



Floristic survey and five new records of fresh-water coccoid green algae (genus *Coenochloris*, *Radiococcus*, *Schizochlamydelia*, and *Thorakochloris*)

Yong Jae Kim*

Department of Life Science, Daejin University, Pocheon 487-711, Korea

Abstract

A study on fresh-water green coccoid algae was carried out at ponds, swamps, reservoirs, lakes and rivers (290 sites) from May 2011 to January 2014. In this study, 4 genera and 13 taxa of the family Radiococcaceae having the remnants of cell wall existing for a long time in the colonial gelatinous envelope are classified and identified from 24 sites. Many taxa of this family, however, have not been recorded in Korea yet. Of these 13 taxa, 5 taxa are newly recorded in Korea by this study: 1) *Schizochlamydelia solitaria*, 2) *Thorakochloris planktonica*, 3) *Radiococcus bavaricus*, 4) *R. nimbatus*, and 5) *R. planktonicus*.

Key words: coccoid green algae, gelatinous envelope, newly recorded, Radiococcaceae, remnants of the mother cell wall

INTRODUCTION

The family Radiococcaceae is distributed in freshwater as well as terrestrial habitats worldwide. This family is defined broadly as coccoid green algae with mucilaginous cover reproducing only by autospores, and it is one of the most taxonomically difficult groups in green algae (Pazoutova 2008). The name Radiococcaceae was first reported by Fott (1959) in German but was not valid according to International Botanical Nomenclature. This family name has been previously used by some researchers (Bourelly 1966, Philipose 1967, Hindak 1977), but since then the family Radiococcaceae have been determined to be valid by the description of Komarek (1979) in Latin. As stressed by Hindak (1977) the present state of the taxonomy of the family Radiococcaceae is not satisfactory (Hindak 1980). Hindak (1980) explained that the acceptance of traditionally acknowledged genera based on characters of a lower taxonomically value in other groups of green algae

produced a subdivision within the system and many other genera. The classification principles of Chlorococcales were adopted based on those for other groups of algae. For example, the presence or absence of mucilage used to be deemed taxonomically significant, but Hindak (1980) pointed out that mucilage sheath was not a meaningful taxonomic characteristics. In the Radiococcaceae, however, several genera were classified according to spherical or oval cells (Korshikov 1953, Hindak 1977, 1980, Komarek and Fott 1983). In addition, many taxa in the genera are classified based on if the mother cell wall gelatinizes relatively quickly after protoplast division and in the process of autospore growth such that its remnants remain only temporarily in the gelatinous envelope of a colony. Some taxa have the characteristics that the remnants of cell wall exist for a long time in the colonial gelatinous envelope.

The family Radiococcaceae is composed of 4 subfami-

<http://dx.doi.org/10.5141/ecoenv.2014.037>



This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received 13 October 2014, Accepted 29 October 2014

*Corresponding Author

E-mail: : yjkim@daejin.ac.kr

Tel: +82-31-539-1851

www.kci.go.kr

lies that are Radiococcoideae, Disporoideae, Dictyochloroideae and Palmodictyoideae. Of these, Radiococcoideae includes the genera *Mycanthococcus*, *Myurococcus*, *Schizochlamydelia*, *Coenochloris*, *Thorakochloris*, *Radiococcus*, *Euteramorus*, *Coenocystis*, *Coccomyxa* and *Gloeocystis* (Komarek and Fott 1983). The genus *Gloeocystis*, however, was included in the family Palmellaceae of the order Tetrasporales by Prescott (1962) and Smith (1950). Komarek and Fott (1983) merged the family Palmellaceae which lack pseudocilia into the family Radiococcaceae.

cystis (Komarek and Fott 1983). The genus *Gloeocystis*, however, was included in the family Palmellaceae of the order Tetrasporales by Prescott (1962) and Smith (1950). Komarek and Fott (1983) merged the family Palmellaceae which lack pseudocilia into the family Radiococcaceae.

Table 1. Sampling sites of genera *Coenochloris*, *Radiococcus*, *Schizochlamydelia* and *Thorakochloris* from 2011 to 2014

Station	Collected data	Locality	Coordinate
Baengduimot	31 May 2014	Guemak, Hanrim, Jeju-do	33°26'14" N, 126°40'48" E
Bongpo Reservoir	03 Apr. 2014	Tosung, Gosung, Gangwon-do	38°14'27" N, 128°34'08" E
Bongwoomot	31 May 2014	Boseong, Seoguipo, Jeju-do	33°15'16" N, 126°16'16" E
Bukhan River	26 Aug. 2012	Yangsoori, Yangpyeong, Gyeonggi-do	37°32'25" N, 127°18'47" E
Pond in Bundang Jungang Park	02 Jun. 2012	Soonae, Boondang, Sungnam city, Gyeonggi-do	37°22'30" N, 127°07'32" E
Pond around Docho elementary School	24 Jun. 2013	Suhang, Docho, Sinan, Jeollanam-do	34°41'46" N, 127°57'52" E
Dombaemul	30 May 2014	Yeoyeom, Aewol, Jeju	33°23'28" N, 126°21'19" E
Dongmyeong Reservoir	10 Jul. 2012	Gudeokri, Dongmyeon, Chilgok, Gyeongsangbuk-do	35°58'42" N, 128°33'50" E
Estuary of the Dongjin River	22 Sep. 2012	Gumpanri, Baeksan, Gunsan, , Jeollabuk-do	35°45'40" N, 126°46'39" E
Euirim Reservoir	31 Aug. 2012	Mosandong, Jecheon, Chungcheongbuk-do	37°10'23" N, 127°12'37" E
Galchi Reservoir	24 Apr. 2013	Daeya, Gunpo, Gyeonggi-do	37°19'06" N, 127°53'15" E
Gobok Reservoir	28 May 2013	Gobokri, Cheonan, Seomyeon, Chungcheongnam-do	36°35'57" N, 127°13'45" E
Estuary lake of Geumgang	22 Mar. 2013	Dosam, Maseo, Seocheon, Chungcheongnam-do	36°01'00" N, 126°44'55" E
Gyodong Reservoir	31 May 2013	Donggodori, Geumma, Iksan, Jeollabuk-do	35°59'43" N, 127°03'49" E
Ilwang Reservoir	24 Apr. 2013	Songchook, Suwon city, Gyeonggi-do	37°17'59" N, 127°00'02" E
Joouel Reservoir	22 Jul. 2012	Gyenamri, Jain, Kungsan, , Gyeongsangbuk-do	35°48'05" N, 128°48'48" E
Lake 88	07 Sep. 2012	Olympic Park, Songpa, Seoul city	37°31'14" N, 127°07'03" E
Lake Seoho	12 Apr. 2013	Whaseo 2, Soowoon city, Gyeonggi-do	37°16'40" N, 126°59'15" E
Okgu Reservoir	22 Sep.2012	Gaesadong, Gunsan, Jeollabuk-do	35°55'34" N, 126°38'50" E
Oknyeo Reservoir	22 Sep. 2012	Gaesadong, Gunsan, , Jeollabuk-do	34°19'34" N, 126°37'24" E
Sampori Reservoir	18 Aug. 2012	Sampo, Jookwang, Goseong, Gangwon-do	38°18'45" N, 128°30'51" E
Samrak Park	03 Nov. 2011	Samrak-dong, Sasang, Busan city	35°10'09" N, 128°58'06" E
Shinweol Reservoir	09 Jul. 2012	Shinwol, Bukgil, Haenam, Jeollanam-do	34°30'34" N, 126°43'06" E
Wetted soil and spring at tennis courts of Daejin University	26 Sep. 2012	Sundan, Pocheon, Gyeonggi-do	37°52'29" N, 127°09'28" E

The purpose of this study is to review and add newly recorded species of 3 genera and 5 taxa in which the remnants of the mother cell wall exist for a long time in the colonial gelatinous envelope.

MATERIALS AND METHODS

The samples of coccoid green algae were collected 290 sites including ponds, swamp, reservoirs, lakes and rivers from May 2011 to January 2014. Thirteen species in these 4 genera were identified and classified from 24 sites (Table 1). Sampling sites were located throughout Korea. All samples were collected by 10- or 20- μm mesh-sized plankton nets with vertical and/or horizontal towing, or were submerged benthic or soil algae collected with spoid or brush. Coccoid green algae samples were immediately fixed with Lugol's iodine solution (0.5%) for immobilizing the cells to facilitate microscopic examination. To examine the fine structures and cellular shapes, and to identify and classify species of the coccoid green algae, temporary slides were made by the following steps: 1) the phytoplankton samples (coccoid green algae) were mixed with glycerin in micro tubes. 2) The mixed sample was placed, drop-wise on a slide glass, and was fixed in position with cover slide. Permanent slides were made using the following steps. 1) The phytoplankton samples (coccoid green algae) were mixed with liquid glycerol gelatin for mounting histochemical slides (Sigma-Aldrich, St. Louis, MO, USA); 2) the mixed sample was placed drop-wise on a slide glass and was fixed in position with a cover slide; 3) The margin of the cover glass was cemented with manure (Thecashop, Seoul, Korea). The temporary and permanent slides were observed at $\times 200$ to $\times 1,000$ magnification using light microscopy (LM) (Axioskop 20 and Axio Imager A2; Carl Zeiss, Jena, Germany) with an attached digital camera (AxioCam HRC; Carl Zeiss) used to capture images. Specimens numbers are listed on the National Institute of Biological Resources (NIBR). The asterisk (*) mark indicates a newly recorded species and two asterisk (**) mark indicates a newly reported genus in Korea.

At each station, physical and chemical factors of the water were recorded during the sampling periods. Water temp. (Water temperature, $^{\circ}\text{C}$) and EC (electric conductivity) was measured in situ using a portable thermometer and EC meter (Orion 5-star; Thermo Scientific, Waltham, MA, USA) and pH was measured in situ using a pH meter (Ultrabasic-5; Denver Instrument, Bohemia, NY, USA). This study obtained data of total nitrogen (TN) and total phosphate (TP) concentrations at each sampling site

from the water information system of the Ministry of Environment (NIER 2014).

The identification of coccoid green algae is mainly based on guidelines from Komarek and Fott (1983), John and Tsarenko (2002), Hindak (1977, 1980, 1984, 1988), Prescott (1962), and Yamagishi and Akiyama (1984-1997).

RESULTS AND DISCUSSION

The family Radiococcaceae is composed of 6 genera, 24 species, 1 variety based on Komarek and Fott (1983), Hindak (1977, 1980, 1984, 1988), John and Tsarenko (2002) and Komarek and Jankovska (2001). *Schizochlamydelia sphaerica*, *Coenochloris piscinalis*, *hindakii*, *C. mucosa*, *C. pyrenoidosa*, *C. helvetica*, *C. planconvexa*, *C. asymmetrica* and *C. pyrenoidosa* were recorded by Kim (2013), and *C. ovalis* was reported by Jeon and Chang (1995). In this study, 5 taxa are newly recorded in Korea: 1) *Schizochlamydelia solitaria*, 2) *Thorakochloris planktonica*, 3) *Radiococcus bavaricus*, 4) *R. nimbatus*, and 5) *R. planctonicus*.

This study details the taxonomic information, illustrations, classifications, references, basionyms, synonyms and distributions of the newly recorded species of these families.

Class Chlorophyceae

Order Chlorococcales

Family Radiococcaceae

Subfamily Radiococcoideae

Genus *Schizochlamydelia* Korshikov 1953: 331

**Schizochlamydelia solitaria* (G.M. Smith) Fott 1974 (Fig. 1a–1c)

Basionym: *Schizochlamydelia solitaria* G.M. Smith 1922.

Illustration: Cells spherical, enclosed by colorless, non-stratified mucilaginous envelope. Cell wall thin, smooth or covered with a few warts. Chloroplast parietal, with a pyrenoid. 4 autospores in the mother cell wall (Fig. 1b, and c), released by the splitting of the mother cell wall. Cells 7–12 μm in diameter, colonies 30–50 μm in diameter of gelatinous envelope.

Key Reference: Fott (1974).

Specimens: DJGC20130424, DJGD20130531.

Information of sampling sites: This species inhabits lakes and reservoirs as plankton and on wetted soil collected from Galchi Reservoir (24 April 2013; water temp. 23.4 $^{\circ}\text{C}$, pH 6.9, EC 143 $\mu\text{S cm}^{-1}$), and Gyodong Reservoir (31 May 2013; water temp. 25.3 $^{\circ}\text{C}$, pH 8.5, EC 204 $\mu\text{S cm}^{-1}$).

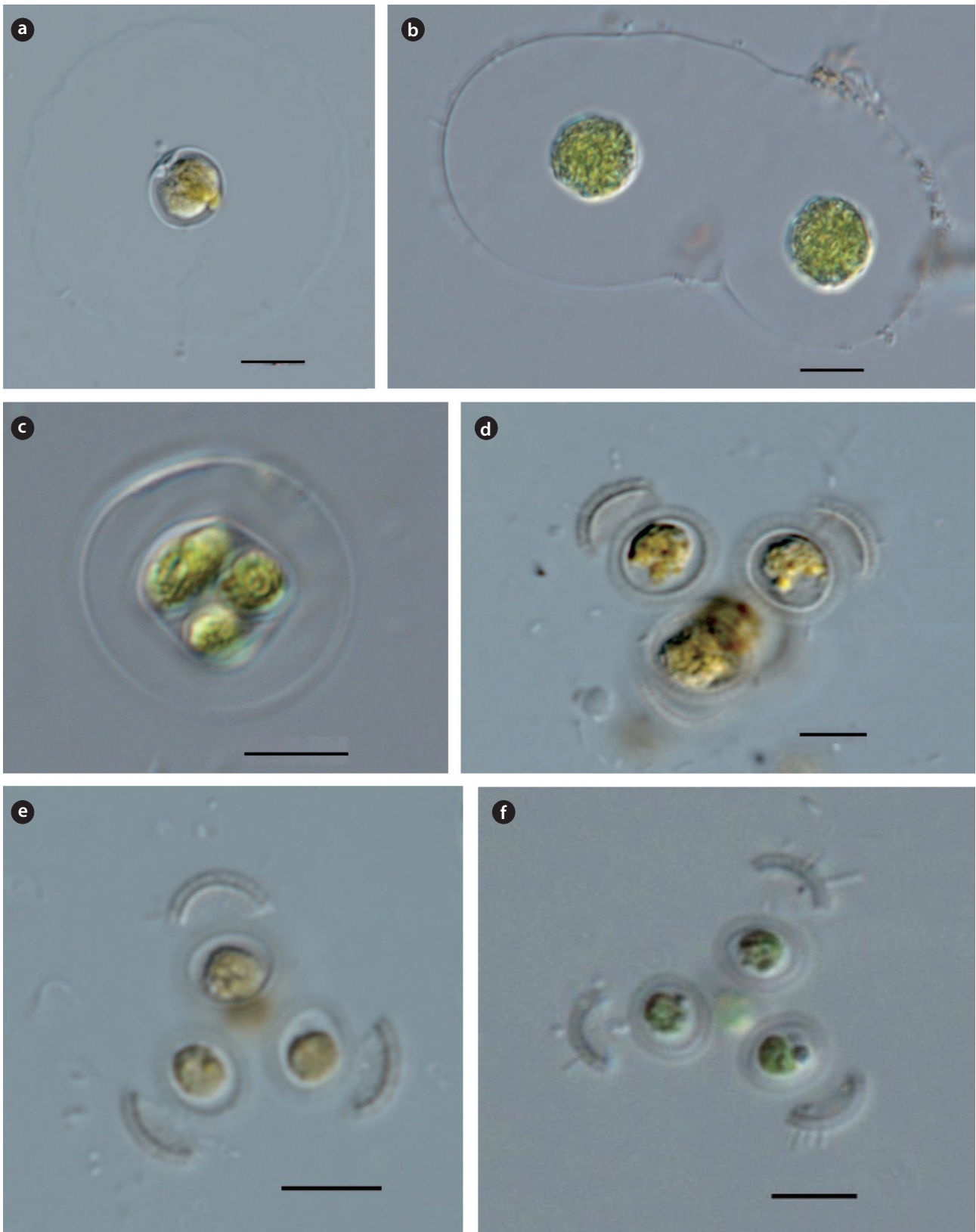


Fig. 1. *Schizochlamydes solitaria* (a–c), *Thorakochloris planktonica* (d–f). Scale bars, 10 µm.

www.kci.go.kr

***Schizochlamydeella sphaerica* S. Watanabe 1977 (Fig. 2a–2c)**

Illustration: Cells spherical, enclosed by colorless, non-stratified mucilaginous envelope. Cell wall thin, smooth or covered with a few warts. Chloroplast parietal, with a pyrenoid. 4–8 autospores in the mother cell wall (Fig. 2b and 2c), released by the splitting of the mother cell wall. Cells 7–10 µm in diameter, colonies 30–50 µm in diameter of mucilaginous envelope.

Key Reference: Watanabe (1977).

Specimens: KOSPCL0000108451, KOSPCL0000108706.

Information of sampling sites: This species inhabits lakes and reservoirs as plankton and on wetted soil collected from Lake 88 in Olympic Park (19 June 2013; water temp. 29.8°C, EC 193 µS cm⁻¹), an estuary of Dongjin River (02. August 2012; water temp. 31.6°C, pH 8.5, EC 1,000 µS cm⁻¹, TN 1.189 mg L⁻¹, TP 0.100 mg L⁻¹), wetted soil at tennis courts of Daejin University (26 September 2012), Baengduimot (30 May 2014; water temp. 31.7°C, pH 6.7, EC 160.4 µS cm⁻¹), and Bongwoomot (31 May 2014; water temp. 30.4°C, pH 7.3, EC 251 µS cm⁻¹).

****Genus *Thorakochloris* Pascher 1932******Thorakochloris planktonica* Fott 1933 (Fig. 1d–1f)**

Illustration: Colonies spherical, consisting of 4 cells, enclosed by colorless, non-stratified gelatinous envelope. Cell wall thin, smooth or covered with a few warts. Chloroplast parietal, with a pyrenoid. 4 autospores arranged in tetrahedral to quadrilateral shapes in the mother cell wall (Fig. 1d–f), released by the splitting of the mother cell wall. cells 5–8 × 4–6 µm, colonies 30–50 µm in diameter of mucilaginous envelope.

Key Reference: Fott (1933).

Specimens: DJBD20140530, DJDB20140530.

Information of sampling sites: This species inhabits lakes and reservoirs as plankton and wetland from Baengduimot (30 May 2014; water temp. 31.7°C, pH 5.3, EC 91.3 µS cm⁻¹), and Dombaemul (30 May 2014; water temp. 28.7°C, pH 6.2, EC 417.1 µS cm⁻¹).

Remarks: *Thorakochloris* is planktonic or metaphytic in freshwater; known from Austria, Czecho Republic, Denmark, France, and Germany. Similar to *Radiococcus* from which it differs principally by the presence of 4 persistent mother cell fragments within the mucilage envelope of each daughter colony. Also similar to *Coenochloris* from which it differs principally by the rupture of the mother cell walls into 4 more or less equal fragments rather than into 2 fragments (Guiry and Guiry 2014).

Genus *Coenochloris* Korshikov 1953***Coenochloris piscinalis* Fott 1974 (Fig. 2d–2f)**

Illustration: Colonies spherical or ovoid, consisting of 4–8 cells in a gelatinous envelope. Cells spherical or ovoid, which develop 4 autospores in the mother cell wall. 2 fragments of remnants persist after by the splitting of the mother cell wall. Chloroplast single parietal, with a pyrenoid. Cells 5–10 µm in diameter, colonies 20–40 µm in diameter.

Key Reference: Fott (1974).

Specimens: KOSPCL0000108394, DJDJ20120926.

Information of sampling sites: Wetted soil and spring at tennis courts in Daejin University (26 September 2012), Okgu Reservoir (22 September 2012; water temp. 25.2°C, pH 8.5, EC 231 µS cm⁻¹, TN 1.315 mg L⁻¹, TP 0.322 mg L⁻¹), Oknyeo Reservoir (22 September 2012; water temp. 25.2°C, pH 9.0, EC 572 µS cm⁻¹, TN 0.855 mg L⁻¹, TP 0.194 mg L⁻¹), and Bongpo Reservoir (03 May 2014; water temp. 22.3°C, pH 8.1, EC 125.7 µS cm⁻¹, TN 0.536 mg L⁻¹, TP 0.036 mg L⁻¹).

Remarks: This species was first reported from Prague in Czech Republic by Fott (1974). This species has also been reported in several other regions – in fish pond at Zelezna Studienka, Slovakia (Hindak 1977, 1980). In a small pool at the Little Carpathians Mountains near Bratislava, Slovakia (Hindak 1988), and in a small pond at Prague, Czech Republic (Komarek and Fott 1983). Fott (1974) reported cells be enclosed by a gelatinous envelope, but their gelatinous envelope has not been investigated from this study.

***Coenochloris hindakii* Komarek 1979 (Fig. 2f–2i)**

Synonym: *Coenochloris piscinalis* Fott sensu Hindak; *Coenochloris pyrenoidosa* Korshikov.

Illustration: Colonies spherical or irregular shaped, consisting of 4–8 cells in a gelatinous envelope. Cells spherical. 4 autospores enclosed with the mother cell wall, released by the splitting the mother cell wall, with wall remnants persisting thereafter. Cells 7–10 µm in diameter, colonies 40–70 µm in diameter.

Key Reference: Komarek (1979).

Specimens: DJSW20120709, DJOP20130619.

Information of sampling sites: Shinweol Reservoir (09 July 2012; water temp. 25.2°C, pH 9.0, EC 572 µS cm⁻¹, TN 0.855 mg L⁻¹, TP 0.194 mg L⁻¹), Lake 88 in Olympic park (19 June 2013; water temp. 29.8°C, EC 572 µS cm⁻¹), and Galchi Reservoir (24 April 2013; water temp. 23.4°C, pH 6.9, EC 143.2 µS cm⁻¹).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic

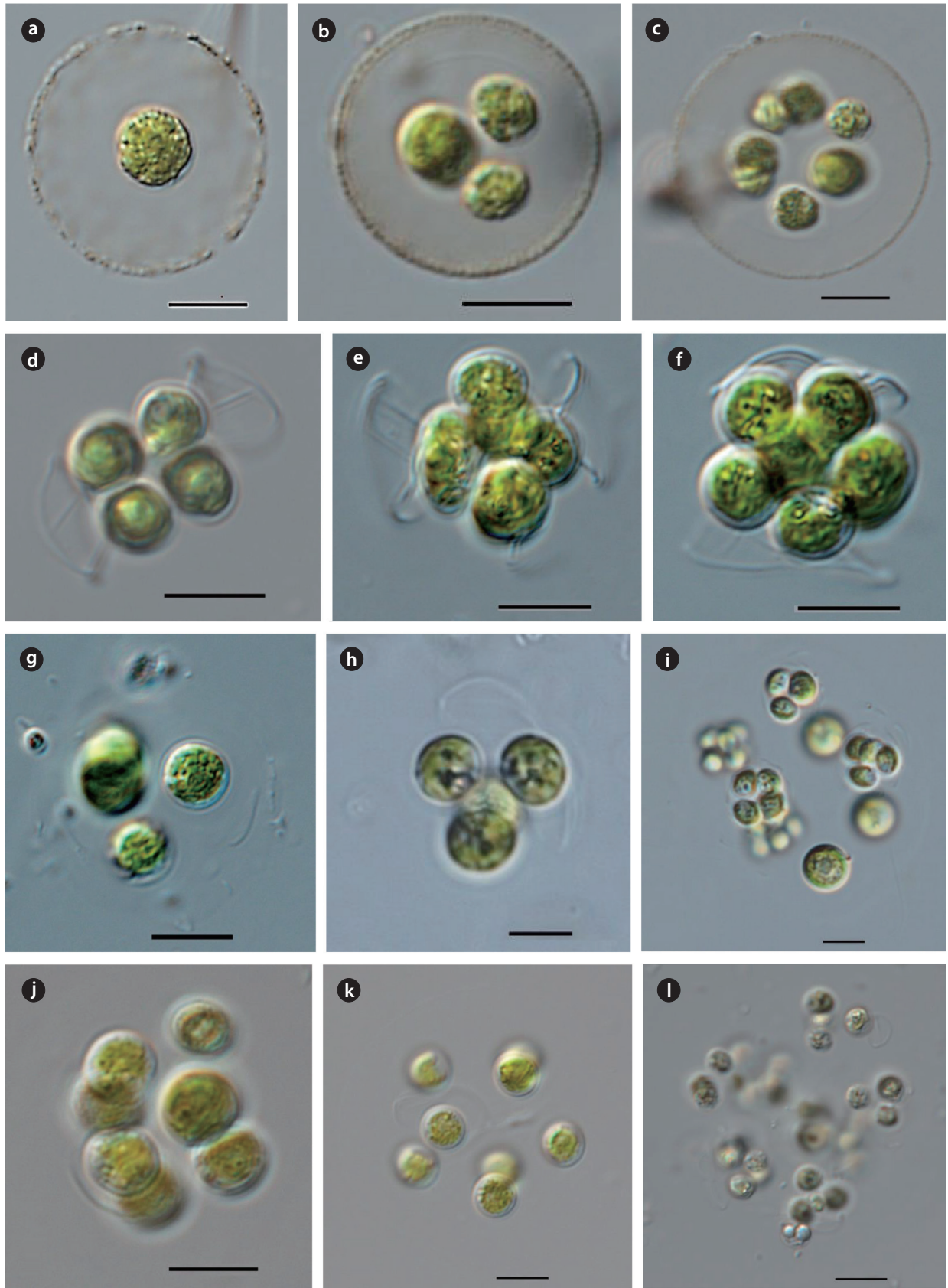


Fig. 2. *Schizochlamydesphaerica* (a–c), *Coenochlorispiscinalis* (d–f), *C. hindakii* (g–i), *C. mucosa* (j–l).

www.kci.go.kr

lakes, ponds, slow flowing river and swamps. This species was first reported from Lake Cicovske Jazero, near the Danube river, Slovakia (Komarek 1979), and was reported from Lake Cicovaske Jazero near the Danube, Slovakia (Hindak 1988) and rivers in Bratislava, Czech Republic (Komarek and Fott 1983).

***Coenochloris mucosa* (Korshikov) Hindak 1977 (Fig. 2j–2l).**

Basionym: *Chlorella mucosa* Korshikov 1953.

Illustration: Colonies spherical, consisting of 4–8 or 16 cells in a gelatinous envelope. Cells spherical, 4–8 auto-spores in the mother cell wall, released by the splitting of the mother cell wall. Chloroplast single parietal, invisible pyrenoid. Cells 5–10 µm in diameter, colonies 40–70 µm in diameter.

Key Reference: Hindak (1977).

Specimens: DJDM20120610, DJON20120922.

Information of sampling sites: Dongmyeong Reservoir (10 July 2012; water temp. 28.7°C, pH 7.3, EC 240.3 µS cm⁻¹, TN 2.321 mg L⁻¹, TP 0.046 mg L⁻¹), Oknyeo Reservoir (22 September 2012; water temp. 25.2°C, pH 9.0, EC 572 µS cm⁻¹, TN 0.855 mg L⁻¹, TP 0.194 mg L⁻¹), and Gobok Reservoir (28 May 2012; water temp. 27.2°C, pH 7.6, EC 209 µS cm⁻¹).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, slow flowing rivers and swamps. This species (strain hindak 1975/158) was first reported from Lake Strokovec, Bratislava in south and west Slovakia by Hindak (1977). This species was also reported from Lake Sempachersee, Switzerland (Hindak 1980), and lakes and ponds from Czech Republic and Ukraina (Komarek and Fott 1983).

***Coenochloris ovalis* Korshikov 1953**

Cells length 5–10 µm, width 4–8 µm, colonies 40–70 µm in diameter.

***Coenochloris pyrenoidosa* Korshikov 1953 (Fig. 3a and 3b)**

Illustration: Colonies spherical or irregular shape, 4–8 or 16 cells in a gelatinous envelope. Cells ellipsoid or wide ovoid. Eight spherical auto-spores in the mother cell wall, released by the splitting of the mother cell wall, with 1–2 fragments of wall remnants persisting thereafter. Chloroplast parietal, with a pyrenoid. Cells 8–6 µm in diameter, colonies more than 70 µm in diameter.

Key Reference: Korshikov (1953).

Specimens: KOSPCL0000107362, DJDM20120610.

Information of sampling sites: Dongmyeong Reservoir (10 July 2012; water temp. 28.7°C, pH 7.3, EC 240.3 µS cm⁻¹, TN 2.321 mg L⁻¹, TP 0.046 mg L⁻¹), the Bukhan River at

Yangsoori (26 August 2012; water temp. 30.2°C, EC 238 µS cm⁻¹), Ilwang Reservoir (24 April 2013; water temp. 20.2°C, pH 6.8, EC 253.2 µS cm⁻¹), and Pond around Docho elementary school (24 June 2013; water temp. 30.2°C, EC 347 µS cm⁻¹).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, slow flowing rivers and swamps. This species was first reported from the Kharkov Area, Lake Liman, Ukraine by Korshikov (1953). It has also been recorded from several other regions: in a fish pond of Central Bohemia (Fott 1974), in stagnant and flowing waters in Bratislava, in the river Danube, in a fish pond at Zelezna Studienka, Slovakia (Hindak 1977), and in an inundation lake at the Morava River at Bratislava-Devin, Slovakia (Hindak 1980).

***Coenochloris helvetica* Hindak 1980 (Fig. 3c–3e)**

Synonym: *Coenochloris piscinalis* Fott sensu Hindak; *Coenochloris pyrenoidosa* Korshikov.

Illustration: Colonies spherical or irregular shaped, consisted of 4–8 or 16 cells in a mucilaginous envelope. Cells ellipsoid or slightly asymmetrically shaped. 8 auto-spores in the mother cell wall, released by the splitting of the walls, with wall remnants persisting thereafter. Chloroplast single parietal, with a pyrenoid. Cells 5–12 µm in length, 4–8 µm in width. Colonies 40–80 µm in diameter.

Key Reference: Hindak (1980).

Specimens: KOSPCL0000107417, KOSPCL0000108372.

Information of sampling sites: Wet soil and spring at tennis courts at Daejin University (26 September 2012; no data), the Bukhan River at Yangsoori (26 August 2012; water temp. 30.2°C, EC 238 µS cm⁻¹), Lake 88 in Olympic Park (19 June 2013; water temp. 29.8°C, EC 572 µS cm⁻¹), and Joeeul Reservoir (22 September 2012; water temp. 22.7°C, EC 267 µS cm⁻¹).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, slow flowing rivers and swamps. This species was first reported from the small dystrophic lake Gerzensee, Kastanienbaum, Switzerland by Hindak (1978, 1980) and littoral of a fish pond in Thienemann-Weiher, near Seeon, Bavaria, Germany (Hindak 1980).

***Coenochloris planoconvexa* Hindak 1977 (Fig. 4a–4c)**

Illustration: Colonies spherical or irregular ovoid, consisted of 4–8 or 16 cells or temporarily 64 cells in a gelatinous envelope. Cells elongated asymmetric reniform or ovoid, cell wall smooth. Usually, 4 auto-spores in the mother cell wall, released by the splitting of the mother

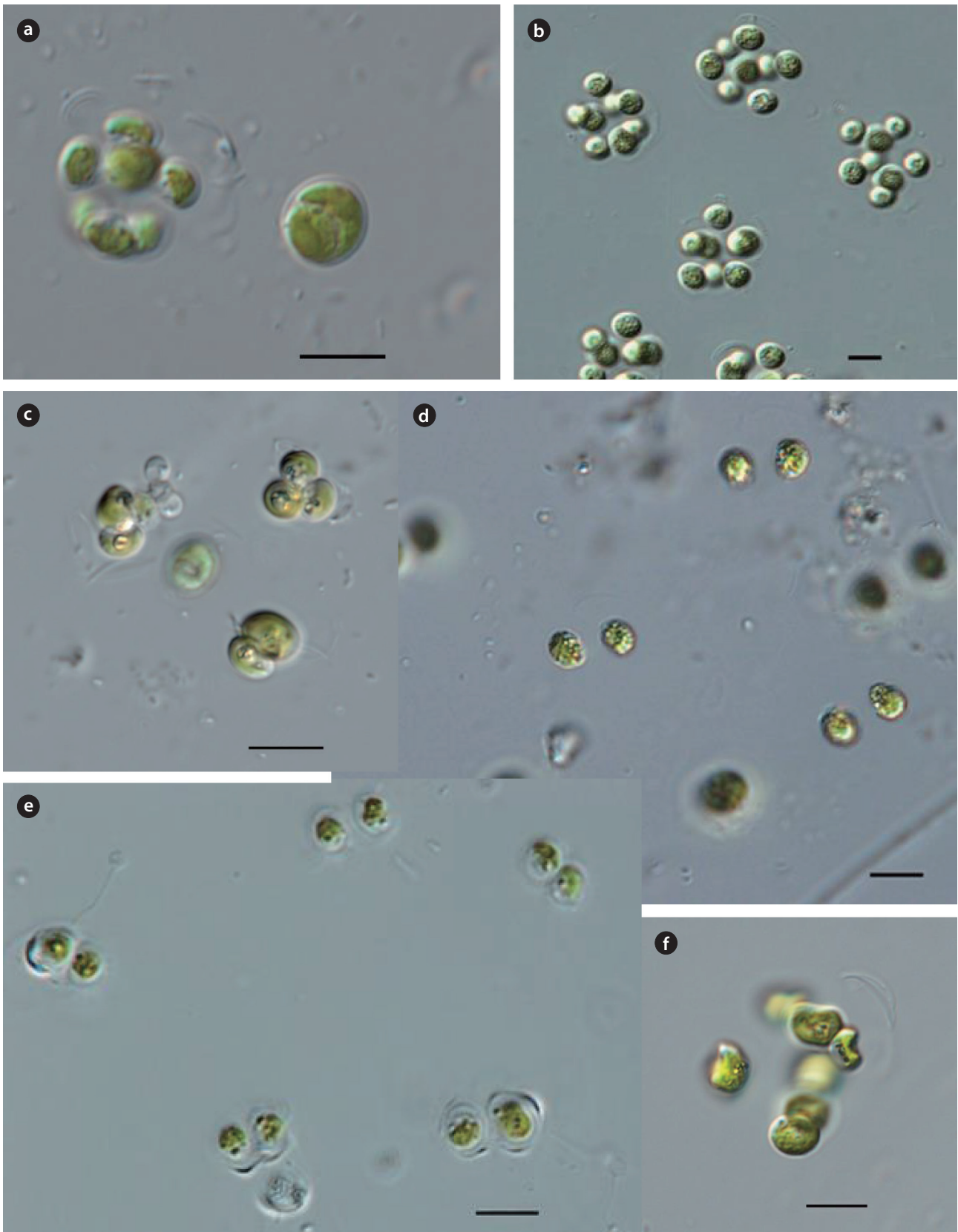


Fig. 3. *Coenochloris pyrenoidosa* (a, b), *C. helvetica* (c-e). Scale bars, 10 μ m.

www.kci.go.kr

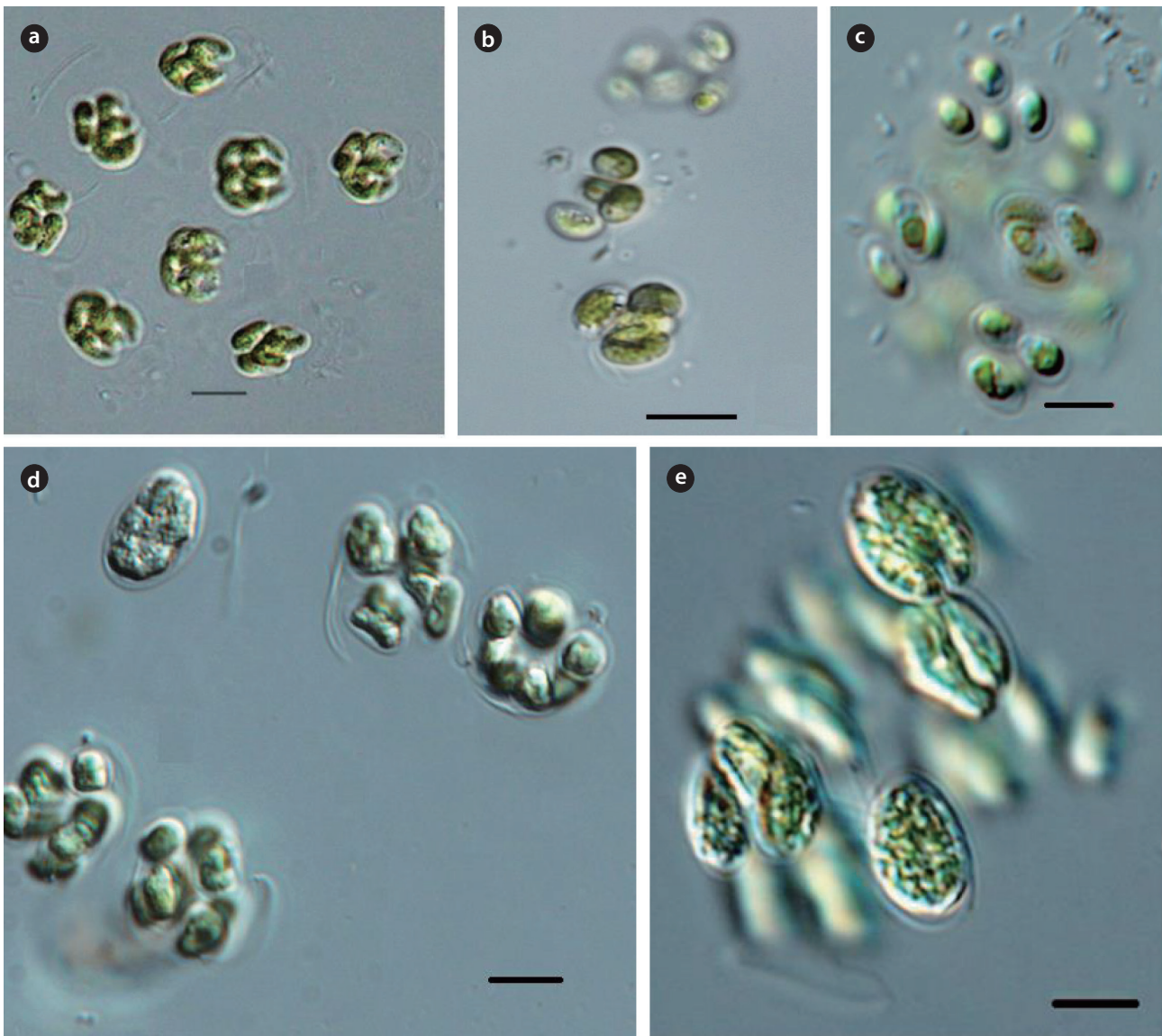


Fig. 4. *Coenochloris planoconvexa* (a-c), *C. asymmetrica* (d, e). Scale bars, 10 μm .

cell wall, with wall remnants persisting thereafter for a long time. Chloroplast single parietal, with a pyrenoid. Cells 8–12 μm in length, and 4–8 μm in width. Colonies 40–100 μm in diameter.

Key Reference: Hindak (1977).

Specimens: KOSPCL0000108410, DJBR20120826.

Information of sampling sites: the Bukhan River at Yangsoori (26 August 2012; water temp. 30.2°C, EC 238 $\mu\text{S cm}^{-1}$), Sampori Reservoir (18 August 2012; water temp. 30.1°C, EC 208 $\mu\text{S cm}^{-1}$), Okgu Reservoir (22 September 2012; water temp. 25.2°C, pH 8.5, EC 231 $\mu\text{S cm}^{-1}$, TN 1.315 mg L^{-1} , TP 0.322 mg L^{-1}), Euirim Reservoir (31 August 2012;

water temp. 28.2°C, pH 7.6, EC 138 $\mu\text{S cm}^{-1}$), and Bongpo Reservoir (03 May, 2014; water temp. 20.8°C, pH 7.6, EC 125.7 $\mu\text{S cm}^{-1}$).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, slow flowing rivers and swamps. This species was reported from plancto fluminum (flumen Danubius in Bratislava, locus classicus), lacus (Bratislava – Trávniky) piscinarumque (Železná Studienka, Bratislava), Slovakia by Hindak (1977). It has also been reported from several other regions: in Lake Velky Les near the Danube in Gabeikovo, Slovakia (Hindak 1977), and in the inunda-

tion lake at the Morava River at Bratislava-Devin, Slovakia (Hindak 1980).

***Coenochloris asymmetrica* Hindak 1980 (Fig. 4d and 4e)**

Basionym: *Coenochloris asymmetrica* Hindak 1980.

Illustration: Colonies spherical or irregular shaped, consisted of 4–8 or 16 cells in a mucilaginous envelope. Cells wide ovoid, ellipsoid or reniform, cell wall smooth, usually 4 autospores in the mother cell wall, released by the splitting of the mother cell wall, with remnants persisting for a long time thereafter. Chloroplast single parietal, with a pyrenoid. Cells 10–15 µm in length and 5–10 µm in width. Colonies 40–80 µm in diameter.

Key Reference: Hindak (1980).

Specimens: DJOP20120907, DJJE20120922.

Information of sampling sites: Lake 88 in Olympic Park (07 September 2012; no data), and Jooeul Reservoir (22 September 2012; water temp. 22.7°C, EC 267 µS cm⁻¹).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, slow flowing rivers and swamps. This species was first reported from Lake Nove Mestonad Vahom, Slovakia by Hindak (1980). It has also been reported from several other regions: in a gravel pit lake at Nove Mestonad Vahom, Slovakia (Hindak 1977) and eutrophic lakes throughout south-western Slovakia (Komarek and Fott 1983).

****Genus *Radiococcus* Schmidle 1902**

****Radiococcus planktonicus* Lund 1956 (Fig. 5a and 5b)**

Synonym: *Eutetramorus lundii* Bourrelly.

Illustration: Colonies spherical, irregularly shaped, consisting of 4–8 or 16 cells randomly arranged, enclosed by a mucilaginous envelope arranged with radial striation. Cells spherical. usually 4 autospores in the mother cell wall, released by the splitting of the mother cell wall, with cap-like remnants persisting thereafter. Chloroplast parietal, with a pyrenoid. Cells 5–10 µm in diameter, colonies 40–120 µm in diameter.

Key Reference: Lund (1956).

Specimens: DJSH20120527, DJOP20130619.

Information of sampling sites: Lake Seocho (27 May 2012; water temp. 30.4°C, pH 7.3, EC 569 µS cm⁻¹), and Lake 88 in Olympic Park (19 June 2013; water temp. 29.8°C, EC 572 µS cm⁻¹).

Key Reference: Lund (1956).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, slow flowing rivers and swamps. This spe-

cies was first reported from Lake District, Great Britain by Lund (1956). It has also reported from many other regions: in the Lake District and Windermere in the British Isles (John and Tsarenko 2002), a fishpond at Zelezna Studienka, at Bratislava and a small pond in the Little Carpathian Mountains. near Bratislava from Slovakia (Hindak 1988).

****Radiococcus nimbatus* (De-Wildeman) Schmidle 1902 (Fig. 5c and 5d)**

Basionym: *Pleurococcus nimbatus* De-Wildemann 1893.

Synonym: *Tetracoccus nimbatus* (De-Wildemann) Schmidle.

Illustration : Colonies spherical, consisting of 4–8 or 16 cells, enclosed by a mucilaginous envelope arranged with radial striation. Cells spherical, 4 autospores in the mother cell wall, released by the splitting of the cell wall, with wall remnants persisting thereafter. Chloroplast parietal, with a pyrenoid. cells 5–12 µm in diameter, colonies 40–70 µm in diameter.

Key Reference: Schmidle (1902).

Specimens: KOSPCL0000106117, DJOP20130619.

Information of sampling sites: Samrak Park in Busan (15 June 2011; no data), and Lake 88 in Olympic Park (19 June 2013; water temp. 29.8°C, EC 572 µS cm⁻¹).

Remarks: This species is widespread throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, and swamps or epiphyton to under the surface of still water. This species was first reported from the Sinai Peninsula and Syria, Egypt by Schmidle (1902). It has also been reported from many other regions: in eutrophic lakes, rivers, and still water throughout the British Isles (John and Tsarenko 2002), in South Carolina and Tennessee of the southeastern United States (Dillard 1989), in Shinobazu, Japan (Yamagishi and Akiyama 1984-1997), in bodies of the water of eastern and north-eastern states throughout India (Jena and Adhikary 2007), in artificial lakes of Goias Municipality, Brazil (Nogueira and Oliveira 2009).

****Radiococcus bavaricus* (Skuja) Komarek 1979 (Fig. 5e and 5f)**

Basionym: *Gloeococcus bavarica* Skuja 1959.

Synonym: *Gloeocystis bavarica* Skuja; *Sphaerocystis bavarica* (Skuja) Bourrelly; *Coenochloris bavarica* (Skuja) Hindak.

Illustration: Colonies spherical, consisting of 4–8 or 16 cells, enclosed by a mucilaginous envelope, arranged with radial striation. Cells spherical, 4 autospores in the mother cell wall, released by the splitting of the mother

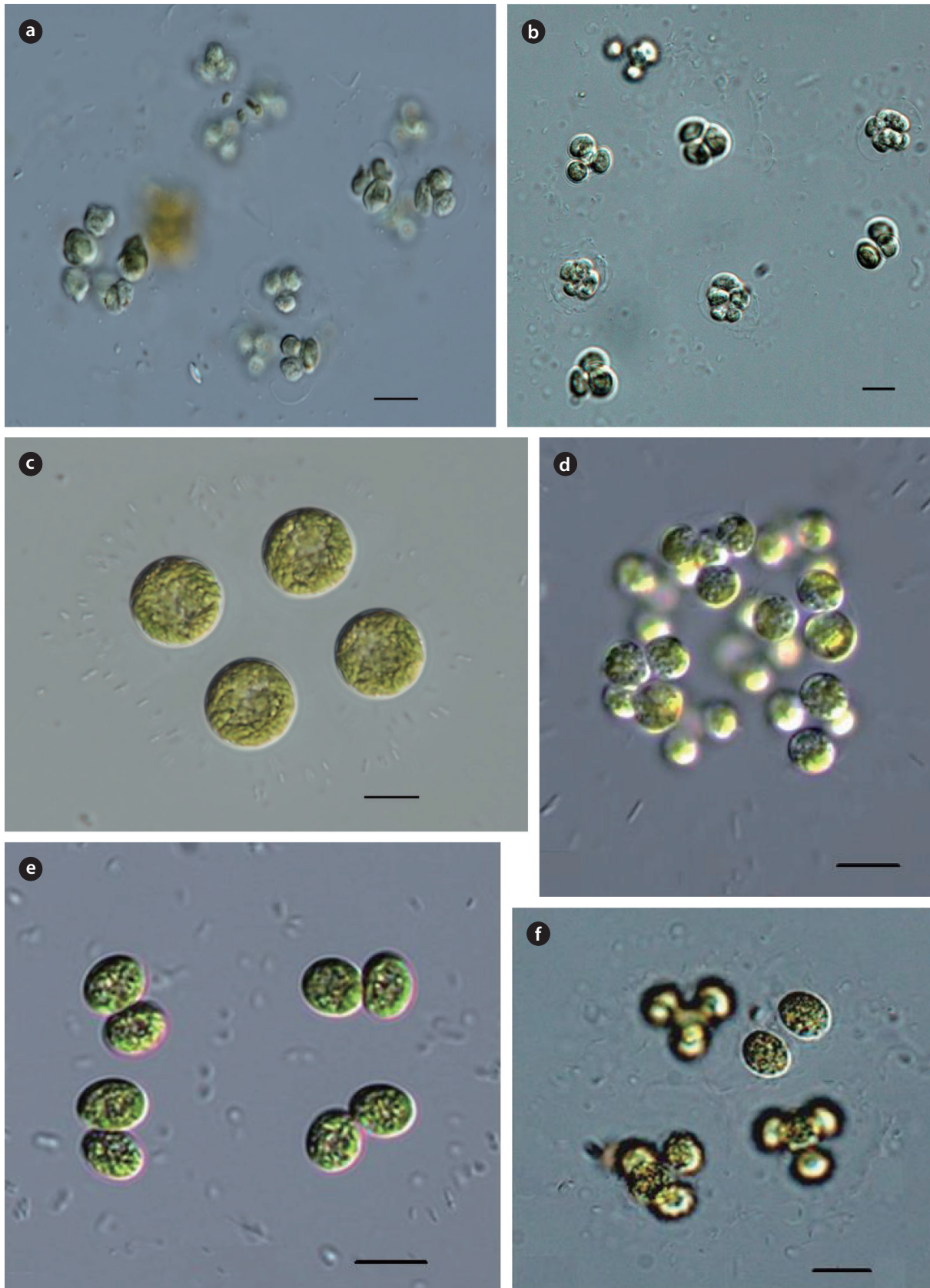


Fig. 5. *Radiococcus planktonicus* (a, b), *R. nimbatus*(c, d), *R. bavaricus* (e, f). Scale bars, 10 μ m.

cell wall, with the remnants of the cell wall remaining thereafter. Chloroplast parietal, with a pyrenoid. cell 5–8 µm in diameter, colonies 40–70 µm in diameter.

Key Reference: Komarek (1979).

Specimens: KOSPCL0000108512, KOSPCL0000106002.

Information of sampling sites: Bundang Jungang Park (02 June 2012; water temp. 26.3°C, pH 8.2, EC 407 µS cm⁻¹), and Lake 88 in Olympic Park (19 June 2013; water temp. 29.8°C, EC 572 µS cm⁻¹).

Remarks: This species occurred throughout the world as plankton in eutrophic or sometimes oligotrophic lakes, ponds, slow flowing rivers and swamps. This species was first reported from Lake Cicovske Jazero, near the Danube River, Hungary by Komarek (1979). It has also been reported from many other regions: in the Danube Rivers, Hungary (Komarek 1979), in Chiemgau, Oberbayern, Germany (Komarek and Fott 1983).

Taxa belonging to 4 genera (*Schizochlamydelia*, *Thorakochloris*, and *Coenochloris*, *Radiococcus*) distributed a cosmopolitan. These genera have the characteristics of a gelatinous sheath and retaining the remnants of the mother cell wall for a long time (Komarek and Fott 1983, Hindak 1977, 1980, 1984, Pazoutova 2008). Komarek (1979), further pointed out the absence of zoospores, characteristics not mentioned in the classification system of Fott (1959). After then, several researchers have accepted the taxonomical system of Komarek (Pazoutova 2008).

Coenochloris ovalis has been reported from Lake Asan and Ansung Stream by Jeon and Chang (1995), and *Coenochloris asymmetrica*, *C. helvetica*, *C. hindakii*, *C. mucosa*, *C. piscinalis*, *C. planoconvexa*, *C. pyrenoidosa* from several lakes, reservoirs, swamps and wetted soil by Kim (2013), but several species of these genera have not been reported yet. These genera are very difficult to identify because their gelatinous envelope and the remnants of the mother cell cannot be observed by light microscopy. The author believes that identification and classification of the many species of these genera will be advanced by improvement in light microscopy and other instruments.

CONCLUSION

A study on fresh-water green coccoid algae was carried out at ponds, swamps, reservoirs, lakes and rivers (290 sites) from May 2012 to January 2014. In this study, 4 genera and 13 taxa of the family Radiococcaceae having the remnants of the cell wall existing for a long time in the colonial gelatinous envelope are identified and classified

from 24 sites. 8 taxa (1 genus) of the family Radiococcaceae in coccoid green algae are reported here based on characteristics by light microscopy: *C. asymmetrica*, *C. helvetica*, *C. hindakii*, *C. mucosa*, *C. piscinalis*, *C. planoconvexa*, and *C. pyrenoidosa* by Kim (2013) and *C. ovalis* by Jeon and Chang (1995), all of which have the remnants of the mother cell wall included in the gelatinous envelope for a long time. Many taxa of this family, however, have not been recorded in Korea yet. Of these, 5 taxa are newly recorded in Korea by this study: 1) *Schizochlamydelia solitaria*, 2) *Thorakochloris planktonica*, 3) *Radiococcus bavaricus*, 4) *R. nimbatus*, and 5) *R. planktonicus*.

ACKNOWLEDGMENTS

This work was supported by a grant from the National Institute of Biological Resources (NIBR), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIBR201401204).

LITERATURE CITED

- Bourelly P. 1966. Les algues d'eau douce. I. Les algues vertes. Boubee and Cie, Paris.
- De-Wildeman E. 1893. Note sur le genre *Pleurococcus* Menegh. Et sur une espece nouvelle, *Pleurococcus nimbatus* nob. Bull Herb Boiss Geneve 1: 337-343.
- Dillard GE. 1989. Freshwater algae of the southwestern Southern United States, Part I. Chlorophyceae: Volvocales, Tetrasporales and Chlorococcales. Bibl Phycol 81: 1-202.
- Fott B. 1933. Einige neue Protococcalen. Beih Bot Centralbl Dresden 50: 577-584.
- Fott B 1959. Algenkunde. Gustav Fischer Verlag, Jena.
- Fott B. 1974. Taxonomy the palmelloid Chlorococcales (Family Palmogloeaceae). Preslia 46: 1-31. (in German)
- Guiry MD, Guiry GM 2014. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. <http://www.algaebase.org>. Accessed 08 August 2014.
- Hindak F. 1977. Studies on the Chlorococcal Algae. Chlorophyceae. Vol I. Biologické práce 23. VEDA, Bratislava.
- Hindak F. 1978. The genus *Gloeocystis* (Chlorococcales, Chlorophyceae). Preslia 50: 5-31.
- Hindak F. 1980. Studies on the Chlorococcal Algae. Chlorophyceae. Vol II. Biologické práce 26. VEDA, Bratislava.
- Hindak F. 1984. Studies on the Chlorococcal Algae. Chlorophyceae. Vol III. Biologické práce 30. VEDA, Bratislava.
- Hindak F. 1988. Studies on the Chlorococcal Algae. Chloro-

- phyceae. Vol IV. Biologické práce 34. VEDA, Bratislava.
- Jena M, Adhikary SP. 2007. Chlorococcales (Chlorophyceae) of Eastern and North-eastern States of India. *Algae* 22: 167-183.
- Jeon SR, Chang YK. 1995. Additions to the Freshwater Algae in Korea (VI). *Korean J Phycol* 10: 29-36. (in Korean with English abstract)
- John DM, Tsarenko PM. 2002. Order Chlorococcales. In: *The Freshwater Algal Flora of the British Isles. An Identification Guide to Freshwater and Terrestrial Algae* (John DM, Whitton BA, Brook AJ. eds). Cambridge University Press, Cambridge. pp. 327-409.
- Kim YJ. 2013. Freshwater green algae - Chlorophyta: Chlorophyceae: Chlorococcales II Hydrodictyaceae, Coelastraceae, Radiococcaceae, Oocystaceae. In: *Freshwater algal flora of Korea. Vol 7 (2)*. (National Institute of Biological Resources ed). National Institute of Biological Resources, Incheon. (in press)
- Komarek J. 1979. Änderungen in der Taxonomie der Chlorokkotalgen. *Arch Hydrobiol Suppl*(56) 24: 239-263.
- Komarek J, Fott B. 1983. Chlorophyceae (Green algae), Order: Chlorococcales. In: *Das Phytoplankton des Süßwassers. Systematik und Biologie. Teil 7(1)*. (Huber Pestalozzi G. ed). Schweiz Verg. Stuttgart.
- Komarek J, Jankovska V. 2001. Review of the green algal genus *Pediastrum*; implication for pollen analytical research. *Bibl Phycol* 108: 1-127.
- Korshikov OA. 1953. The Freshwater Algae of the Ukrainian SSR. V. Subclass Protococcineae. Vacuolales and Protococcales. *Akad Nauk URSR, Kyjv [Kiev]*. (in Russian)
- Lund JWG. 1956. On certain planktonic palmelloid green algae. *J Linn Soc London Bot* 55: 593-613.
- NIER. 2014. Water Information System of the Ministry of Environment. <http://water.nier.go.kr>. Accessed 08 August 2014.
- Nogueira ID, Oliveira JE. 2009. Chlorococcales and Ulothricales of colonial habit from four artificial lakes in the municipality of Goiânia-GO. *Iheringia Ser Bot Proto Algae* 64: 123-143. (in Portuguese)
- Pascher A. 1932. Drei neue Protococcalen gattungen. *Arch Protistenk Jena* 76: 409-419.
- Pazoutova M. 2008. Phylogenetic diversity and generic concept in the family Radiococcaceae, Chlorophyta. *Diplomove prace, Univerzita Karlova v Praze, Praha*.
- Philipose MT. 1967. Chlorococcales. *Indian council for Agricultural Research Monographs on Algae, New Dehli*.
- Prescott GW. 1962. *Algae of the Western Great Lakes Area*. Wm C Brown Company Publishers, Dubuque, IA.
- Schmidle W. 1902. Algen, insbesondere solche des Plankton, aus dem Nyassa-See und seiner Umgebung, gesammelt von Dr. Fülleborn. *Bot Jahrb Syst* 32: 56-88. (in German)
- Skuja H. 1959. *Gloeococcus bavaricus* n. sp. and *Coelastrella compacta* n. sp. *Protoplasma* 50: 493-497. (in German)
- Smith GM. 1922. The phytoplankton of some artificial pools near Stockholm. *Ark Bot* 17: 1-8.
- Smith GM. 1950. *The Freshwater Algae of the United State*. 2nd ed. McGraw-Hill, New York.
- Watanabe S. 1977. *Schizochlamydelia sphaerica* sp. Nov. (Chlorococcales) from Japanese soil. *J Jap Bot* 52: 338-343.
- Yamagishi T, Akiyama M. 1984-1997. Photographs of the Fresh-water Algae. Vol 1-19. Ukida Rokakuho, Tokyo.