



# A study of newly recorded genera and species of filamentous blue-green algae (Cyanophyceae, cyanobacteria) in Korea

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## Abstract

Cyanobacteria were sampled at five sites in the Han River, Nakdong River, and Geum River watershed from June 2014 to May 2015 and then cultivated. Two genera and five species of the cyanobacteria were newly recorded in Korea. The newly recorded species were *Limnothrix redekei*, *Pseudanabaena galeata*, *Pseudanabaena amphigranulata*, *Sphaerospermopsis aphanizomenoides*, and *Calothrix parietina*. As a result, the Korean flora of the cyanobacteria now include four orders, 22 families with 73 genera, 143 species, and two varieties, giving a total of 146 taxa.

**Key words:** benthic habitats, filamentous blue-green algae, new records from Korea, planktonic cyanobacteria

## INTRODUCTION

Cyanobacteria are widely occurring throughout freshwater environments where they may form nuisance blooms (Chorus and Bartram 1999, Huisman et al. 2005). These species may be toxic and may cause serious environmental and socioeconomic problems. Until recently, the taxonomy of cyanobacteria used its morphological characteristics as its standard (Anagnostidis and Komárek 1985, 1988, Komárek and Anagnostidis 1986, 1989), but this changed particularly with the introduction of electron microscopy and molecular and genetic methods for characterizing cyanobacterial taxa.

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 is recommended by Hoffmann et al. (2005a, 2005b), who divide the class Cyanophyceae into four subclasses: Gloeobacteriophycidae, Synechococcophycidae, Oscillatoriophycidae, and Nostocophycidae. Moreover, Komárek et al. (2014) recently reviewed the new studies and various approaches (polyphasic approach) and organized it in eight orders: Gloeobacterales, Synechococcales, Spirulinales, Chroococcales, Pleurocapsales, Chroococciopsidales, Oscillatoriales, and Nostocales.

In Korea, most studies of cyanobacteria have focused on harmful algae that cause blooms (Choi et al. 1996, 2012, Kim et al. 2014), and taxonomic studies and studies of other types of cyanobacteria besides harmful algae are lacking. Regarding the classification system and the number of taxa for cyanobacteria, five subclasses, 10 orders, 51 families, 15 subfamilies, 469 genera, and 4,494 species

<http://dx.doi.org/10.5141/ecoenv.2015.062>



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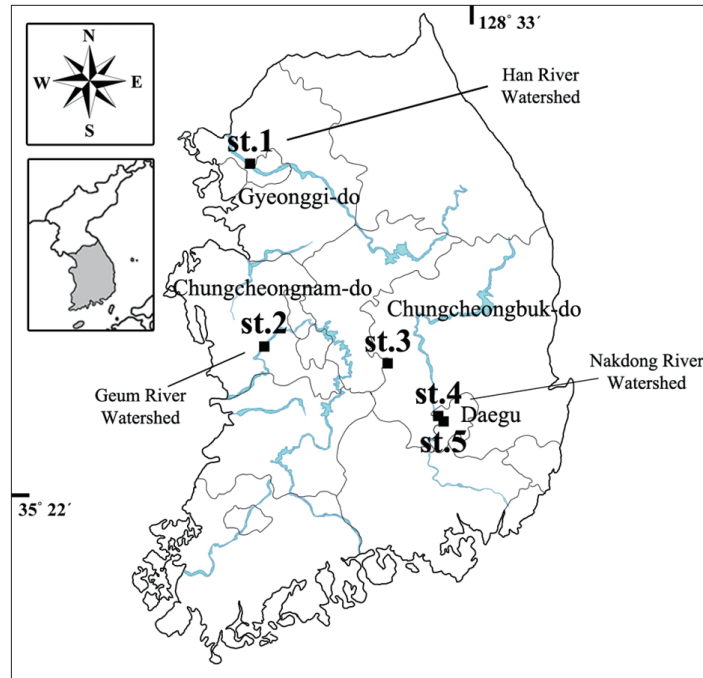
Received 12 October 2015, Accepted 03 November 2015

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**Fig. 1.** A map showing the sampling sites (st) for the filamentous blue-green algae from June 2014 to May 2015.

have been reported to Algaebase (Guiry and Guiry 2015), but in Korea, only four orders, 22 families, 71 genera, 138 species, and two varieties have been found.

Hence, we collected planktonic and benthic cyanobacteria in rivers and reservoirs in Korea and newly recorded species to contribute the Korean flora in cyanobacteria.

**MATERIALS AND METHODS**

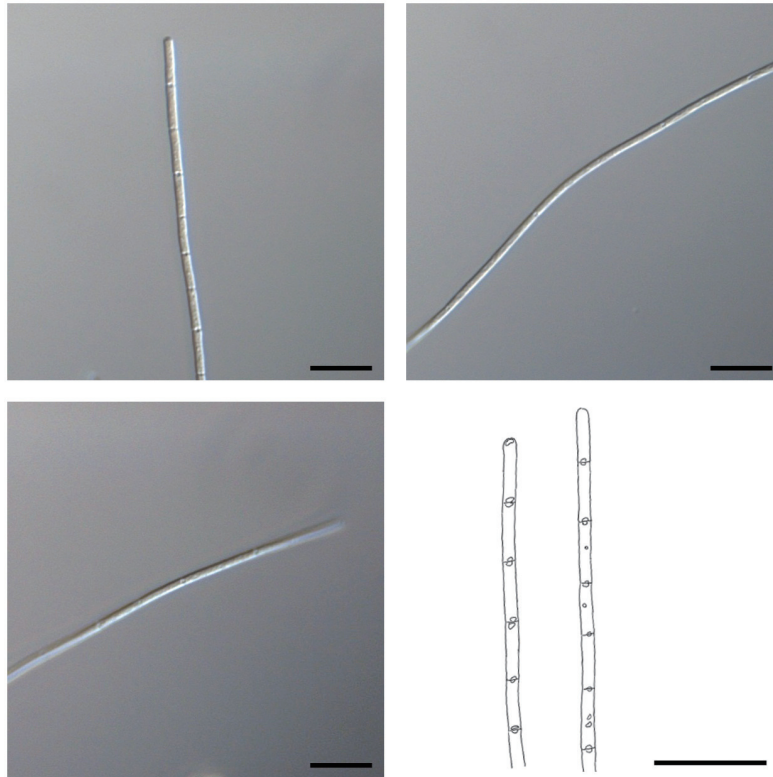
Collections of blue-green algae were sampled at five sites from June 2014 to May 2015 in the Han River, Nakdong River, and Geum River watershed (Table 1 and Fig. 1). Aquatic plants, submerged land plants, and rocks were scrubbed off to collect the attached algae, and surface water was sampled with a 20-µm-mesh 30-cm-diameter phytoplankton net to collect phytoplankton. For sampling benthic cyanobacteria, samples were collected us-

ing an Ekman grab sampler or detached mats along the shoreline. Each sample was sealed and refrigerated in a light-tight container with sterilized distilled water and transferred 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 2015), and cyanobacteria were identified referring to 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. Species were illustrated using a drawing attachment together with light microscope photographs.

**Table 1.** The locational information of five sites which collected the filamentous blue-green algae from June 2014 to May 2015

Sites	Location				Latitude	Longitude
st.1	Haengjuoe-dong	Deogyang-gu	Goyang-si	Gyeonggi-do	37°36'09.0"	126°48'45.3"
st.2	Jawang-ri	Buyeo-eup	Buyeo-gun	Chungcheongnam-do	36°19'05.0"	126°56'30.6"
st.3	Jukjeon-ri	Chupungnyeong-myeon	Yeongdong-gun	Chungcheongbuk-do	36°12'56.5"	128°01'25.1"
st.4	Jukgok-ri	Dasa-eup	Dalseong-gun	Daegu	35°50'30.0"	128°27'29.6"
st.5	Seongsan-ri	Hwawon-eup	Dalseong-gun	Daegu	35°48'43.3"	128°28'38.5"

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**Fig. 2.** Microscopic photographs and illustrations of *Limnothrix redekei* (Goor) Meffert, taken from the fixed samples. Scale bars represent 10  $\mu\text{m}$ .

## RESULTS AND DISCUSSION

Two genera and five species of the cyanobacteria were newly recorded in Korea. The newly recorded species were *Limnothrix redekei*, *Pseudanabaena galeata*, *Pseudanabaena amphigranulata*, *Sphaerospermopsis aphanizomenoides*, and *Calothrix parietina*.

**Phylum Cyanobacteria**  
**Class Cyanophyceae**  
**Subclass Synechococcophycideae**  
**Order Synechococcales**  
**Family Pseudanabaenaceae**

***Limnothrix redekei* (Goor) Meffert (Fig. 2)**

Trichome straight, not branched, not narrowed toward ends. Cells 1.0–1.5  $\mu\text{m}$  wide, 5–12  $\mu\text{m}$  long; end cell blunt or somewhat rounded, not capitate, calyptra absent. Gas vacuoles usually obvious in planktonic trichomes, localized at either side of the cross wall, sometimes small. Thylakoids sometimes slightly wavy, localized parallel to the cell walls. Heterocysts and akinetes absent. Komárek and Anagnostidis (2005) mentioned that the apical cell sometimes had an elongated hyaline process.

**Ecology:** Planktonic in lakes, but especially abundant in shallow high-eutrophic ones (John et al. 2011). We collected this species from eutrophic reservoirs on May 12, 2015.

**Distribution:** Arctic: Svalbard (Matula et al. 2007); Europe: Baltic Sea (Hällfors 2004), Germany (Täuscher 2014), Lithuania (Vitenaitė 2001), Poland (Kokocinski et al. 2010), Romania (Carauș 2012).

**Site of Collection:** Site 3 (st.3 in Table 1).

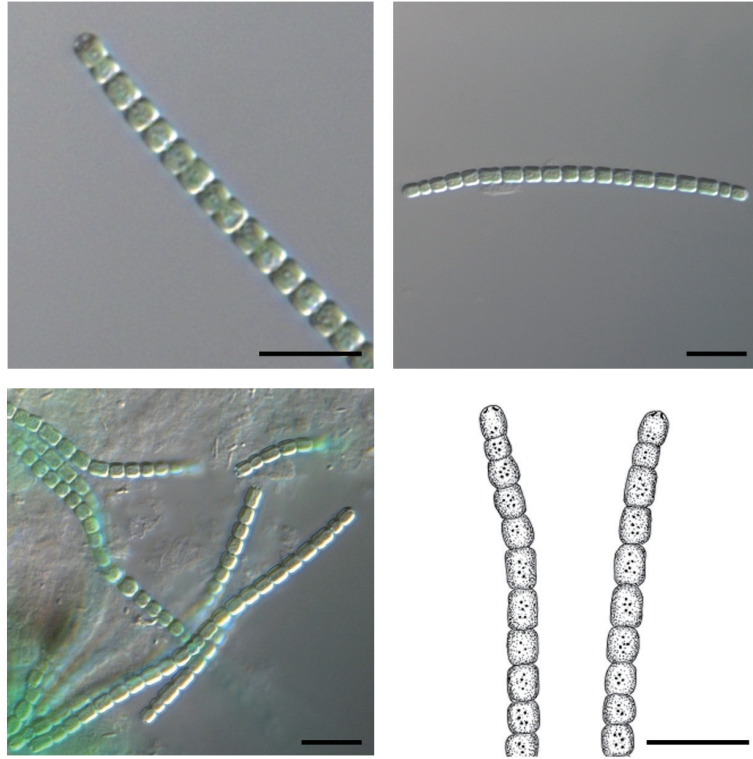
**Specimen Locality:** ACKU (fixed).

***Pseudanabaena amphigranulata* (Van Goor) Anagnostidis 2001 (Fig. 3)**

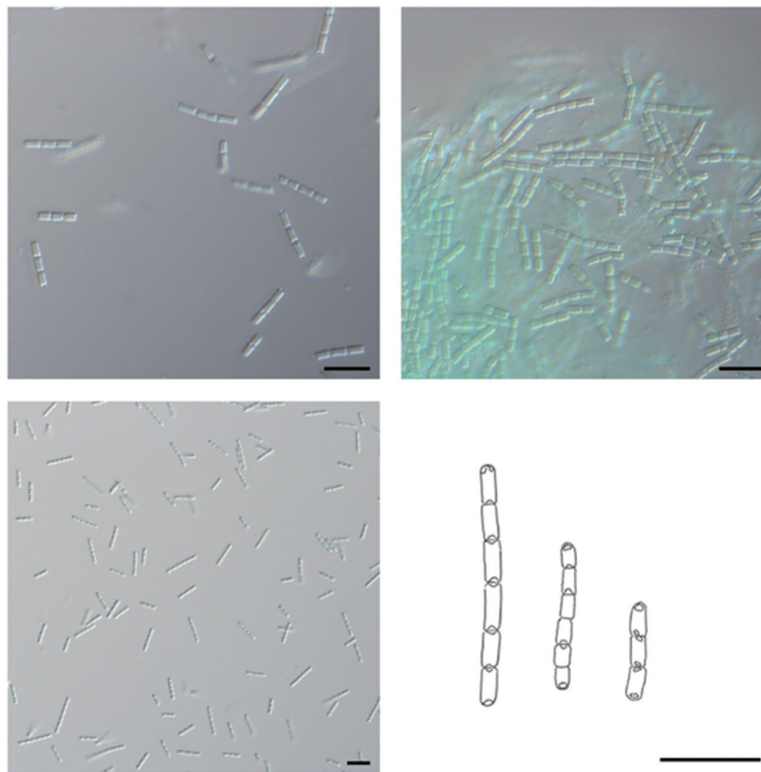
Trichome straight or slightly curved, single, but more usually in thin mats; not attenuated toward ends. Cells 1–4  $\mu\text{m}$  wide, 2–5  $\mu\text{m}$  long; slightly or distinctly constricted at cross walls with small gas vacuoles at ends. Thylakoids localized parallel to cell walls.

**Ecology:** Among periphyton or on bottom silt of at least moderately nutrient-rich freshwater (John et al. 2011). We collected at sediment sample on February 25, 2015.

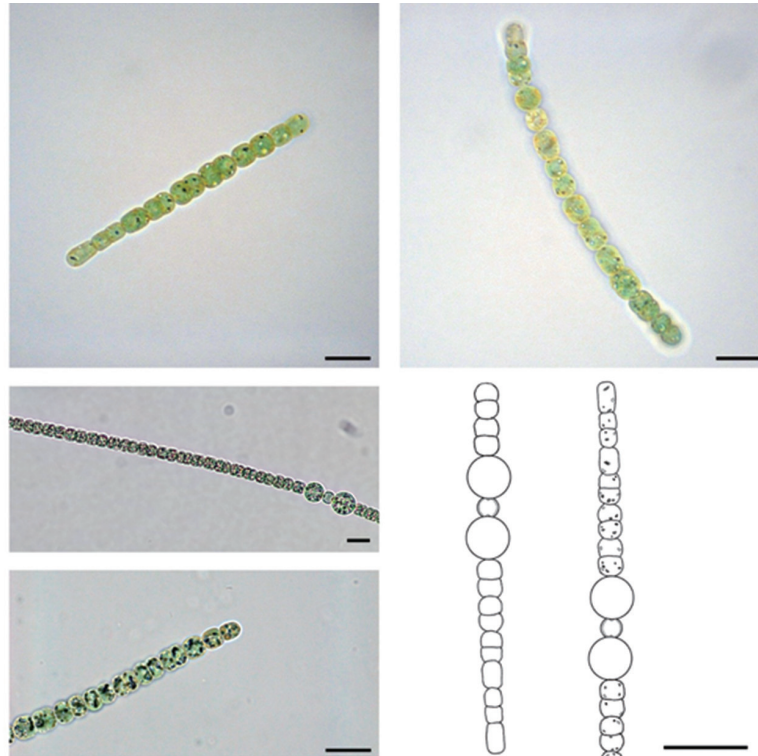
**Distribution:** Australia and New Zealand: Victoria (Day et al. 1995), Queensland (Bostock and Holland 2010); Europe: Britain (John et al. 2011), Romania (Carauș 2012);



**Fig. 3.** Microscopic photographs and illustrations of *Pseudanabaena amphigranulata* (Van Goor) Anagnostidis 2001, taken with the cultured samples from algal culture collection of Kyonggi University. Scale bars represent 10  $\mu$ m.



**Fig. 4.** Microscopic photographs and illustrations of *Pseudanabaena galeata* Böcher, taken with the cultured samples from algal culture collection of Kyonggi University. Scale bars represent 10  $\mu$ m.



**Fig. 5.** Microscopic photographs and illustrations of *Sphaerospermopsis aphanizomenoides* (Forti) Zapomelova, Jezberova, Hrouzek, Hisem, Rehakova and Komarkova, taken with the cultured samples from algal culture collection of Kyonggi University. Scale bars represent 10  $\mu\text{m}$ .

North America: Arkansas (Smith 2010).

**Site of Collection:** Site 5 (st. 5 in Table 1).

**Specimen Locality:** NIBRCY0000000570.

***Pseudanabaena galeata* Böcher (Fig. 4)**

Trichomes occasionally single, but usually in thin mats. Trichomes straight or curved and entangled with constricted cross walls. Cells 0.6–1.5  $\mu\text{m}$  wide, 3–8  $\mu\text{m}$  long, usually with one or two small gas vacuoles at ends. In young trichomes, cross walls thin and unclear, without firm sheaths. Cell division perpendicular to longer trichome axis, cells grow into original shape and size before next division (Guiry and Guiry 2015).

**Ecology:** Freshwaters, on bottom sediments, epiphytic or among mucilaginous algae (John et al. 2011). We collected this strain in sediment sample on June 23, 2014.

**Distribution:** Arctic: Svalbard (Matula et al. 2007); Europe: Baltic Sea (Mazur-Marzec et al. 2015), Britain (John et al. 2011), Germany (Täuscher 2011), Romania (Caras 2012), Spain (Aboal et al. 1996); North America: Oklahoma (Kirkwood and Henley 2006); South America: Brazil (Werner 2010); Australia and New Zealand: Queensland (Bosstick and Holland 2010), South Australia (Day et al. 1995).

**Site of Collection:** Site 1 (st. 1 in Table 1).

**Specimen Locality:** NIBRCY0000000571.

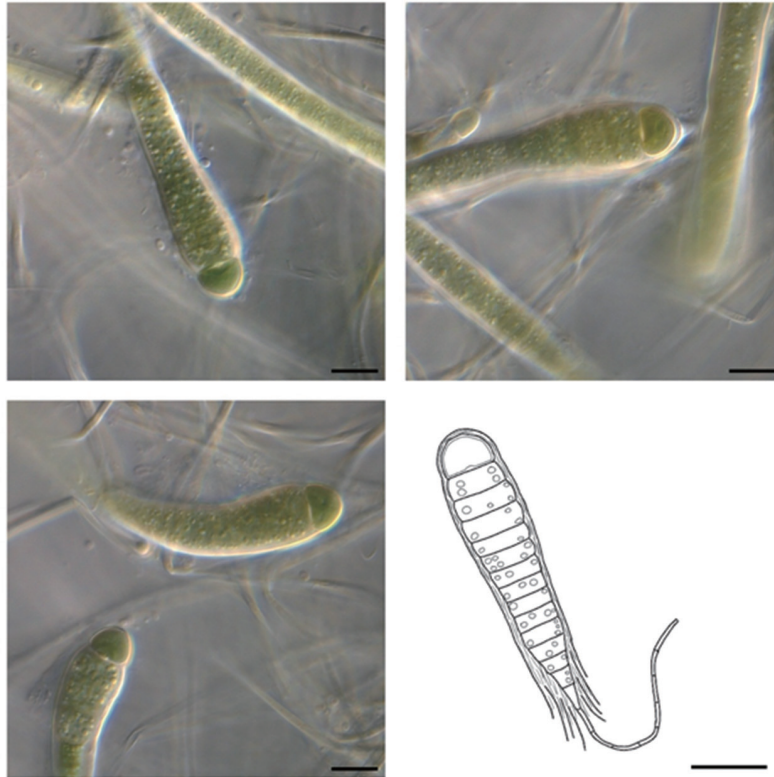
**Subclass Nostocophycideae**  
**Order Nostocales**  
**Family Aphanizomenonaceae**

***Sphaerospermopsis aphanizomenoides* (Forti) Zapomelova, Jezberova, Hrouzek, Hisem, Rehakova, and Komarkova (Fig. 5)**

Trichomes straight or slightly curved. Cells 4–6  $\mu\text{m}$  wide, 1–3 times longer than wide. Trichomes weakly narrowed at cross walls, dark-green-colored to brownish vegetative cells containing gas vacuoles and elongated. Heterocysts almost rounded or slightly ellipsoid, 4–7  $\mu\text{m}$  wide. Akinetes subspherical, single or several adjacent to heterocysts, 9–12  $\mu\text{m}$ . In culture, the terminal cell morphology was not as clearly differentiated as under field conditions, but terminal cells were always detectable on at least some trichomes (Zapomelová et al. 2009).

**Ecology:** Plankton in freshwater ponds and lakes (John et al. 2011). We collected this specimen in planktonic samples in retention area on July 17, 2014.

**Distribution:** Europe: Britain (Whitton et al. 2003), Czech Republic (Zapomelová et al. 2009), Germany (Täuscher 2011), Romania (Caras 2012), Turkey (Europe) (Ersanli and Gönülol 2006); Asia: China (Wu et al. 2010),



**Fig. 6.** Microscopic photographs and illustrations of *Calothrix parietina* Thuret ex Bornet and Flahault, taken with the cultured samples from algal culture collection of Kyonggi University. Scale bars represent 10  $\mu\text{m}$ .

Turkey (Asia) (Varol and Sen 2014); South-east Asia: Singapore (Pham et al. 2011).

**Site of Collection:** Site 2 (st. 2 in Table 1).

**Specimen Locality:** NIBRCY0000000572.

## Family Rivulariaceae

### *Calothrix parietina* Thuret ex Bornet and Flahault (Fig. 6)

Colony a mat on rocks and other substrates, cells 3–13  $\mu\text{m}$  wide, trichomes narrowed. Sheath yellow to brown, lamellated. Heterocyst basal and occasionally intercalary, the latter feature probably differing between populations and not just an environmental effect (John et al. 2011).

**Ecology:** This species is a freshwater and terrestrial species. We collected scrubbed sample on rock on June 23, 2014.

**Distribution:** Arctic: Ellesmere Island (Croasdale 1973); Europe: Britain (John et al. 2011), Italy (Furnari et al. 2003), Romania (Caraus 2012), Spain (Aboal and Puig 2005), Turkey (Europe) (Taskin et al. 2008); North America: Arkansas (Smith 2010), Florida (Dawes 1974), Great Lakes (Prescott 1962), Northwest Territories (Sheath and Steinman 1982), Virginia (Humm 1979); Africa: Benin (Lawson and John

1987), Togo (Lawson and John 1987); Indian Ocean Islands: Seychelles (Silva et al. 1996); South-west Asia: Bangladesh (Silva et al. 1996), Israel (Vinogradova et al. 2000), Pakistan (Mehwish and Aliya 2005), Turkey (Asia) (Taskin et al. 2008); Asia: Nepal (Rai et al. 2010), Russian Far East (Medvedeva and Nikulina 2014), Turkey (Asia) (Varol and Sen 2014); South-east Asia: Vietnam (Nguyen et al. 2013); Australia and New Zealand: New South Wales (Day et al. 1995), New Zealand (Chapman 1956), Queensland (Bostock and Holland 2010), Tasmania (Day et al. 1995), Victoria (Day et al. 1995); Pacific Islands: Federated States of Micronesia (Lobban and Tsuda 2003), Marshall Islands (Taylor 1950).

**Site of Collection:** Site 4 (st. 4 in Table 1).

**Specimen Locality:** NIBRCY0000000573.

## 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 (NIBR 201501204), and a grant from the National Institute

of Environmental Research (NIER), “a research for the biomass measurement of cyanobacteria based on phycocyanin analysis.”

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