Anabaena koreana sp. nov. (Cyanophyceae), a new species, and new record of fresh-water blue-green algae from Korea

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Abstract
The present study summarizes the occurrence, distribution and autecology of 12 taxa of the class Cyanophyceae collected from several swamps, reservoir and highland wetlands in South Korea from 2009 to 2012. A new species, Anabaena koreana sp. nov. and 11 taxa of blue-green algae newly recorded are described and illustrated. Anabaena koreana is similar to A. oumiana, A. spiroides and A. crassa in that the trichomes form regular coils. However, A. koreana is distinguished from these three species by the morphological characteristics of the vegetative cell, heterocyst, and akinet shape and size. This study considers 12 blue-green algal species, including a new species, Anabaena koreana sp. nov. and 11 species that are recorded for the first time in the Korean freshwater algal flora. Among them, the genus Nostochopsis Wood ex Bornet et Flahault 1886 had not previously been recorded in Korea.

Key words: Anabaena koreana sp. nov., Cyanophyceae, new species, Nostochopsis

INTRODUCTION

Many investigations of the freshwater algal flora have been conducted by a number of workers in various regions of Korea since Kawamura (1918) reported a species of Centritractus at lake Seoho, Suwon (Chung 1968, Chung 1970, 1975, 1976, 1979, 1993, Chung et al. 1972a, 1972b, Chung and Lee 1986, Wui and Kim 1987a, 1987b, Kim 1992, 1996, Kim and Chung 1993, 1994, Kim et al. 2009). Until now, about 1,800 taxa of freshwater algae have been reported, excluding diatoms. Among them, about 200 taxa of blue-green algae have been recorded, excluding diatoms. This represents only 10% of the blue-green algae species (about more than 150 genera and 2,000 species) reported worldwide (Van den Hoek et al. 1995), and it is only about 40% of the species reported in England (439 species), Sweden (559 species) and Japan (443 species) (Hirose and Yamagishi 1977, Willen 2001, John et al. 2011). Most floristic or taxonomic studies of blue-green algae from Korea have investigated blue-green algae along with other taxonomic groups of freshwater algae, but only a few studies on blue-green algal flora have been carried out in Korea (Chung 1976, Wui and Kim 1987b).

The importance of biological diversity has been emphasized, and the discovery of indigenous species for securing the sovereignty over biological resources is recognized as an urgent national task. Therefore, studies on the freshwater algal flora of uninvestigated regions in Korea including unusual environments (e.g., highland moorlands, mountain sphagnum bogs, wet-lands and crater) are required. In this study, more than 500 samples were collected from various water bodies throughout the country and investigated to establish freshwater algal flora of Korea. This study reports 12 species of blue-green algae for the first time in Korea including a new species, Anabaena koreana sp. nov.
MATERIALS AND METHODS

Over 500 samples were collected from various wetland habitats ranging from oligotrophic to eutrophic reservoirs, lowland swamps, acidic mountainous wetlands, sphagnum bogs and orum (crater, very small and shallow caldera lakes) from 2009 to 2012. The samples were obtained by means of plankton net (mesh size 25 µm), spoid, or by squeezing submerged macrophytes, and living materials was examined immediately. After the initial examination, materials were fixed with 5% formalin for permanent preservation and detail identification. Microscopic examinations were made at ×200 to ×1,000 magnification with an Axio Imager microscope (A2; Carl Zeiss, Oberkochen, Germany). Water temperature, pH, and conductivity were measured in the field with a HI8314 membrane pH meter (Hanna instruments, Smithfield, RI, USA) and a HI9835 EC meter (Hanna instruments). One new species and 11 species which had not previously been recorded from the Korean freshwater algal flora are described and illustrated with microscopy. All material was deposited at the National Institute of Biological Resources (NIBR) and Department of Biology, Kyungpook National University.

RESULTS AND DISCUSSION

Class Cyanophyceae
Order Chroococcales
Family Cyanobacteriaceae

Aphanotoche microscopica Nägeli (Fig. 1A and 1B)

Synonyms: Coccochloris stagnina Sprengel 1807, Aphanotoche piscinalis Rabenhorst 1865, Aphanotoche tuberculata (Areschoug) Forti 1907.

References: Komárek and Anagnostidis 2008a, p 84, fig. 72-73; John et al. 2011, p 45, pl. 9, fig. D.

Description: Colony mucilaginous, bright blue-green or yellow-green, initially small, spherical to ellipsoidal, later becoming diffusent margin and irregularly shaped, up to 2 mm in diameter; cells oblong, more or less ellipsoidal to cylindrical with rounded ends, densely or sparsely arranged in a homogenous, gelatinous matrix, generally densely arranged in the peripheral region and sparsely in the inside of the colony, often with their own indistinct colorless gelatinous envelopes; cells 4-6 µm in diameter, 5-11 µm long.

This species commonly occurs in moorland waters, peaty swamps, pools or in littoral of oligotrophic lakes, rarely subaerophytic on moist peaty soils.

Occurrence: Collected at Sunenmulbaengdi located in middle latitude of Mt. Hanla (33°22′00″N, 126°27′00″E, pH 5.2-6.0, EC 35-52 µs/cm) and Mujechineup of Mt. Jongjok (35°27′40″N, 129°08′30″E, pH 5.5-6.5, EC 25-35 µs/cm).

Cyanotoche aeruginosa (Nägeli) Komárek (Fig. 1C-1F)


References: Komárek and Anagnostidis 2008a, p 49, fig. 28; John et al. 2011, p 58, pl. 14, fig. E.

Description: Cells free-floating in vicinity of submerged plants, sometimes among other algae and bryophytes in swamps and mountain sphagnum bogs or wetlands, solitary or a pair during division; ellipsoid to short cylindrical with widely rounded ends, rarely slightly more oval, occasionally enveloped with a thin mucilaginous layer; cells contents blue-green, rarely brownish-green, usually with obvious fine vacuoles; cells 11-16 µm in diameter, 15-22 µm long.

This species commonly occurs in clear, cold moorland waters, mountain sphagnum bogs or wetlands.

Occurrence: Collected at Sunenmulbaengdi located in middle latitude of Mt. Hanla (33°22′00″N, 126°27′00″E, pH 5.2-6.0, EC 35-52 µs/cm), Mujechineup of Mt. Jongjok (35°27′40″N, 129°08′30″E, pH 5.5-6.5, EC 25-35 µs/cm), and Yongneup of Mt. Daeam (38°13′00″N, 128°07′30″E, pH 6.0-7.0, EC 18-35 µs/cm).

Order Oscillatoriales
Family Oscillatoriaceae

Oscillatoria kawamurae Negoro (Fig. 1G)


Description: Trichomes free-floating, straight, with uniformly parallel sides, nearly not attenuated at apex, not constricted at the cross walls; end cells flatly rounded or slightly capitate but without a thickened wall; cells violet or brownish pale-green in color, with minute granules filling in entire cells, and 3-4 reddish-brown gas vacuoles which are large, transverse liner and regular, centrally arranged by the cross walls, forming a loose spiral in whole length of the trichome; cells 70-80 µm in diameter, 10-15 µm long.

This species commonly occurs in shallow, mesotrophic to eutrophic water bodies such as old reservoirs and swamps.
**Occurrence:** Collected at Jangcheok reservoir (35°26′10″N, 128°29′05″E, pH 6.8-7.5, EC 103-135 µs/cm) at located in Changnyong county in 18 Aug 2012.

**Microcoleus paludosus** Gomont ex Gomont (Fig. 1H)

**References:** Komárek and Anagnostidis 2008b, p 534, fig. 803.

**Description:** Filaments solitary or forming dark blue-green filamentous mat; sheath slightly mucilaginous, colourless, broad, open and diffluent at the ends, containing many straight, parallel arranged or rope-like twisted trichomes; trichomes bright blue-green, 4.5-6 µm wide, not constricted at the cross wall, not attenuated at the ends; cells nearly isodiametric or up to 2 times longer than...
wide, 5-7.5 µm long; apical cells not capitate, rounded conical or rounded.

This species commonly occurs in stagnant waters, on wet rocks and soil, at margin of shallow reservoir.

**Occurrence:** Collected at Jangcheok reservoir (35°26'10"N, 128°29'05"E, pH 6.8-7.5, EC 103-135 µs/cm) located in Changnyong county on 18 Aug 2012.

**Order Nostocales**

**Family Nostocaceae**

*Anabaena koriana* sp. nov. Han Soon Kim

**Description:** Filaments usually in small flocs, free-floating; individual filaments straight, with single trichome and distinct sheath; sheath firm and relatively wide; cells short cylindrical-shape and smaller size, both terminal cells of trichome are conical shaped attenuated toward the end. Also, *A. koriana* sp. nov differs from these three species with spherical or barrel-shaped vegetative and terminal cells and a spherical heterocyst, and the vegetative cells are cylindrical-shape and smaller size, both terminal cells of trichome are conical shaped attenuated toward the end.

**Occurrence:** In this study, it collected at Jangcheok reservoir (35°26'10"N, 128°29'05"E, pH 6.8-7.5, EC 103-135 µs/cm) located in Changnyung county on 18 Aug 2012.

**Anabaena koreana** sp. nov. Han Soon Kim

**Description:** Trichomes solitary, free-floating, forming regular coils, without gelatinous sheath; coils about 13-20 µm in diameter, 8-18 µm apart; cells short cylindrical to barrel-shaped, constricted at the cross walls, with gas vesicles, terminal cells conical; heterocysts elliptic to ovate shaped, slightly larger than vegetative cell; akinets spherical, solitary, attaching at one or both sides of the heterocyst. Cells are 3-3.5 µm in diameter, 4-7 µm long. Terminal cells 3-3.5 µm in diameter, 6-9 µm long. Heterocyst 4-6 µm in diameter, 7-10 µm long. Akinets 9-10 µm in diameter.

*Anabaena koreana* sp. nov. is similar to *A. oumiana* M. Watanabae, *A. spiroides* Klebahn, and *A. ucrainica* (Schkorbatow) M. Watanabae within the genus *Anabaena* in that trichomes form regular coils. However, *A. koreana* sp. nov is distinguished from these three species in the shape and size of the vegetative cell, heterocyst and akinet, coiling size, and with or without a sheath. *A. koreana* sp. nov clearly differs from these three species with spherical or barrel-shaped vegetative and terminal cells and a spherical heterocyst, and the vegetative cells are cylindrical-shape and smaller size, both terminal cells of trichome are conical shaped attenuated toward the end. Also, *A. koreana* sp. nov is similar to *A. oumiana* in that the spherical akinet is attached at one or both sides of the heterocyst, but is clearly distinguished from the latter by conical terminal cell, ovate heterocyst, and lack of a mucilaginous sheath. *A. koreana* sp. nov differs from *A. spiroides* by having bent cylindrical akinet with the spherical akinet (Table 1).

**Type locality:** Buje reservoir, Kyungsan city, South Korea (35°47'30"N, 128°53'00"E; pH, 9.4; water temperature, 29°C; EC, 213 µs/cm).

**Holotype:** Fig. 2A (iconotypus) from material collected on 18 Aug 2009 deposited at the National Institute of Biological Resources (NIBR), Inchon species no. NIBRCY000000094.

### Table 1. Morphological characteristics of *Anabaena koreana* sp. nov., and related taxa

<table>
<thead>
<tr>
<th></th>
<th><em>A. koriana</em></th>
<th><em>A. oumiana</em></th>
<th><em>A. spiroides</em></th>
<th><em>A. crassa</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetative cell</td>
<td>Cylindrical, 3-3.5 x 4-7 µm</td>
<td>Subspherical or barrel-shape, 6-7.1 x 3-6.5 µm</td>
<td>Spherical to barrel-shaped 5.5-6.8 µm in diameter</td>
<td>Spherical to short barrel-shaped About 9-15 µm in diameter</td>
</tr>
<tr>
<td>Terminal cell</td>
<td>Conical, 3-4 x 6-9 µm</td>
<td>Same shape with other cells</td>
<td>Same shape with other cells</td>
<td>Same shape with other cells</td>
</tr>
<tr>
<td>Heterocyst</td>
<td>Elliptic to Ovate, 4-6 x 7-10 µm</td>
<td>Spherical, 6-8.5 µm in diameter</td>
<td>Spherical 18-23 µm in diameter</td>
<td>Spherical, Smaller than the vegetative cell</td>
</tr>
<tr>
<td>Akinet</td>
<td>Spherical, 9-10 µm in diameter, attached both side of the heterocyst</td>
<td>Spherical, 10-12 µm in diameter, attached of the heterocyst</td>
<td>Bent cylindrical, 7.5-11.3 x 16.8-21.3 µm, next to or apart from heterocyst</td>
<td>Widely ellipsoid 18-23 µm in diameter, Apart from the heterocyst</td>
</tr>
<tr>
<td>Coils</td>
<td>13-20 µm in diameter, 8-18 µm apart</td>
<td>28-46 µm in diameter, 10-20 µm apart</td>
<td>18-20 µm in diameter, 7 µm apart</td>
<td>40-70 µm in diameter, 30-40 µm apart</td>
</tr>
<tr>
<td>Mucilage sheath</td>
<td>Without</td>
<td>Thick mucilaginous sheath</td>
<td>Indiscernible sheath</td>
<td>Thick mucilaginous sheath</td>
</tr>
</tbody>
</table>
Fig. 2. (A-D) Anabaena koreana sp. nov., (E- F) Rivularia globiceps. Scale bars, 10 µm.
Etymology: The specific epithet “koreana” refers to the fact that the species was first found in Korea.

Family Rivulariaceae

*Rivularia globiceps* G.S. West (Fig. 2E and 2F)

**Reference:** Hirose and Yamagishi 1977, p 85, pl. 36, fig. 8.

**Description:** Colonies hemispherical or subspherical, up to 2 mm diameter, dark blue-green; mucilage soft; tri- 

chomes radiate arranged, gradually tapered toward the apex and terminal cells developed with colorless long 

hair, with basal heterocyst towards the inside of the col- 

ony, slightly constricted at cross wall; cells towards het- 

erocyst at the base cylindrical, 6.5-7.5 μm. wide, length 

up to about 2.5 times of wide (14-22 μm long), midregion 

cells nearly quadrate; heterocysts only single at the base, 

globose or subglobose, 12-15 μm long, 10.5-12 μm wide. 

This species occurs as an epiphytic on submerged 

plants in peaty bogs and shallow reservoirs.

**Occurrence:** Collected at unnamed small pond (36°23′ 

00″N, 128°28′00″E, pH 7.0-8.1, EC 118-253 μs/cm) located in 


Family Rivulariaceae

*Homoeothrix varians* Geitler (Fig. 3A and 3B)

**Reference:** Komárek and Anagnostidis 2008b, p 598, fig. 


**Description:** Thalli growing on submerged substra-

tum; sheath colorless or yellow, with a single trichome; 

trichomes gradually attenuated toward the end, up to 270 

μm long, without constriction at the cross wall, 16-19 μm 

in diameter at the base; cells flat, 1/3-1/4 as long as broad, 

2-3 μm long; heterocyst more or less semi-globose to sub-

globose, 13-16 μm in diameter.

This species common occurs together with submerged 

plants in the marginal of mesotrophic to eutrophic 

swamp or reservoir.

**Occurrence:** Collected at Woopo swamp (35°33′40″N, 

126°27′00″E, pH 5.2-6.0, EC 35-52 μs/cm) located in 


Family Hapalosiphonaceae

*Hapalosiphon arboreus* W. et G. S. West (Fig. 4A and 4B)

**Reference:** Hirose and Yamagishi 1977, p 141, pl. 49, fig. 6.

**Description:** Colony forming a mass of interwoven fil-

aments, composed of creeping main axes and branches 

perpendicular to main axis; main axis straight or slightly 

curved, with numerous short branches; branches in a 

plane perpendicular to the main axis, slightly narrower 

than main axis; cells of main axis usually quadrate or 

slightly longer than broad, 7-8 μm long, 5.5-7 μm wide, 

cells of branches nearly same to main axis cells; hetero-

cysts intercalary in main axis, almost resemble to vegeta-

tive cells, quadrate, 5.5-7 μm wide, 7-10.5 μm long; sheath 

thin and colorless.

This species commonly occurs mixed with other algae 

or Sphagnum in swamps, moorland waters, mountain 

sphagnum bogs or wet-lands with low pH.

**Occurrence:** Collected at 1100 latitude wet-lands 

(33°21′40″N, 126°27′50″E, pH 6.2, EC 45 μs/cm) located in 

Jeju Island on 15 Apr 2013.

*Hapalosiphon intricatus* W. et G. S. West (Fig. 4C)

**Reference:** Hirose and Yamagishi 1977, p 143, pl. 50, 

fig. 1; John et al. 2011, p 155, pl. 33, fig. C; Yamagishi and 

Akiyama 1989, p 55.

**Description:** Colony forming a mass of interwoven fil-

aments, composed of creeping main axes and branches 

perpendicular to main axis; main axis straight or slightly 

curved, with numerous perpendicular branches; main 

filaments 4-7 μm wide, branches slightly narrower than 

main axis; cells usually quadrate, 3-4 μm wide, 5-8 μm 

long, heterocysts in main axis and branches, ellipsoid or 

quadrate, 5-6 μm wide, 8-10 μm long; sheath thin and color-

less.

This species commonly occurs mixed with other algae 

bundles, each filament (7)8.5-(12)15 μm wide, sometimes 

wider, false branches sparse; cells 5-7 μm in diameter, in 

older parts of trichome mostly longer than wide, in meri-

stem region shorter; typically blue-green. Sheath thin, 

firm, colorless or yellow to yellow-brown; heterocysts 

single or in pairs, rounded cylindrical; cells 6-8 μm in di-

ameter, 6-10 μm long; heterocyst 6-8 μm in diameter, 8-12 

μm long.

This species commonly occurs in swamps, moorland 

waters, mountain sphagnum bogs or wet-lands.

**Occurrence:** Collected at Sumenmulbaengdi (33°22′ 

00″N, 126°27′00″E, pH 5.2-6.0, EC 35-52 μs/cm) located in 


Family Scytonemataceae

*Scytonema hofmannii* Bornet et Flahault (Fig. 3C)

**Synonym:** *Scytonema hofmanii* Agardh 1817.

**Reference:** Hirose and Yamagishi 1977, p 71, pl. 31, fig. 

2; John et al. 2011, p 148, pl. 30, fig. 1.

**Description:** Colony cushion-like, widely expended, 

1-2 mm high, blackish blue-green; filaments often in 

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Fig. 3. (A-B) Homoeothrix varians, (C) Scytonema hofmannii. Scale bars, 10 µm.
or *Sphagnum* in swamps, moorland waters, mountain sphagnum bogs or wetlands with low pH.

**Occurrence:** Collected at Mulyoungari (33°22'50"N, 126°45'00"E, pH 5.6, EC 36 µs/cm) located in Jeju island, Seogwipo city on 9 Sep 2009.

**Family Nostochopsaceae**

*Nostochopsis lobatus* Wood ex Bornet et Flahault (Fig. 5)

**References:** Yamagishi and Akiyama 1989, p 55.

**Description:** Thallus attached to the substrate, gelatinous, irregularly subspherical, spherical or lobate, with smooth mucilaginous surface, solid mass up to 3 cm in diameter, olive-green or yellowish-green; trichomes irregularly branched, radially arranged in the outer parts, flexuous, entangled in the inner parts; branches lateral (T- or V-shaped), long, many-celled, terminated by slightly narrowed or widened, rounded terminal cells, or very short, cylindrical branches composed with one to several-celled, terminated by heterocysts; basal cells of thallus ellipsoidal to barrel-shaped, 5.4-7.2 µm wide, 7-13 µm long, somewhat irregularly elongated at the slowly growing parts, 4-6 µm wide, 7-10 µm long; heterocysts lateral or terminal on 1-3 celled lateral branch, spherical or subspherical, 5-8 µm wide, 6-10 µm long.

This species commonly occurs as epiphyte in stream of...
high speed of a running fluid.

Occurrence: Collected at middle part of Hoecheon stream (35°44′00″N, 128°16′20″E, pH 9.2, EC 365 µs/cm) located in Goryeong county on 2 Sep 2011.

CONCLUSION

The present study, a new species, *Anabaena koreana* sp. nov., and 11 species and one genus, *Nostochopsis* Wood ex Bornet et Flahault, of Cyanophyceae were newly added to the Korean freshwater algal flora.

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LITERATURE CITED


