

〈Original article〉

A Study of Nine Unrecorded Species of Planktonic Cyanobacteria (Cyanophyceae, Cyanophyta) in Korea

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Abstract - Samples were collected from planktonic habitats of the fresh and brackish waters in Korea from August 2016 to May 2018. As a result, three genera and nine species were newly recorded in Korea. The unrecorded indigenous genera were *Anathece*, *Chondrocystis* and *Geminocystis*, and nine species were *Anabaenopsis arnoldii*, *Anathece smithii*, *Chondrocystis dermochroa*, *Coelosphaerium aerugineum*, *Eucapsis microscopica*, *Geminocystis herdmanii*, *Microcystis panniformis*, *Synechococcus nidulans* and *Woronichinia karelica*. *Anathece smithii*, *Coelosphaerium aerugineum*, *Eucapsis microscopica*, *Microcystis panniformis* and *Synechococcus nidulans* had been reported to inhabit freshwater, but these were found in brackish water in this study. *Microcystis panniformis*, which is a potential genus for causing green-tide, is taxonomically valuable in Korea.

Keywords : brackish water, cyanobacteria, Korean unrecorded species, planktonic

INTRODUCTION

Cyanobacteria or blue-green algae are a prokaryote that plays a role of primary producer through photosynthesis since about 3.5 billions years (Graham *et al.* 2009). The cyanobacteria are found in various environments even extreme conditions like hot spring, polar region, ultra-oligotrophic or high pH/salinity water (Parker *et al.* 1981; Wharton *et al.* 1983; Whitton 2012).

Planktonic cyanobacteria are floating algae suspended in slow moving water such as in a lake. They usually clustered within 30 cm of the water surface caused by colonization, mucilaginous sheath and gas vesicles. It often produces bright green or blue-green soup-like scums (Samuel *et al.* 2014).

Nowadays, freshwater habitats are threatened worldwide by blooming of cyanobacteria, such as *Microcystis*, *Anabaena*. Once they are bloomed, they can cause the problems in water environments and drinking water supplies by

producing toxins like microcystin and anatoxin (Codd 1995; Kim *et al.* 1995). Therefore, continuous researches of cyanobacteria, especially *Microcystis*, *Anabaena*, *Oscillatoria*, and *Aphanizomenon* are being conducted worldwide (Park and Kim 1995; Park 2005; Lee *et al.* 2017).

The 4,617 taxa of cyanobacteria have been reported to AlgaeBase (Guiry and Guiry 2018), and 377 taxa have been reported in Korea (Kim 2015; Song and Lee 2017; Yim *et al.* 2017). *Microcystis* have been reported 51 taxa in worldwide, and 7 species in Korea. *Anabaena* have been reported 151 taxa in worldwide (Guiry and Guiry 2018), and 10 taxa in Korea.

For this study, we collected unrecorded cyanobacteria from fresh and brackish waters to add the algal flora of Korea.

MATERIALS AND METHODS

We collected planktonic cyanobacteria from nine sites in Korea from August 2016 to May 2018 (Fig. 1; Tables 1,

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Table 1. Sampling sites in Korea from where planktonic samples were collected from August 2016 to May 2018

Site	Local name	Latitude (N)	Longitude (E)
st.1	629-3, Bangsan-dong, Siheung-si, Gyeonggi-do	37.413256	126.755274
st.2	1169, Jangcheon-ri, Ibang-myeon, Changnyeong-gun, Gyeongsangnam-do	35.610430	128.357497
st.3	1-5, Deokcheon-ri, Byeonggok-myeon, Yeongdeok-gun, Gyeongsangbuk-do	36.568571	129.420167
st.4	49, Uljindaegae-ro, Hupo-myeon, Uljin-gun, Gyeongsangbuk-do	36.677738	129.446123
st.5	1061-3, Gupo-dong, Buk-gu, Busan	35.203433	128.992730
st.6	1-55, Nonhyeon-dong, Namdong-gu, Incheon	37.412225	126.748987
st.7	150, Yonggok-ri, Jangdong-myeon, Jangheung-gun, Jeollanam-do	34.718328	126.955823
st.8	1108-14, Anseong-ri, Dongjin-myeon, Buan-gun, Jeollabuk-do	35.784821	126.755452
st.9	275-6, Daeum-ri, Inju-myeon, Asan-si, Chungcheongnam-do	36.854477	126.851721

Table 2. The environment of sampling sites from August 2016 to May 2018

Site	Collection date	Environment	Salinity (‰)
st.1	May 4, 2018	Eutrophic and brackish paddy field	0.6
st.2	Aug. 24, 2016	Midstream of Nakdong river	—
st.3	Mar. 30, 2018	Eutrophic and brackish riverside nearby farmlands	1
st.4	Sep. 23, 2017	Eutrophic brackish waterway	5.1
st.5	Jun. 9, 2017	Downstream of Nakdong river	—
st.6	May 4, 2018	Mesotrophic and brackish wetland	6.6
st.7	Aug. 7, 2017	Mesotrophic reservoir at mountainside	—
st.8	Sep. 26, 2017	Brackish waterway at reclaimed land	0.2
st.9	Aug. 7, 2017	Deep-water of seawall	—

2). They were collected using phytoplankton net with mesh size 20 µm and diameter 30 cm (Sournia 1978). Each sample was sealed in sterile bottles and transported to the laboratory (Crispim *et al.* 2004). Measurement of salinity was performed by marine tester (DMT-10, DYS, Korea).

The samples were examined under BX53 light microscope at ×400–1,000 (Olympus, Tokyo, Japan) and photographed using AxioCam HRC camera (Carl Zeiss, Oberkochen, Germany). The taxonomic classification system was based on Komárek *et al.* (2014) and Algaebase (Guiry and Guiry 2018). In this study, identification of cyanobacteria referred to Hirose *et al.* (1977), Prescott (1982) Chung (1993), Komárek and Anagnostidis (1999, 2005), John *et al.* (2011) and Komárek (2013).

RESULTS AND DISCUSSION

Three genera and nine species of planktonic cyanobacteria were newly recorded in Korea. The newly recorded genera were *Anathece*, *Chondrocystis* and *Geminocystis*, and the newly recorded species were *Anabaenopsis arnoldii*, *Anathece smithii*, *Chondrocystis dermochroa*, *Coelosphae-*

rium aeruginum, *Eucapsis microscopica*, *Geminocystis herdmanii*, *Microcystis panniformis*, *Synechococcus nidulans* and *Woronichinia karelica*.

Order Chroococcales Schaffner 1922

Family Chroococcaceae Rabenhorst 1863

Genus *Chondrocystis* Lemmermann 1899

Colonies are free-living and more or less irregular or irregular-polygonal. Colonies are surrounded by packet-like outline, gelatinous, laterally usually flattened or (in masses) slimy mucilage envelopes. They are composed of numerous partial subcolonies. Subcolonies are surrounded by more or less cubic or polygonal flattened, widened, colourless, delimited slime, cells with individual thin, gelatinous, slightly stratified envelopes. Envelopes are partially thickened. Reproduction is occurred by small subcolonies after colony disintegration. This genus is newly recorded in Korea.

Chondrocystis dermochroa (Nägeli ex Kützing)

Komárek and Anagnostidis 1995 (Fig. 2)

Synonym: *Gloeocapsa dermochroa* Nägeli ex Kützing 1849

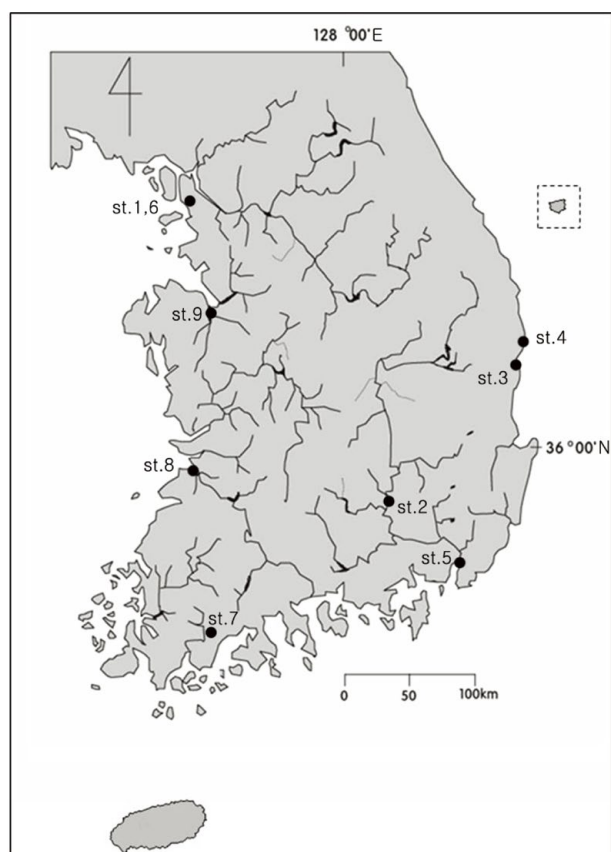


Fig. 1. The map showing the nine sampling sites in Korea from August 2016 to May 2018.

Colony size is microscopic or rarely macroscopic. Colonies are more or less spherical, hemispherical or oval. Large colonies are composed of very densely packed and small subcolonies. Subcolonies are spherical or polygonally-rounded, and composed of clustered cells. Mucilaginous envelope that surround the subcolony is narrow and firm, but later diffluent. Mucilaginous envelope forms single or slightly lamellated layers. The cell is spherical and blue-green in color. Cell diameter is 1.5–3 μm .

Ecology: This species appears in freshwater and subaerobic habitat. This species lives usually in limestone areas or on rocks with periodically flowing water, but rarely in the water-level zone of streams (Komárek and Anagnostidis 1999). We collected it from midstream of Nakdong river.

Distribution: Arctic: Svalbard (Matula *et al.* 2007); North America: Arkansas (Smith 2010).

Site of collection: Yulji-gyo, Changnyeong-gun, Gyeong-

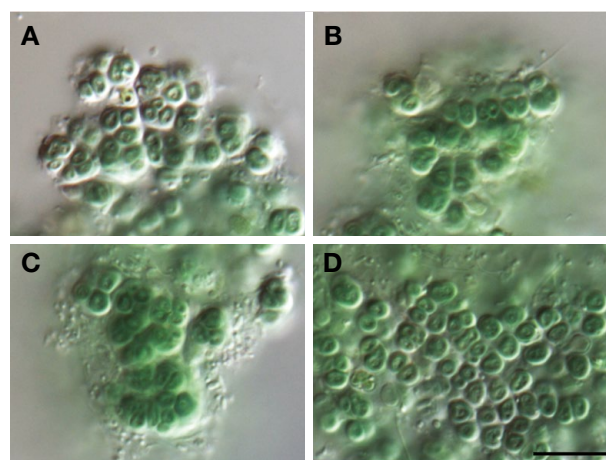


Fig. 2. Microscopic photographs of *Chondrocystis dermochoera* (Nägeli ex Kützing) Komárek and Anagnostidis. The photographs show the pellets of cells (A–C) and the shape of cells (D). Scale bar: 10 μm .

sangnam-do (August 24, 2016).

Specimen Locality: ACKU2018MD03

Genus *Geminocystis* Korelusová *et al.* 2009

Cells are solitary, and spherical or slightly oval, after division hemispherical. Cell's diameter is 3–10 μm . Mucilage is absent or narrow, fine, colorless, and usually diffluent and indistinct mucilaginous envelopes. Cell contents are homogeneous, without separation of centro- and chromatoplasma, sometimes with lengthwise striation (thylakoids situated in cells lengthwise). Color of cells is pale blue-green, bright-green, grey, or pinkish. Cells are divided by binary fission into two morphologically equal, hemispherical daughter cells, which reach the original globular shape before next division. This genus is newly recorded in Korea.

Geminocystis herdmanii Korelusová *et al.* 2009 (Fig. 3)

They are solitary, not forming a colony. The cell is spherical but hemispherical after cell division by binary fission. Cell contents are homogeneous or has slightly irregularly keritomic thylakoid content. Thylakoids in cells are arranged irregularly or in parallel. The cell is blue-green in color and diameter is 3–5 μm .

Ecology: This species appears in freshwater and planktonic

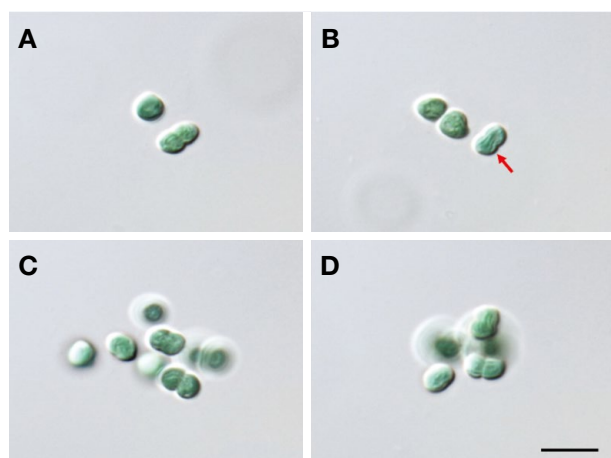


Fig. 3. Microscopic photographs of *Geminocystis herdmanii* Korelusová *et al.* The photographs show the shape of cells and arrangement of thylakoids (red point). Scale bar: 10 μm .

habitat. They lives in oligotrophic lakes (Komárek and Anagnostidis 1999). We collected it from mesotrophic reservoir at mountainside.

Distribution: North America: Wisconsin (Korelusová *et al.* 2009).

Site of collection: Yonggok-reservoir, Jangdong-myeon, Jangheung-gun, Jeollanam-do (August 7, 2017).

Specimen Locality: ACKU2018MD02

Family Synechococcaceae Komárek and Anagnostidis 1995

Genus *Anathece* (Komárek and Anagnostidis) Komárek *et al.* 2011

Colonies are multicellular, irregular, microscopic or rarely macroscopic. They are composed of irregularly arranged cells and surrounded by fine, colourless, homogeneous and diffuent mucilage, but sometimes they disintegrated in solitary cells. Colonies fragment into solitary cells. Mostly planktonic, rarely benthic. Cells are oval to rod-like, straight or slightly arcuate, without own mucilaginous envelopes. Cells are pale-grey, blue-green or olive-green colored, and (0.8)1–2 (6) μm long, 0.3–2 μm width. Cell division is occurred by binary fission, perpendicular to the long axis. This genus is newly recorded in Korea.

Anathece smithii (Komárková-Legnerová and Cronberg) Komárek *et al.* 2011 (Fig. 4)

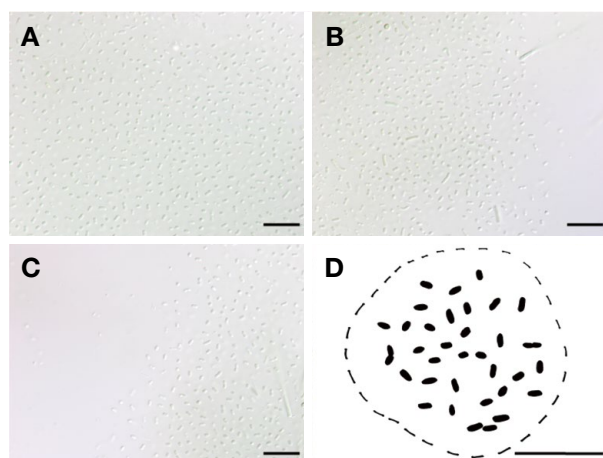


Fig. 4. Microscopic photographs (A, C) and illustration (D) of *Anathece smithii* (Komárková-Legnerová and Cronberg) Komárek *et al.* The photographs show the cells enveloped in very diffuent and hyaline mucilaginous sheath. Scale bars: 10 μm .

Synonym: *Aphanothece smithii* Komárková-Legnerová and G. Cronberg 1994

Colonies are microscopic and free floating. Colonies are more or less spherical or irregular in outline and sometimes elongated. Cells that form colonies are usually arranged regularly, not very densely. Mucilage is colorless and usually wraps all the cells by a narrow, hyaline. The cell is more or less oval to cylindrical and straight. The cell is pale blue-green or grey-blue in color. The cell's length is 2–3.5 μm and width is 1–1.5 μm .

Ecology: This species occurs in freshwater and planktonic habitat. They lives in mesotrophic and slightly eutrophic, usually large water bodies (Komárek and Anagnostidis 1999). In this study, we collected it from eutrophic brackish waterway (salinity 5.1‰).

Distribution: Australia and New Zealand: Queensland (Bostock and Holland 2010).

Site of collection: Eutrophic waterway, Hupo-myeon, Uljin-gun, Gyeongsangbuk-do (September 23, 2017).

Specimen Locality: ACKU2017IR10

Genus *Synechococcus* Nägeli 1849

Synechococcus nidulans (Pringsheim) Komárek in Bourrelly 1970 (Fig. 5)

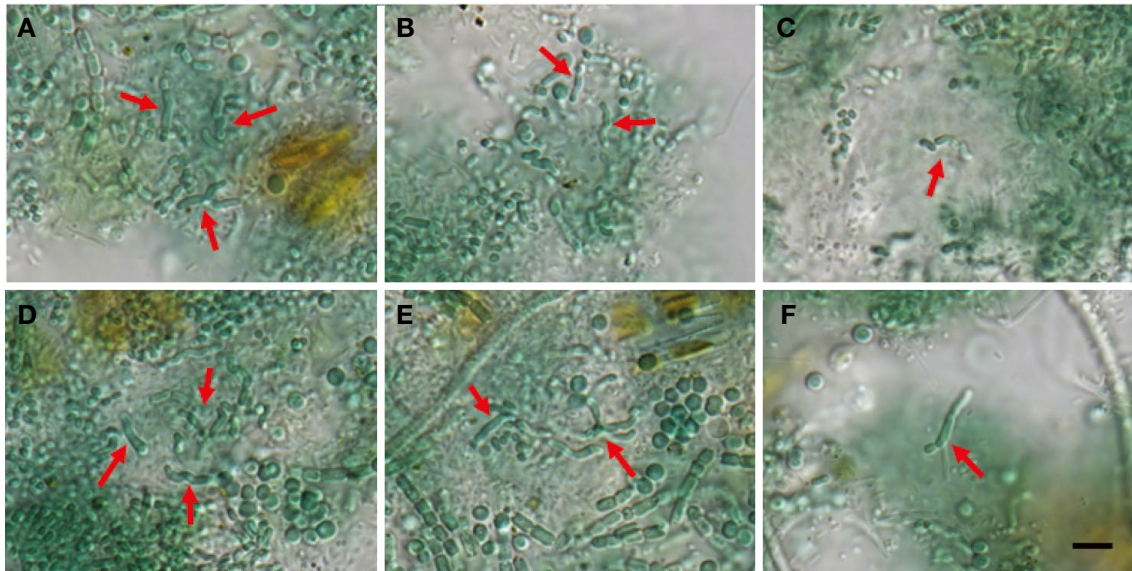


Fig. 5. Microscopic photographs of *Synechococcus nidulans* (Pringsheim) Komárek in Bourrelly. The photographs show the irregular shape of cells (red arrows) and the cells surrounded by other cyanobacteria. Scale bar: 5 μm .

Synonym: *Lauterbornia nidulans* Pringsheim 1968

Cells are solitary and free-floating. The cells are straight or sometimes slightly sigmoid or arcuate and without mucilage. Cell contents are homogeneous and pale blue-green in color. Cell's length is 1.5–6.5 μm and width is 1–1.5 μm .

Ecology: This species appears in freshwater and planktonic habitat. They lives in small water bodies, ditch ponds and large lakes (Komárek and Anagnostidis 2005). We collected it from eutrophic and brackish waterway (salinity 1‰).

Distribution: South America: Brazil (Lopes *et al.* 2005); Australia and New Zealand: Queensland (Bostock and Holland 2010).

Site of collection: Goraebuldae-gyo, Byeonggok-myeon, Yeongdeok-gun, Gyeongsangbuk-do (March 30, 2018).

Specimen Locality: ACKU2018IR06

Order Nostocales Borzi 1914
Family Aphanizomenonaceae
Genus *Anabaenopsis* Miller 1923

***Anabaenopsis arnoldii* Aptekar 1926 (Fig. 6)**

Trichomes are free-floating, solitary or clustered in small,

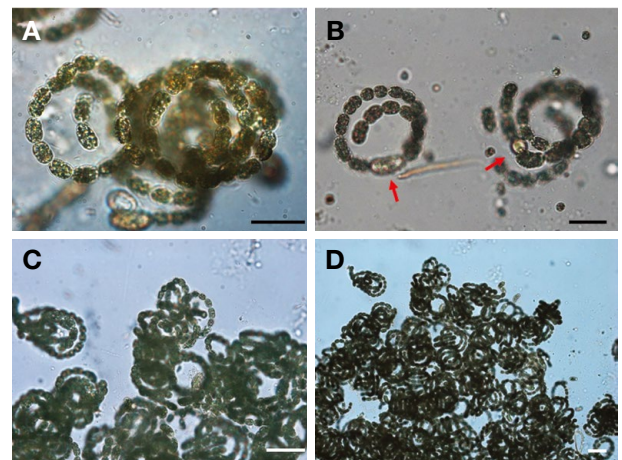


Fig. 6. Microscopic photographs of *Anabaenopsis arnoldii* Apteka. The photographs show the specific coiling arrangement of cells. The red arrows point towards the heterocyst (right) and akinete (left). Scale bars: 10 μm (A, B), 20 μm (C, D).

irregular colonies, irregularly screw-like coiled, with 1–12 coils. The coil width is $\pm 25 \mu\text{m}$, and the length is 7–30 μm , constricted at the cross-walls, with wide, colourless, diffuent mucilaginous envelopes. Cells are spherical or widely barrel-shaped, yellow-green. Heterocytes are spherical, 8–10 \times 7–10 μm .

Ecology: This species occurs in freshwater ponds and lakes

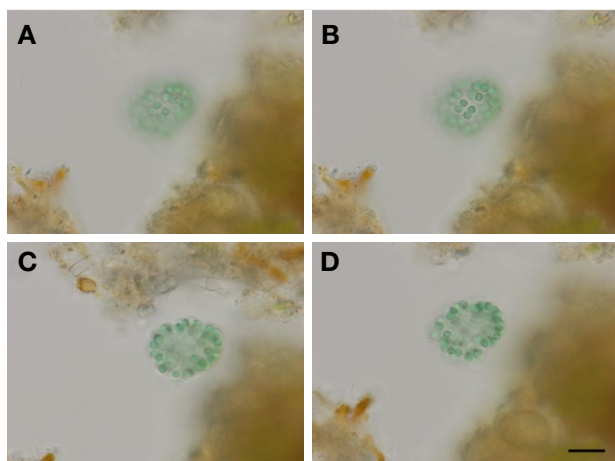


Fig. 7. Microscopic photographs of *Coelosphaerium aeruginum* Lemmermann with focus on the surface of the colony (A, B) and absence of stalks (C, D). Scale bar: 10 μ m.

(Komárek 2013). We collected it from seawall.

Distribution: Russia (Medvedeva and Nikulina 2014); Australia and New Zealand: Queensland (Bostock and Holland 2010).

Site of collection: Deep-water of seawall, Inju-myeon, Asan-si, Chungcheongnam-do (August 7, 2017).

Specimen Locality: ACKU2017NR17

Family Coelosphaeriaceae Elenkin 1933

Genus *Coelosphaerium* Nägeli 1849

***Coelosphaerium aeruginum* Lemmermann 1898 (Fig. 7)**

Colonies are free floating and spherical. However, sometimes they consist of 2–3 hemispherical subcolonies with irregularly and sparsely or densely aggregated cells (where they never touch one another). Cells are spherical or hemispherical after division and have a bit of a granule, but without gas vesicles. The cells are usually bright blue-green in color and diameter is 2.2–3.5 μ m.

Ecology: This species appears in freshwater and mainly planktonic habitat. They lives in eutrophic to mesotrophic water bodies (Komárek and Anagnostidis 1999). We collected it from brackish waterway (salinity 0.2‰).

Distribution: North America: Arkansas (Smith 2010).

Site of collection: Okpo-gyo, Dongjin-myeon, Buan-gun,

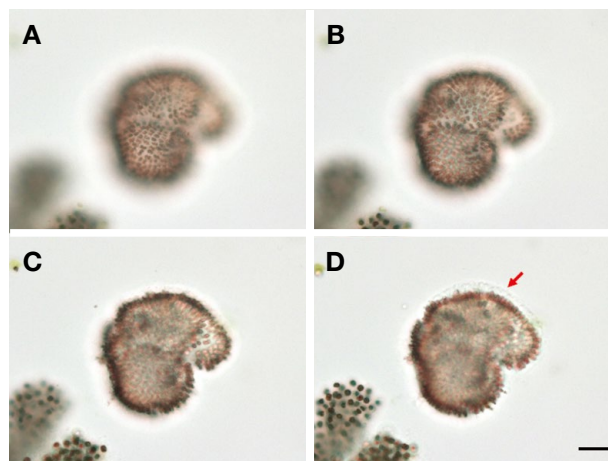


Fig. 8. Microscopic photographs of *Woronichinia karelica* Komárek and Komárková-Legnerová with focus on the surface (A, B) and the middle part (C, D) of the colonies. The red arrow points towards the mucilaginous sheath. Scale bar: 10 μ m.

Jeollabuk-do (September 26, 2017).

Specimen Locality: ACKU2017IR01

Genus *Woronichinia* Elenkin 1933

***Woronichinia karelica* Komárek and Komárková-Legnerová 1992 (Fig. 8)**

Colonies are solitary and irregularly spherical or oval, and they are composed of subcolonies when matured. The colonies are composed of cells that arranged radially and densely packed in the peripheral layer, and which grow up to 50 μ m in diameter. The cells joined by the faintly visible, colorless and thick stalks radiating from the colonial center. The cells are more or less elongated and obovated with a homogeneous contents and pale blue-green in color. The cell's length is 3–3.5 μ m and width is 1.5–2 μ m.

Ecology: This species appears in freshwater and planktonic habitat. They lives in oligo- or mesotrophic lakes and ponds of northern part of the whole temperate zone (Komárek and Anagnostidis 1999). We collected it from downstream of Nakdong river.

Distribution: Asia: Russia (Medvedeva and Nikulina 2014).

Site of collection: Gupodae-gyo, Gupo-dong, Buk-gu, Bu-

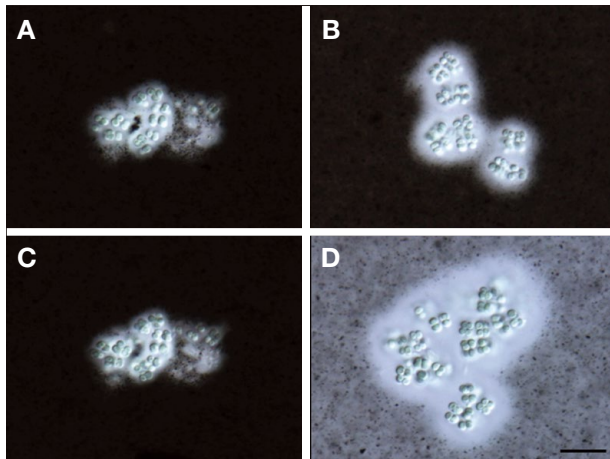


Fig. 9. Microscopic photographs of *Eucapsis microscopica* (Komárková-Legnerová and G. Cronberg) Komárek and Hindák, dyed with India ink. The photographs show the pellets of cells surrounded by very diffuent and hyaline mucilaginous sheath. Scale bar: 10 μm .

san (June 9, 2017).

Specimen Locality: ACKU2017NR18

Family Merismopediaceae Elenkin 1933

Genus *Eucapsis* Clements and Shantz 1909

***Eucapsis microscopica* (Komárková-Legnerová and G. Cronberg) Komárek and Hindák 2016 (Fig. 9)**

Synonym: *Chroococcus microscopicus* Komárková-Legnerová and G. Cronberg 1994

Colonies are microscopic and free floating. They are composed of numerous cumulus-like densely packed groups of cells. Mucilage is colorless, without structure, delicate and more or less clearly delimited or diffuent. Cells are spherical and usually 4–8 cells forms subcolonies arranged regularly and surrounded by a mucilage, which is easily recognizable after staining or in phase contrast. The cell contents are homogeneous and pale blue-green in color. The cell's diameter is 0.9–1.3 μm .

Ecology: This species appears in freshwater and planktonic habitat. They lives in mesotrophic lakes; known only from Sweden, but probably more widely distributed in northern lakes (Komárek and Anagnostidis 1999). We collected it from mesotrophic and brackish wetland (salinity 6.6‰).

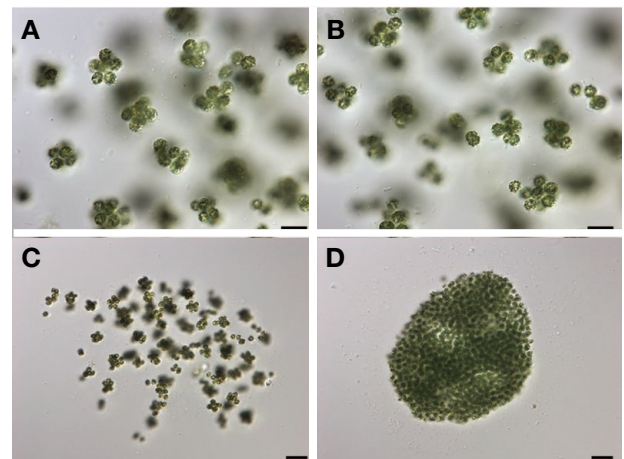


Fig. 10. Microscopic photographs of *Microcystis panniformis* Komárek, Komárková-Legnerová, Sant'Anna, Azevedo and Senna. The photographs show aggregates of young subcolonies (A, C) and old colonies (D). Scale bars: 10 μm (A, B), 20 μm (C, D).

Distribution: Europe: Baltic Sea (Hällfors 2004).

Site of collection: Soreapogu-wetland, Nonhyeon-dong, Namdong-gu, Incheon (May 4, 2018).

Specimen Locality: ACKU2018IR01

Family Microcystaceae Elenkin 1933

Genus *Microcystis* Lemmermann 1907

***Microcystis panniformis* Komárek, Komárková-Legnerová, Sant'Anna, Azevedo and Senna 2002 (Fig. 10)**

Colonies are microscopic and macroscopic. The young colonies are subspherical close to a sphere; as they mature, they get somewhat flattened, growing irregularly into a lobe-shape. Cells that form colonies are arranged homogeneously or slightly clathrate. Mucilage is colorless, homogeneous, diffuent and indistinct of the margin. Reproduction of cells happen on the margin of matured colonies. Cells are spherical or hemispherical after division, and they have gas vesicles. The cells are yellow-green or olive brown in color, and their diameter is 3.5–4.5 μm .

Ecology: This species are founded in freshwater and planktonic habitat. They lives in subtropical eutrophic lakes and ponds (Komárek *et al.* 2002). We collected it from eutrophic and brackish paddy pond (salinity 0.6‰).

Distribution: Australia and New Zealand: Queensland (Bostock and Holland 2010).

Site of collection: Paddy field nearby Jangsu-stream, Bangsan-dong, Siheung-si, Gyeonggi-do (May 4, 2018).

Specimen Locality: ACKU2018IR02

ACKNOWLEDGEMENTS

This study was supported by a grant from the National Institute of Biological Resources (NIBR201801205) and the Nakdonggang National Institute of Biological Resources (NNIBR2017287), funded by the Ministry of Environment (MOE) of the Republic of Korea.

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Received: 20 August 2018

Revised: 11 September 2018

Revision accepted: 12 September 2018