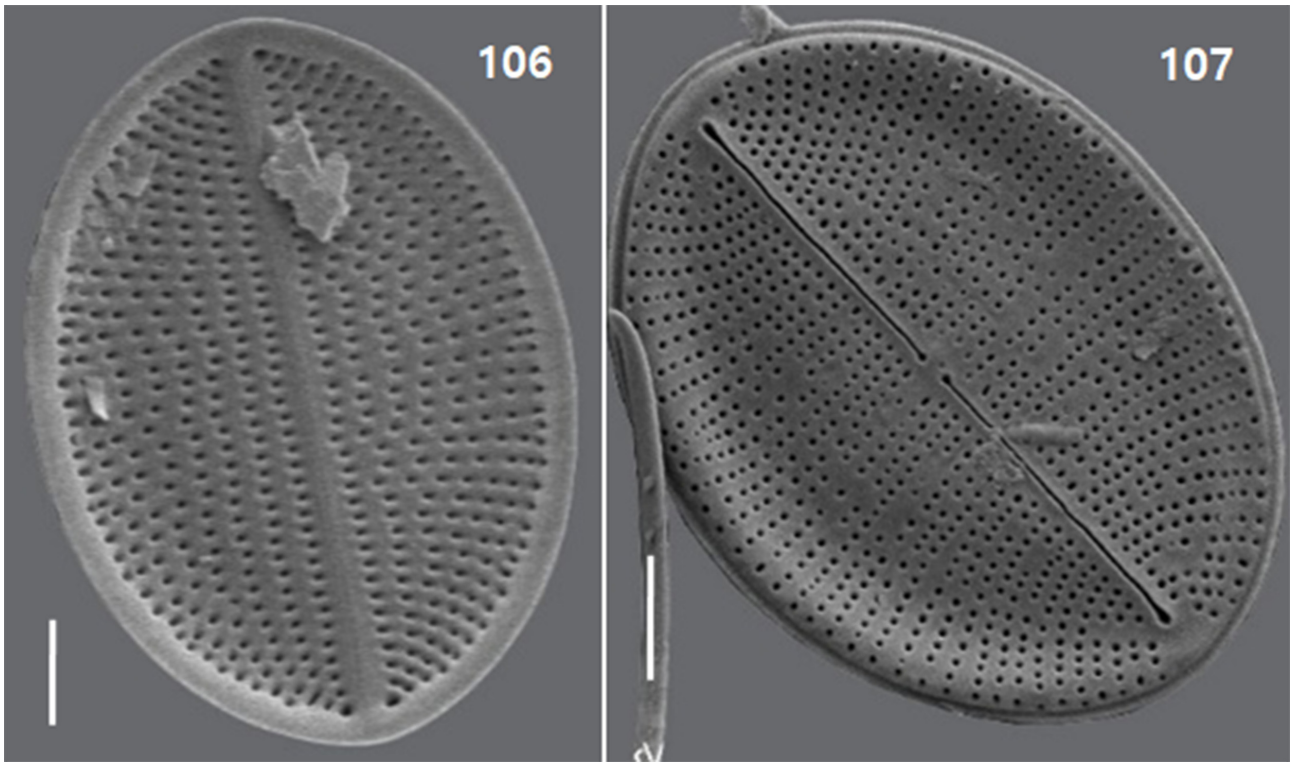
Reference: Riaux-Gobin *et al.* 2017, p. 46, figs 1, 24–29.

Description: Valves elliptical, 32–58 μm long, 24–45 μm wide. SV: sternum broadly lanceolate, the terminal ends of the sternum slightly large and formed as a pear-shaped hyaline area, and connected to the submarginal hyaline band. Transapical striae slightly radiate towards the apices, 17–21 in 10 μm, crossed by 2–3 longitudinal hyaline lines, outer striae between the sternum and submarginal hyaline band crossed by narrow and wavy longitudinal lines. RV: raphe weakly sigmoid, sternum very narrow and connected to crescent-shaped hyaline area in the apices, the ends of raphe distant from the apices. Central area small and rhombic. A longitudinally depressed area between the raphe and valve margins forming clear submaginal rims. Transapical striae distinctly punctate and radiate towards the apices, striae of inner parts 19–25, with 18–20 areolae in 10 μm of stria.

Remarks: The original description of this taxon was emended by Riaux-Gobin *et al.* (2017), adding the description of its RV. Previously, the species appears to only have been found at the type locality of Nagasaki, Japan. Along the Seogwipo coast of Jeju Island, it was encountered infrequently as epiphyte from a small rock pool (St. 2), and is herein newly reported for South Korea.



FIGURES 100–105. SEM micrographs of *Cocconeis* species (10). Figs 100–102. *Cocconeis convexa*, the external view of SV (Fig. 100), the external view of RV (Fig. 101) and internal view of RV (Fig. 102). Figs 103, 104. *C. stauroneiformis*, the external views of SV. Fig. 105. *Cocconeis conspicua*, SV, the original drawing of Schmidt (1894b, pl.196, fig. 27). Scale bars = 1 µm (Fig. 103), 2 µm (Figs 100–102, 104), 10 µm (Fig. 105).



FIGURES 106, 107. SEM micrographs of *Cocconeis* species (11). Figs 106, 107. *Cocconeis schmidtii*, the internal view of SV (Fig. 106), the external view of RV (Fig. 107). Scale bars = 2 μm (Figs 106, 107).

Discussion

Diatoms were collected from the epiphytic, epipelic, epipsammic, and attached materials, but the samples were small except for epiphytes. Many living diatoms containing chloroplasts were encountered in epiphytic assemblages, while dead frustules outnumbered the living species in the bottom sediments. After cleaning, RVs are less abundant than SV in the supernatant due to the frequent breakage of fragile RVs during acid-cleaning procedures (Romero & Navarro 1999). Furthermore, only one of the two valves, i.e. the SVs, may be released from the substrates during the shaking harvest. SVs are more strongly silicified frustules and are therefore easily detached from the substratum (Tiffany 2011). In some cases, *Cocconeis* taxa were identified even in the absence of RVs. The lack of information regarding a single valve side complicated the identification of taxa occasionally.

To further find out the floral characteristics of the local area, the *Cocconeis* taxa were divided into five groups, based on the apparent morphology of valves. The key index of Hustedt (1933) in the classification of *Cocconeis* taxa was used for the divisions. The first group comprises *C. capensis*, *C. clandestina*, *C. costata* and *C. pinnata* which carry double rows of areolae in the SV. The second group includes *C. delicata*, *C. dirupta*, *C. dirupta* var. *flexella* and *C.* cf. *diruptoides*, which sigmoid raphe and a broadly elliptical sternum. The third comprises large taxa such as *C. convexa*, *C. pellucida*, *C. pseudomarginata*, bearing sigmoid raphe and longitudinal folds of SVs. The other two groups are represented by *C. scutellum* and *C. shikinensis*. The third group, in which hyaline axial area and axial rows of elongated areolae alternate in the SV, include *C. conspicua*, *C. heteroidea*, *C. suzuki* and *C. voigtii*, in addition to the three taxa described above.

Among the five groups, the second and the third group of *Cocconeis*, and *C. scutellum* showed increased frequency and abundance. Among the groups belonging to the third group, *C. subtilissima* Meister that Suzuki *et al.* (2008) reported in Japan was abundant in the local area. However, the lectotype of *C. subtilissima* Meister was newly designated by Riaux-Gobin *et al.* (2014b), and the description of the species was emended. Therefore, *C. subtilissima* Meister sensu Suzuki *et al.* (2008) is no longer valid because it was morphologically different from the newly emended species. However, the proportion of diatoms that do not belong to the five groups were negligible.

Cocconeis scutellum and neighboring species represent epiphytic diatoms that grow on seaweeds and are most abundant in the Seogwipo coast. In many cases, *C. scutellum* has been known as a dominant epiphyte on seaweeds and seagrasses (Tanaka 1986, Romero 1996, Sawai 2001, De Stefano *et al.* 2008, Totti *et al.* 2009, Da Silva-Costa *et al.* 2016), and colonized the surface of marine biota such as gastropod and hydroids (Totti *et al.* 2010, D'alelio *et al.* 2011)

Under LM, the schematic form shows robust and distinct areolae on the SV. The areolae are round or square and often enlarge towards the margins. In SEM morphology, *C. scutellum* and the allied taxa are known to carry a variety of areolae in the SV and valvocopulae of RV (De Stefano *et al.* 2000, De Stefano *et al.* 2008). In addition, overlapping or continuous morphological characters exist between the taxa of the *C. scutellum* group. There were many suspected infraspecific forms of *C. scutellum* or those closely related to *C. scutellum*. However, they can not be confirmed to species level and only *C. scutellum* s.s was defined. Further studies are needed to identify the diatoms of *C. scutellum* group in the local area. It is worth noting that several taxa similar to *C. scutellum*, but with ultrastructural specificities, particularly concerning their valvocopulae, were recently created (e.g., *C. alucitae* Riaux-Gobin & Compère*, C. coronatoides* Riaux-Gobin & Romero*, C. sagaraensis* Suzuki*, C. nosybetiana* Riaux-Gobin, A.Witkowski, Bemiasa & Bemanaja*, C. spina-christi* Riaux-Gobin, Romero, Coste & Galzin*, Cocconeis vrangoensis* Al-Handal & Riaux-Gobin).

Nevertheless, the present floristic study reveals the existence of rare species and expands some of their biogeography. Some retrieved species were not known until recently, while others were newly shown through taxonomic classification to occur in the local area. The four species, *C. callosa*, *C. cyclophora* var. *decora*, *C. delicata*, and *C. voigtii*, were originally sampled from Nagasaki, Japan, in 1933–1934, stored in F. Meister's collections, and recently described in detail by Riaux-Gobin *et al.* (2017). *C. subtilissima* Meister was re-established via lectotypification and emended description of Riaux-Gobin *et al.* (2014b). *C. cyclophora* var. *meisteri* was newly described from the same materials by Riaux-Gobin *et al.* (2017). In particular, many *Cocconeis* taxa described in the Nagasaki materials were found in Jeju Island as newly recorded taxa in South Korea, reflecting the geographic proximity of Jeju Island to Nagasaki, Japan, and facilitated by re-erection of unknown *Cocconeis* taxa by Riaux-Gobin *et al.* (2017). However, the existence of *C. shikinensis* but not Nagasaki materials is still unknown in other regions and was traced in the Seogwipo coast finally.

During this survey, many taxa were observed, mainly pantropical, such as those of the Pacific Ocean (e.g., Lobban *et al.* 2012, Stidolph *et al.* 2012) and the Indian Ocean (e.g., Riaux-Gobin *et al.* 2011). Many of the species found in the local area were previously reported to be distributed along the coasts of tropical and subtropical regions. These species included *Cocconeis convexa*, *C. dirupta* var. *flexella*, *C. heteroidea*, *C. pellucida*, *C. pseudomarginata*, and *C. pseudomarginata* var. *intermedia*. In addition, some taxa, originally discovered in Japan have been rarely reported yet. However, they are likely to be inhabitants of warmer oceans. They include *Cocconeis callosa*, *C. delicata*, *C. suzuki*, and *C. voigtii* collected from Nagasaki, and *C. cyclophora* var. *decora*, *C. delicata* in Yokohama, and *C. shikinensis* in Tokyo.

This study contributed to the point on all the *Cocconeis* that were not previously recorded from South Korea. The *Cocconeis* taxa recorded in Korea's marine waters was counted as 11 in the checklist compiled in 1995 (Lee 1995, Lee *et al.* 1995), and 20 taxa in 2015 (Lee & Joh 2015). Of the 26 *Cocconeis* taxa here reported, 14 are new for South Korea. Based on their global distribution, they can be pantropical as also present in Japanese marine waters. It is impossible to estimate the extent of the change due to the lack of studies investigating epiphytes or *Cocconeis* taxa along the coasts of Jeju Island in the past. Considering that Seogwipo is a humid subtropical area (Cfa) in the Köppen climate system (Weatherbase, https://www.weatherbase.com), the number of species inhabiting warmer coast would increase in this area. Many taxa previously absent from Korean assemblages, were found from a few samples of seaweeds collected in rock pools (St. 2) in March 2018. They are as follows: *Cocconeis callosa*, *C. capensis*, *C. clandestina*, *C. conspicua*, *C. costata*, *C. cyclophora* var. *decora*, *C. cyclophora* var. *meisteri*, *C. delicata*, *C. dirupta* var. *flexella*, *C. pinnata*, *C. schmidtii*, *C. shikinensis*, C. *suzukii* and *C. voigtii*. This is the first report of a taxonomic study of diatoms off the coast of Jeju Island. Among the *Cocconeis* species occurring in the local area studied herein, many specimens remain unidentified. Further studies will elucidate the taxonomic position of several taxa enough documented by now and will permit to precise the richness of Jeju Island.

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