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The distribution and three newly reported species of aerial algae at Mt. Gwanggyo, Korea

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Abstract

This research includes the identification and cultivation of aerial algae from 33 sites located in Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012. The ecological factors of aerial algae were analyzed and a total of 29 taxa were identified in 4 phyla, 5 classes, 11 orders, 15 families, 19 genera, 28 species and 1 variety; 12 taxa of cyanophytes, 8 taxa of chrysophytes, and 9 taxa of chlorophytes were found. As for newly recorded cyanophytes of Korea, *Komvophoron jovis*, *Microcoleus steenstrupii*, and *Nostoc edaphicum* appeared. *Komvophoron jovis*, previously known to grow on rocks and boulders, appeared in soil. *Microcoleus steenstrupii*, reported to appear in desert soils, appeared on the wet surface of the soil after rain. *Nostoc edaphicum*, in symbiosis with fungi, appeared on tree bark as the lichen. Thus, there are a total of 99 reported taxa of Korean aerial algae, including 3 species that were discovered in this study.

Key words: aerial algae, cyanophytes, newly recorded species

INTRODUCTION

Aerial algae have been found in a vast range of environments, including soils, rocks, tree barks and surfaces of buildings. Aerial algae contributes to carbon and nitrogen fixation, the release of organic material, and the coalescing of soil particles (Goyal 1997, Graham et al. 2009). In order to adapt to land environments, aerial algae display simplified shapes, such as globular, oval and filaments (Hoffmann 1989). Consequently, understanding the minute differences in form and alterations of shape is required to identify aerial algae based on morphology (Neustupa and Skaloud 2010).

Overseas, studies on distribution of soil algae have been performed in Texas (King and Ward 1977), North-Eastern Italy (Zancan et al. 2006), and Egypt (Mansour and Shaaban 2010). Research on the distribution of algae on tree barks has been done in India (Mikter and Shukla 2006), Singapore (Neustupa and Skaloud 2010), and Brazil (Lemes-Da-Silva et al. 2010). Studies on distribution of aerial algae in specific locations and on the walls of buildings have been done in Latin America (Gaylarde and Gaylarde 2000), Europe (Rindi and Guiry 2004), India (Samad and Adhikary 2008), Spain (Macedo et al. 2009) and the USA (Khaybullina et al. 2010). Domestically, with regard to aerial algae, research on distribution of soil algae in Seoul, Gyeonggi-do, Chungcheong-do has been done (Chang et al. 1998). In addition, studies by Klochkova et al. (2006), Lim and Lee (2008a, 2008b), and Kim et al. (2010, 2011) on aerial algae in Korean stone cultural heritages sites have been performed. In Korea, a total of 96 taxa, including 39 taxa of cyanophytes, 14 taxa of chrysophytes, and 43 taxa of chlorophytes have been found (Chung 1968, 1993, Chang et al. 1998, Lim and Lee 2008a, 2008b).

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The current study aims to add newly recorded species of aerial algae, investigate the environmental factors of their habitats, and clarify the distribution of species in Mt. Gwanggyo of Gyeonggi-do, Korea.

MATERIALS AND METHODS

Aerial algae were collected from a total of 33 sites—5 soil sites, 14 tree bark sites, and 14 rock sites—in Mt. Gwanggyo from March 2011 to August 2012. Basic environmental factors such as air temperature, surface temperature, humidity, and intensity of illumination were analyzed when collecting the aerial algae. Testo 625 (Testo, Lenzkirch, Germany) was used to measure temperature and humidity, Testo 830-T1 (Testo) for surface temperature, and LX-1108 (Lutron, Taipei, Taiwan) for illumination.

The samples were collected using a soft brush and sterilized spatula. All samples were collected and transported to the lab in sterilized distilled water in dark bottles (Crispim et al. 2004). Unialgal culture of aerial algae was done by separating it on agar medium using a pasteur-pipette. For culture media, Bold 3N medium (Bold and Parker 1962), Bold basal medium (Bold and Wynne 1978), WEES medium (Kies 1967), and M chu No. 10 medium (Chu 1942) were used. An appropriate culture medium was used to culture aerial algae by manipulating factors such as[ph] (Stein 1979). The aerial algae increased a cell

Table 1. The 33 sampling sites and ecological factors in Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012

Site	Date	Location		Biotope	T[a] (°C)	ST[b] (°C)	Illu[c] (Lux)	Hu[d] (%)
1	Mar. 2011	37° 20′ 41.11″ N	127° 02′ 03.02″ E	Rock	9.3	9	39,100	20.3
2		37° 20′ 45.11″ N	127° 01′ 51.76″ E	Rock	4.3	3.5	62,600	18.5
3		37° 20′ 40.67″ N	127° 01′ 46.26″ E	Rock	3.8	0	36,350	16.2
4		37° 20′ 37.05″ N	127° 01′ 42.62″ E	Rock	6.5	5	35,000	45.2
5		37° 20′ 30.48″ N	127° 01′ 26.08″ E	Tree bark	5.2	6.5	23,360	15.2
6		37° 20′ 05.94″ N	127° 01′ 06.27″ E	Tree bark	7.1	9.5	30,980	18.1
7	Aug. 2011	37° 20′ 41.76″ N	127° 02′ 04.06″ E	Rock	24.8	24.5	10,730	71.5
8		37° 20′ 42.12″ N	127° 01′ 59.00″ E	Rock	24.5	23.5	7,560	70.7
9		37° 20′ 26.84″ N	127° 01′ 56.10″ E	Tree bark	24.8	23.5	7,670	69.3
10		37° 20′ 23.18″ N	127° 01′ 47.21″ E	Tree bark	25.2	25	3,885	67.5
11		37° 19′ 54.79″ N	127° 01′ 33.23″ E	Tree bark	24.8	24.5	3,925	74.6
12		37° 19′ 50.40″ N	127° 01′ 24.53″ E	Rock	27	27	10,210	67.3
13	Nov. 2011	37° 20′ 41.11″ N	127° 02′ 03.02″ E	Rock	12.6	11.5	5,240	89
14		37° 20′ 45.11″ N	127° 01′ 51.76″ E	Rock	11.9	10.5	2,262	91.4
15		37° 20′ 38.99″ N	127° 01′ 44.44″ E	Rock	13.2	10	2,860	85.5
16		37° 20′ 30.48″ N	127° 01′ 26.08″ E	Rock	14.7	10.5	1,585	76.6
17		37° 20′ 05.94″ N	127° 01′ 06.27″ E	Rock	14.5	10	1,674	75
18	Feb. 2012	37° 18′ 38.83″ N	127° 01′ 20.92″ E	Rock	4.3	0.5	4,500	48.5
19		37° 18′ 35.62″ N	127° 01′ 23.60″ E	Rock	4.3	1	4,500	48.5
20		37° 18′ 31.25″ N	127° 01′ 25.09″ E	Tree bark	4.3	1.5	4,500	48.5
21		37° 18′ 22.10″ N	127° 01′ 37.04″ E	Tree bark	5.8	2.5	9,200	65.5
22		37° 18′ 14.50″ N	127° 01′ 41.03″ E	Tree bark	5.8	3	9,200	65.5
23		37° 18′ 10.31″ N	127° 01′ 41.22″ E	Tree bark	5.8	3.8	9,200	65.5
24	Aug. 2012	37° 17′ 56.21″ N	127° 02′ 18.67″ E	Soil	22.2	24.5	8,510	100
25		37° 18′ 03.53″ N	127° 02′ 20.31″ E	Tree bark	20.9	24.5	8,510	95.2
26		37° 18′ 17.78″ N	127° 02′ 03.10″ E	Tree bark	28.5	23	1,654	64.6
27		37° 18′ 17.56″ N	127° 02′ 03.76″ E	Tree bark	28.5	25.5	1,914	64.6
28		37° 18′ 17.47″ N	127° 02′ 03.77″ E	Soil	28.5	25	2,018	64.6
29		37° 18′ 15.99″ N	127° 02′ 03.28″ E	Tree bark	28.4	31.5	8,740	64.7
30		37° 18′ 09.95″ N	127° 01′ 59.21″ E	Soil	24.5	16.5	524	69
31		37° 18′ 09.31″ N	127° 01′ 59.84″ E	Tree bark	24	17	1,520	72.6
32		37° 18′ 08.69″ N	127° 02′ 00.52″ E	Soil	24	16.5	1,950	70.5
33		37° 18′ 09.33″ N	127° 02′ 02.28″ E	Soil	24.2	21	10,130	70.3

[a]T, Temperature(°C); [b]ST, Surface temperature (°C); [c]Illu, intensity of illumination(Lux); [d]Hu, humidity (%).

number for three to five days in the algae culture room with a temperature of 25°C, photoperiodic control of 16:8, and intensity of illumination of 40 μm $m^{-2} s^{-1}$.

Species were identified using optical microscope (BX41; Olympus, Tokyo, Japan) under ×400-1,000 magnification. Pictures of cells' outer shape were captured by a digital camera (C-5060; Olympus) attached to the microscope. A drawing attachment (BX40F4; Olympus) was used for drawing of the morphologies. Prescott et al. (1972, 1977, 1981, 1982), Prescott (1973), Hirose et al. (1977), Chung (1993), John et al. (2002), and John and Robert (2003) were used as references for each taxonomic group that appeared.

RESULTS AND DISCUSSION

Ecological factors

The ecological conditions of Mt. Gwanggyo, where the aerial algae were found, were measured (Table 1). Air temperature ranged from 3.8°C to 28.5°C and surface temperature ranged from 0°C to 31.5°C at the time of collection. Intensity of illumination ranged from 524 to 62,600 lux, and humidity ranged from 15.2% to 100% at the collection sites.

A total of 29 taxa were identified, with 4 phyla, 5 classes, 11 orders, 15 families, 19 genera, 28 species and 1 variety. Among the taxa identified, there were 12 taxa of cyano-

Table 2. The biotope types of the aerial algae appeared at Mt. Gwanggyo of Gyeonggi-do in Korea, from March 2011 to August 2012

Species	Previous studies		Sites of this study		
	aquatic	aerial	Soil	Tree bark	Rock
CYANOPHYCEAE					
Aphanothece naegelii	+	+		31	
Chroococcus bituminosus	+				2, 4
Chroococcus limneticus	+		24		
Chroococcus turgidus	+	+			17
Chroococcus varius	+	+		5, 10, 11, 21	3, 4, 19
**Microcoleus steenstrupii*	+	+	33	25	
**Nostoc edaphicum*	+	+		22	
Oscillatoria chlorina	+	+		22	
**Komvophoron jovis*	+	+	24		
Scytonema crispum	+	+		22	
Synechocystis aquatilis	+	+		6, 9, 25	12
Tolypothrix distorta	+			23	
Bacillariophyceae					
Achnanthes convergens	+		28		
Cocconeis placentula var. *lineata*	+		13, 18, 22		
Hantzschia amphioxys	+	+	24, 28	22, 25	
Navicula contenta	+		24	25	
Navicula goeppertiana	+		28	26, 27	
Nitzschia palea	+				7, 17
Pinnularia borealis	+		24	22, 25	17, 19
Pinnularia subcapitata	+		28		
Klebsormidiophyceae					
Klebsormidium crenulatum	+	+			2, 12, 14, 15, 19
Klebsormidium dissectum	+	+	28, 30, 32	10, 20, 22, 23, 25, 26, 27, 29, 31	1, 4, 15, 17, 19
Klebsormidium flaccidum	+	+	24, 30	6, 9, 11, 22	1, 8, 12, 13, 14, 15, 17, 18
Klebsormidium klebsii	+	+	24		2
Zygnematophyceae					
Cosmarium decedens	+	+	22, 28		
Cylindrocystis brebissonii	+	+		22	2, 4
Trebouxiophyceae					
Chlorella ellipsoidea	+	+		20, 22, 29	8, 12, 14, 15, 16, 17, 19
Chlorella minutissima	+	+		29	17
Chlorella vulgaris	+	+	28, 32, 33	5, 6, 22, 26, 19	13, 15, 16, 17, 18, 19

*Newly recorded aerial algae in Korea; +, the appearance; site numbers correspond to Table 1.

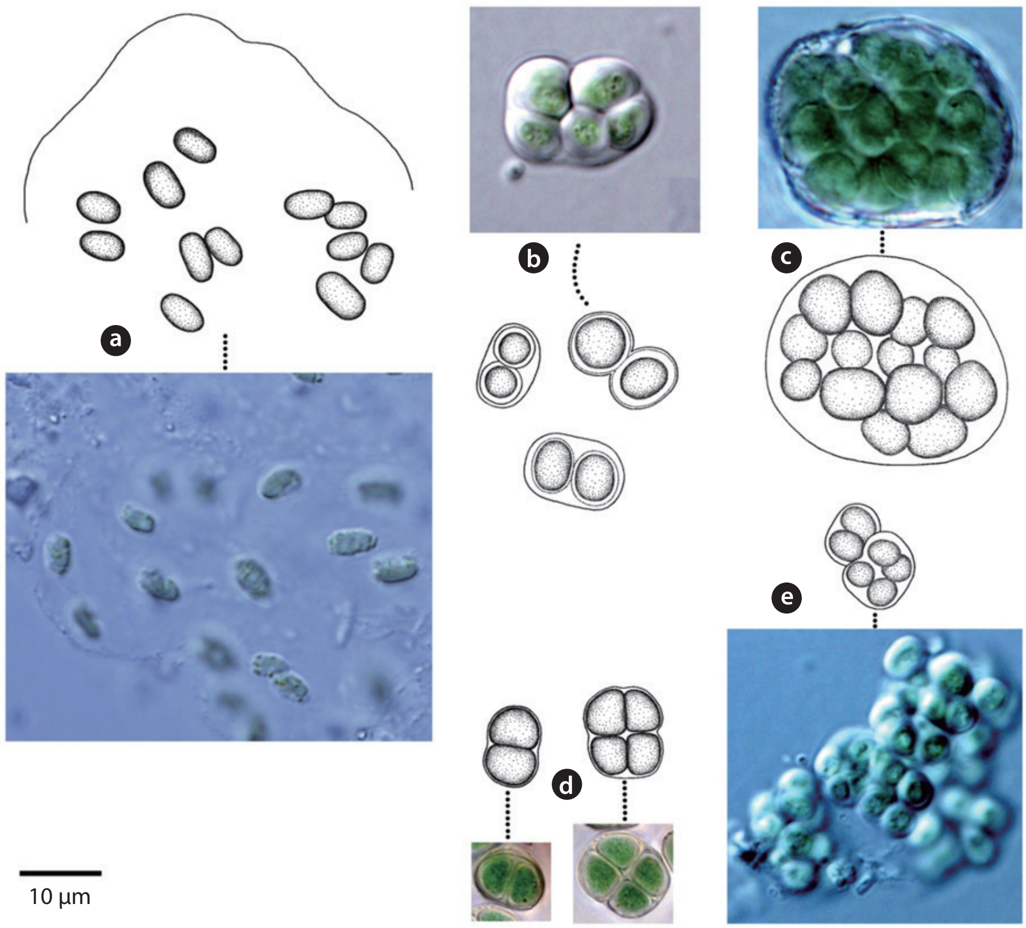

Fig. 1. The photographs and drawings of (a) *Aphanothece naegelii,* (b) *Chroococcus bituminosus,* (c) *Chroococcus limneticus,* (d) *Chroococcus turgidus,* and (e) *Chroococcus varius*, appeared from Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012. Scale bar, 10 μm.

phytes including 3 newly recorded species for Korea, 8 taxa of chrysophytes and 9 taxa of chlorophytes. In soils, a total of 10 species—*Achnanthes convergens, Chroococcus limneticus, Cocconeis placentula* var. *lineata, Microcoleus steenstrupii, Oscillatoria chlorina, Komvophoron jovis, Pinnularia subcapitata, Hantzschia amphioxys, Cosmarium decedens,* and *Cylindrocystis brebissonii*—were found. In tree barks, a total of 4 species—*Nostoc edaphicum, Scytonema crispum, Synechocystis aquatilis* and *Tolypothrix distorta*—appeared. In rocks, 2 species—*Aphanothece naegelii* and *Chroococcus bituminosus*—were found. *Chlorella ellipsoidea, C. vulgaris, Chroococcus varius, Klebsormidium crenulatum, K. dissectum, K. flaccidum*, and *K. klebsii* were found on a wide range of biotopes containing soils, tree barks and rocks (Table 2). The morphological and ecological factors for the 29 taxa found at Mt. Gwanggyo of Gyeonggi-do are described as follows (Guiry and Guiry 2013).

CYANOPHYCEAE

1. *Aphanothece naegelii* Wartmann (Fig. 1a)

Colony microscopic; cell spherical to ovoid, irregularly arranged in a mucilage (Chung 1993), 5-7 μm long, 3-4 μm wide.

This species, which has been reported to inhabit streams and moist rocks, and to symbiose with bryophytes (Tilden 1901, 1902, MacCaughey 1917, 1918a, 1918b, Chung 1993), appeared on tree bark (Site 31; see Table 1 for site number hereafter) in this study.

2. *Chroococcus bituminosus* (Bory) Hansgirg (Fig. 1b)

Colony containing 2-8 cells. The sheath contains 1-8 cells (Chung 1993). Cells 2-4 μm excepting the sheath.

This species has been reported to inhabit streams (Chung 1993), and appeared on rocks (Sites 2, 4) in this study.

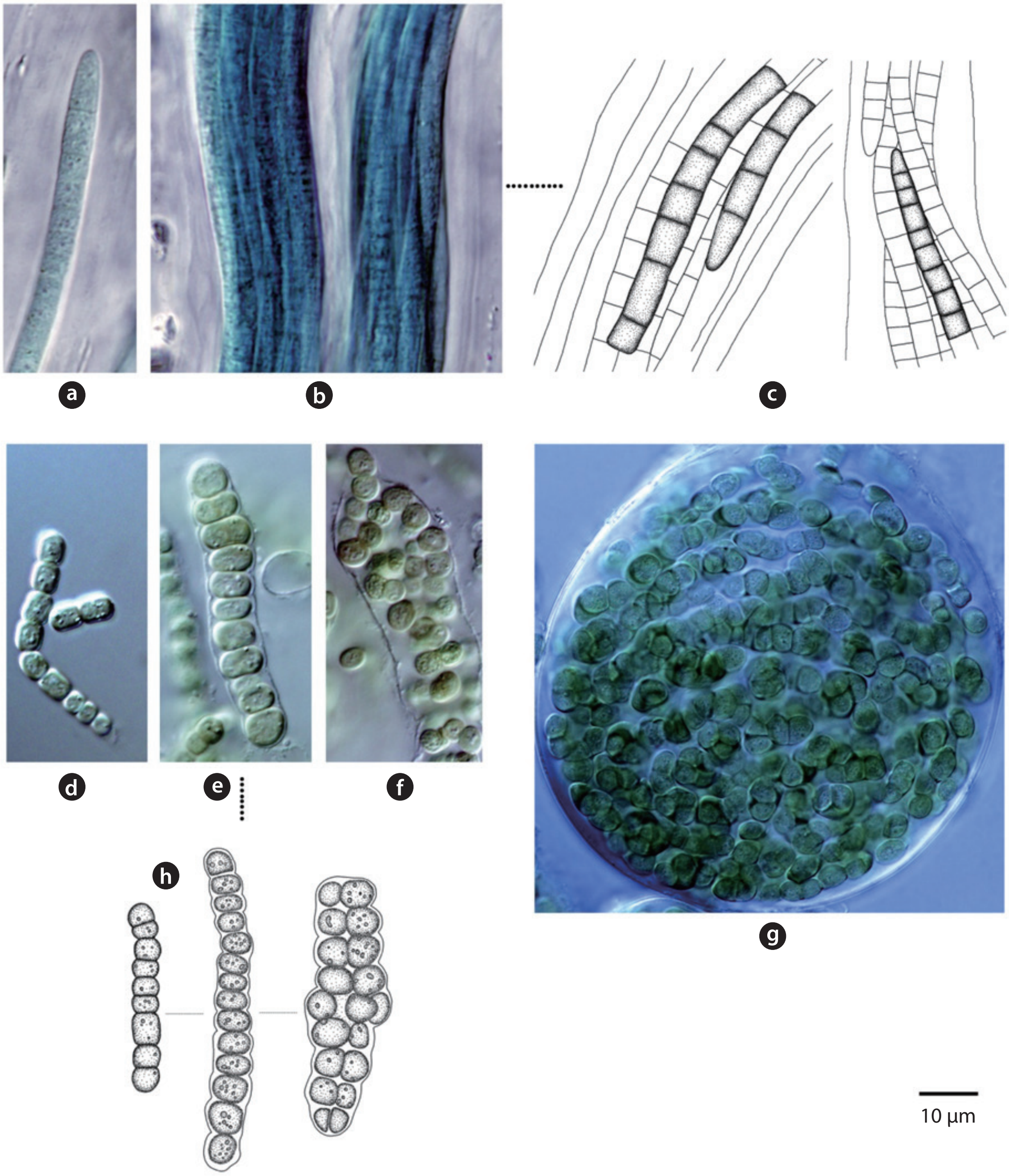

Fig. 2. The photographs and drawings of newly recorded species, (a-c) *Microcoleus steenstrupii* and (d-h) *Nostoc edaphicum,* appeared from Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012. Scale bar, 10 μm.

3. *Chroococcus limneticus* Lemmermann (Fig. 1c)

Colony ovoid or irregular, cells occurring within the mucilage. Outer margin of the colony usually distinct, mucilage colourless. Cells subspherical, 8-10 μm.

In previous studies, this species has been reported to inhabit streams (Chung 1993), and appeared on the surface of the soil (Site 24) in this study.

4. *Chroococcus turgidus* (Kützing) Nägeli (Fig. 1d).

Synonym: *Gloeocapsa turgida* (Kutz.) Hollerb.

Colony microscopic, usually 2-4 cells, with the outermost sheath layer forming the margin of the colony. Blue-green or yellowish-green cells (John et al. 2002). Cells spherical or subspherical, 10-18 μm in diameter including the sheath. In previous studies, this species has been reported to inhabit streams, caves, rocks, and soil, and to symbiose with bryophytes (Chung 1993, John et al. 2002).

It appeared on rock (Site 17) in this study. Although the cell diameter of *C. turgidus* is described as 8-32 μm without sheath and 13-40 μm with sheath in Chung (1993), the organisms that appeared in this research were relatively smaller in size.

5. *Chroococcus varius* A.Braun (Fig. 1e)

Colony microscopic, but forming large gelatinous groups of 2-4 cells embedded in mucilage. Mucilage colorless and the sheath displays a layered structure. Cells spherical or subspherical, 2-4 μm excepting the sheath, 4-8 μm including the sheath.

In previous studies, this species has been reported to inhabit streams and building walls (Samad and Adhikary 2008). It appeared on tree barks (Sites 5, 10, 11, 21), and rocks (Sites 3, 4, 19) in this study.

6. *Microcoleus steenstrupii* Boye-Petersen (Fig. 2a-2c): newly recorded species of Korea

Trichomes loosely arranged with many filaments per sheath. Trichomes bright blue-green, tapering toward end, indistinctly constricted at the cross-walls. End cell not capitate, rounded-conical. Sheaths colourless. Cells 3-8 μm long, 3-5 μm wide.

Specimen: NIBRCY0000000450.

This species has been found to be distributed in desert soils (Komárek and Anagnostidis 2005). In this study, it was found at the surface of wet soil after rainfall (Site 33) but was not found in dry soils. Moreover, it was found in tree barks that had humidity of approximately 90% (Site 25). Thus, this species showed low distribution in dry conditions.

7. *Nostoc edaphicum* Kondrat (Fig. 2d-2h): newly recorded species of Korea

Colony irregularly arranged in the mucilage. Filaments commonly flexuous, loosely entangled. Cells spherical or subspherical, 2-4 μm, blue-green or brownish-green (Komárek 2013). Heterocyte usually many.

Specimen: NIBRCY0000000448.

This species appeared as an irregular colony surrounded by mucilage when collected, but appeared as a single strand colony in the culture medium. In previous studies, this species was reported to be a Cyanolichen—a lichen containing blue-green algae (Syiem et al. 2011). In this study, they were found as lichen in tree bark (Site 22).

8. *Oscillatoria chlorina* Kützing ex Gomont (Fig. 3a)

Colony yellowish-green and blue-green (Hirose et al. 1977). Trichomes straight, cross-walls not narrowed. Filaments 6-9 μm long, 4 μm wide.

This species has been reported to inhabit Brackish waters and the surface of moist soil (Hirose et al. 1977). It appeared on tree bark (Site 22) in this study. From the data, with humidity of 65.5% and appearance on tree bark with a water distance of 5 m, *O. chlorina* is thought to dwell in areas with high humidity.

9. *Komvophoron jovis* (Copeland) Anagnostidis and Komárek (Fig. 3b): newly recorded species of Korea

Synonym: *Oscillatoria jovis* Copeland.

Trichomes lacking a mucous sheath, straight or loosely flexuous. End cell thin, spherical or conical (Komárek and Anagnostidis 2005). No cell granule, 3.4-4.2 μm wide.

Specimen: NIBRCY0000000449.

This species was first published in Anagnostidis and Komárek (1988), and was reported as inhabiting rocks, boulders, and roadside paths as *Oscillatoria jovis* (Protist Information Server 2007). In this study, it appeared in soil (Site 24).

10. *Scytonema crispum* (C.Agardh) Bornet (Fig. 3d-3f)

Synonym: *Scytonema cincinnatum* Bornet et Flahault.

Colony brown or blue-green, often spread out. Filaments firm with false branches, mostly arranged in pairs. Sheath colourless or yellowish-brown . Heterocyte oval or square, single or many (Chung 1993). Cells 12-25 μm wide, 3-7 μm long. Cross-walls narrowed.

This species has been reported to inhabit the surfaces of buildings after rainfall (Samad and Adhikary 2008), and appeared on tree bark (Site 22) in this study.

11. *Synechocystis aquatilis* Sauvageau (Fig. 3c)

Unicellular or colonial (2-4 cells) and spherical 3-7 μm cells.

This species has been reported as inhabiting fresh and brackish waters (John et al. 2002) and highly weathered sand stone (Makandar and Bhatnagar 2010). It appeared on tree barks (Sites 6, 9, 25) and rock (Site 12) in this study.

12. *Tolypothrix distorta* Kützing ex Bornet and Flahault (Fig. 4)

Colony a mat or spread, blue-green or brown. Filaments repeatedly branched, false branches often deeply or sharply erect (John et al. 2002). Cells 5-7 μm long, 12-15 μm wide. Heterocyte single.

In previous studies, this species has been reported as

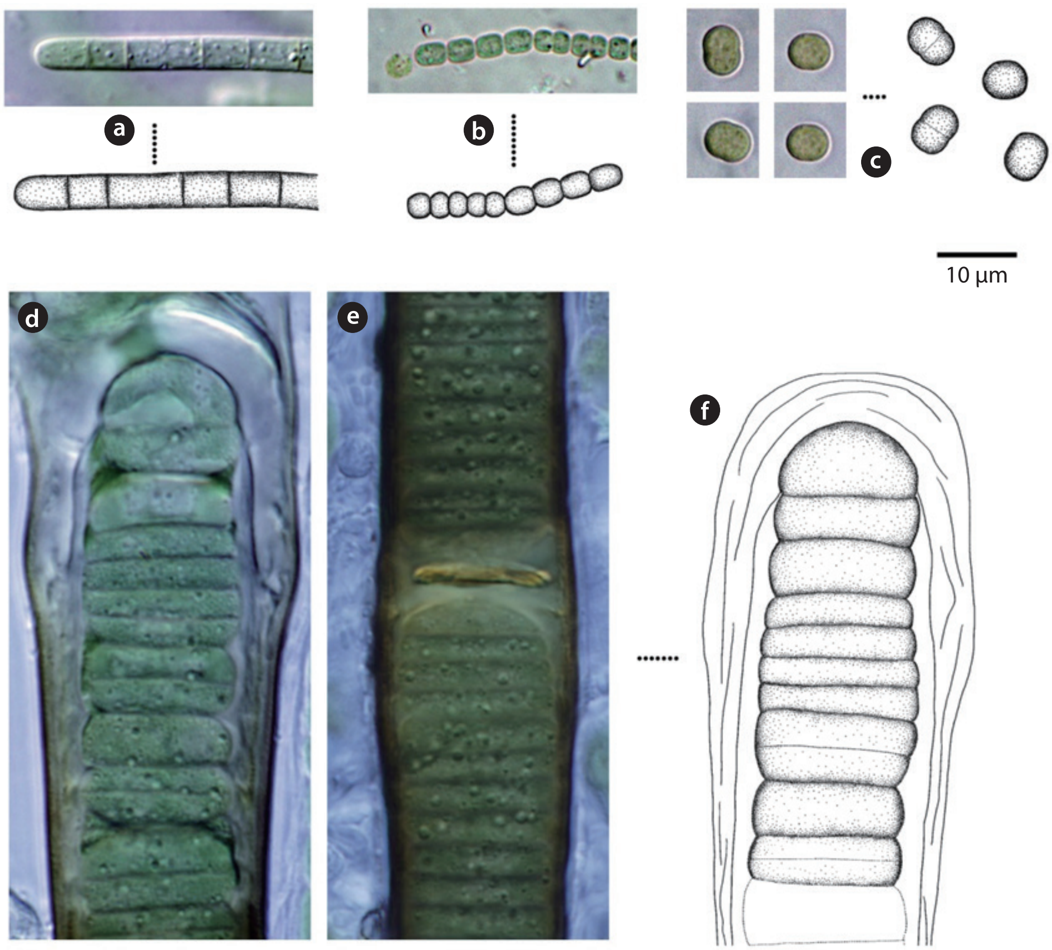

Fig. 3. The photographs and drawings of (a) *Oscillatoria chlorine*, (b) *Komvophoron jovis* (: a newly recorded species), (c) *Synechocystis aquatilis*, and (d-f) *Scytonema crispum*, appeared from Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012. Scale bar, 10 μm.

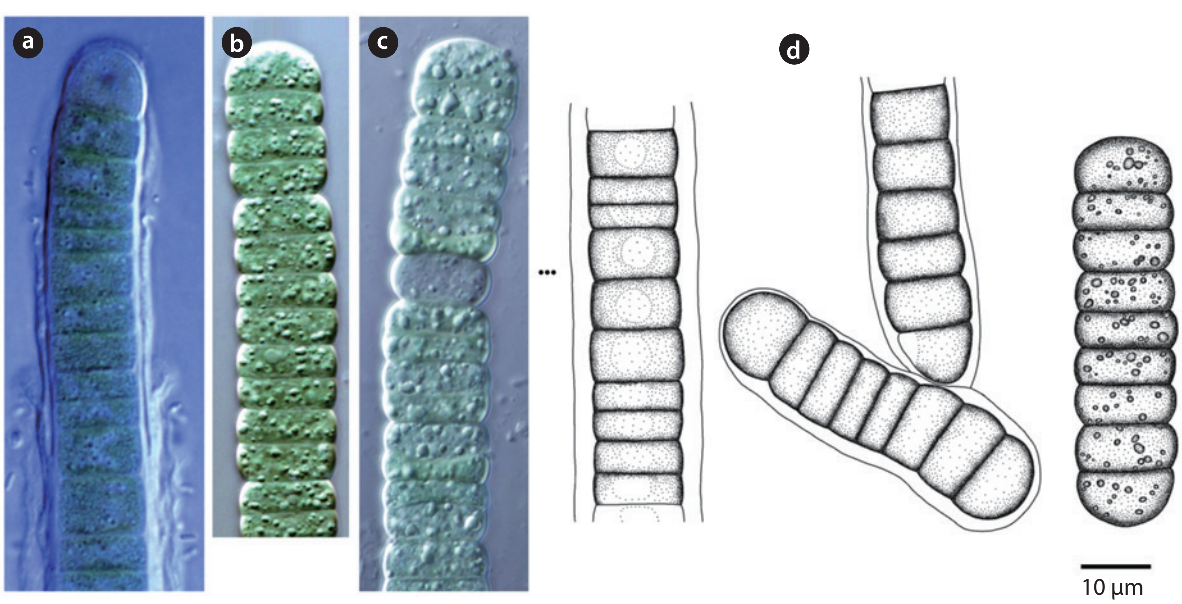

Fig. 4. The photographs (a-c) and drawing (d) of *Tolypothrix distorta*, Korea, from March 2011 to August 2012. Scale bar, 10 μm.

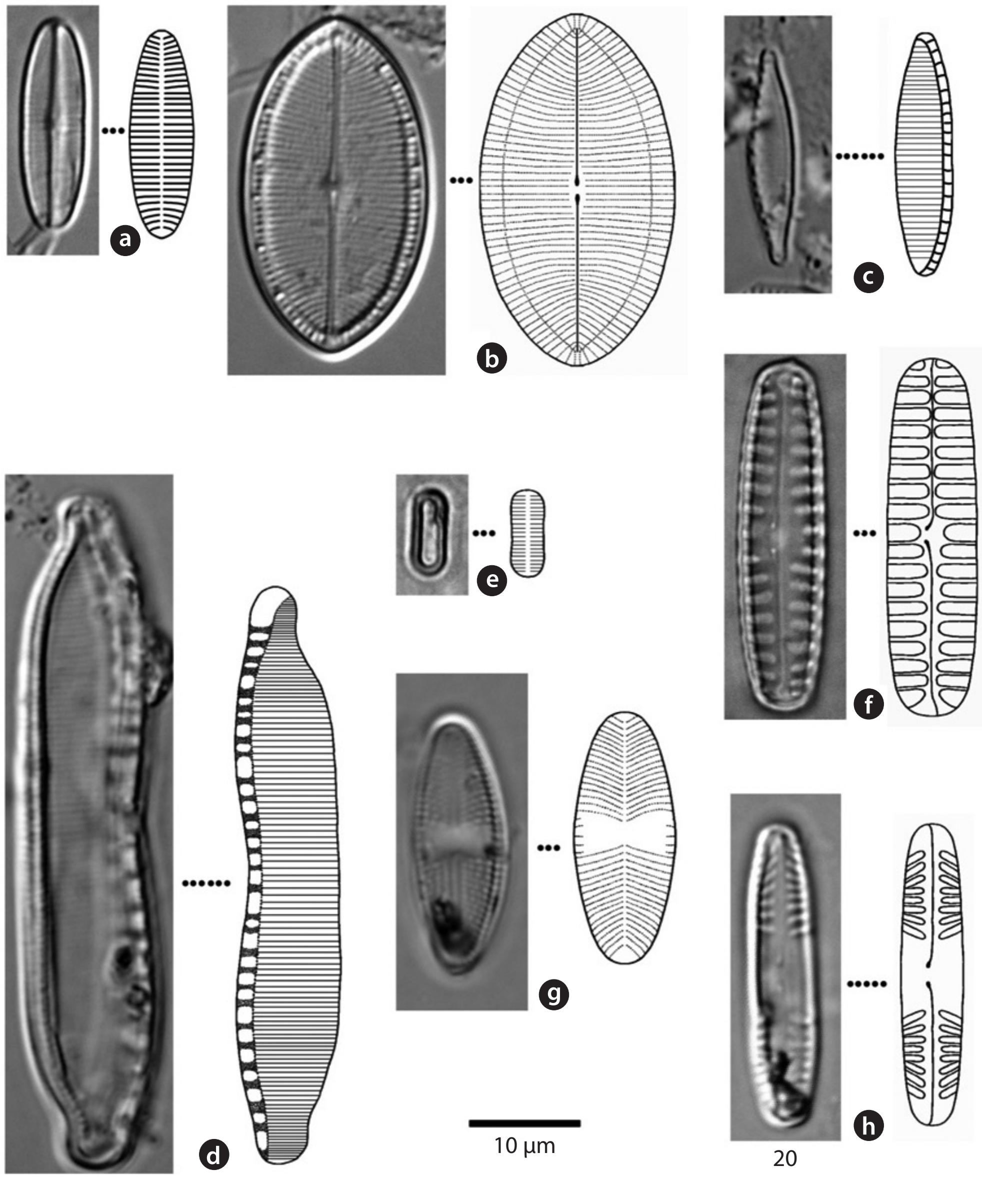

Fig. 5. The photographs and drawings of (a) *Achnanthes convergens*, (b) *Cocconeis placentula* var. *lineata*, (c) *Nitzschia palea*, (d) *Hantzschia amphioxys*, (e) *Navicula contenta,* (f) *Pinnularia borealis*, (g) *Navicula goeppertiana*, and (h) *Pinnularia subcapitata,* appeared from Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012. Scale bar, 10 μm.

living in attached or free-floating form in ponds and shallow lakes (John et al. 2002). It appeared on tree bark (Site 23), humidity of 65.5%, in this study. Although the shape of *Tolypothrix distorta* is similar in air and under water, when they were grown on the culture medium, the distance between cells became tighter as the sheath was lost. This may be caused by the fact that the function of the sheath—to retain moisture—becomes useless when it is grown in liquid culture media; therefore, it is important to identify it as a sample before placing it on a growth medium.

BACILLARIOPHYCEAE

13. *Achnanthes convergens* H.Kobayasi (Fig. 5a)

Valve broadly linear, with simple rounded or slightly protracted ends. Striae in the central area parallel or radial in both valves (Chung 1993). Striae of raphe valve 15-18 rows within 10 μm in the central area and 35-40 rows at the terminal ends. Valves 10-15 μm long and 4-4.5 μm wide.

This species appeared in soils (Site 28) in this research.

14. *Cocconeis placentula* var. *lineata* (Ehrenberg) P. Cleve (Fig. 5b)

Cocconeis placentula var. *lineata* has fewer striae than *Cocconeis placentula* (Chung 1993). Valve ellipsoidal. The puncta are more distant forming several (up to 12) hyaline lines. Striae of raphe valve 19-23 rows within 10 µm, valve 11-30 µm long and 12-14 µm wide.

This species appeared in soils (sites 13, 18, 22) in this research.

15. *Hantzschia amphioxys* (Ehrenberg) Grunow (Fig. 5d)

Apical plane of valve asymmetry, arch-shaped. Fibulae 4-11 rows within 10 µm, striae 11-28 rows in 10 µm. Valve 40-60 µm long, 8-10 µm wide. The length of this species has been found to be up to 300 µm at the longest (Chung 1993), but in this study, a maximum length of 60 µm was found.

The species has been reported to grow both under water and in soil (Chung 1993, John et al. 2002, Lin et al. 2013). In this research, it was found in soils (Sites 24, 28) and tree barks (Sites 22, 25).

16. *Navicula contenta* Grunow ex Van Heurck (Fig. 5e)

Valve ellipsoidal. The central area of the valve flattened, both ends broad and rounded. Striae parallel or slight radial, striae of the terminal area inverse radial, 25-40 rows within 10 µm (Chung 1993). Valve 6-10 µm long and 2-4 µm wide.

This species appeared in soil (Site 24) and tree bark (Site 25) in this research.

17. *Navicula goeppertiana* (Bleisch) H. L. Smith (Fig. 5g)

Synonym: *Navicula mutica* var. *goeppertiana* (Bleisch) Grunow in Van Heurck.

Valve ellipsoidal or narrow ellipsoidal, with terminal ends sharp or round (Chung 1993). Median ends of the raphe turned slightly to one side. Central area broad, striae punctate, about 15 rows within 10 µm. Valve 10-30 µm long, 4-10 µm wide.

In this research, this species appeared in soils (Site 28) and tree barks (Sites 26, 27).

18. *Nitzschia palea* (Kützing) W.Smith (Fig. 5c)

Valve narrow sharp or linear, apices of valve round or rostrate-capitate (Chung 1993). Fibulae 9-17 rows in 10 µm, striae 20-40 rows in 10 µm. Valve 15-70 µm long, 2.5-5 µm wide.

This species appeared on rocks (Sites 7, 17) in this research.

19. *Pinnularia borealis* Ehrenberg (Fig. 5f)

Valve broad linear, terminal ends rounded. Median ends of the raphe turned slightly to one side, axial area narrow. Striae usually parallel, 4-6 rows in 10 µm (Chung 1993). Valve 30-40 µm long, 8-12 µm wide.

This species appeared in soil (Site 24), and on tree barks (Sites 22, 25) and rocks (Sites 17, 19) in this research.

20. *Pinnularia subcapitata* W. Gregory (Fig. 5h)

Valve linear with capitate to subcapitate ends. Axial area narrow, central area rounded or elliptical (Chung 1993). Striae somewhat radiating at the center of the valve, convergent at the ends. Striae, 12-13 in 10 µm; toward the center of the valve, sometimes 10 in 10 µm. Valve 24-42 µm long, 4-6 µm wide.

This species appeared in soil (Site 28) in this research.

KLEBSORMIDIOPHYCEAE

21. *Klebsormidium crenulatum* (Kützing) H.Ettl & Gärtner (Fig. 6a)

Cells cylindrical, walls thick. Chloroplast encircles up to about 80% of cell circumference (John et al. 2002). Cells 7-15 µm long, 10-14 µm wide, 0.5-2 times longer than wide.

This species has been reported to inhabit aquatic and subaquatic biotopes (John et al. 2002) and appeared on rocks (Sites 2, 12, 14, 15, 19) in this study.

22. *Klebsormidium dissectum* (F.Gay) H.Ettl & Gärtner (Fig. 6b)

Filaments straight or slightly bent. Cell walls straight. Chloroplast encircling half to just over two-thirds of cell circumference. Cells 7-15 µm long, 5-8 µm wide.

This species has been reported as inhabiting aquatic and subaquatic biotopes (John et al. 2002) and appeared mostly in aerial biotopes in this study.

23. *Klebsormidium flaccidum* (Kützing) P.C.Silva, K.R.Mattox and W.H.Blackwell (Fig. 6c)

Filaments long, bent or twisted. Cells cylindrical, walls thin, chloroplast encircles up to about two-thirds of cell circumference. Cells 8-20 µm long, 6.5-7 µm wide, 1 to 3 times longer than wide.

This species has been reported to inhabit aquatic and subaquatic biotopes (John et al. 2002) and appeared mostly in aerial biotopes in this study.

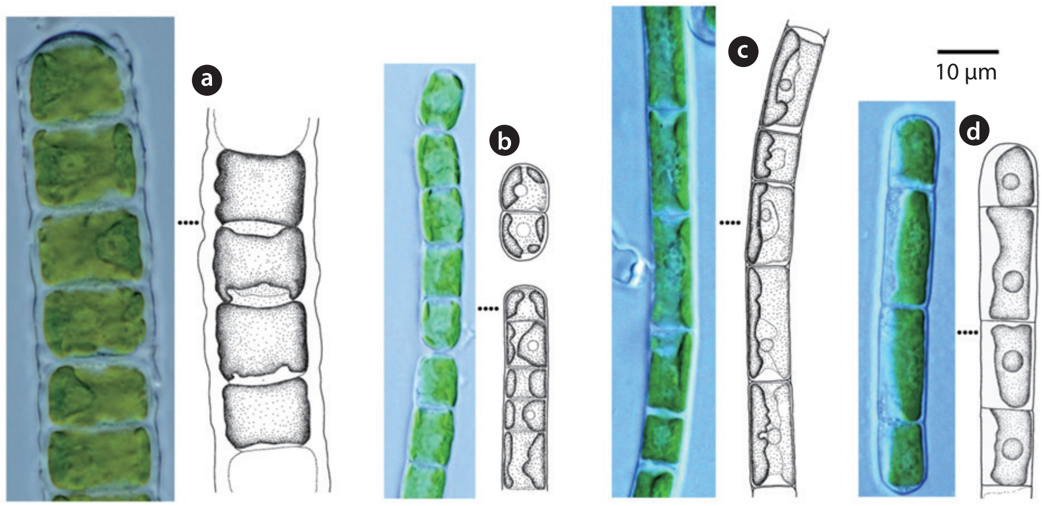

Fig. 6. The photographs and drawings of (a) *Klebsormidium crenulatum*, (b) *Klebsormidium dissectum,* (c) *Klebsormidium flaccidum*, (d) *Klebsormidium klebsii,* appeared from Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012. Scale bar, 10 µm.

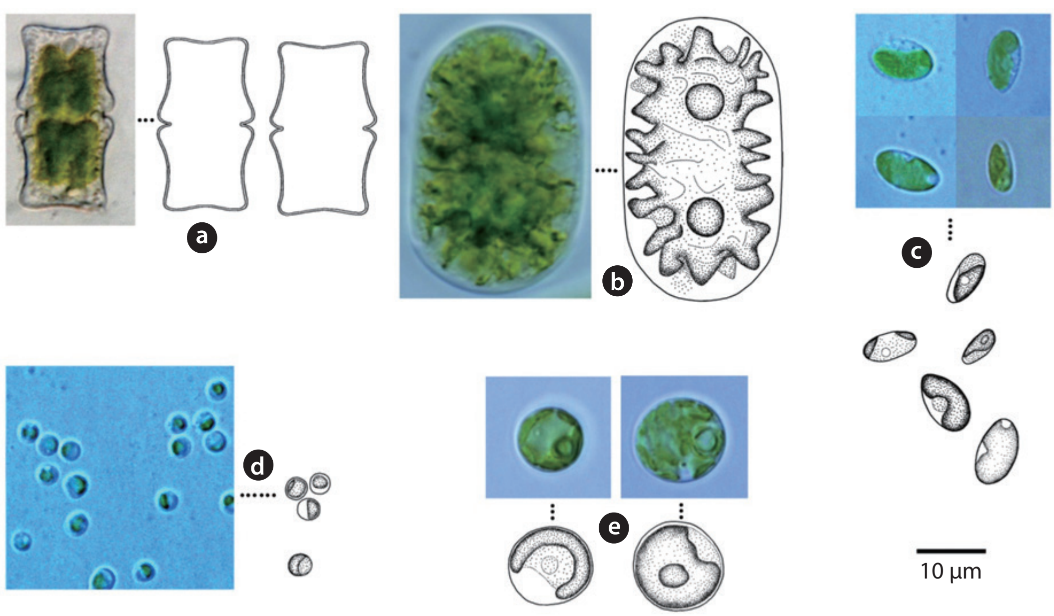

Fig. 7. The photographs and drawings of (a) *Cosmarium decedens*, (b) *Cylindrocystis brebissonii*, (c) *Chlorella ellipsoidea*, (d) *Chlorella minutissima,* (e) *Chlorella vulgaris,* appeared from Mt. Gwanggyo of Gyeonggi-do, Korea, from March 2011 to August 2012. Scale bar, 10 µm.

24. *Klebsormidium klebsii* (G. M. Smith) P.C. Silva, K.R.Mattox and W.H.Blackwell (Fig. 6d)

Filament not branched. Chloroplast encircles about 50% of cell circumference. Cells 12-25 µm long, 5-6 µm wide.

This species has been reported to inhabit aquatic and subaquatic biotopes (John et al. 2002) and appeared in soil (Site 24) and on rock (Site 2) in this study.

ZYGNEMATOPHYCEAE

25. *Cosmarium decedens* (Reinsch) Raciborski (Fig. 7a)

Cells twice as long as wide, medium-sized; median constriction shallow, the sinus open; semicells rectangular, the basal angles rounded, the lateral margins retuse to the apical angles, which are slightly more broadly rounded (John et al. 2002). Semicell 14-16 µm long, 13-15 µm wide, 11-12 µm Isthmus.

This species has been reported as inhabiting aquatic and subaquatic biotopes (John et al. 2002) and appeared in soils (Sites 24, 28) in this study.

26. *Cylindrocystis brebissonii* Menehini (Fig. 7b)

Cells cylindrical, apices rounded, 30-35 µm long, 20-23 µm wide. Chloroplasts star-shaped, a central spherical pyrenoid.

This species has been reported to inhabit aquatic and subaquatic biotopes (John et al. 2002) and appeared on tree bark (Site 22) and rocks (Sites 2, 4) in this study.

TREBOUXIOPHYCEAE

27. *Chlorella ellipsoidea* Gerneck (Fig. 7c)

Cells cylindrical-ellipsoidal, ellipsoidal or ovoid-ellipsoidal (John et al. 2002). Chloroplast trough-like or band-shaped, covering one half of cell, margins irregularly undulate and occasionally incised. An indistinct pyrenoid visible or invisible. Cells 5-7 µm long, 3-4 µm wide.

This species has been reported to inhabit aquatic and subaquatic biotopes (John et al. 2002) and appeared on tree barks (Sites 20, 22, 29), and rocks (Sites 8, 12, 14, 15, 16, 17, 19) in this study.

28. *Chlorella minutissima* Fott and Nováková (Fig. 7d)

Cells spherical, 1-2 µm. Chloroplast cup-shaped. Pyrenoid invisible.

In previous studies, this species has been reported as inhabiting aquatic and subaquatic biotopes (John et al. 2002). It appeared on tree bark (Site 29) and rock (Site 17) in this study.

29. *Chlorella vulgaris* Beyerinck [Beijerinck] (Fig. 7e)

Cells spherical. Chloroplast broadly cup-shaped or band-shaped, filling one-half to three-quarters (Chung 1993). A pyrenoid visible. Cells 5-3 µm diameter..

This species has been reported to inhabit soil, tree bark, and rock, and to symbiose with lichen, according the studies by Aleksahina and Shtina (1984), Andreyeva (1988), Rindi and Guiry (2004), and Khaybullina et al. (2010). It appeared on tree bark (Site 23) in this study.

In total, including 3 species that were newly found in this study, there are reported to be a total of 99 Korean aerial algae taxa (Chung 1968, 1993, Chang et al. 1998, Lim and Lee 2008a, 2008b).

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LITERATURE CITED

Aleksahina TI, Shtina EA. 1984. Terrestrial Algae of Forest Biogeocoenoses (Pochvennye Vodorosli Lesnych Biogeotsenozov). Nauka, Moscow.

Anagnostidis K, Komárek J. 1988. Modern approach to the classification system of cyanophytes. 3. Oscillatoriales. Arch Hydrobiol Suppl 80: 327-472.

Andreyeva VM. 1988. Terrestrial and Aerophilic Green Algae-Chlorophyta: Tetrasporales, Chlorococcales, Chlorosarcinales (Pochvennyei Aerofil'nye Zelenye Vodorosli-Chlorophyta: Tetrasporales, Chlrococcales, Chlorosarcinales). Nauka, St. Petersburg.

Bold HC, Parker BC. 1962. Some supplementary attributes in the classification of *Chlorococcum* species. Arch Microbiol 42: 267-288.

Bold HC, Wynne MJ. 1978. Introduction to the Algae: Structure and Reproduction. Prentice Hall, NJ.

Chang YK, Lee JW, Jeon SL, Kim MR. 1998. A taxonomic study of the soil algae in Korea. J Natl Sci Sookmyung Women's Univ 9: 39-43.

Chu SP. 1942. The influence of the mineral composition of the medium on the growth of planktonic algae. Part I. Methods and culture media. J Ecol 30: 284-325.

Chung J. 1993. Illustration of the Freshwater Algae of Korea. Academy Publishing Co., Seoul. (in Korean)

Chung YH. 1968. Illustrated Encyclopedia of Fauna & Flora of Korea. Vol. 9. Fresh water algae. Samhwa Publishing Co., Seoul. (in Korean)

Crispim CA, Gaylarde CC, Gaylarde PM. 2004. Biofilms on church walls in Porto Alegre, RS, Brazil, with special attention to cyanobacteria. Int Biodeterior Biodegrad 54: 121-124.

Gaylarde PM, Gaylarde CC. 2000. Algae and cyanobacteria on painted buildings in Latin America. Int Biodeter Biodegr 46: 93-97.

Goyal SK. 1997. Algae and the soil environment. Phykos 36: 1-13.

Graham LE, Graham JM, Wilcox LW. 2009. Algae. 2nd ed. Benjamin Cummings, San Francisco, CA.

Guiry MD, Guiry GM. 2013. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway.

http://www.algaebase.org. Accessed 01 January 2013.

Hirose HM, Akiyama T, Imahori H, Kasaki H, Kumano S, Kobayasi H, Takahashi E, Tsumura T, Hirano M, Yamagishi T. 1977. Illustrations of the Japanese Freshwater Algae. Uchidarokakuho publishing Co. Ltd., Tokyo.

Hoffmann L. 1989. Algae of terrestrial habitats. Bot Rev 55: 77-105.

John DM, Whitton BA, Brook AJ. 2002. The Freshwater Algal Flora of the British Isles: An Identification Guide to Freshwater and Terrestrial Algae. Cambridge University Press, Cambridge.

John DW, Robert GS. 2003. Freshwater Algae of North America : Ecology and Classification. 1st ed. Academic Press, San Diego, CA.

Khaybullina LS, Gaysina LA, Johansen JR, Krautova M. 2010. Examination of the terrestrial algae of the Great Smoky Mountains National Park, USA. Fottea 10: 201-215.

Kies L. 1967. Über Zellteilung und Zygotenbildung bei *Roya obtusa* (Bréb.) West et West. Mitt Staatsinst Allg Bot12: 35-42.

Kim YJ, Kim OJ, Lee OM. 2010. The distribution of aerial algae and the assessment of biological pollution class at 8 stone cultural heritages in Korea. J Conserv Sci 26: 259-268. (in Korean with English abstract)

Kim YJ, Kim OJ, Lee OM. 2011. The community of aerial algae and the biological pollution coverage at 9 stone cultural heritages in Korea. J Conserv Sci 27: 145-154. (in Korean with English abstract)

King JM, Ward CH. 1977. Distribution of edaphic algae as related to land usage. Phycologia 16: 23-30.

Klochkova TA, Kang SH, Cho GY, Pueschel CM, West JA, Kim GH. 2006. Biology of a terrestrial green alga, *Chlorococcum* sp. (Chlorococcales, Chlorophyta), collected from the Miruksazi stupa in Korea. Phycologia 45: 349-358.

Komárek J. 2013. Süsswasserflora von Mitteleuropa. Cyanoprokaryota: 3rd part: heterocystous genera. Springer Spektrum, Heidelberg.

Komárek J, Anagnostidis K. 2005. Cyanoprokaryota 2. Teil/ Part 2: Oscillatoriales. In: Epipelic Filamentous Cyanobacteria Mitteleuropa (Büdel B, Gärdner G, Krienitz L, Schagerl M,eds). Elsevier, Heidenberg.

Lemes-Da-Silva NM. Branco LHZ, Necchi-Junior O. 2010. Corticolous green algae from tropical forest remnants in the northwest region of Sao Paulo State, Brazil. Rev Bras Bot 33: 215-226.

Lim AS, Lee OM. 2008a. Distribution of aerial algae and biological classes in five stone cultural properties of Korea. Algae 23: 63-69.

Lim AS, Lee OM. 2008b. The distribution of aerial algae and the evaluation of algal inhabitation on five stone cultural properties in Gyeonggi-do. Algae 23: 269-276.

Lin CS, Chou TL, Wu JT. 2013. Biodiversity of soil algae in the farmlands of mid-Taiwan. Bot Stud 54: 41-51.

MacCaughey V. 1917. The phytogeography of Manoa Valley, Hawaiian Islands. Am J Bot 4: 561-603.

MacCaughey V. 1918a. Algae of the Hawaiian Archipelago I. Bot Gaz 65: 42-57.

MacCaughey V. 1918b. Algae of the Hawaiian Archipelago II. Bot Gaz 65: 121-149.

Macedo MF, Miller AZ, Dionisio A, Saiz-Jimenez C. 2009. Biodiversity of cyanobacteria and green algae on monuments in the Mediterranean Basin: an overview. Microbiology 155: 3476-3490.

Makandar MB, Bhatnagar A. 2010.Morphotypic diversity of microalgae from arid zones of Rajasthan (India). J Algal Biomass Utln 1: 74-92.

Mansour HA, Shaaban AS. 2010. Algae of soil surface layer of Wadi Al-Hitan protective area (world heritage site), El-Fayum Depression, Egypt. J Am Sci 6: 243-255.

Mikter SS, Shukla SP. 2006. Study on algal flora of algae-moss association on barks of some selected tree species at rono-hills of papum pare district in arunachal pradesh, India. Bull Aruna For Res 22: 1-8.

Neustupa J, Skaloud P. 2010. Diversity of subaerial algae and cyanobacteria growing on bark and wood in the lowland tropical forests of Singapore. Plant Eco Evol 143: 51-62.

Prescott GW. 1973. Algae of the Western Great Lakes Area. Otto Koeltz Science Publishers, Koenigstein.

Prescott GW, Bicudo CEM, Vinyard WC. 1982. A Synopsis of North American Desmids. Part II. Secton 4. The University of Nebraska Press, Lincoln, NE.

Prescott GW, Croasdale HT, Bicudo CEM, Vinyard WC. 1981. A Synopsis of North American Desmids. Part II. Section 3. The University of Nebraska Press, Lincoln, NE.

Prescott GW, Croasdale HT, Vinyard WC. 1972. North American Flora, Desmidiales. New York Botanical Garden, New York, NY.

Prescott GW, Croasdale HT, Vinyard WC. 1977. A Synopsis of North American Desmids. Part II. Desmidiaceae: Placodermae. Section 2. The University of Nebraska Press, Lincoln, NE.

Protist Information Server. 2007. Japan Science and Technoloy Corporation. http://protist.i.hosei.ac.jp. Accessed 24 June 2007.

Rindi F, Guiry MD. 2004. Composition and spatial variability of terrestrial algal assemblages occurring at the bases of urban walls in Europe. Phycologia 43: 225-235.

Samad LK, Adhikary SP. 2008. Diversity of micro-algae and cyanobacteria on building facades and monuments in India. Algae 23: 91-114.

Stein JR. 1979. Handbook of Phycological Methods. Cambridge University Press, Cambridge.

Syiem MB, Hynniewta L, Pinokiyo A. 2011. *Nostoc* cyanobiont in the Cyanolichen, Sticta weigelii of Eastern Himalayan region: isolation, physiological and biochemical characterization. J Exp Sci 2: 36-40.

Tilden JE. 1901. Algae collecting in the Hawaiian Islands. Postelsia 1: 135-175.

Tilden JE. 1902. Collection of algae from the Hawaiian Islands. Hawaiian Annual 1902: 106-113.

Zancan S, Trevisan R, Paoletti MG. 2006. Soil algae composition under different agro-ecosystems in North-Eastern Italy. Agric Ecosyst Environ 112: 1-12.