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# New Record of Dinoflagellates around Jeju Island

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**Abstract**

Dinoflagellate species composition has changed around Jeju Island as well as in Korean waters due to global warming and climate changes. An investigation was conducted to monitor changes in planktonic dinoflagellates around Jeju Island from June 2006 to September 2009. A total of 86 species belonging to 14 families and 15 genera were identified, of which 34 species were newly recorded in Korean waters. Among the newly recorded species, >20 were confirmed as tropical species. Thus, the occurrence of such tropical dinoflagellates could be an indicator to monitor of environmental changes including global warming around Jeju Island and in Korean waters.

**Key words:** climate change, global warming, Jeju Island, tropical dinoflagellates, unrecorded species

## INTRODUCTION

The marine ecosystem around Jeju Island has been changing from temperate to sub-tropical and/or tropical conditions over the last two decades. We have several clues for the change such as occurrence of tropical fish, invertebrates and macro-algae. Here we propose two possibilities to explain these changes: 1) the increase in seawater temperature around Jeju Island by the East China Sea is occurring due to atmospheric circulation (Yeh and Kim 2010) and 2) expansion of the Kuroshio Current by rising sea level caused by global warming (Pang et al. 1996). Increasing seawater temperature and expansion of the high salinity and high temperature Kuroshio Current could have affected the marine ecosystem around Jeju Island, which would result in tropical planktonic and benthic species adapting to survive around Jeju Island.

Dinoflagellates are a major taxon in the phytoplankton community and are comprised of various species in terms of habitat and nutrient uptake. These species contribute to primary production in oceans and include diverse tropical species reported in many waters worldwide (Dodge 1982). Dinoflagellates produce resting cysts as a survival strategy in unfavorable conditions (Anderson and Wall 1978). The evidence for an ecosystem change around Jeju Island includes increases in sea surface water temperature and a rising sea level, as well as some changes in macroalgae and fish, but little planktonic evidence is available indicating these. Dinoflagellates could potentially be used as an indicator species for the changing marine ecosystem. A total of 153 planktonic dinoflagellates were described from Korean waters so far (Shim et al. 1981, Han and Yoo 1983a, 1983b, Yoo and Lee 1986, Lee et al. 1993, Shim 1994). However, no more dinoflagellates were taxonomically described until this present study.

The objectives of study were to collect planktonic evidence for the marine environmental changes near Jeju Island and to confirm the occurrence of newly recorded and tropical dinoflagellates, which may have been introduced by the Kuroshio Current.

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## MATERIALS AND METHODS

Monthly sampling was performed at 14 stations around the coastal waters of Jeju Island from June 2006 to September 2009 (Table 1). Planktonic dinoflagellates were collected in a plankton net with 20 μm mesh and fixed in formaldehyde (final concentration of 0.4%). The dinoflagellate samples were washed with distilled water and then dehydrated in an alcohol series (30%, 50%, 70%, 90%, and 100%) to prepare slide specimens. One drop of mount media was added to a cover slide and mounted upside down on the slide where some dinoflagellates had dried after the alcohol series. Successfully prepared slides were selected for use in identification. The preparations for scanning electron microscopy followed a method described in Yoo and Lee (1986).

Light microscopy (Axioplan; Carl Zeiss, Oberkochen, Germany) and scanning electron microscopy (JSM-6700F; JEOL, Tokyo, Japan) were used to identify specimens, and several monographs were cited from different oceans such as the Indian Ocean (Taylor 1976), Japanese adjacent sea (Yamaji 1984), British Isles (Dodge 1982), Atlantic Ocean (Dodge 1985), and Kuroshio Current (Fujioka 1990).

The dinoflagellate classification system according to Shim (1994) was applied. The genera *Ornithocercus*, *Oxytoxum*, *Ptychodiscus* followed the classification of Steidinger and Tangen (1996), *Dissiodinium asymmetricum* followed that of Dodge (1982), and *Gyrodinium falcatum* from *Pseliodinium vaubanii* followed that of Gomez (2007).

## RESULTS

Eighty-six dinoflagellate species belonging to 7 orders, 14 families, and 15 genera were identified during the study period. Among them, 34 species were recorded for the first time in the sea adjacent to Jeju Island and in Korean waters. Of the unrecorded species, 23 were defined as tropical species and have been reported in tropical waters worldwide. The species that occurred are listed below and an asterisk (*) mark indicates a newly recorded species in Korean waters and newly described in this study. The species written in bold indicate tropical species among the newly recorded species in this study.

### Systematics of Occurring Species

**Class Dinophyceae**
**Order Prorocentrales Lemmermann**
**Family Prorocentraceae Stein**
**Genus *Prorocentrum* Ehrenberg 1833**
*Prorocentrum balticum* (Lohmann) Loeblich
*Prorocentrum compressum* (Bailey) Abé ex Dodge
*Prorocentrum micans* Ehrenberg
*Prorocentrum triestinum* Schiller
**Order Dinophysiales Lindemann 1928**
**Family Dinophysiaceae Stein 1883**
**Genus *Dinophysis* Ehrenberg 1839**
*Dinophysis acuminata* Claparède & Lachmann
*Dinophysis caudata* Saville-Kenk
***Dinophysis cuneus*** (Schütt) Abé
***Dinophysis hastata*** Stein

**Table 1.** Latitude and longitude of the sampling stations

| Sampling stations | Local name | Latitude | Longitude |
|---|---|---|---|
| J1 (Bukchon) | Bukchon-ri coast | 33°34′30.83″ | 126°41′02.64″ |
| J2 (Samyang) | Samyang coast | 33°32′08.16″ | 126°35′59.75″ |
| J3 (Tapdong) | Tap-dong coast | 33°32′18.72″ | 126°33′02.94″ |
| J4 (Iho) | Iho coast | 33°30′18.78″ | 126°27′05.16″ |
| J5 (Aewol) | Aewol-ri coast | 33°29′37.79″ | 126°20′31.13″ |
| J6 (Hallim) | Hallim-ri coast | 33°26′34.25″ | 126°14′01.38″ |
| J7 (Chagwido) | Chagwido coast | 33°19′02.70″ | 126°08'02.40″ |
| J8 (Gosan) | Gosan-ri coast | 33°15′31.85″ | 126°09′52.61″ |
| J9 (Hamo) | Hamo-ri coast | 33°11′44.75″ | 126°13′57.59″ |
| J10 (Hwasun) | Hwasun-ri coast | 33°10′56.51″ | 126°20′00.00″ |
| J11 (Seogwipo) | Seogwipo coast | 33°13′31.43″ | 126°34′17.16″ |
| J12 (Namwon) | Namwon-ri coast | 33° 14′53.03″ | 126°43′10.62″ |
| J13 (Pyoseon) | Pyoseon-ri coast | 33°17′01.38″ | 126°49′27.89″ |
| J14 (Seongsan) | Seongsan-ri coast | 33°26′26.87″ | 126°57′11.70″ |

*__Dinophysis mitra__ Schütt
*Dinophysis ovum* Schütt
*Dinophysis rotundata* Claparède & Lachmann
*__Dinophysis schuettii__ Murray & Whitting
*Dinophysis* sp.
**Genus *Ornithocercus* Stein 1883**
*__Ornithocercus heteroporus__ Kofoid
*__Ornithocercus magnificus__ Stein
*__Ornithocercus quadratus__ Schütt
*__Ornithocercus steinii__ Schütt
*__Ornithocercus thumii__ (A.Schmidt) Kof. & Skogs.
**Order Gonyaulacales F.J.R. Taylor 1980**
**Family Ceratiaceae Lindemann 1928**
**Genus *Ceratium* Schrank 1793**
*Ceratium arietinum* Cleve
*__Ceratium azoricum__ Cleve
*Ceratium candelabrum* (Ehrenberg) Stein
*Ceratium contortum* (Gourret) Cleve
*Ceratium deflexum* (Kofoid) Jörgensen
*Ceratium extensum* (Gourret) Cleve
*Ceratium furca* (Ehrenberg) Claparède& Lachmann
*Ceratium fusus* (Ehrenberg) Dujardin
*Ceratium gibberum* Gourret
*Ceratium horridum* (Cleve) Gran
*Ceratium horridum* var. *claviger* (Kofoid) Graham & Bronikowski
*Ceratium inflatum* (Kofoid) Jörgensen
*Ceratium lineatum* (Ehrenberg) Cleve
*Ceratium longirostrum* Gourret
*Ceratium lunula* Schimper
*Ceratium massiliense* (Gourret) Jörgensen
*Ceratium pentagonum* Gourret
*Ceratium platycorne* Daday
*__Ceratium praelongum__ (Lemmermann) Kofoid
*Ceratium ranipes* Cleve
*Ceratium trichoceros* (Ehrenberg) Kofoid
*Ceratium tripos* (O.F.Müller) Nitzsch
*Ceratium vultur* Cleve
**Family Ceratocoryaceae Lindemann 1928**
**Genus *Ceratocorys* Stein 1883**
*__Ceratocorys gourretii__ Paulsen
*Ceratocorys horrida* Stein
**Family Gonyaulacaceae Lindemann**
**Genus *Gonyaulax* Diesing**
*Gonyaulax polyedra* Stein
*Gonyaulax polygramma* Stein
*Gonyaulax spinifera* (Claparède& Lachmann) Dissing
**Family Pyrophaceae Lindemann 1928**
**Genus *Pyrophacus* Stein 1883**
*Pyrophacus horologium* Stein
*__Pyrophacus steinii__ (Schiller) Wall & Dale
**Family Oxytoxaceae**
**Genus *Oxytoxum* Stein 1883**
*__Oxytoxum constrictum__ (Stein) Bütschli 1885
**Oxytoxum milneri* Murray & Whitting 1899
**Oxytoxum reticulatum* (Stein) Schütt
**Oxytoxum sceptrum* (Stein) Schröder 1906
*__Oxytoxum scolopax__ Stein 1883
*__Oxytoxum tesselatum__(Stein) Schütt 1895
**Order Pyrocystales**
**Family Pyrocystaceae**
**Genus *Pyrocystis* Murray ex Haeckel 1890**
*__Pyrocystis hamulus__ Cleve
**Pyrocystis robusta* Kofoid
**Order Peridiniales**
**Family Peridiniaceae**
**Genus *Dissodium* Abé 1941**
**Dissodium asymmetricum* (Morgin) Loeblich
**Family Goniodomataceae**
**Genus *Goniodoma***
*Goniodoma polyedricum* (Pouchet) Jörgensen
*Goniodoma sphaericum* (Murray &Whitting)
**Family Podolampaceae Lindemann 1928**
**Genus *Podolampas* Stein 1883**
*__Podolampas bipes__ Stein
*__Podolampas palmipes__ Stein
*Podolampas spinifera* Okamura
**Family Protoperidiniaceae F.J.R. Taylor 1987**
**Genus *Protoperidinium* Bergh 1881**
*Protoperidinium brochii* (Kofoid et Swezy) Balech
*Protoperidinium cerasus* (Paulsen) Balech
*Protoperidinium claudicans* (Paulsen) Balech
*Protoperidinium conicoides* (Paulsen) Balech
*Protoperidinium conicum* (Gran) Balech
*Protoperidinium curvipes* (Ostenfeld) Balech
*Protoperidinium depressum* (Bailey) Balech
*Protoperidinium divergens* (Ehrenberg) Balech
*Protoperidinium marielebouriae* (Paulsen) Balech
*Protoperidinium nipponicum*Abé
**Protoperidinium oblongum* (Aurivillius) Parke & Dodge 1976
*__Protoperidinium obtusum__ (Karsten) Parke & Dodge 1976
*Protoperidinium oceanicum* (vanHöffen) Balech
**Protoperidinium oviforme* (Dangeard) Balech 1974
*Protoperidinium pallidum* (Ostenfeld) Balech
*Protoperidinium pellucidum* Bergh
*Protoperidinium pentagonum* (Gran) Balech
*__Protoperidinium quinquecorne__ (Abé) Balach 1974
*Protoperidinium roseum* (Paulsen) Balech

**Protoperidinium steinii* (Jörgensen) Balech 1974
**Protoperidinium thorianum* (Paulsen) Balech 1973
*Protoperidinium* sp.
**Order Gymnodiniales Lemmermann 1910**
**Family Gymnodiniaceae Lankester 1885**
**Genus *Pseliodinium* Sournia 1972**
*****Pseliodinium vaubanii*** Sournia 1972
**Order Ptychodiscales**
**Family Ptychodiscaceae**
**Genus *Ptychodiscus* Stein 1883**
*****Ptychodiscus noctiluca*** Stein 1883

## Description of Unrecorded Dinoflagellates

### Genus *Dinophysis* Ehrenberg 1840

***Dinophysis cuneus* (Schütt) Abé 1967 (Fig. 1A and 1B)**

**Synonym:** *Phalacroma cuneus* Schütt 1895.

**References:** Steidinger et al. 1967, pp 28–29, pl. I. f; Dodge 1985, p 19; Fujioka 1990, pp 42–43, fig. 11; Steidinger and Tangen 1996, pp 438–439, pl. 14.

**Specimen examined:** Slide LJB2006-01 at the National Institute of Biological Resources (NIBR), Incheon.

**Description:** Epitheca looks like a dome and is relatively broad, but hypotheca is narrow like a reversed triangle. Cell surface has irregular reticulate ornamentation. This species is tropical or subtropical.

**Size:** Length 83–96 µm, width 96–116 µm.

**Occurrence:** Sep 2006 (J8 Gosan); Sep Nov Dec 2007 (J14 Seongsan).

**Distribution:** Oceanic, tropical species; worldwide distribution.

***Dinophysis hastata* Stein 1883 (Fig. 1C and 1D)**

**Synonym:** *Dinophysis uracantha* (Stein) E.S. Silva 1956.

**References:** Dodge 1982, p 47, 49, fig. 4C; Dodge 1985, p 19; Taylor 1987, p 31, fig. 2.4a; Fujioka 1990, pp 44–45, fig. 5; Steidinger and Tangen 1996, pp 432–433, pl. 12.

**Specimen examined:** Slide LJB2006-02 at the NIBR, Incheon.

**Description:** Cell shape is subovate in later view with characteristic elongated triangular sail at the posterior end of hypotheca, ventral of the midline. Hypotheca round, deepest around the middle and the posterior end is narrower than anterior end.

**Size:** Length 83–84 µm, width 66–76 µm.

**Occurrence:** Dec 2006 (J7 Chagwido); Jan 2007 (J14 Seongsan); Aug 2007 (J13 Pyoseon); Oct 2007 (J9 Hamo).

**Distribution:** Mainly neritic species; distributed in temperate to tropical waters.

***Dinophysis mitra* Schütt 1895 (Fig. 1E and 1F)**

**Synonym:** *Phalacroma mitra* Schütt 1895.

**References:** Fujioka 1990, pp 44–45, fig. 8; Steidinger and Tangen 1996, pp 438–439, pl. 14.

**Specimen examined:** Slide LJB2008-06 at the NIBR, Incheon.

**Description:** Cell forms a reverse triangle in side view. The epitheca looks like a dome, and the hypotheca is slightly concave under the sulcus forming a slightly convex end in lateral view. This is a known toxic species.

**Size:** Length 60–70 µm.

**Occurrence:** Oct 2008 (J9 Hamo); Sep Nov 2008 (J14 Seongsan); Nov 2008 (J13 Pyoseon).

**Distribution:** Neritic and oceanic species; distributed in temperate to tropical waters.

***Dinophysis schuettii* Murray & Whitting 1899 (Fig. 1G and 1H)**

**Synonyms:** *Dinophysis uracantha* Schütt 1895; *Dinophysis uracantha* Stein 1883.

**References:** Wood 1963, pp 7–8, fig. 17; Fujioka 1990, pp 46–47, fig. 1; Steidinger and Tangen 1996, pp 432–433, pl. 12.

**Specimen examined:** Slide LJB2009-14 at the NIBR, Incheon.

**Description:** Spherical shape with a relatively small size in lateral outline. The sulcal list is supported by very sharp, rigid ribs. Posterior end of hypotheca has another sharp, rigid rib like spine.

**Size:** Cell size without list 40–45 µm.

**Occurrence:** Dec 2007 (J14 Seongsan); Oct 2008 (J9 Hamo).

**Distribution:** Oceanic, tropical species; worldwide distribution.

### Genus *Ornithocercus* Stein 1883

***Ornithocercus heteroporus* Kofoid 1907 (Fig. 1I)**

**Synonyms:** *Ornithocercus biclavatus* Wood 1954; *Ornithocercus triclavatus* Wood 1954.

**References:** Fujioka 1990, pp 46–47, fig. 7; Steidinger and Tangen 1996, pp 435–436, pl. 13; Jyothibabu et al. 2008, fig. 13c.

**Specimen examined:** Slide LJB2007-04 the NIBR, Incheon.

**Description:** Small compared to other species within the same genus. Cell is spherical, and the epitheca is much eliminated. Girdle list shaped like a skirt spreading anteriorly. The sulcal list is very widely spreading with a wide list below the sulcus. *Synechococcus*, cyanobacterial

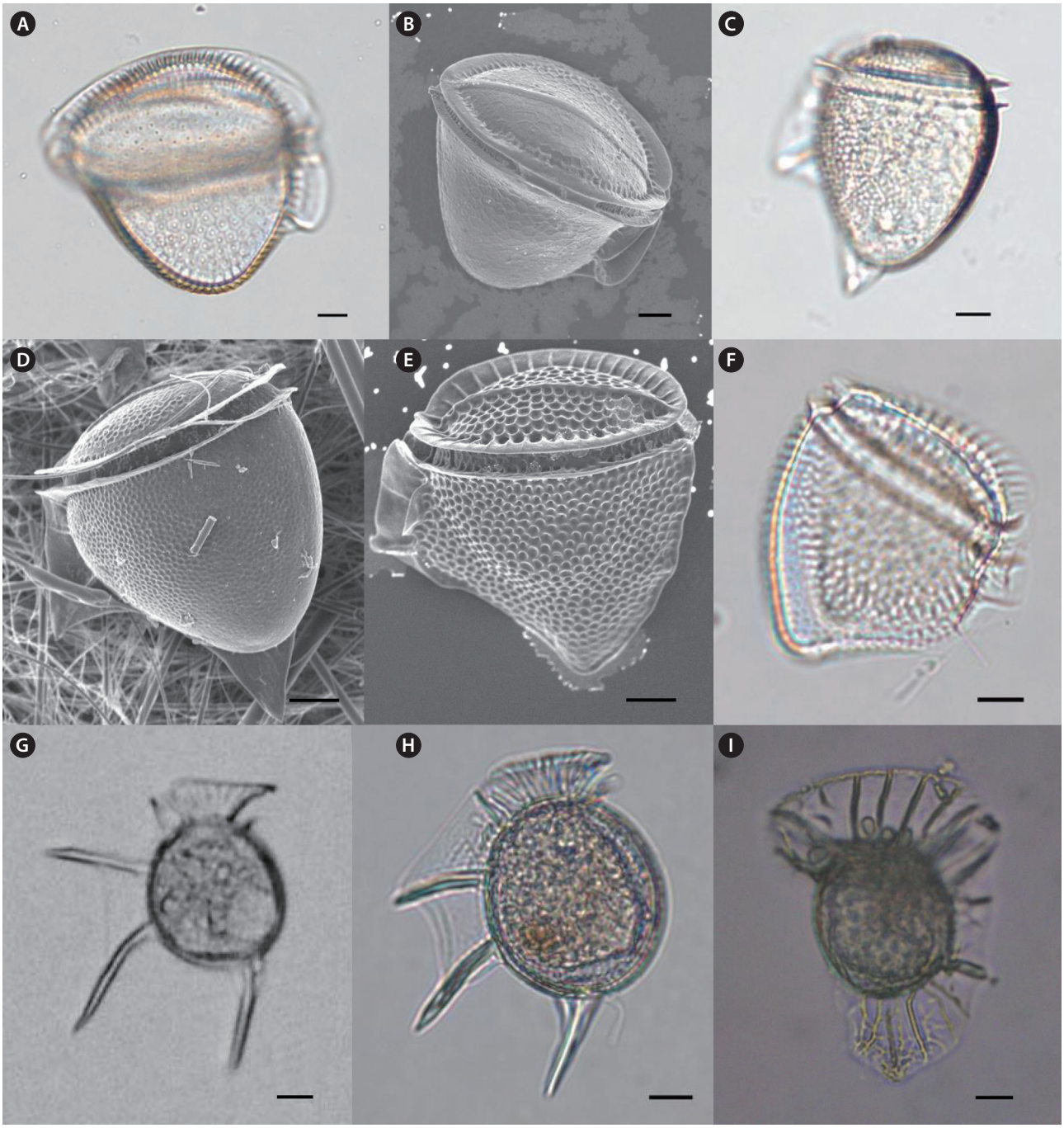


**Fig. 1.** Light microscopy (LM) and scanning electron microscopy (SEM). (A) *Dinophysis cuneus* (LM), lateral view, (B) *D. cuneus* (SEM), (C) *Dinophysis hastata* (LM), (D) *D. hastata* (SEM), (E) *Dinophysis mitra* (SEM), (F) *D. mitra* (LM), (G-H) *Dinophysis schuettii* (LM), (I) *Ornithocercus heteroporus* (LM). Scale bars, 10 μm.

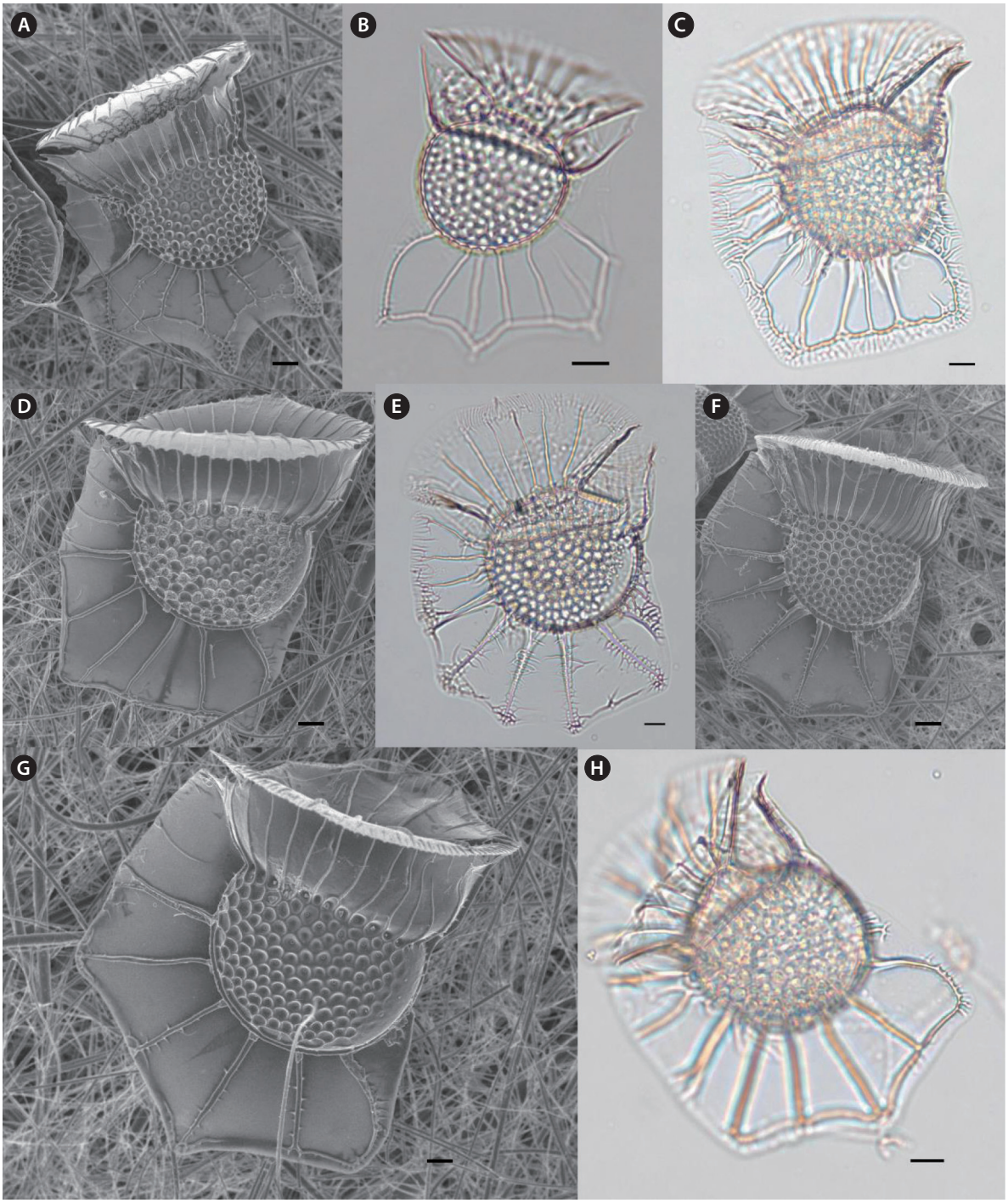


**Fig. 2.** Light microscopy (LM) and scanning electron microscopy (SEM). (A) *Ornithocercus magnificus* (SEM), lateral view, (B) *O. magnificus* (LM), (C) *Ornithocercus quadratus* (LM), (D) *O. quadratus* (SEM), (E) *Ornithocercus steinii* (LM), (F) *O. steinii* (SEM), (G) *Ornithocercus thumii* (SEM), (H) *O. thumii* (LM). Scale bars,10 μm.

symbiont, is frequently observed inside of the girdle list.

**Size:** Length 50–55 µm.

**Occurrence:** Nov 2006 (J7 Chagwido); Jan 2007 (J2 Samyang).

**Distribution:** Oceanic, tropical species; worldwide distribution.

***Ornithocercus magnificus* Stein 1883 (Fig. 2A and 2B)**

**Synonyms:** *Ornithocercus minor* Jörgensen 1923; *Ornithocercus magnificus* Butschli 1885.

**References:** Hallegraeff and Jeffrey 1984, p 69, fig. 17; Dodge 1985, p 28; Fujioka 1990, pp 46–47, fig. 8; Steidinger and Tangen 1996, pp 435–436, pl. 13; Fernandez and García 1998, pp 557–558, fig. 38; Jyothibabu et al. 2008, fig. 13a.

**Specimen examined:** Slide LJB2006-03 at the NIBR, Incheon.

**Description:** Well known as a tropical planktonic species indicator. The girdle list is very large with a spreading anterior skirt-like wing. The sulcal list is supported by radial ribs. The girdle list characterizes a convex and concave outline compared to other *Ornithocercus* species. *Synechococcus*, a cyanobacterial symbiont, is frequently observed inside of the girdle list.

**Size:** Length 88–100 µm.

**Occurrence:** Feb Sep Oct Nov Dec 2006 (J7 Chagwido); Aug Sep Dec 2007 (J14 Seongsan); Aug Dec 2007 (J12 Namwon); Aug Oct 2007 (J9 Hamo); Aug 2007 (J6 Hallim).

**Distribution:** Oceanic, tropical species; worldwide distribution.

***Ornithocercus quadratus* Schütt 1900 (Fig. 2C and 2D)**

**Synonyms:** *Ornithocercus assimilis* Jörgensen 1923; *Ornithocercus galea* (Pouchet) Abé 1967; *Histioneis quadrata* Lemmermann 1901.

**References:** Dodge 1985, p 29; Steidinger and Tangen 1996, pp 435–436, pl. 13; Fernandez and García 1998, pp 557-558, fig. 36; Taylor et al. 2008, pp 410–411, fig. 2d; Jyothibabu et al. 2008, fig. 13b.

**Specimen examined:** Slide LJB2007-02 at the NIBR, Incheon.

**Description:** Characteristic wide girdle list and quadrated list of the sulcus. This species also has *Synechococcus* cyanobacterial symbionts inside the girdle list.

**Size:** Length 122 µm, width 91 µm.

**Occurrence:** Nov 2006 (J7 Chagwido); Jan 2007 (J2 Samyang); Nov 2007 (J14 Seongsan).

**Distribution:** Oceanic, tropical species.

***Ornithocercus steinii* Schütt 1900 (Fig. 2E and 2F)**

**Synonym:** *Ornithocercus orbiculatus* Kofoid & Michener 1911.

**References:** Steidinger et al. 1967, pp 30–31, pl. II-c; Hallegraeff and Jeffrey 1984, p 67, fig. 6; Fujioka 1990, pp 48–49, fig. 5; Steidinger and Tangen 1996, p 435, 437, pl. 13; Fernandez and García 1998, pp 557–558, fig. 37.

**Specimen examined:** Slide LJB2006-05 at the NIBR, Incheon.

**Description:** Girdle list is supported by rigid ribs. Sulcal list has several radial ribs with round outline.

**Size:** Length 116–166 µm, width 111–123 µm.

**Occurrence:** Feb Aug Sep Oct Nov Dec 2006 (J7 Chagwido); Aug Sep 2007 (J14 Seongsan); Aug 2007 (J6 Hallim); Oct 2007 (J9 Hamo).

**Distribution:** Oceanic, tropical species; worldwide distribution.

***Ornithocercus thumii* (A. Schmidt) Kof. & Skogs. 1928 (Fig. 2G and 2H)**

**References:** Fujioka 1990, pp 48–49, fig. 6; Steidinger and Tangen 1996, pp 435–437, pl. 13; Jyothibabu et al. 2008, fig. 13d.

**Specimen examined:** Slide LJB2007-03 at the NIBR, Incheon.

**Description:** Girdle list spreads anteriorly like a skirt and the sulcus is supported by ribs with regular intervals. The outline of sulcal list is distinctively divided into three parts.

**Size:** Length 120 µm, width 87 µm.

**Occurrence:** Mar 2007 (J9 Hamo); Aug 2007 (J7 Chagwido); Aug 2007 (J6 Hallim); Sep 2007 (J14 Seongsan).

**Distribution:** Neritic/oceanic species; tropical species; worldwide distribution.

## Genus *Ceratium* Schrank 1793

***Ceratium azoricum* Cleve 1900 (Fig. 3A and 3B)**

**References:** Dodge 1982, pp 232–233, fig. 29, F; Dowidar 1983, p 523, 539, pl. IV, fig. 7; Fujioka 1990, pp 50–51, fig. 4.

**Specimen examined:** Slide LJB2007-05 at the NIBR, Incheon.

**Description:** Cell is relatively small and dorso-ventrally flattened. Anterior horn short and broad, hypotheca rounded with the broad posterior horns pointing in an anterior direction. Posterior horns with pointed tips.

**Size:** Length 100–110 µm, width 97 µm.

**Occurrence:** Aug Sep 2007 (J14 Seongsan).

**Distribution:** Found in Mexico Current; distributed in temperate and tropical areas.

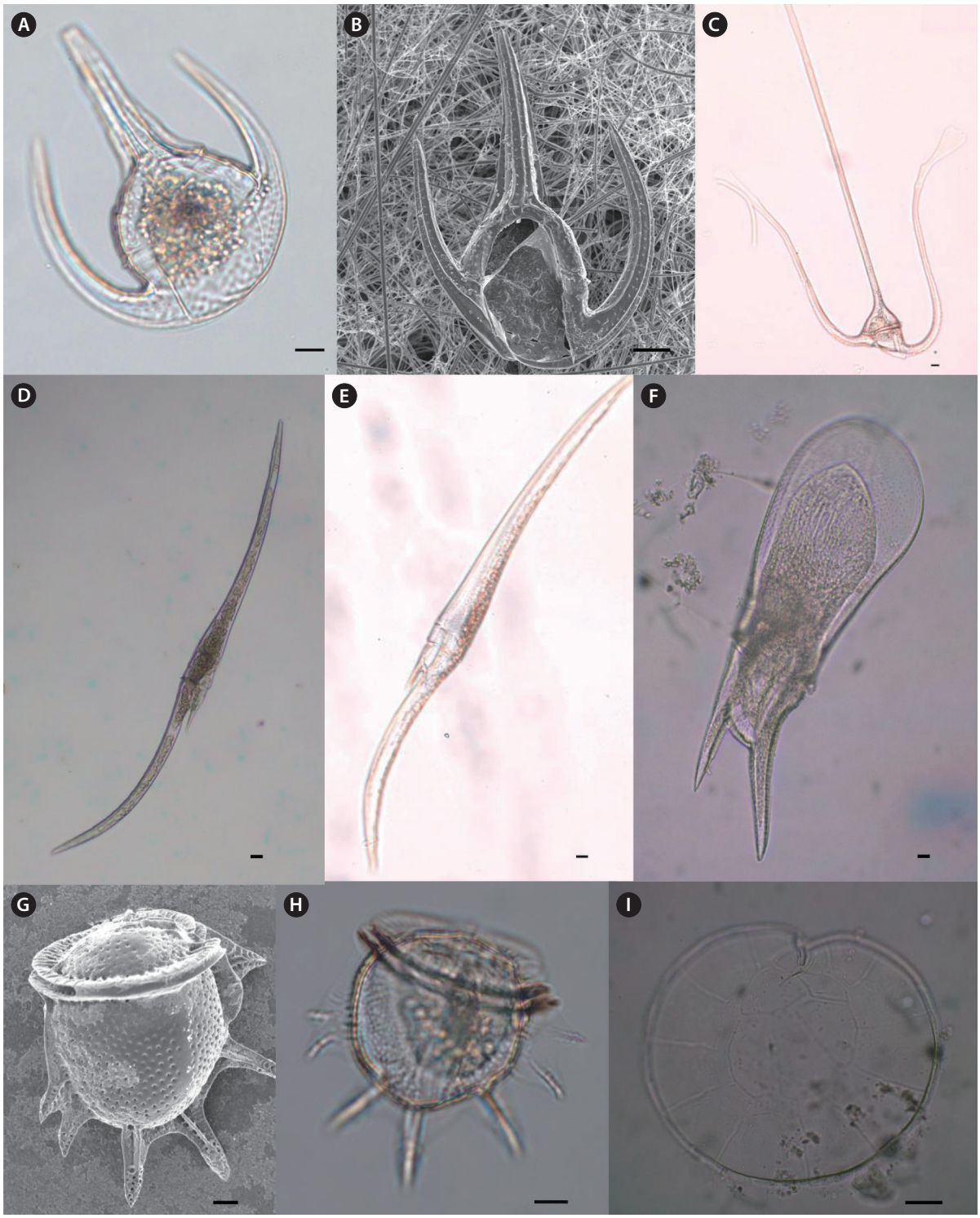


**Fig. 3.** Light microscopy (LM) and scanning electron microscopy (SEM). (A) *Ceratium azoricum* (LM), dorsal view, (B) *C. azoricum* (SEM), ventral view, (C) *Ceratium horridum* var. *claviger* (LM), dorsal view, (D-E) *Ceratium longirostrum* (LM), dorsal and ventral views, (F) *Ceratium praelongum* (LM), (G) *Ceratocorys gourretii* (SEM), lateral view, (H) *C. gourretii* (LM), lateral view, (I) *Pyrophacus steinii* (LM), hypotheca. Scale bars, 10 µm.

***Ceratium horridum* var. *claviger* (Kofoid) Graham & Bronikowski (Fig. 3C)**

**References:** Fujioka 1990, pp 54–55, fig. 6.

**Specimen examined:** Slide LJB2008-01 at the NIBR, Incheon.

**Description:** This species is medium sized and fairly delicate with short open-ended horns. The epitheca is higher than the hypotheca in body length. Anterior horn width is equal and straight to a pointed end. The left and right horns of the hypotheca are nearly parallel but bent at the middle of both horns. Both ends of the hypotheca horn are flattened.

**Size:** Body length 50–60 µm without horn.

**Occurrence:** Aug 2008 (J9 Hamo).

**Distribution:** Found in Kuroshio Current.

***Ceratium longirostrum* Gourret 1883 (Fig. 3D and 3E)**

**Synonyms:** *Ceratium scapiforme* Kofoid 1907; *Ceratium pennatum* var. *scapiforme* (Kofoid) Jörgensen 1911.

**References:** Dodge 1982, p 231, 233, fig. 29D; Carbonell 1982, pp 80–81, fig. 6; Dowidar 1983, p 521, 537, pl. II, fig. 8; Fernandez and García 1998, p 542, fig. 4.

**Specimen examined**: Slide LJB2008-02 at the NIBR, Incheon.

**Description:** This species is very similar to *Ceratium fusus* but longer and more rigid. Anterior horn is almost straight and thicker, and the posterior horn perhaps more curved. Epitheca is longer than hypotheca.

**Size:** Length 494–514 µm, width 34–37 µm.

**Occurrence:** Apr 2006 (J7 Chagwido); Aug Sep 2006, Aug 2007, Sep 2008 (J14 Seongsan).

**Distribution:** Found in Atlantic Ocean.

***Ceratium praelongum* (Lemmermann) Kofoid 1907 (Fig. 3F)**

**Synonym:** *Ceratium gravidum* var. *praelongum* Lemmermann.

**References**: Wood 1963, pp 40–41, fig. 148; Carbonell 1982, p 77, 81, fig. 2; Dowidar 1983, p 517, 536, pl. I, fig. 1; Taylor 1987, pp 34–35, fig. 2.6d; Fujioka 1990, pp 58–59, fig. 3; Steidinger and Tangen 1996, p 473, 477, pl. 25.

**Specimen examined:** Slide LJB2007-07 at the NIBR, Incheon.

**Description:** The round end of the epitheca like a duck foot with no anterior horn. However the left and right horns of the hypotheca are thick and strait to posterior ends. The right horn is longer than the left.

**Size:** Length 250–260 µm.

**Occurrence:** Feb 2007 (J7 Chagwido).

**Distribution:** Oceanic, tropical species; worldwide distribution.

**Genus *Ceratocorys* Stein 1883**

***Ceratocorys gourretii* Paulsen 1931 (Fig. 3G and 3H)**

**Synonyms:** *Ceratocorys allenii* Osorio-Tafall 1942; *Phalacroma jourdanii* (Gourret) Schütt 1895.

**References:** Fujioka 1990, pp 62–63, fig. 3.

**Specimen examined:** Slide LJB2007-10 at the NIBR, Incheon.

**Description:** Epitheca is short and slightly convex in lateral view, but hypotheca is round and ovate. The sulcal list is very short and rigid. The hypotheca has no list but five spines with a rigid list.

**Size:** Length 80–90 µm, width 75–85 µm.

**Occurrence:** Aug Oct Nov 2007 (J14 Seongsan); Sep 2007 (J2 Samyang); Nov 2007 (J8 Gosan); Aug Oct Nov 2007 (J14 Seongsan); Sep 2007 (J2 Samyang); Nov 2007 (J8 Gosan); Nov 2007 (J12 Namwon).

**Distribution:** Tropical or subtropical species.

**Genus *Pyrophacus* Stein 1883**

***Pyrophacus steinii* (Schiller) Wall & Dale 1971 (Fig. 3I and 4A)**

**Synonyms:** *Pyrophacus horologium* var. *stenii* Schiller 1935; *Pyrophacus vancampoae* (Rossignol) Wall & Dale 1971.

**References:** Fujioka 1990, pp 68–69, fig. 7; Fukuyo et al. 1990, pp 116–117; Steidinger and Tangen 1996, pp 522–523, pl. 46.

**Specimen examined:** Slide LJB2008-13 at the NIBR, Incheon.

**Description:** Cell is dorso-ventrally strongly flattened like a lens shape. The plate of hypotheca is Po, 6-8", 0-2a, 9-14", 11- 12"', 3p, 2-3"".

**Size:** Cell width 110–120 µm.

**Occurrence:** Aug 2008 (J1 Bukchon); Jul Nov 2008(J6 Hallim); Oct 2008 (J14 Seongsan); Nov 2008 (J7 Chagwido).

**Distribution:** Widely distributed from temperate to tropical areas worldwide.

**Genus *Oxytoxum* Stein 1883**

***Oxytoxum constrictum* (Stein) Bütschli 1885 (Fig. 4B and 4C)**

**References:** Wood 1963, p 44, 47, fig. 163; Dodge 1985, p 107; Gomez et al. 2008, figs. 15–16.

**Specimen examined:** Slide LJB2006-08 at the NIBR,

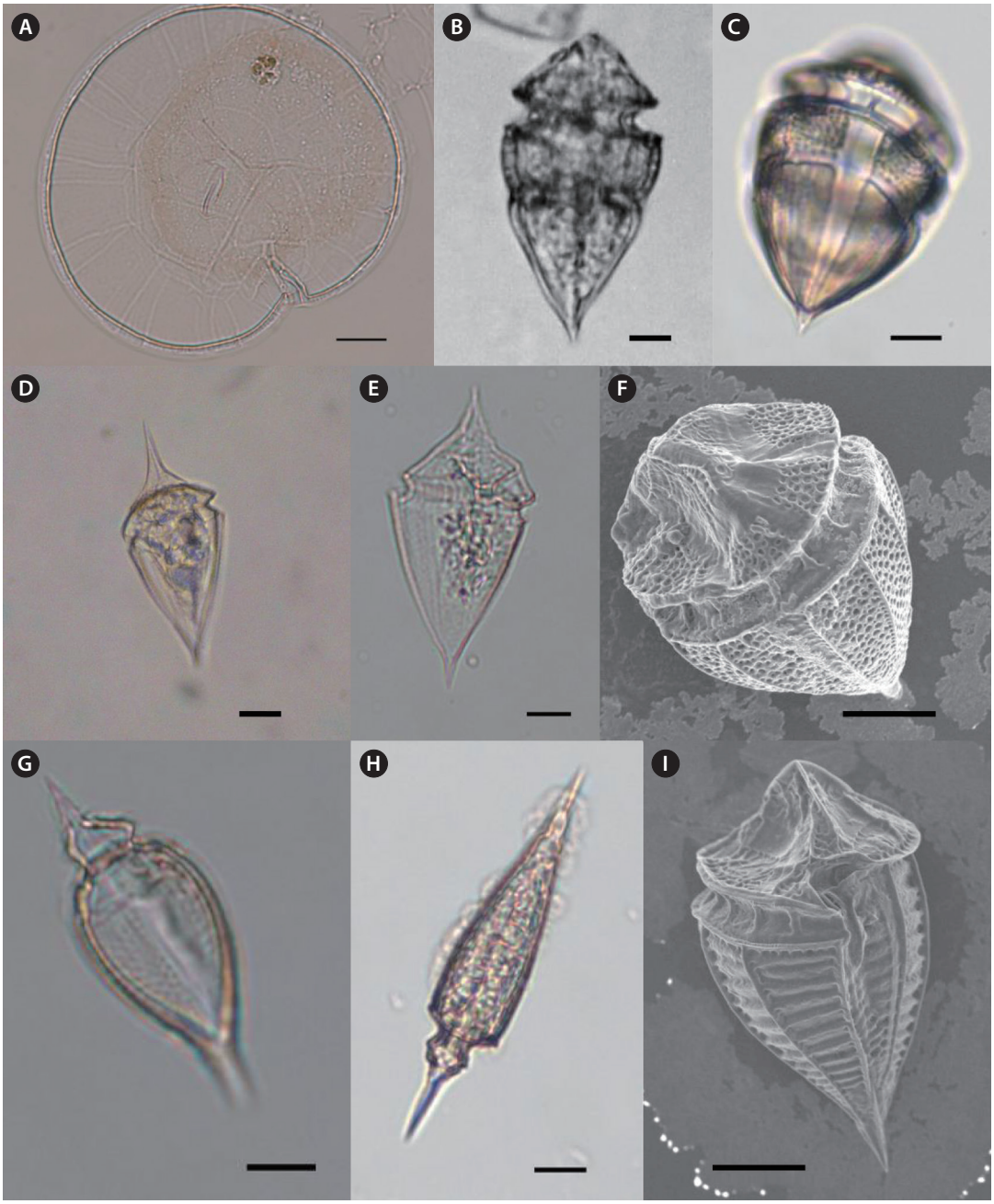


**Fig. 4.** Light microscopy (LM) and scanning electron microscopy (SEM). (A) *Pyrophacus steinii* (LM), epitheca (B) *Oxytoxum constrictum* (SEM), lateral view, (C) *O. constrictum* (LM), (D-E) *Oxytoxum milneri* (LM), lateral view, (F) *Oxytoxum reticulatum* (SEM), epitheca, (G) *Oxytoxum sceptrum* (LM), lateral view, (H) *Oxytoxum scolopax* (LM), lateral view, (I) *Oxytoxum tesselatum* (SEM), ventral view. Scale bars, 10 μm.

Incheon.

**Description:** The cell is spindle in form. In lateral view, epitheca is pyramid shaped and one-third of total body length. The middle part of hypotheca has a hole-like depression. The end of the hypotheca is pointed.

**Size:** Length 40–60 µm.

**Occurrence:** Oct 2006 (J14 Seongsan).

**Distribution:** Tropical species; reported in Mediterranean Sea and around coral reefs.

***Oxytoxum milneri* Murray & Whitting 1899 (Fig. 4D and 4E)**

**Synonym:** *Oxytoxum subulatum* Kofoid 1907.

**References:** Wood 1963, pp 46–47, fig. 173; Dodge 1982, p 243, 246, fig. 32G; Dodge 1985, p 109; Gomez et al. 2008, fig. 9.

**Specimen examined:** Slide LJB2007-14 at the NIBR, Incheon.

**Description:** Cell is a spindle form. Both ends of epitheca and hypotheca are very sharp like a stinger.

**Size:** Length 70–75µm, width 37µm.

**Occurrence:** Aug Oct 2007, Aug 2009 (J14 Seongsan); Oct 2007 (J4 Iho).

**Distribution:** Reported in Atlantic Ocean, Mediterranean Sea, Indian Ocean, Tasmanian Sea, Caribbean Sea, Florida Strait, and Brazil Sea.

***Oxytoxum reticulatum* (Stein) Schütt (Fig. 4F)**

**Synonyms:** *Pyrigidium reticulatum* Stein 1883; *Oxytoxum brunellii* Rampi 1939; *Oxytoxum reticulatum* Butschli 1885.

**References:** Dodge 1982, p 243, 245, fig. 32F.

**Specimen examined:** Slide LJB2009-22 at the NIBR, Incheon.

**Description:** Cell elongated with hypotheca at least twice as long as epitheca. Epitheca short and conical with longitudinal lines radiating from the apex. Thecal plates have many poroids. Hypotheca width is broadly wide and rounded anteriorly tapering to a point at the antapex.

**Size:** Length 53 µm.

**Occurrence:** Aug 2009 (J14 Seongsan).

**Distribution:** Found in Mediterranean Sea and Atlantic Ocean.

***Oxytoxum sceptrum* (Stein) Schröder 1906 (Fig. 4G)**

**Synonyms:** *Oxytoxum longiceps* Schiller 1937; *Oxytoxum aceratum* Rampi 1951.

**References:** Wood 1963, p 47, 49, fig. 179; Dodge 1985, p 111.

**Specimen examined:** Slide LJB2009-23 at the NIBR, Incheon.

**Description:** Cell elongated with pointed apices. Epitheca short and conical with sharp spine at the apex. Hypotheca is slightly long and broad with pointing spine at the antapex.

**Size:** Length 62 µm, width 22 µm.

**Occurrence:** Aug 2009 (J14 Seongsan).

**Distribution**: Reported in Indian Ocean.

***Oxytoxum scolopax* Stein 1883 (Fig. 4H)**

**References:** Steidinger et al. 1967, pp 38–39, pl. VI. f; Dodge 1982, p 243, 247, fig. 32H; Dodge 1985, p 108; Fujioka 1990, pp 64–65, fig. 10; Steidinger and Tangen 1996, p 519; Gomez et al. 2008, figs. 6–7; Taylor et al. 2008, pp 410-411, fig. 2j.

**Specimen examined:** Slide LJB2006-09 at the NIBR, Incheon.

**Description:** Cell spindle-shaped with acutely pointed ends. Hypotheca about three times the length of the epitheca. Hypotheca has small swelling at the base of the antapical point. Epitheca is tapered to apex.

**Size:** Length 56µm, width 15µm.

**Occurrence:** Oct 2006 (J14 Seongsan).

**Distribution:** Oceanic, tropical species; reported in Pacific and Atlantic Oceans.

***Oxytoxum tesselatum* (Stein) Schütt 1895 (Fig. 4I and 5A)**

**Synonyms:** *Oxytoxum tessellatum* (Stein) Loeblich Jr. et Loeblich III 1966; *Oxytoxum michaelsarsii* Gaarder 1954.

**References:** Dodge 1985, p 113; Fujioka 1990, p 66–67, Fig. 2; Steidinger and Tangen 1996, p 517–518, pl. 45; Gomez et al. 2008, fig. 11.

**Specimen examined:** Slide LJB2007-13 at the NIBR, Incheon.

**Description:** Cell spindle-shaped with pointed apices. Epitheca conical with reticulated plate. Hypotheca tapering to the antapex with a sharp spine. The hypothecal plate has regularly rectangular ornamentations.

**Size:** Length 45–55µm, width 28µm.

**Occurrence:** Aug Nov 2007 (J14 Seongsan); Sep Oct 2007 (J7 Chagwido).

**Distribution:** Tropical species; reported in Atlantic Ocean.

**Genus *Pyrocystis* Murray ex Haeckel 1890**

***Pyrocystis hamulus* Cleve 1900 (Fig. 5B)**

**References:** Dodge 1982, p 137, fig. 16I.

**Specimen examined:** Slide LJB2009-34 at the NIBR, Incheon.

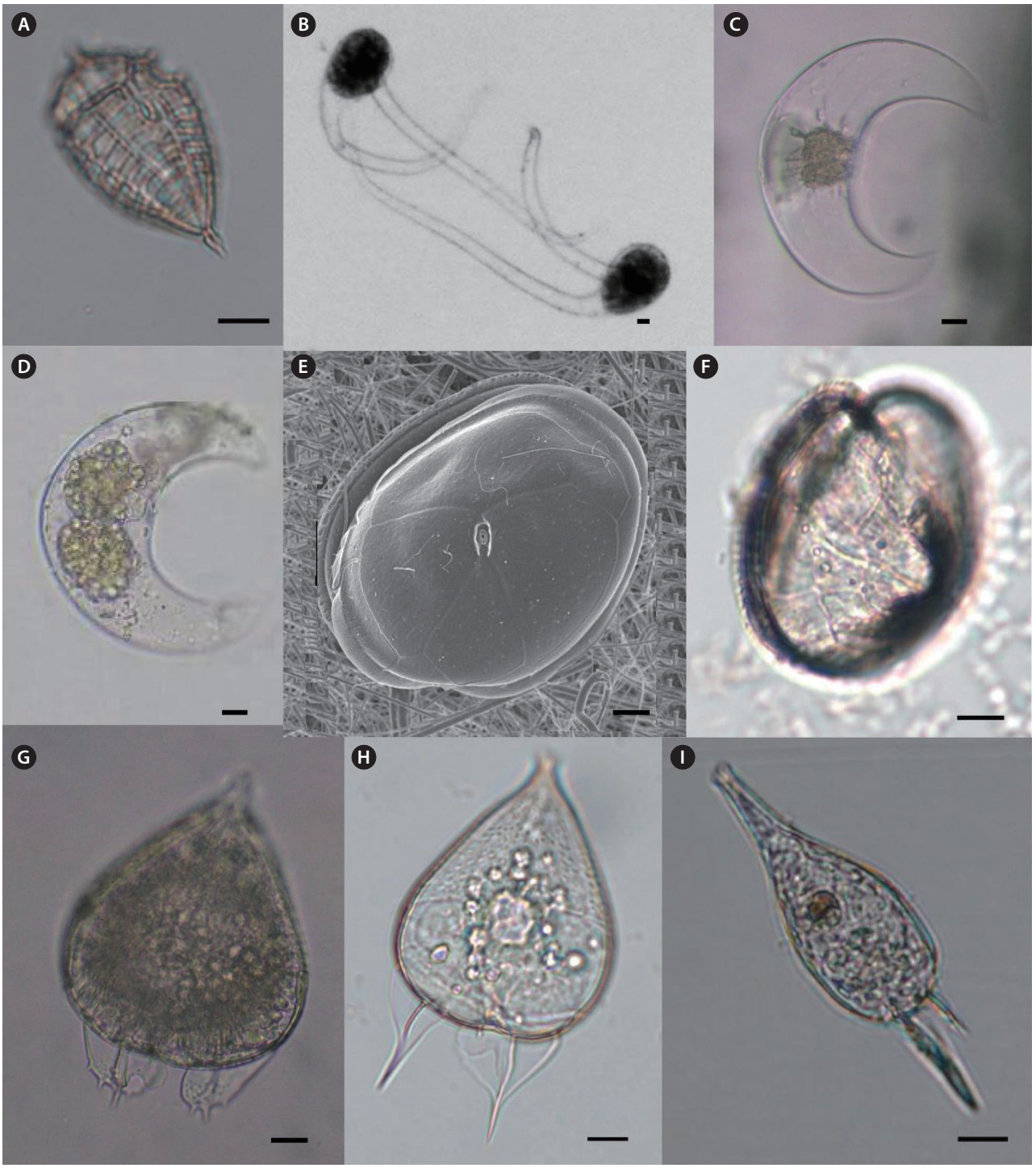


**Fig. 5.** Light microscopy (LM) and scanning electron microscopy (SEM). (A) *Oxytoxum tesselatum* (LM), lateral view, (B) *Pyrocystis hamulus* (LM), (C-D) *Pyrocystis robusta* (LM), (E) *Dissodium asymmetricum* (SEM), epitheca, (F) *D. asymmetricum* (LM), hypotheca, (G-H) *Podolampas bipes* (LM), (I) *Podolampas palmipes* (LM). Scale bars, 10 μm.

**Description:** This genus has two forms of coccoid and thecate. The coccoid form is normally found as a cyst of the thecate form. The cysts are elongated and curved, with a central swelling containing the cytoplasm. Usually occur in pairs with attached form of the distal ends of the arms. The genus is known to occur mainly in warm water.

**Size:** Length 400–450 µm.

**Occurrence:** Feb 2007 (J7 Chagwido); Jan 2007 (J14 Seongsan).

**Distribution:** Tropical species; Reported in English Channel and in southern bay of Scotland.

***Pyrocystis robusta* Kofoid 1907 (Fig. 5C and 5D)**

**References:** Fujioka 1990, pp 40–41, fig. 4.

**Specimen examined:** Slide LJB2006-14 at the NIBR, Incheon.

**Description:** This species is lunate in form with jelly-like cyst body. Cytoplasm is located in the center of the cyst. Similar to *P. lunula* but relatively small.

**Size:** Length 90–100 µm.

**Occurrence:** Feb 2007 (J9 Hamo).

**Distribution:** Reported in Kuroshio Current.

### Genus *Dissodium* Abé 1941

***Dissodium asymmetricum* (Morgin) Loeblich 1970 (Fig. 5E and 5F)**

**Synonyms:** *Diplopsails asymmetrica* Drebes & Elbrachter 1976; *Diplosalis lenticula* f. *asymmetrica* Steidinger & Williams 1970; *Peridiniopsis asymmetrica* Mangin 1911; *Peridiniopsis asymmetrica* Lebour 1922; *Peridinium lenticula* Paulsen 1912; *Diplopelta bomba* Jörgensen 1913; *Diplopelta symmetrica* Pavillard 1913; *Preperidinium asymmetricum* Mangin 1913; *Peridinium asymmetricum* Ostenfeld 1915; *Glenodinium lenticulum* f. *asymmetrica* Schiller 1937.

**References:** Subrahmanyan 1971, p 156, 158, pl. I, figs. 10–11, 15, pl. II, figs. 1–4, 6, 8, 10, 12–15; Dodge 1982, p 153, 157, fig. 18F-G; Skaloud et al. 2006, p 726, fig. 38.

**Specimen examined:** Slide LJB2007-06 at the NIBR, Incheon.

**Description:** Circular in apical view and lenticular to globular in ventral view. Epitheca with convex sides ending in a small apical projection surrounding the apical pore. Intercalary striae may be present. The girdle is equatorial and not displaced or excavated but bordered by a list, typically without supporting spines. Hypotheca equal in depth to epitheca with convex sides.

**Size:** Length 30–50 µm, width 48–70 µm.

**Occurrence:** Aug 2007 (J14 Seongsan).

**Distribution:** Reported in Baltic Sea, Atlantic Ocean, Mediterranean Sea, Indian Ocean, and Mexico Bay.

### Genus *Podolampas* Stein 1883

***Podolampas bipes* Stein 1883 (Fig. 5G and 5H)**

**References:** Steidinger et al. 1967, pp 34–35, pl. IV, a; Dodge 1985, p 117; Taylor 1987, pp 58–59, fig. 2.16d; Fujioka 1990, pp 66–67, figs. 4–5; Steidinger and Tangen 1996, p 399, 534, pl. 7.

**Specimen examined:** Slide LJB2006-10 at the NIBR, Incheon.

**Description:** The genus is characterized by the presence of a distinct apical horn ending in an apical poreand is generally pyriform in shape bearing two antapical spines. Cell looks like a slightly depressed chestnut. Epitheca is triangular, ending in two unequal antapical spines. Hypotheca is half spherical form, with two left and right wing-like structures with sharp and strong spines at the antapical end.

**Size:** Length 95–106 µm, width 55–77 µm.

**Occurrence:** Feb 2006 (J4Iho); Aug 2006 (J14 Seongsan); Apr Oct Nov 2006 (J7 Chagwido); Feb 2007 (J5 Aewol).

**Distribution:** Oceanic and worldwide tropical species.

***Podolampas palmipes* Stein 1883 (Fig. 5I)**

**References:** Dodge 1982, p 251, 254, fig. 33I; Fujioka 1990, pp 66–67, fig. 7; Steidinger and Tangen 1996, pp 534–535, pl. 50.

**Specimen examined:** Slide LJB2006-11 at the NIBR, Incheon.

**Description:** Cell pyriform, narrow, ending in two unequal antapical spines. The epitheca is drawn out into a long, slender neck. The right-hand spine is much shorter than the left antapical spine.

**Size:** Length 88–97 µm, width 26 µm.

**Occurrence:** Sep 2006 (J2 Samyang); Oct Nov 2006 (J7 Chagwido); Aug Oct Nov 2006 (J14 Seongsan); Nov 2006 (J1 Bukchon); Nov 2006 (J8 Gosan); Nov 2006 (J4 Iho); Nov 2006 (J13 Pyoseon); Oct 2006 (J10 Hwasun); Aug 2007 (J14 Seongsan); Sep 2007 (J2 Samyang).

**Distribution:** Oceanic, worldwide tropical species.

### Genus *Protoperidinium* Bergh 1881

***Protoperidinium oblongum* (Aurivillius 1898) Parke & Dodge 1976 (Fig. 6A)**

**Synonyms:** *Peridinium divergens* var. *oblongum* Aurivillius 1898; *Protoperidinium divergens* (Ehrenb.) Bergh 1882; *Protoperidinium oceanicum* Lebour 1925; *Proto-*

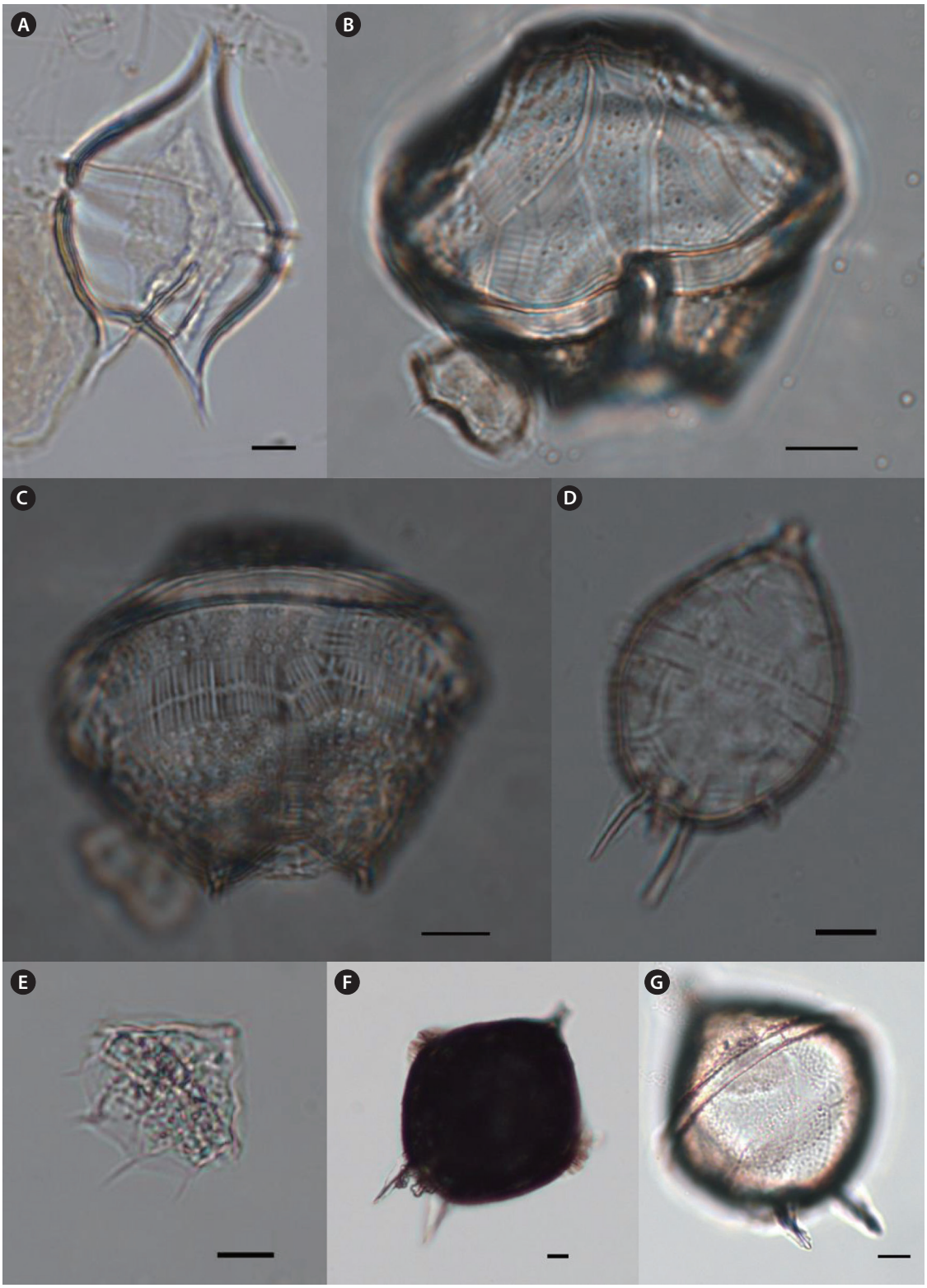


**Fig. 6.** Light microscopy (LM). (A) *Protoperidinium oblongum*, ventral view, (B) *Protoperidinium obtusum*, ventral view of epitheca, (C) *P. obtusum*, dorsal view of hypotheca, (D) *Protoperidinium oviforme*, lateral view, (E) *Protoperidinium quinquecorne*, lateral view, (F) *Protoperidinium steinii*, lateral view, (G) *P. steinii*, dorsal view of hypotheca. Scale bars, 10 μm.

*peridinium oceanicum* Balech 1974.

**References:** Steidinger et al. 1967, pp 42–43, pl. VIII, b; Dodge 1982, pp 179–180, fig 20B–D; Dodge 1985, p 58; Steidinger and Tangen 1996, p 539, p 541, pl. 52; Evagelopoulos 2002, p 44, 49, 51, figs. 7–9, 36; Skaloud et al. 2006, p 726, fig. 47; Okolodkov 2008, pp 142–143, pl. 15, fig. 6.

**Specimen examined:** Slide LJB2009-25 at the NIBR, Incheon.

**Description:** Cell shape is similar to *Protoperidinium oceanicum* but smaller. Sulcus deep and bordered by lists. Girdle not excavated but bordered by narrow list supported by spines. Cell compressed dorsoventrally, longer than broad in dorsoventral view with long apical horn and two long, subequal antapical horns.

**Size:** Length 92 µm, width 60 µm.

**Occurrence:** Sep 2009 (J7 Chagwido).

**Distribution:** Worldwide distributed from neritic to oceanic areas.

***Protoperidinium obtusum* (Karsten) Parke & Dodge 1976 (Fig. 6B and 6C)**

**Synonyms:** *Protoperidinium obtusum* Schiller 1937; *Protoperidinium obtusum* (Karsten) Balech 1988; *Protoperidinium divergens* var. *obtusum* Karsten 1906; *Protoperidinium okamurai* Marukawa 1921; *Protoperidinium okamurai* Abé 1927; non *Protoperidinium obtusum* Faure-Fremiet 1908.

**References:** Dodge 1982, p 185, fig. 21C; Dodge 1985, p 59; Steidinger and Tangen 1996, pp 542–543, pl. 53; Evagelopoulos 2002, p 45, pp 51–52, figs. 17–19, 42–43; Okolodkov 2008, p 119, 121, pl. 6. figs. 8–10.

**Specimen examined:** Slide LJB2009-26 at the NIBR, Incheon.

**Description:** Cell length is similar to width, and it has a blunt apex, a rounded dorsal surface and is dorso-ventrally flattened. The hypotheca has two hollow antapical horns.

**Size:** Length 65–68 µm, width 65 µm.

**Occurrence:** Aug 2009 (J14 Seongsan).

**Distribution:** Tropical species from neritic to oceanic area; worldwide distribution.

***Protoperidinium oviforme* (P. Dangeard 1927) Balech 1974 (Fig. 6D)**

**References:** Evagelopoulos 2002, pp 47–48, 52, fig. 49; Okolodkov 2008, pp 139–140, pl. 14, figs. 5–8.

**Specimen examined:** Slide LJB2009-27 at the NIBR, Incheon.

**Description:** Cell shaped generally similar to *Protoperidinium nipponicum*, but the length of this species is longer. Cell shape is spherical or oviform with a small spine of epitheca end. Hypotheca has two spines at the end with membrane like wing.

**Size:** Length 76 µm, width 42 µm.

**Occurrence:** Aug 2009 (J14 Seongsan).

**Distribution:** Worldwide distribution.

***Protoperidinium quinquecorne* (Abé) Balach 1974 (Fig. 6E)**

**References:** Dodge 1985, p 37; Fukuyo et al. 1990, pp 138–139.

**Specimen examined:** Slide LJB2009-28 at the NIBR, Incheon.

**Description:** A small and delicate species in the genus *Protoperidinium*. Cell is dorsoventrally flattened and like a diamond shape. Hypotheca rounded to angular bearing four or more spines.

**Size:** Length 40 µm, width 35 µm.

**Occurrence:** Aug 2009 (J14 Seongsan).

**Distribution:** Reported in red-tide areas and in shallow waters of tropical areas.

***Protoperidinium steinii* (Jörgensen 1899) Balech 1974 (Fig. 6F and 6G)**

**Synonyms:** *Peridinium steinii* Jörgensen 1889; *Peridinium michaelis* Stein 1883.

**References:** Subrahmanyan 1971, p 200, pl. XXIII, figs. 1–13; Dodge 1982, p 197, 199, fig. 23C; Dodge 1985, p 65; Fujioka 1990, pp 68–69, fig. 3.

**Specimen examined:** Slide LJB2006-15 at the NIBR, Incheon.

**Description:** Cell pyriform with elongated apical horn and rounded hypotheca bearing two long three-winged spines. Epitheca and hypotheca are almost equal in length.

**Size:** Length 110–161 µm, width 80–119 µm.

**Occurrence:** Jan 2007 (J7 Chagwido).

**Distribution:** Worldwide distribution; reported around English Strait, Baltic Sea, Atlantic Ocean, Caribbean Sea.

***Protoperidinium thorianum* (Paulsen 1905) Balech 1973 (Fig. 7A and 7B)**

**Synonyms:** *Peridinium thorianum* Paulsen 1905; *Properidinium thorianum* Meunier 1919.

**References:** Dodge 1982, pp 175–176, fig. 19E; Dodge 1985, p 67; Steidinger and Tangen 1996, p 543, 546, pl. 53; Okolodkov 2008, pp 107–108, pl. 2, figs. 1–4; Morquecho et al. 2009, p 19, figs. 28–33.

**Specimen examined:** Slide LJB2009-29 at the NIBR, Incheon.

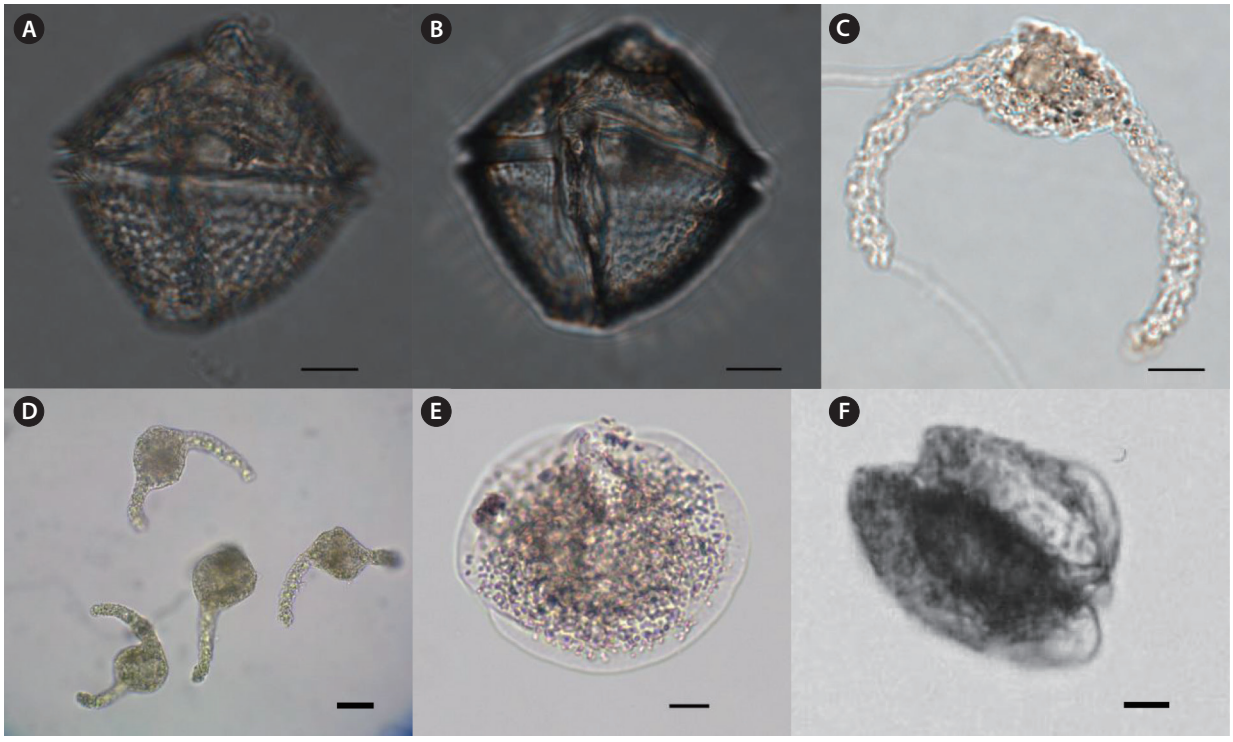


**Fig. 7.** Light microscopy (LM). (A-B) *Protoperidinium thorianum*, ventral view, (C-D) *Pseliodinium vaubanii*, (E) *Ptychodiscus noctiluca*, epitheca, (F) *P. noctiluca*, lateral view. Scale bars, 10 µm.

**Description:** Cell rhombic shaped; epitheca and hypotheca almost equal in length, with strong papillate or wavy thecal surface. Sides are rounded on ventral view. Sulcus straight, narrow, and not usually reaching the center of hypotheca. Girdle distinctively excavated.

**Size:** Length 60 µm, width 60 µm.

**Occurrence:** Aug 2009 (J14 Seongsan).

**Distribution:** Reported around English Strait, near Island Strait, Atlantic Ocean.

### Genus *Pseliodinium* Sournia 1972

***Pseliodinium vaubanii* Sournia 1972 (Fig. 7C and 7D)**

**Synonym:** *Gyrodinium falcatum* Kofoid & Swezy 1921.

**References:** Steidinger et al. 1967, pp 32–33, pl. III-c; Fujioka 1990, pp 42–43, fig. 1; Fukuyo et al. 1990, pp 60–61; Gomez 2007, pp 274–275, figs. 16–19.

**Specimen examined:** Slide LJB2006-12 at the NIBR, Incheon.

**Description:** Cell round shaped with two slightly curved arms. Girdle located in the center of cell and apparently distinguished. This species was deformed by physical force during the sampling process, which resulted in shrunken and curved form from *Gyrodinium falcatum*. Thus, this form of *P. vaubanii* was much more frequently observed than that of *G. falcatum* in the sampled material.

**Size:** Length 70–75 µm.

**Occurrence:** Aug 2006 (J8 Gosan); Feb Apr Nov 2006 (J7 Chagwido); Jan 2007 (J9 Hamo).

**Distribution:** Known to be a red-tide causative organism in warm waters; reported in the Kuroshio Current.

### Genus *Ptychodiscus* Stein 1883

***Ptychodiscus noctiluca* Stein 1883 (Fig. 7E and 7F)**

**Synonyms:** *Ptychodiscus carinatus* Kofoid 1907; *Ptychodiscus inflatus* Pavillard 1916; *Diplocystis antarctica* Cleve 1900.

**References:** Dodge 1982, p 113, fig. 13B-C; Taylor 1987, p 43, fig. 2.10c; Steidinger and Tangen 1996, p 462, 463, pl. 22; Gomez 2007, p 279, figs. 37–39.

**Specimen examined:** Slide LJB2006-13 at the NIBR, Incheon.

**Description:** Cell compressed apically, antapically like a shape of two sliced stones overlapped. Epicone flattened with a prominent heel on the ventral side, hypocone domed. Girdle horizontal, wide deep and bounded

by substantial ridges or flaps. Sulcus starting on the heel and forming a groove in the epicone.

**Size:** Length 30–35 μm, width 70–82 μm.

**Occurrence:** Oct 2006 (J2 Samyang); Feb Nov 2006 (J7 Chagwido).

**Distribution:** Widely distributed from neritic to oceanic waters and from tropical to cold water areas.

## DISCUSSION

About 153 dinoflagellates have been recorded in Korea waters. Shim (1994) described the highest number of species (n = 120). Shim et al. (1981) included descriptions of 49 species around Yeosu Bay. Han and Yoo (1983a, 1983b) described 61 species from Jinhae Bay. Yoo and Lee (1986) reported five species in the genus *Prorocentrum* based on scanning electron microscopy observations. Lee et al. (1993) also reported 17 species with a description of red tide causative organisms.

Thirty-four species including one variety were newly recorded in Korean waters from the present study. An unrecorded species is one in which no taxonomic description is available in monographs or taxonomic studies. The morphological observations of the dinoflagellates collected in this study generally agreed with previous taxonomic descriptions from other geographical locations. However, the 34 newly recorded species included some species reported in a check list of ecological studies without taxonomic descriptions, including *Ornithocercus steinii* (Shim and Lee 1983), *O. thumii* (Shim and Lee 1983), *Pyrophacus steinii* (Shim and Yeo 1988, Yoon 2000, Park et al. 2004), *Dissodium asymmetricum* (Shim and Yeo 1988), *Protoperidinium oblongum* (Lee and Yoo 1991,Choa and Lee 2000, Lee et al. 2002,Park et al. 2004), *P. quinquecorne* (Shim and Yeo 1988, Yoon 2000, Choa and Lee 2000, Lee et al. 2002), *P. steinii* (Lee et al. 2002, Jeong et al. 2002), and *P. thorianum* (Lee et al. 2002).

Kim et al. (2008) reported seasonal variation in the genus *Ornithocercus*, a famous tropical genus of dinoflagellates, near western Jeju Island, where the occurrence of tropical dinoflagellates was first confirmed. Kim (2008) also reported some tropical dinoflagellates near the Jeju Island coast line. In this study 23 dinoflagellates species were tropical based on several references of dinoflagellates from tropical oceans, including *Ceratium azoricum, C. praelongum,Ceratocorys gourrettii*, *Dinophysis cuneus, D. hastata, D. mitra, D. schuettii, Ornithocercus heteroporus, O. magnificus, O. quadratus, O. steinii, O. thumii, Oxytoxum constrictum, O. scolopax, O. tesselatum, Podolampas bipes, P. palmipes, Protoperidinium obtusum, P. quinquecorne, Pseliodinium vaubanii, Ptychodiscus noctiluca,Pyrocystis hamulus,Pyrophacus steinii*. No other species could be confirmed as tropical, but they may be, as indicated in a Kuroshio Current report (Fujioka 1990, Kim 2008).

We have confirmed changes in the phytoplankton community in Korean waters by identifying tropical/newly recorded dinoflagellates around Jeju Island. These recent changes in species composition are greater than those reported previously. These changes may be the result of increasing sea surface temperature by global warming and expansion of the Kuroshio Current (Pang et al. 1996, Yeh and Kim 2010). Thus, tropical dinoflagellates could be planktonic evidence for global warming and marine ecosystem changes around Korea, but quantitative data based on the planktonic ecosystem are required to provide concrete evidence of climate change. An interdisciplinary study with long term monitoring is needed to explain such an ecosystem shift.

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