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A study of six newly recorded species of cyanobacteria (Cyanophyceae, Cyanophyta) in Korea

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The aim of this study was to discover and describe new genera and species of cyanobacteria in Korea. Aquatic and aerial algae were collected from various environments in the Han River and Nakdong River watersheds between August 2009 and October 2015. As a result, one genus and six species of cyanobacteria were newly recorded in Korea. The newly recorded genus for Korea was *Capsosira*; newly recorded species were *Capsosira brebissonii*, *Rivularia minutula*, *Chamaesiphon amethystinus*, *Leptolyngbya margaretheana*, *Pseudanabaena arcuata*, and *Rhabdoderma lineare*.

Keywords: aerial algae, Cyanophyta, Cyanophyceae, newly recorded species

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Introduction

Cyanobacteria occur widely throughout freshwater environments and some species may be toxic, causing serious environmental and socioeconomic problems (Chorus and Bartram, 1999; Huisman *et al*., 2005). Until recently, the taxonomy of cyanobacteria was based on morphological characteristics (Anagnostidis and Komárek, 1985; 1988; Komárek and Anagnostidis, 1986; 1989). The taxonomic classification of many morphologically defined species is unclear and some genera urgently need revision (Komárek and Anagnostidis, 2005). However, the introduction of electron microscopy and molecular and genetic methods for characterizing cyanobacterial taxa has greatly improved the taxonomic accuracy of many species. Rippka *et al*. (1979) recommended five sections, which became the primary basis for the nomenclatural classification in Bergey's Manual of Systematic Bacteriology, which recognized five subsections instead of orders: Chroococcales, Pleurocapsales, Oscillatoriales, Nostocales, and Stigonematales (Castenholz, 2001). The use of more modern higher-level systematics was recommended by Hoffmann *et al*. (2005a; 2005b), who divided the class Cyanophyceae into four subclasses: Gloeobacteriophycidae, Synechococcophycideae, Oscillatoriophycideae and Nostocophycideae. Recently, Komárek *et al*. (2014) reviewed these new studies and organized the cyanobacteria into eight orders: Gloeobacterales, Synechococcales, Spirulinales, Chroococcales, Pleurocapsales, Chroococcidiopsidales, Oscillatoriales, and Nostocales, adopting the polyphasic approach and the monophyletic species concept (Johansen and Casamatta, 2005; Dvorak *et al*., 2015). In Korea, most studies of cyanobacteria have focused on harmful algae that cause blooms (Choi *et al*., 1996; 2012; Kim *et al*., 2014). However, there has been a paucity of taxonomic studies overall, particularly studies of types of cyanobacteria other than harmful algae (Song and Lee, 2015). Regarding the classification system and the number of taxa for cyanobacteria, five subclasses, 10 orders, 51 families, 13 subfamilies, 481 genera, and 4,513 species have been reported to Algaebase (Guiry and Guiry, 2016). However, only three orders, 23 families, 84 genera, 330 species, nine varieties and four forms have been found in Korea (NIBR, 2015). Hence, this study aimed to contribute to our knowledge of Korean flora by collecting cyanobacteria in diverse ecosystems and adding newly recorded species.

Materials and Methods

Cyanobacteria were sampled at six sites from Aug. 2009 to Oct. 2015 in the Han River and Nakdong River

Table 1. The locational information of six sites which collected the cyanobacteria from Aug. 2009 to Oct. 2015.

Sites	Location				Latitude	Longitude
St.1	Haengju-dong	Deogyang-gu	Goyang-si	Gyeonggi-do	37°36′01.0″	126°48′47.7″
St.2	Seongsan-dong	Mapo-gu		Seoul	37°33′37.5″	126°53′43.9″
St.3	Samji-ri	Yeongyang-eup	Yeongyang-gun	Gyeongsangbuk-do	36°40′25.5″	129°08′12.2″
St.4	Jukgok-ri	Dasa-eup	Dalseong-gun	Daegu	35°50′31.6″	128°27′37.0″
St.5	Wicheon-ri	Nongong-eup	Dalseong-gun	Daegu	35°45′13.5″	128°23′15.8″
St.6	Jangcheon-ri	Ibang-myeon	Changnyeong-gun	Gyeongsangbuk-do	35°36′40.4″	128°21′34.0″

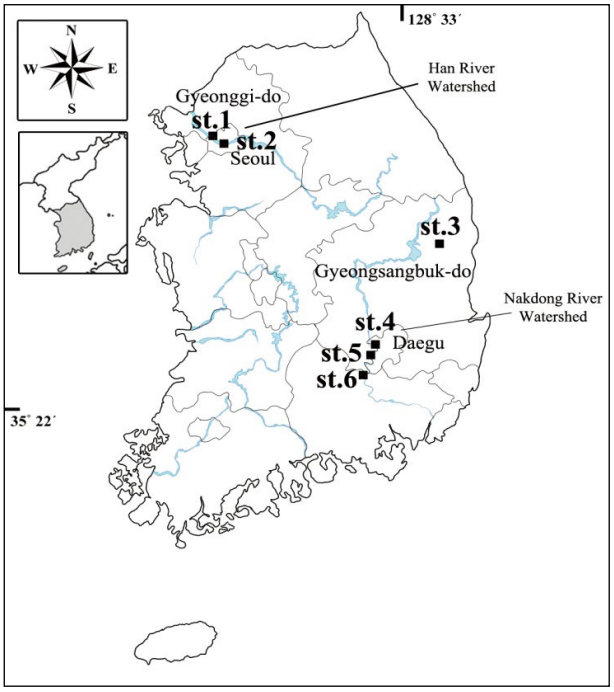

Fig. 1. A map showing the sampling sites (st) for blue-green algae from Aug. 2009 to Oct. 2015.

watersheds (Table 1 and Fig. 1). Aquatic plants, submerged land plants, and rocks were scrubbed to collect the attached algae and surface water was sampled with a 20 μm mesh 30 cm diameter phytoplankton net to collect phytoplankton. For benthic cyanobacteria, samples were collected using an Ekman grab sampler or detached mats along the shoreline. The aerial algae samples were collected from the stoneworks using a soft brush and sterilized depressor. Each sample was sealed and refrigerated in a light-tight container with sterilized distilled water and was transported to the laboratory (Crispim *et al*., 2004). Some of the samples were stored fixed in 1% formalin. Enrichment cultures of algae were made in Bold's basal medium (Stein, 1973) and maintained in the algal culture collection of Kyonggi University (ACKU). The taxonomic classification system was based on Komárek *et al*. (2014) and Algaebase (Guiry and Guiry, 2016), and cyanobacteria were identified by referring to Komárek and Anagnostidis (1999; 2005), Chung (1993), Hirose *et al*. (1977) and John *et al*. (2002; 2011). The collected samples were examined under an Olympus BX41 light microscope (at ×400-1,000 magnification; Tokyo, Japan) equipped with Nomarski differential-interference optics.

Results and Discussion

One genus and six species of cyanobacteria were newly recorded in Korea. The newly recorded genus for Korea was *Capsosira*. The newly recorded species for Korea were *Capsosira brebissonii*, *Rivularia minutula*, *Chamaesiphon amethystinus*, *Leptolyngbya margaretheana*, *Pseudanabaena arcuata*, and *Rhabdoderma lineare*.

Phylum Cyanobacteria
Class Cyanophyceae
Subclass Nostocophycideae
Order Nostocales
Family Capsosiraceae
Genus *Capsosira* (unrecorded genus)

Capsosira is a genus of heterocytous cyanobacteria described from Europe. This genus includes subaerial algae, which could be found attached to aquatic plants, stones, or submerged wood. The genus also includes epiphytic algae found on other algae (*Stigonema* and *Bactrachospermum*) on submerged rocks (Guiry and Guiry, 2016).

Capsosira brebissonii Kützing ex Bornet and Flahault (Fig. 2)

Cells forming heteropolar colonies are arranged in a row or irregularly in mucilaginous sheath. Colonies are either connected to each other or, attached to the substrate. Cells are 2-8 μm in diameter, has subspherical, spherical, or rounded-polygonal shape, with blue-green content. *C. lowei* is similar this species but, *C. lowei* was collected as a phycobiont from the lichen *Hydrotheria venosa* (Casamatta *et al*., 2006).

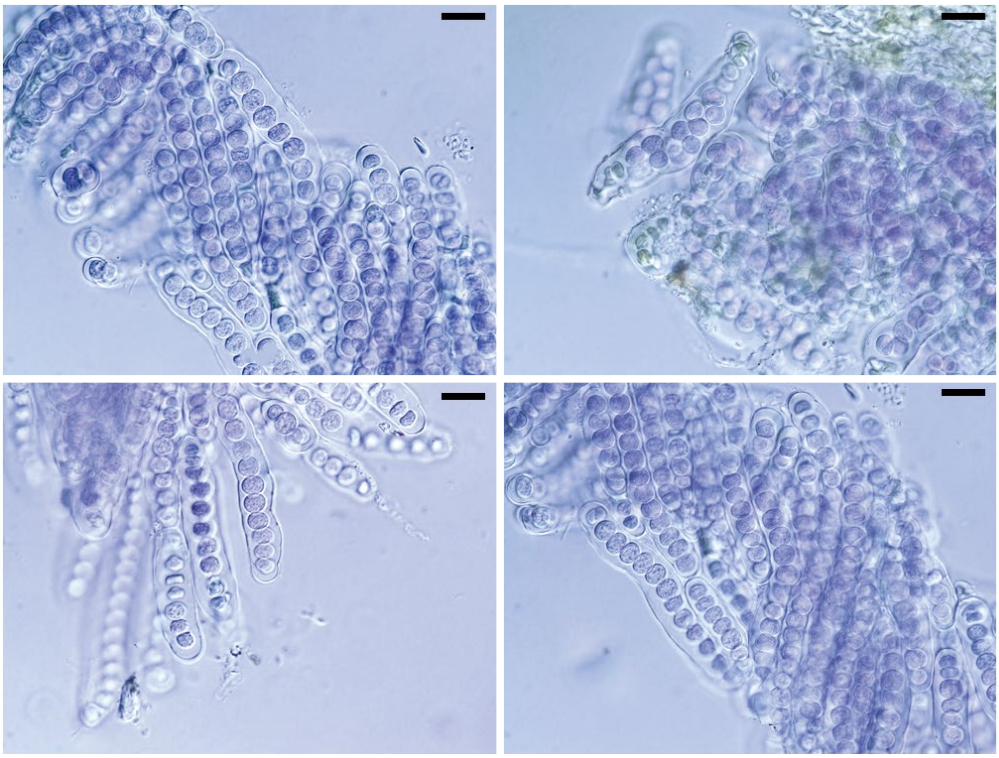

Fig. 2. Microscopic photographs of *Capsosira brebissonii* Kützing ex Bornet and Flahault, taken from the fixed samples. Scale bars represent 10 μm.

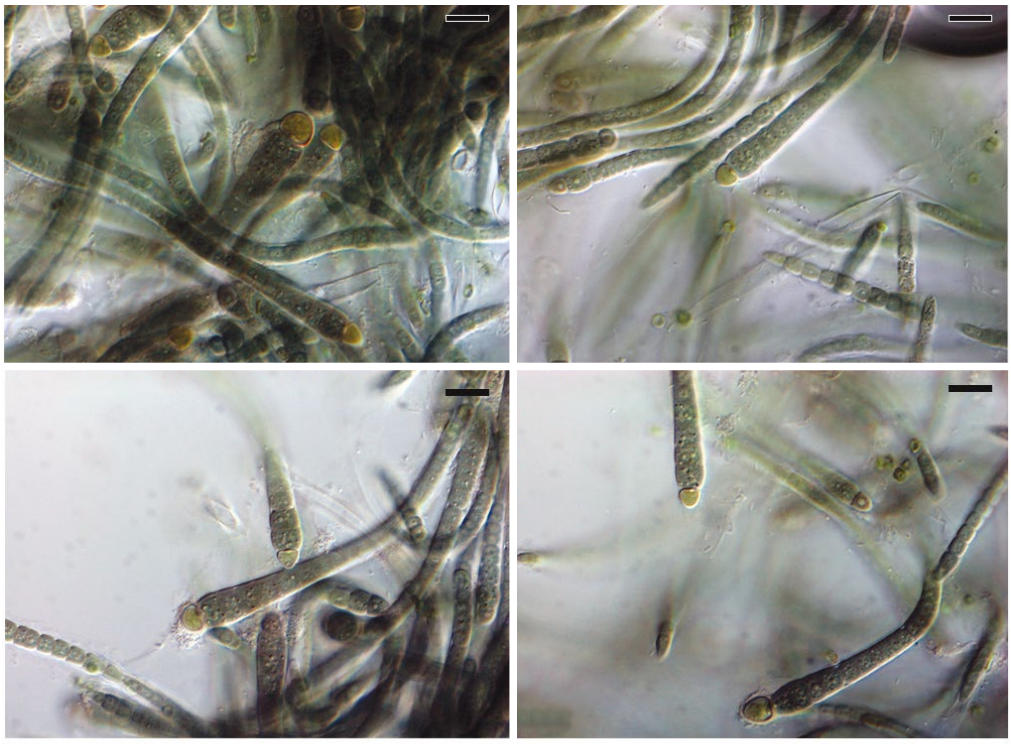

Fig. 3. Microscopic photographs of *Rivularia minutula* Bornet and Flahault, of the cultured samples from the algal culture collection at Kyonggi University. Scale bars represent 10 μm.

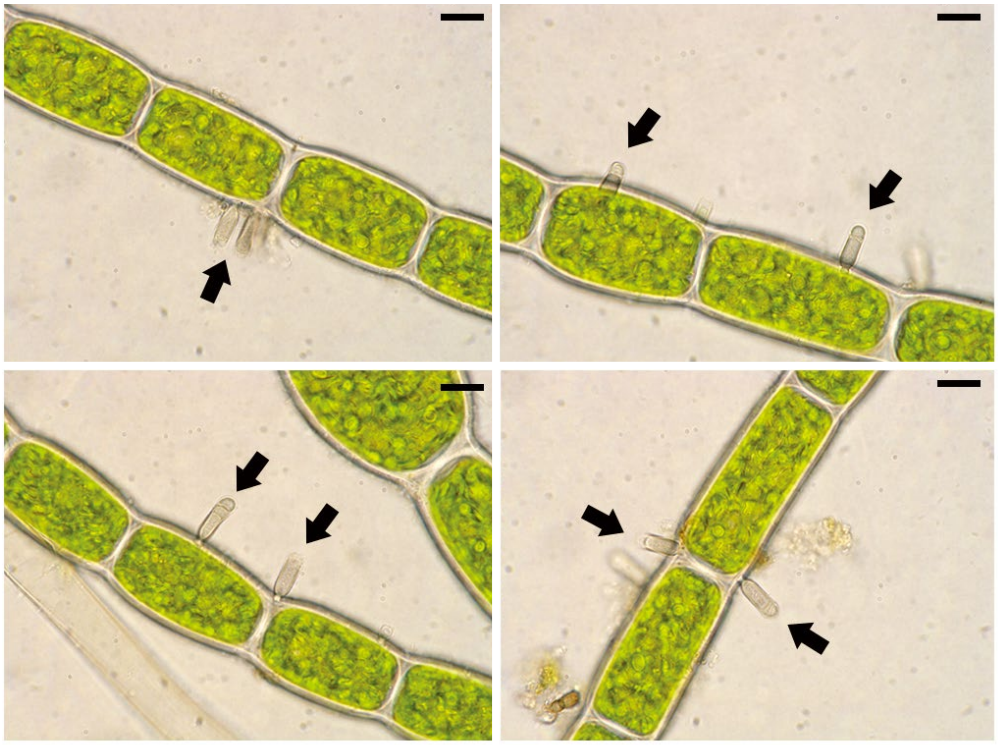

Fig. 4. Microscopic photographs of *Chamaesiphon amethystinus* (Rostafinski) Lemmermann (arrow) of the cultured samples from algal culture collection at Kyonggi University. Scale bars represent 10 μm.

Ecology: Attached to aquatic plants, stones and submerged wood in swamps and on wet rocks (Guiry and Guiry, 2016). We collected this species from the surface of stoneworks (Yeondae small temple) on Aug 21, 2009.
Distribution: Europe: Ukraine (Vinogradova, 2016); North America: Tennessee (Johansen *et al*., 2007); Asia: China (Hu and Wei, 2006); Australia and New Zealand: Queensland (Day *et al*., 1995; Phillips, 2002, Bostock and Holland, 2010).
Site of Collection: Site 3

Family Rivulariaceae
Genus *Rivularia*

***Rivularia minutula* Bornet and Flahault (Fig. 3)**

Colonies are hemispherical with 2 mm in diameter. Cells are cylindrical with 3-10 μm width. Trichomes are narrowed, ending with radially arranged hairs. Sheath is colorless to brown and heterocyst is in basal.

Ecology: We collected scrubbed samples from a rock on June 29, 2015. This species was founded in moist calcareous surfaces or in shallow streams and ditches (John *et al*., 2011).
Distribution: Europe: Britain (John *et al*., 2011); North America: Great Lakes (Prescott, 1962); South-west Asia: Pakistan (Leghari *et al*., 2005); Asia: Nepal (Rai *et al*., 2010).
Site of Collection: Site 4
Specimen Locality: NIBRCY0000000769

Subclass Synechococcophycideae
Order Synechococcales
Family Chamaesiphonaceae
Genus *Chamaesiphon*

***Chamaesiphon amethystinus* (Rostafinski) Lemmermann (Fig. 4)**

Cells are attached individually or arranged parallel to one another. Cells cover the substrate, cylindrical or slightly narrowed, widely rounded at the apex, straight or rarely very slightly curved, gelatinous pad. Cells content pale blue-green or grey-blue, brownish. Cells are 5-15 μm long and 2-5 μm wide. Habitat of this species was recorded as clear streams (Komárek and Anagnostidis, 1999); however, we collected this species from eutrophic reservoirs. This species is probably widely distributed.

Ecology: We collected this species from eutrophic reser-

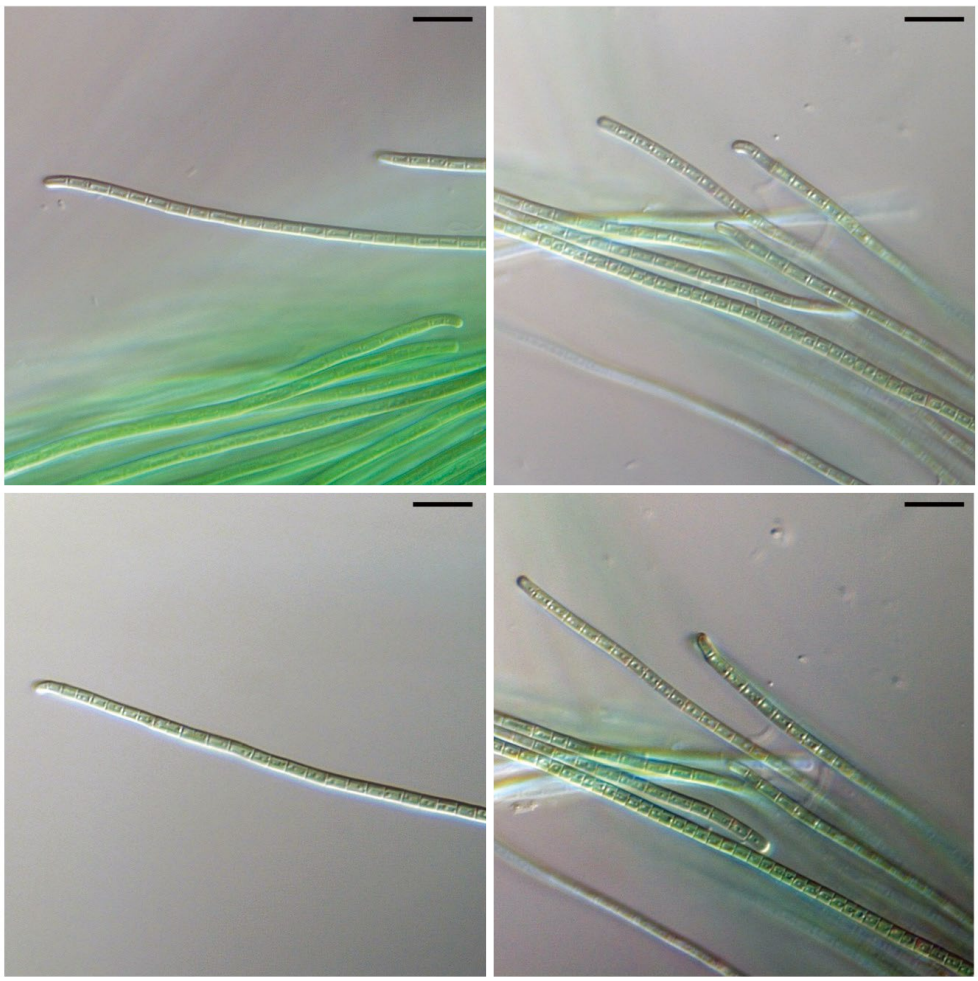

Fig. 5. Microscopic photographs of *Leptolyngbya margaretheana* (G. Schmid) Anagnostidis and Komárek, of the cultured samples from algal culture collection at Kyonggi University. Scale bars represent 10 μm.

voirs on October 24, 2015. This species occurs in freshwater, epiphytic in clear streams in temperate zones, or in tropical countries (Komárek and Anagnostidis, 1999).
Distribution: Europe: Lithuania (Vitonyte and Kostkeviciene, 2008); Australia and New Zealand: New Zealand (Broady and Merican, 2012).
Site of Collection: Site 5
Specimen Locality: NIBRCY0000000767

Family Leptolyngbyaceae
Genus *Leptolyngbya*

***Leptolyngbya margaretheana* (G. Schmid) Anagnostidis and Komárek (Fig. 5)**

Cells are 2-3 μm wide, 2-5 μm long, slightly elongated along trichome axis, blue-green. Sheaths are fine, colorless in field sample, but not observed in cultured samples (Fig. 5). Cell content has 2-5 granules with one or two granules on either side of cross-walls.

Ecology: We collected this species from eutrophic reservoirs on June 29, 2015. This species was distributed in freshwater, found among *Phormidium* and *Oscillatoria* species, in tropical and subtropical wetland (Komárek and Anagnostidis, 2005).
Distribution: Arctic: Svalbard (Spitsbergen) (Matula *et al*., 2007); Australia and New Zealand: New Zealand (Broady and Merican, 2012).
Site of Collection: Site 1

Family Pseudanabaenaceae
Genus *Pseudanabaena*

***Pseudanabaena arcuata* (Skuja) Anagnostidis and Komárek (Fig. 6)**

Trichomes are solitary, short. Cells are 1-2 μm wide,

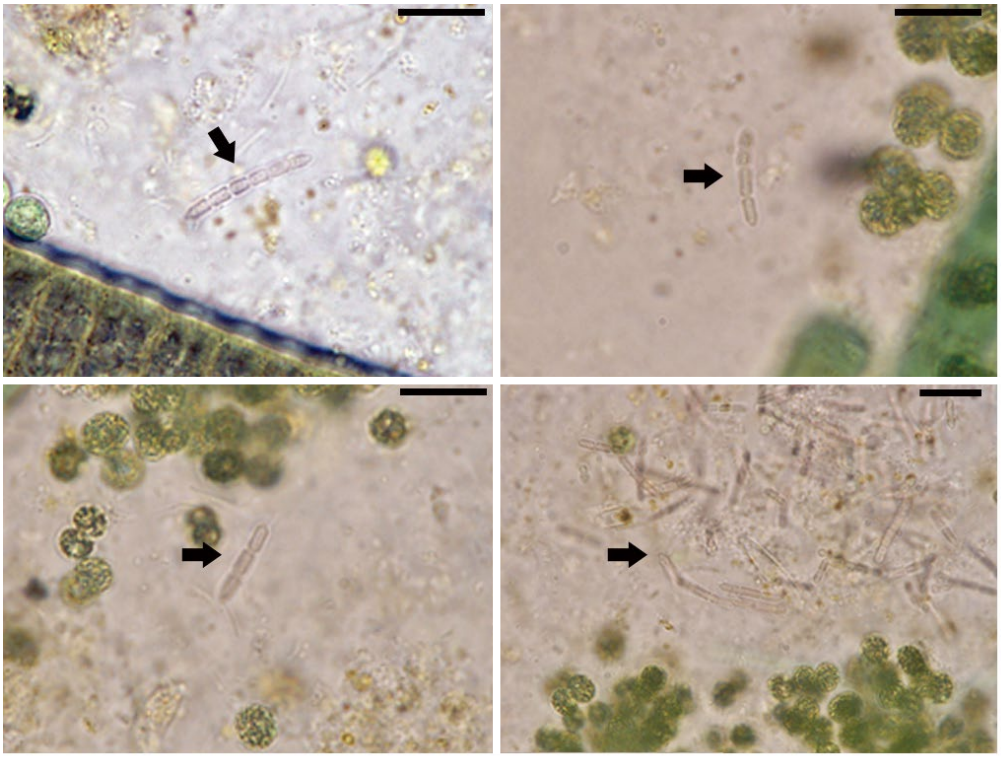

Fig. 6. Microscopic photographs of *Pseudanabaena arcuata* (Skuja) Anagnostidis and Komárek (arrow) of the cultured samples from algal culture collection at Kyonggi University. Scale bars represent 10 μm.

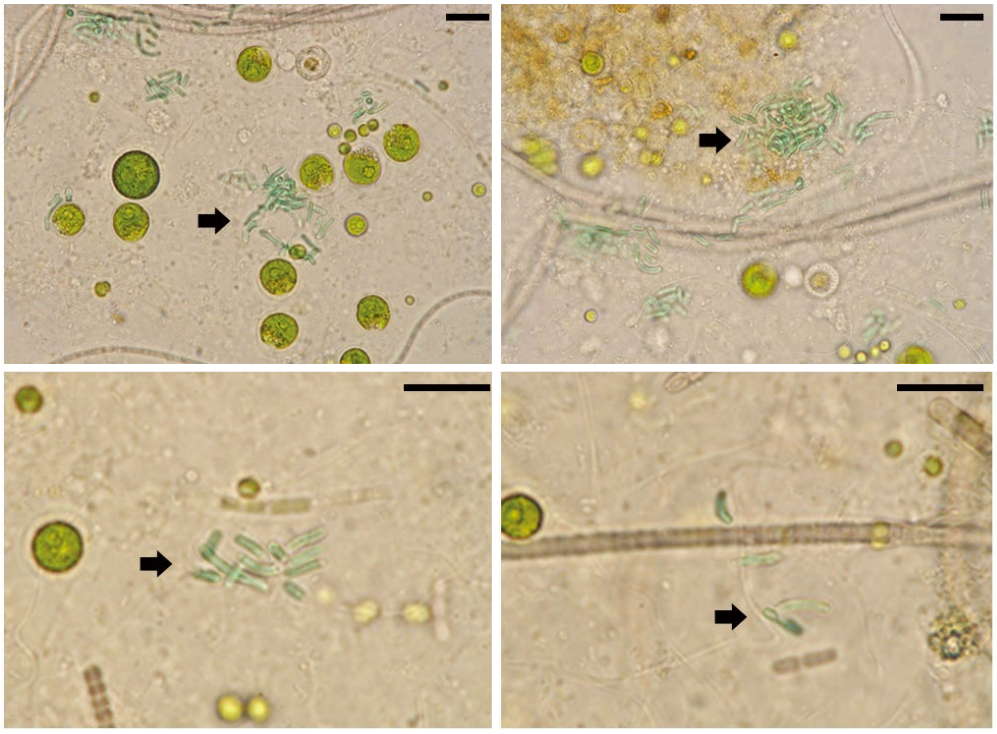

Fig. 7. Microscopic photographs of *Rhabdoderma lineare* Schmidle and Lauterborn (arrow) of the cultured samples from algal culture collection at Kyonggi University. Scale bars represent 10 μm.

2-10 μm long, cylindrical, pale blue-green to pale grey-olive-green, cell content finely granulated. Apical cell is acute, cylindrical and conical, or slightly truncate.

Ecology: We collected this species from eutrophic reservoirs on September 23, 2015. This species was distributed in freshwater in mucilaginous layers and as free-floating specimens from mucilage (Komárek and Anagnostidis, 2005).
Distribution: Asia: Russia (Siberia) (Smirnova, 2014).
Site of Collection: Site 6

Family Synechococcaceae
Genus *Rhabdoderma*

***Rhabdoderma lineare* Schmidle and Lauterborn (Fig. 7)**

Colonies are small, irregularly elongate. Cells oriented more or less in one direction or irregularly arranged with mucilage. Cell is 1-3 μm wide, 4-15 μm long, long cylindrical, rod-shaped, straight, slightly arcuate and cell content is pale blue-green or grey-green, with fine granular.

Ecology: We collected this species from eutrophic reservoirs on June 29, 2015. This species was found in shallow oligotrophic and mesotrophic lakes and ponds with submerged macrophytes (John *et al*., 2011). It was also commonly found in temperature zones (Komárek and Anagnostidis, 1999).
Distribution: Arctic: Svalbard (Spitsbergen) (Skulberg, 1996); Europe: Baltic Sea (Hallfors, 2004), Britain (John *et al*., 2011), Germany (Täuscher, 2011), Romania (Cărăuş, 2012), Russia (Europe) (Patova, 2014), Spain (Alvarez-Cobelas and Gallardo, 1988), Sweden (Skuja, 1948), Lithuania (Vitenaite, 2001); North America: Arkansas (Smith, 2010); South America: Argentina (Tell, 1985), Brazil (Ferragut *et al*., 2005); Asia: China (Hu and Wei, 2006); Australia and New Zealand: New Zealand (Broady and Merican, 2012), Queensland (Bostock and Holland, 2010).
Site of Collection: Site 2
Specimen Locality: NIBRCY0000000768

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