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# Diversity of phytoplankton species in Cheonjin Lake, northeastern South Korea

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## Abstract

**Background:** Several investigations carried out from large brackish lagoons in South Korea. However, no studies have yet examined phytoplankton in lagoons that changed to freshwater, such as Cheonjin Lake. The present study examined the algae from Cheonjin Lake.

**Methods:** Samples were collected at monthly intervals from May 2017 to April 2018, from the surface layer using a plankton net (mesh size 20  $\mu\text{m}$ ), and squeezing submerged macrophytes. Microscopic examinations were conducted at a magnification of 200 to 1000x using a Zeiss microscope (Axio Imager. A2), and photographs were taken with an AxioCam HRC camera. Silica-scaled samples of Chrysophyta for SEM were placed on coverglass, air dried, coated with gold, and then examined with a Hitachi SV8220 SEM.

**Results:** A total of 376 taxa from six major algal groups (Chlorophyta, Chrysophyta, Euglenophyta, Cyanophyta, Dinophyta, and Cryptophyta) were identified. Among these algae, 28 taxa of desmids, 9 taxa of Euglenophyceae, 4 taxa of Chlorophyceae, 2 taxa of Chrysophyceae, and 1 taxon of Xanthophyceae are reported for the first time in Korea. A new species, *Cosmarium hexagonum* sp. nov. was described. The phytoplankton communities were characterized by an abundance of Desmids (within Charophyceae) accounted for 148 taxa from 22 genera. Species richness were particularly high in the Autumn.

**Conclusion:** In this study, a total 376 taxa of 148 desmids (Charophyceae), Chlorophyceae (103 taxa), Chrysophyceae (53 taxa), Euglenophyta (49 taxa), Dinophyta (8 taxa), and Cryptophyta (2 taxa) were identified from Cheonjin Lake. Twenty-eight taxa of desmids including a new species (*Cosmarium hexagonum* sp. nov.), 9 taxa of Euglenophyceae, 4 taxa of Chlorophyceae, 2 taxa of Chrysophyceae, and 1 taxon of Xanthophyceae were newly recorded in Korea.

**Keywords:** Lagoon, Phytoplankton, Desmids, For the first time in Korea, New species

## Background

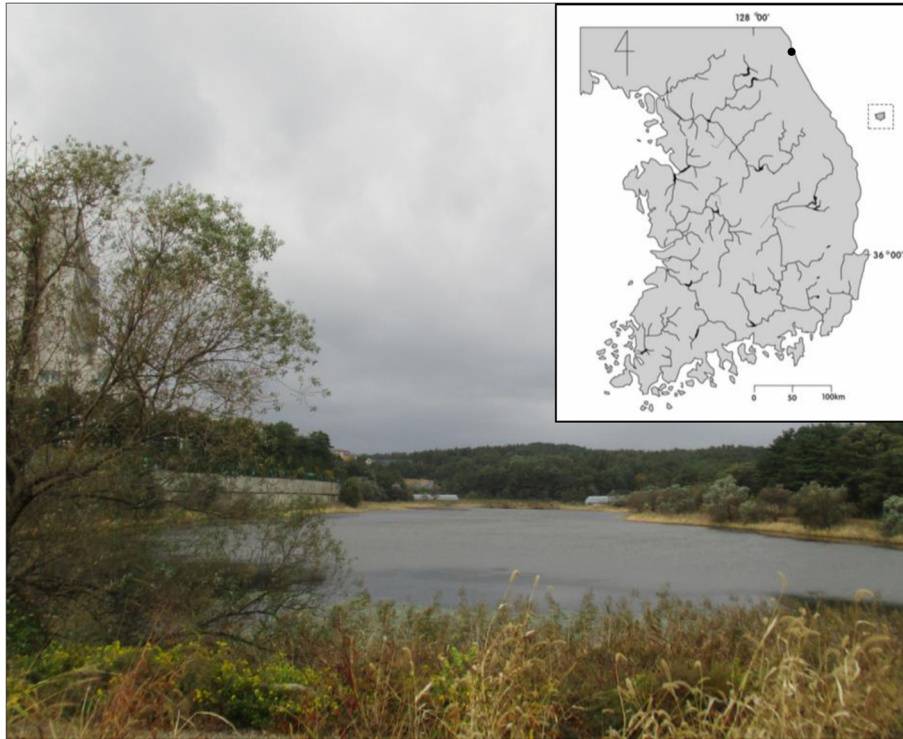
Many investigations of freshwater algae in different regions of Korea have examined reservoirs, dam lakes, swamps, lagoons, streams, and rivers (Chung et al. 1968; Chung 1975, 1976, 1979; Chung et al. 1972a, 1972b; Chung and Lee 1986; Wui and Kim 1987a, 1987b; Kim and Chung 1993a, 1993b; Kim 1996, 1997; Kim et al. 1995; Kim et al. 2007; Kim et al. 2009; Kim 2013a, b, c, 2014a, b). There are currently about 3888 known taxa of freshwater algae in Korea, and these taxa are in Cyanophyta (343 taxa), Chlorophyta (1542 taxa), Ochrophyta (167 taxa), Cryptophyta (12 taxa), Euglenophyta (329

taxa), and Bacillariophyceae (1495 taxa) (Kim 2015, Lee and Joh 2015, Lee and Kim 2015, Lee and Kim 2015). Most previous freshwater floristic and taxonomic studies of algae in Korea have examined lowland habitats, such as reservoirs, dam lakes, swamps, ponds, streams, and rivers, and only a few have examined highland wetlands.

There are 18 lagoons in Korea, and these are concentrated on the middle-eastern coast of the Korean peninsula (Gangwon Province). More than half of these lagoons were previously freshwater lakes, or seriously damaged by road construction, reclamation to cultivated land, or development. Some previous investigations have examined phytoplankton from large brackish lagoons in South Korea (Cho and Park 1969; Hong et al. 1969; Cho et al. 1975; Lee et al. 2000; Moon and Lee 2002; Heo et al.

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**Fig. 1** Map showing the Cheonjin Lake located in northeastern South Korea

2004; Kwon et al. 2005). However, no studies have yet examined phytoplankton in lagoons that changed to freshwater, such as Cheonjin Lake.

Desmids, a group of green algae within the Charophyceae, occur in diverse freshwater habitats, most of which have low salinity and hence low specific conductivity. This includes reservoirs, lakes, ponds, ditches, and bogs, but desmids are especially abundant in acid bogs, in association with *Sphagnum* and *Utricularia* species (Brook 1981; Brook and Williamson 2010).

The present study examined the phytoplankton from Cheonjin Lake, formerly a small lagoon, but now a freshwater lake in northeastern South Korea.

## Methods

### Study site

Cheonjin Lake is located in the near the coastal region of South Korea (Fig. 1) at latitude 38° 15' 14" N and longitude 128° 33' 22" E. This lake was originally a brackish lagoon connected to the East Sea, but it changed to a freshwater lake following road construction. Over time, it was polluted and reduced in size because of various development projects and reclamation for farmland. The surface area is about 0.28 km<sup>2</sup> and the depth is about 1.5 m. The vegetation is abundant and mainly consists of reeds (Poales) and water lilies (*Nymphaea* spp.).

### Sample collection and identification

Samples were collected at monthly intervals from May 2017 to April 2018, from the surface layer using a plankton net (mesh size 20 μm), and by squeezing submerged macrophytes. All living materials were immediately examined, and after an initial examination, materials were fixed with 5% formalin for permanent preservation and detail identification. Microscopic examinations were conducted at a magnification of 200 to 1000× using a Zeiss microscope (Axio Imager.A2), and photographs were taken with an AxioCam HRC camera (Carl Zeiss). Silica-scaled samples of Chrysophyta for scanning electron microscopy (SEM) were placed on coverglass, air dried, coated with gold, and then examined with a Hitachi SV8220 SEM. Bacillariophyceae were not examined. The materials were deposited at the Department of Biology, Kyungpook National University.

## Results

### Algae in Cheonjin Lake

I identified 376 taxa from seven major algal groups in Cheonjin Lake. There were 148 desmids (Charophyceae), the most abundant group. This was followed by Chlorophyceae (103 taxa), Chrysophyta (53 taxa), Euglenophyta (49 taxa), Cyanophyta (13 taxa), Dinophyta (8 taxa), and Chryptophyta (2 taxa) (Table 1). There were 28 species of desmids new to Korea, and one newly identified species—

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula

## Division Cyanophyta Class Cyanophyceae

*Anabaena* sp.  
*Aphanothece microscopica*  
*Chroococcus minutus*  
*Cyanothece aeruginosa*  
*Geitlerinema splendidum*  
*Hapalosiphon hibernicus*  
*Merismopedia glauca*  
*Merismopedia tenuissima*  
*Oscillatoria agardhii*  
*Oscillatoria princeps*  
*Oscillatoria tenuis*  
*Phormidium simplicissimum*  
*Scytonema* sp.

## Division Chlorophyta Class Chlorophyceae

*Ankistrodesmus densus*  
*Ankistrodesmus faciculatus*  
*Ankistrodesmus falcatus*  
*Ankistrodesmus fusiformis*  
*Ankistrodesmus spiralis*  
*Asterococcus superbus*  
*Botryococcus braunii*  
*Botryococcus sudetica*  
*Bulbochaete* sp.  
*Chaetophora pisiformis*.  
*Chaetosphaeridium globosum*  
*Chlamydomonas* sp.  
*Coelastrum asteroideum*  
*Coelastrum indicum*  
*Coelastrum microporum*  
*Coelastrum probocideum*  
*Coelastrum pulchrum*  
*Coelastrum sphaericum*  
*Crucigenia fenestrata*  
*Crucigenia tetrapedia*  
*Crucigeniella apiculata*  
*Crucigeniella crucifera*  
*Crucigeniella pulchra*  
*Crucigeniella quadrata*  
*Crucigeniella rectangularis*  
*Diacanthos belenophorus*  
*Dictyosphaerium ehrenbergianum*  
*Dictyosphaerium pulchellum*  
*Dictyosphaerium sphagnale*  
*Dimorphococcus lunatus*

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

*Elakatothrix genevensis*  
*Geminella spiralis*  
*Gloeocystis gigas*  
*Gonium sociale*  
*Kirchneriella aperta*  
*Kirchneriella contorta*  
*Kirchneriella contorta* var. *gracillima*  
*\*Kirchneriella diana*  
*Kirchneriella irregularis*  
*Kirchneriella lunaris*  
*Kirchneriella obesa*  
*Micractinium pusillum*  
*Monoraphidium contortum*  
*Monoraphidium griffithii*  
*Nephrocytium limneticum*  
*\*Oligochaetophora simplex*  
*Oocystis borgei*  
*Oocystis lacustis*  
*Palmodictyon varium*  
*Pandorina morum*  
*Pediastrum angulosum*  
*Pediastrum boryanum*  
*Pediastrum duplex*  
*Pediastrum duplex* var. *asperum*  
*Pediastrum duplex* var. *gracilimum*  
*Pediastrum duplex* var. *rugulosum*  
*Pediastrum tetras*  
*Quadrigula closterioides*  
*Quadrigula lacustris*  
*\*Radiofilum conjunctivum*  
*Radiofilum flavescens*  
*Scenedesmus acuminatus*  
*Scenedesmus acutus*  
*Scenedesmus arcuatus*  
*Scenedesmus arcuatus* var. *platydiscus*  
*Scenedesmus armatus*  
*Scenedesmus armatus* var. *bicaudatus*  
*Scenedesmus armatus* var. *boglariensis*  
*Scenedesmus bicaudatus*  
*Scenedesmus brasiliensis*  
*Scenedesmus carinatus*  
*Scenedesmus circumfsus*  
*Scenedesmus denticulatus*  
*Scenedesmus disciformis*

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

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<i>Scenedesmus dispar</i>
<i>Scenedesmus ecornis</i>
<i>Scenedesmus ellipsoides</i>
* <i>Scenedesmus gutwinskii</i> var. <i>bacsensis</i>
<i>Scenedesmus intermedius</i>
<i>Scenedesmus opoliensis</i>
<i>Scenedesmus quadricauda</i> var. <i>longispina</i> f. <i>capricornus</i>
<i>Scenedesmus quadricauda</i>
<i>Scenedesmus quadrispina</i>
<i>Scenedesmus quadrispina</i> var. <i>longispina</i>
<i>Scenedesmus serratus</i>
<i>Scenedesmus spinosus</i>
<i>Selenastrum bibrianum</i>
<i>Selenastrum westii</i>
<i>Sorastrum spinulosum</i>
<i>Sphaerocystis schroeteri</i>
* <i>Tetrademus lunatus</i>
<i>Tetraedron constrictum</i>
<i>Tetraedron enorme</i>
<i>Tetraedron incus</i> var. <i>regulare</i>
<i>Tetraedron planktonicum</i>
<i>Tetraedron regulare</i>
<i>Tetraedron trigonum</i>
<i>Tetraedron trigonum</i> var. <i>gracile</i>
<i>Tetraedron tumidulum</i>
<i>Tetrallantos lagerheimii</i>
<i>Tetrastrum triangulare</i>
<i>Westella botryoides</i>
<i>Westella linearis</i>
Class Charophyceae(Desmids)
<i>Actinotaenium australe</i>
* <i>Actinotaenium cucurbitinum</i>
<i>Actinotaenium turgidum</i>
<i>Arthrodesmus convergens</i>
<i>Closterium acutum</i>
* <i>Closterium angustum</i>
<i>Closterium attenuatum</i>
<i>Closterium caciculare</i>
<i>Closterium calosporum</i>
<i>Closterium closterioides</i> var. <i>intermrdium</i>
<i>Closterium cornu</i>
<i>Closterium costatum</i>
<i>Closterium diana</i>
<i>Closterium diana</i> var. <i>minus</i>

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

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<i>Closterium directum</i>
<i>Closterium gracile</i>
<i>Closterium incurvum</i>
<i>Closterium intermedium</i>
* <i>Closterium juncidium</i>
<i>Closterium kuetzingii</i>
<i>Closterium littorale</i>
<i>Closterium navicula</i>
<i>Closterium navicula</i> var. <i>crassum</i>
<i>Closterium parvulum</i>
<i>Closterium parvulum</i> var. <i>angustum</i>
<i>Closterium pronum</i>
<i>Closterium ralfsii</i> var. <i>hybridum</i>
<i>Closterium rostratum</i>
<i>Closterium setaceum</i>
<i>Closterium strigosum</i>
<i>Closterium striolatum</i>
<i>Closterium tumidulum</i>
* <i>Cosmarium abbreviatum</i> var. <i>germanicum</i>
<i>Cosmarium auriculatum</i>
<i>Cosmarium binum</i>
<i>Cosmarium connatum</i>
<i>Cosmarium contractum</i>
<i>Cosmarium contractum</i> var. <i>ellipsoideum</i>
* <i>Cosmarium contractum</i> var. <i>incrasatum</i>
* <i>Cosmarium contractum</i> var. <i>minutum</i>
<i>Cosmarium decachondrum</i>
<i>Cosmarium depressum</i>
<i>Cosmarium</i> cf. <i>depressum</i> var. <i>planktonicum</i>
* <i>Cosmarium exiguum</i>
* <i>Cosmarium geminatum</i>
<i>Cosmarium globosum</i>
<i>Cosmarium granatum</i>
<i>Cosmarium hammeri</i> var. <i>protuberans</i>
* <i>Cosmarium hexagonum</i> sp. nov.
<i>Cosmarium impressulum</i>
<i>Cosmarium impressulum</i> var. <i>crenulatum</i>
* <i>Cosmarium inornatum</i>
<i>Cosmarium lundellii</i> var. <i>ellipticum</i>
* <i>Cosmarium medioscrobiculatum</i> var. <i>egranulatum</i>
<i>Cosmarium moniliforme</i>
<i>Cosmarium navicula</i>
<i>Cosmarium navicula</i> var. <i>crassum</i>
<i>Cosmarium obsoletum</i>

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

*Cosmarium obsoletum* var.*sitvense*  
*Cosmarium obtusatum*  
 \**Cosmarium ocellatum* var.*glabrum*  
 \**Cosmarium ocellatum* var.*notatum*  
 \**Cosmarium ordinatum* var.*borgei*  
*Cosmarium pachydermum*  
*Cosmarium polonicum*  
*Cosmarium portianum*  
*Cosmarium pseudomagnificum*  
*Cosmarium quadriparum* var.*hexastichum*  
*Cosmarium quadrum*  
*Cosmarium regnesii*  
 \**Cosmarium reniforme* var.*elevatum*  
 \**Cosmarium stigmosum*  
*Cosmarium subauriculatum*  
*Cosmarium subcucumis*  
*Cosmarium subimpressulum*  
*Cosmarium subspeciosum*  
*Cosmarium turgidum*  
*Cosmarium zonatum*  
*Cosmarium* sp.  
*Cosmocladium constrictum*  
*Cylindrocystis brebissonii*  
*Cylindrocystis gracilis*  
*Desmidium aptogonum*  
 \**Desmidium baileyi* var.*caleatum*  
*Desmidium coarctatum*  
*Desmidium swartzii*  
*Euastrum ansatum* var.*pyxidatum*  
*Euastrum binale* var.*gutwinskii*  
*Euastrum denticulatum*  
*Euastrum sinuosum*  
*Euastrum spinulosum* var. *inermius*  
*Gonatozygon aculeatum*  
*Gonatozygon brebissonii*  
*Gonatozygon kinahanii*  
*Gonatozygon monotaenium*  
 \**Haplotaenium minutum* var.*elongatum*  
*Hyalotheca disciliens*  
*Mesotaenium degreyii*  
*Micrasterias crux-melitensis*  
*Micrasterias decemdentata*  
*Micrasterias foliacea*  
*Micrasterias pinnatipida*

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

*Netrium digitus*  
*Netrium interruptum*  
*Netrium lamellosum*  
*Netrium naegeli*  
*Onychonema filiforme*  
*Penium cylindrus*  
*Penium margaritaceum*  
*Penium spirostriolatum*  
*Pleurotaenium baculoides*  
*Pleurotaenium ehrenbergii*  
*Pleurotaenium ehrenbergii* var.*elongatum*  
 \**Pleurotaenium simplicissimum*  
*Pleurotaenium trabecula*  
*Sphaeroszma planum*  
 \**Spirotaenia kirchneri* var.*erythropunctata*  
*Spirogyra* sp.  
*Staurastrum alternans*  
 \**Staurastrum arachne*  
*Staurastrum asterias*  
*Staurastrum avicula*  
*Staurastrum brachiatum*  
*Staurastrum chaetoceras*  
 \**Staurastrum cyrtoceram* var.*inflexum*  
*Staurastrum gladiusum*  
*Staurastrum iotatum* var.*curvatum*  
*Staurastrum laponicum*  
*Staurastrum manfeldtii*  
*Staurastrum muticum*  
*Staurastrum orbiculare* var.*depressum*  
*Staurastrum pseudotetracerum*  
 \**Staurastrum sexangulare* var.*productum*  
 \**Staurastrum sinense*  
*Staurastrum tetracerum*  
*Stauroidesmus dejectus*  
*Stauroidesmus extensus* var.*josua*  
*Stauroidesmus extensus* var.*rectus*  
*Stauroidesmus glaber*  
*Tellingia granulata*  
*Tortitaenia obscura*  
 \*\**Triploceras gracile*  
*Xanthidium antilopaeum*  
*Xanthidium antilopaeum* var.*javanicum*  
 \**Xanthidium cristatum* var.*papilliferum*  
*Xanthidium cristatum* var.*uncinatum*

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

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\**Xanthidium octocorne*  
*Zygnemasp.*  
 Division Euglenophyta Class Euglenophyceae  
 \**Cyclidiopsis acus*  
*Euglena acus*  
*Euglena ehrenbergii*  
*Euglena oxyuris*  
*Euglena spirogyra*  
*Euglena sp.*  
 \**Lepocinclis acicularis*  
*Lepocinclis fusiformis*  
 \**Lepocinclis fusiformis var.amphirhynchus*  
 \**Lepocinclis fusiformis var.minor*  
*Lepocinclis marssonii*  
 \**Lepocinclis marssonii var.sinensis*  
*Lepocinclis ovum var.dimidiominor*  
*Lepocinclis ovum var.gracilicauda*  
 \**Lepocinclis ovum var.palatina*  
 \**Lepocinclis pseudovum*  
*Lepocinclis salina*  
*Menoidium gracile*  
 \**Phacus brevicaudatus*  
*Phacus curvicauda*  
*Phacus elegans*  
*Phacus helicoides*  
*Phacus horridus*  
 \**Phacus lefebri*  
*Phacus longicauda*  
*Phacus longicauda var. insecta*  
*Phacus longicauda var.major f.insecta*  
*Phacus orbicularis*  
*Phacus raciborskii*  
*Phacus ranula*  
*Phacus sp.*  
*Phacus suesicus*  
*Phacus undulatus*  
*Trachellomonas abrupta*  
*Trachellomonas acanthostoma*  
*Trachellomonas allia*  
*Trachellomonas armata*  
*Trachellomonas armata var. longispina*  
*Trachellomonas armata var.steinii*  
*Trachellomonas cylindricum*  
*Trachellomonas hispida*

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

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*Trachellomonas intermedia*  
*Trachellomonas oblonga*  
*Trachellomonas oblonga var.attenuata*  
*Trachellomonas oblonga var.punctata*  
*Trachellomonas planktonica var.oblonga*  
*Trachellomonas robusta*  
*Trachellomonas suferva*  
*Trachellomonas volvocina*  
 Division Chrysophyta Class Chrysophyceae  
*Chrysopyxis bipes*  
*Dinobryon bavaricum*  
*Dinobryon cylindricum*  
*Dinobryon divergens*  
*Dinobryon sociale*  
*Dinobryon suesicum var.longispinum*  
 \**Epipyxis ramosa*  
*Epipyxis utriculus*  
*Lagynion scherffelii*  
 \**Lagynion triangulare*  
 Class Synurophyceae  
*Chrysosphaerella coronacircumspina*  
*Chrysosphaerella longispina*  
*Chrysosphaerella sp.*  
*Mallomonas acaroides*  
*Mallomonas adamas*  
*Mallomonas areolate*  
*Mallomonas caudata*  
*Mallomonas clavus*  
*Mallomonas crassisquama*  
*Mallomonas cristata*  
*Mallomonas harisiae*  
*Mallomonas heterospina*  
*Mallomonas insignis*  
*Mallomonas lelymene*  
*Mallomonas mangofera var.foveata*  
*Mallomonas matvienkoeae*  
*Mallomonas multisetigera*  
*Mallomonas oviformis*  
*Mallomonas paxillata*  
*Mallomonas punctifera*  
*Mallomonas racilis*  
*Mallomonas sp.*  
*Mallomonas splendens*  
*Mallomonas striata*

**Table 1** A list of phytoplankton species of the Cheonjin Lake. \* indicates new to Korea, \*\* indicates new to Korean peninsula (Continued)

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<i>Mallomonas tonsurata</i>
<i>Paraphysomonas imperforata</i>
<i>Paraphysomonas vestita</i>
<i>Spiniferomonas trioralis</i>
<i>Synura curtispina</i>
<i>Synura petersenii</i>
<i>Synura sphagnicola</i>
<i>Synura uvella</i>
<i>Synuropsis uvella</i>
Class Rhaphidohycae
<i>Gonyostomum depressum</i>
<i>Gonyostomum semen</i>
Class Xanthophyceae
<i>Centritractus belenophorus</i>
<i>Ducellieria chodatii</i>
<i>Goniochloris contorta</i>
<i>Goniochloris smitii</i>
<i>Ophiocytium capitatum</i>
<i>Ophiocytium majus</i>
<i>Ophiocytium parvum</i>
* <i>Tetraedriella polychloris</i>
Division Chryptophyta Class Chryptohycae
<i>Cryptomonas ovata</i>
<i>Cryptomonas sp.</i>
Division Dinophyta Class Dinophyceae
<i>Cystodinium steinii</i>
<i>Dinococcus bicornus</i>
<i>Gymnodinium sp. 1</i>
<i>Gymnodinium sp. 2</i>
<i>Peridinium bipes</i>
<i>Peridinium cunningtonii</i>
<i>Peridinium sp. 1</i>
<i>Peridinium sp. 2</i>

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*C. hexagonum* sp. nov.. There were also 9 species of Euglenophyceae, 4 species of Chlorophyceae, 2 species of Chrysophyceae, and 1 species of Xanthophyceae that were new to Korea. I photographed and briefly discussed the taxonomy of all species (Plates 1, 2, 3, 4, 5, 6, and 7), including the one newly identified species of desmids.

Table 1 lists all algal species from Cheonjin Lake. Cheonjin Lake had abundant Charophyta, especially desmids, and significantly greater phytoplankton richness during the autumn (September and October; 180 taxa)

than during the cold season (December to March; 44 to 54 taxa) (Fig. 2).

### Chlorophyta

I identified 103 taxa in the Chlorophyceae, 4 of which are new to Korea. Also, we identified 148 taxa in the Charophyceae, and desmids were the most abundant and widely distributed throughout the year. We identified one new species—*Cosmarium hexagonum* sp. nov.—and 27 taxa that were new to Korea. Notably, we recorded *Triploceras gracile* for the first time in the Korean peninsula.

### Systematic enumeration and descriptions

#### *Oligochaetophora simplex* (West) G.S. West (Plate 1, Fig. 1)

John et al. 2011, p. 567, Pl. 135, Fig. G.

Thallus composed of 2–6 loose cells enclosed within a gelatinous envelope. Cells 12–15 µm in diameter, spherical or ovoid, with thin walls, each with 2–4 flexuous setae (50–210 µm long).

#### *Parallela transversalis* (Brébisson) Novis, M. Lorenz, Broady & E.A. Flint (Plate 1, Fig. 5)

#### (Syn.: *Radiofilum irregulare* (Wille) Brunthaler)

Prescott 1962, p. 104, Pl. 7, Figs. 3–5.

Thallus unbranched and uniseriate, short filaments enclosed by a mucilaginous envelop; cells compressed and lenticular, with walls divided into two distinct halves, and adjoined in midregion by a prominent transverse ring. Cell diameter 15–20 µm, length 4–8 µm. Cells very similar to *R. conjunctivum*, but compressed and lenticular.

#### *Kirchneriella diana* (Bohl.) Comas (Plate 1, Fig. 2)

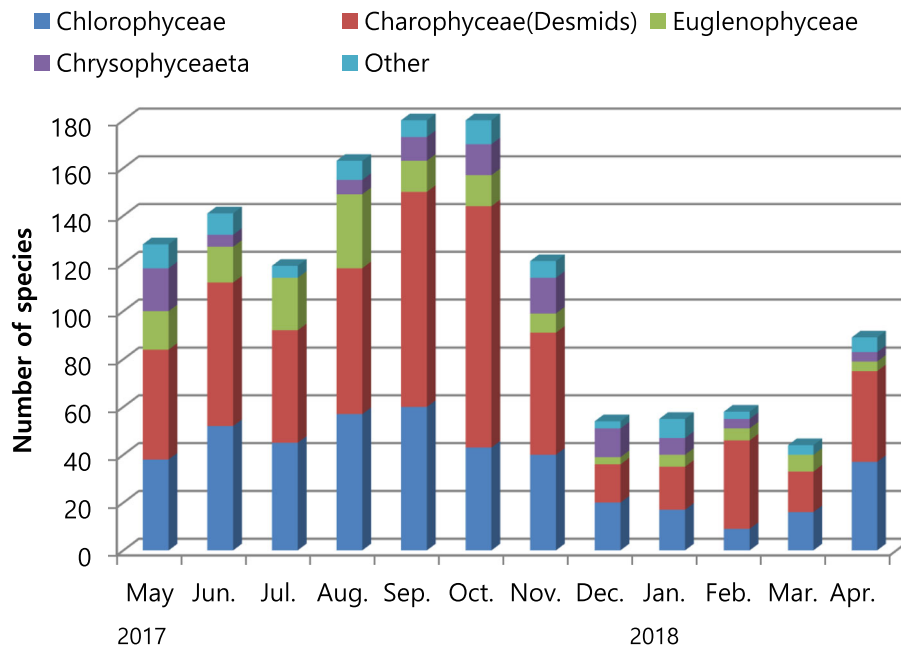
Yamagishi and Akiyama 1989, 9. 47; Komárek and Fott 1983, p. 668, Pl. 187, Fig. 1.

Colony free-floating, with 4, 8, 16, or more cells densely arranged, enclosed by a hyaline mucilaginous sheath; cells flattened, strongly curved, crescent-shaped, with pointed ends, sometimes almost touching, and frequently slightly twisted; single chloroplast with a pyrenoid fills the entire cell. Cell length 10–15 µm, width 3–5 µm.

#### *Tetrademus lunatus* Koršikov (Plate 1, Fig. 4)

Komárek and Fott 1983, p. 806, Pl. 223, Fig. 5.

Coenobium with 4 cells, quadrate arrangement in two planes, and parallel longitudinal axes; cells lunate, adjoined lengthwise along 1/3 of lateral walls; outer wall concave, apices narrowed. Cell length 17–18 µm, breadth 3–5 µm.



**Fig. 2** Monthly changes in the number of phytoplankton species in Cheonjin Lake from May 2017 to April 2018

***Spirotaenia kirchneri* var. *erythropunctata* (Lagerh.) Krieger (Plate 2, Figs. 21 and 22)**

Brook and Williamson 2010, p. 71. Pl. 27, Figs. 2 and 3.

Cell 6–8 times as long as broad; small reddish granules between ends of chloroplast and apices; chloroplast single, 2–3 turns of the cells. Cell length 22–27  $\mu\text{m}$ , breadth 3–5  $\mu\text{m}$ .

***Closterium angustatum* Kützing ex Ralfs (Plate 5, Figs. 1–3)**

Coesel and Meesters K(J). 2007, p. 39, Pl. 25, Fig. 4; Brook and Williamson 2010, p. 204, Pl. 85, Figs. 1–7, Pl. 86, Figs. 1–4.

Cell narrow, elongated, about 12–20 times longer than broad, slightly curved or straight, central margins nearly parallel, each apex slightly attenuated; cell ends slightly swollen and capitate; cell walls having girdle bands and a broad costa (2–3 striation/10  $\mu\text{m}$ ). Cell length 250–500  $\mu\text{m}$ , breadth 19–28  $\mu\text{m}$ , breadth of apex 4–6  $\mu\text{m}$ .

***Closterium juncidum* Ralfs (Plate 5, Figs. 4 and 5)**

Coesel and Meesters K(J). 2007, p. 45, Pl. 26, Figs. 2–3; Brook and Williamson 2010, p. 219, Pl. 96, Figs. 1–8, Pl. 97, Figs. 1–10, Pl. 98, Figs. 1–8.

Cell narrow, slender, about 20–35 times longer than broad, almost straight and fusiform, slightly curved and attenuated near the apex, apices obliquely truncately rounded; cell walls with girdle bands, finely striate (10–15 striation/10  $\mu\text{m}$ ). Cell length 200–220  $\mu\text{m}$ , breadth 9–11  $\mu\text{m}$ , breadth of apex 4–6  $\mu\text{m}$ .

***Haplotaenium minutum* var. *elongatum* (West & West) Cedergrén (Plate 5, Figs. 6 and 7)**

(Syn.: *Pleurotaenium minutum* var. *elongatum* (West & West) Cedergrén)

Prescott et al. 1975, p. 123. Pl. 39, Fig. 61.

Cell slender, very long, about 25–30 times longer than broad, slightly attenuated at both ends; semicells without basal inflation, both apices smooth and truncately rounded. Cell length 250–300  $\mu\text{m}$ , breadth 9–12  $\mu\text{m}$ .

***Pleurotaenium simplicissimum* Grönblad (Plate 5, Figs. 8–10)**

Yamagishi and Akiyama 1986, 5: 73; Coesel and Meesters K(J). 2007, p. 68, Pl. 36, Figs. 1–3.

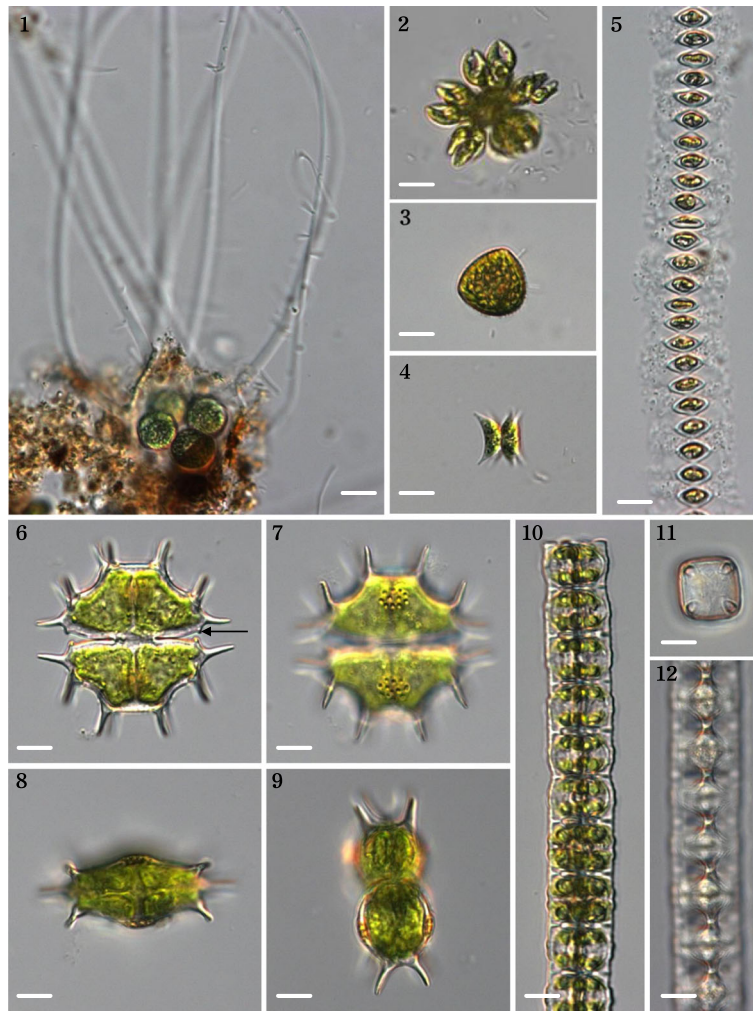
Cell cylindrical, elongate, about 18–24 times longer than broad, not tapering toward the apices; semicells with a very slightly basal inflation, both apices truncate, with a whorl of tiny granules, 8–12 visible in face view. Cell length 600–800  $\mu\text{m}$ , breadth 31–42  $\mu\text{m}$ .

***Actinotaenium cucurbitinum* (Bisset) Teiling (Plate 2, Fig. 1)**

(Syn.: *Cosmarium cucurbitinum* (Bisset) Lütkemüller)

Hirano 1955, p. 80. Pl. 16, Fig. 23; Prescott et al. 1981, p. 11, Pl. 151, Figs. 1–3.

Cell medium-size, about 2–2.5 times longer than broad, ellipsoid to broadly fusiform, median constriction shallow, apices rounded; cell walls with distinct pores; chloroplast star shaped. Cell length 60–70  $\mu\text{m}$ , breadth 25–30  $\mu\text{m}$ , isthmus 22–28  $\mu\text{m}$ .



**Plate 1 Fig. 1** *Oligochaetophora simplex*. **2** *Kirchneriella diana*. **3** *Tetraedriella polychloris*. **4** *Tetrademus lunatus*. **5** *Parallela transversalis*. **6–9** *Xanthidium cristatum* var. *papilliferum*. **10–12** *Desmidium baileyi* var. *caleatum*. Scale bars here and below: 10  $\mu$ m

***Cosmarium hexagonum* sp. nov. Han Soon Kim (Plate 2, Figs. 14 and 15)**

Cell small, about as long as broad, median constriction deep, sinus open outward; semicells rhomboid, lower lateral margins rounded, slightly convex, median part slightly pronounced, apex straight, symmetrically elliptic, poles pronounced or rounded; in vertical view semicell octagonal shape, with a prominent conical tumor in the midregion on either side, lateral margins straight to slightly retuse. Cell length 25–27  $\mu$ m, breadth 24–25  $\mu$ m, isthmus 5–6  $\mu$ m.

This species is similar to *C. praecisum* Borge, *C. polygonatum* Halász, *C. polygonum* var. *polygonum* f. *rectum* Bicudo and *C. polygonum* var. *hexagonum* Grönblad in hexagonal semicell shape and having tubercles in median region of semicell. However, *C. hexagonum* sp. nov. is distinguished from the others by the more large size, more hexagonal outline of the semicells and octagonal shape with retuse margins

and more conical tumor in the median region of semicell in vertical view (Table 2).

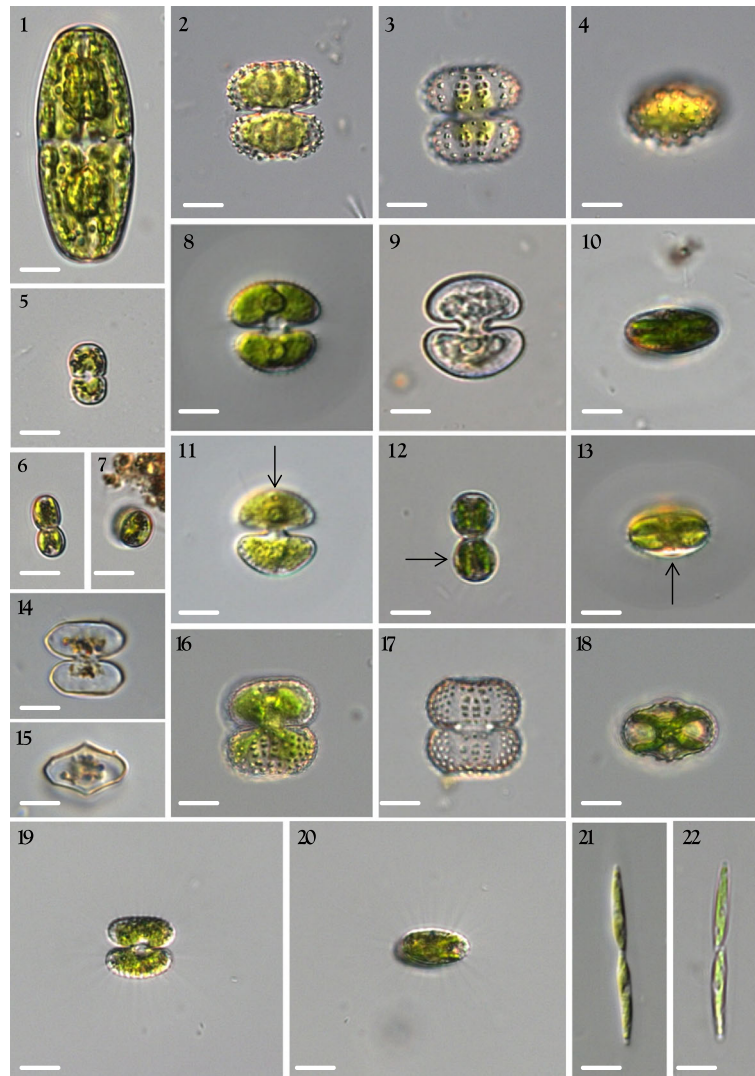
*Type locality*: Cheonjin Lake, Kangwon Province, Goseong County, South Korea (128° 33' 22" E, 38° 15' 14" N).

*Holotype*: Figures 16 and 17 from materials collected on 1 May 2017 deposited at the National Nakdong River Institute of Biological Resources (NNIBR) and Department of Biology, Kyungpook National University.

***C. cf. depressum* var. *planktonicum* Reverdin (Plate 2, Figs. 19 and 20)**

Croasdale and Flint 1988. p. 65. Pl. 34, Figs. 7 and 8; Yamagishi and Akiyama 1997. 18. 24.

Cell small, slightly broader than long, median constriction deep, sinus narrowly open, enclosed in thick mucilaginous sheath, with numerous radiating fibrils; semicells elliptic, upper margins straight to slightly convex, elliptic with poles broadly rounded in vertical



**Plate 2 Fig. 1** *Actinotaenium cucurbitinum*. 2–4 *Cosmarium geminatum*. 5–7 *C. exiguum*. 8–10 *C. ocellatum* var. *glabrum*. 11–13 *C. ocellatum* var. *notatum*. 14–15 *C. hexagonum* sp. nov.. 16–18 *C. pseudoornatum*. 19–20 *C. cf. depressum* var. *planktonicum*. 21–22 *Spirotaenia kirchneri* var. *erythropunctata*

view; cell wall punctate. Cell length 15–17  $\mu\text{m}$ , breadth 17–20  $\mu\text{m}$ , isthmus 4–5  $\mu\text{m}$ . This specimen is similar to *C. depressum* var. *planktonicum*. However, it differing from the nominate variety by elliptic shape compare to trapeziform of semicell in front view.

***Cosmarium abbreviatum* var. *germanicum* (Raciborski) Krieger & Gerloff (Plate 3, Figs. 4–6)**

Hirano 1957, p. 159. Pl. 25, Fig. 38; Krieger and Gerloff 1969, p. 242, Pl. 42, Fig. 16.

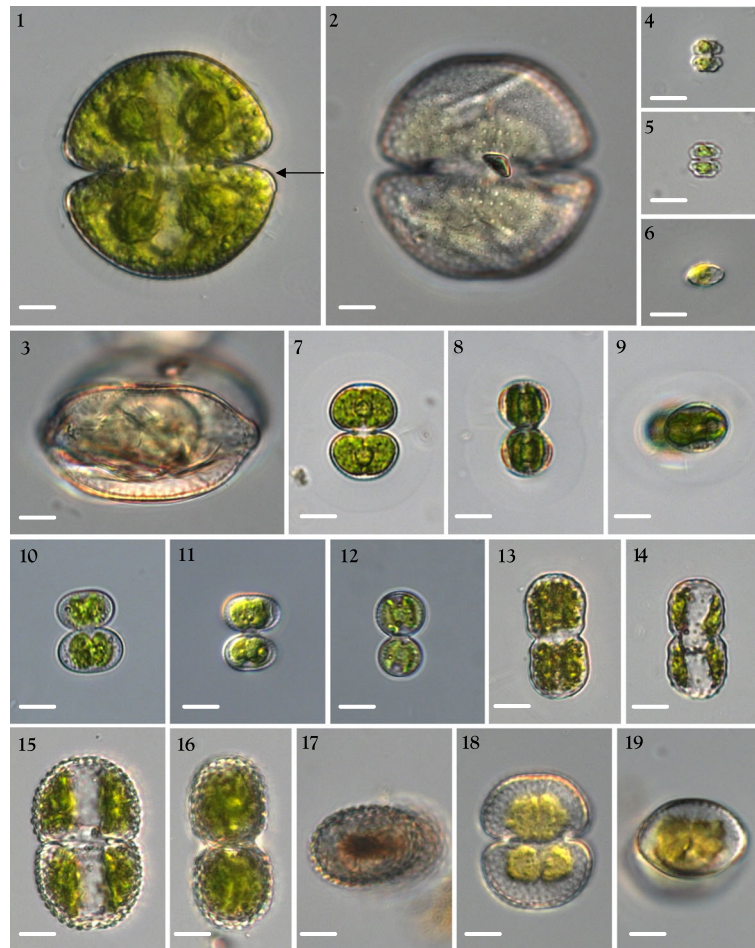
Cell small, as long as broad, median constriction deep, sinus linear, closed; semicells subhexagonal, lateral, upper margins slightly concave, elliptic with poles

broadly rounded in vertical view. Cell length 10–11  $\mu\text{m}$ , breadth 10–11  $\mu\text{m}$ , isthmus 3–3.5  $\mu\text{m}$ .

***Cosmarium contractum* var. *incrassatum* Scott & Prescott (Plate 3, Figs. 7–9)**

Prescott et al. 1981. p. 107. Pl. 177, Figs. 1–3; Yamagishi and Akiyama 1987. 6. 20.

Cell small, about 1.3–1.4 times longer than broad, median constriction deep, sinus acutely open, often enclosed by thick gelatinous sheath; semicells broadly elliptic, elliptic with a lenticular thickening at both sides in vertical view, circular with a lenticular thickening at both sides and often brown in lateral view (Figures 9 and 10, arrow). Cell length 28–30  $\mu\text{m}$ , breadth 21–23  $\mu\text{m}$ , isthmus 4–5  $\mu\text{m}$ .



**Plate 3** Figs. 1–3 *Cosmarium medioscrobiculatum* var. *egranulatum*. 4–6 *C. abbreviatum* var. *germanicum*. 7–9 *C. contractum* var. *incrassatum*. 10–12 *C. contractum* var. *minutum*. 13, 14 *C. inornatum*. 15–17 *C. reniforme* var. *elevatum*. 18, 19 *C. stigmatosum*

***Cosmarium contractum* var. *minutum* Scott & Prescott**  
(Plate 3, Figs. 10–12)

Prescott et al. 1981. p. 108. Pl. 175, Figs. 16 and 17.

Cell small, less than 28  $\mu\text{m}$  long, about 1.3–1.4 times longer than broad, median constriction deep, sinus acutely open, often enclosed by thick gelatinous sheath; semicells broadly elliptic in vertical view, circular in lateral view. Cell length 22–26  $\mu\text{m}$ , breadth 17–21  $\mu\text{m}$ , isthmus 4–5  $\mu\text{m}$ .

***Cosmarium exiguum* Archer (Plate 2, Figs. 5–7)**

Prescott et al. 1981. p. 136. Pl. 206, Fig. 4.

Cell small, about two times as long as broad, median constriction deep, sinus acutely open, closed outwardly; semicells subquadrate with rounded angles, lateral margins and apex almost straight, elliptic in vertical view, broadly elliptic in lateral view; cell wall smooth; Cell length 14–29  $\mu\text{m}$ , breadth 7–15  $\mu\text{m}$ , isthmus 3–5  $\mu\text{m}$ .

***Cosmarium geminatum* P. Lundell (Plate 2, Figs. 2–4)**

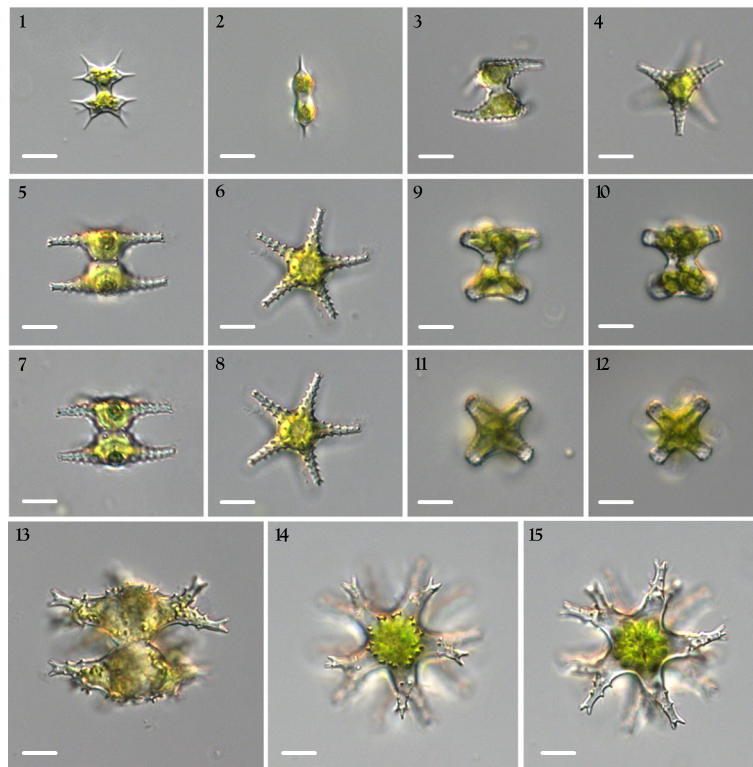
Dillard 1991: 73. Pl. 30, Fig. 4; Coesel and Meesters K(J). 2007: 118. Pl. 69, Figs. 26 and 27.

Cell small, subcylindrical, as long as broad, median constriction deep, sinus acutely open and rounded at extremity; semicells transversely elliptic, apical margin flat to slightly convex, lateral margins convex, apical and basal angles rounded, elliptic in vertical view with a pair of small emarginated warts at middle on each side, nearly circular with granules in lateral view; cell wall granulate, midregion with a pair of 4 small granules transversely disposed. Cell length 26–27  $\mu\text{m}$ , breadth 25–27  $\mu\text{m}$ , isthmus 7–9  $\mu\text{m}$ .

***Cosmarium inornatum* Joshua (Plate 3, Figs. 13 and 14)**

Yamagishi and Akiyama 1987. 7. 19.

Cell medium in size, subcylindrical, about two-times longer than broad, median constriction very shallow, sinus widely open; semicells subquadrate, apex convex and undulate, apical angle broadly rounded, lateral margins



**Plate 4 Figs. 1, 2** *Xanthidium octocorne*. **3, 4** *Staurastrum cyrtocerum* var. *inflexum*. **5–8** *S. arachne*. **9–12** *S. sinense*. **13–15** *S. sexangulare* var. *productum*

parallel, lower lateral undulations rather larger than upper undulation, broadly elliptic to nearly circular in vertical view; cell wall with regularly disposed granules. Cell length 34–36  $\mu\text{m}$ , breadth 18–20  $\mu\text{m}$ , isthmus 11.5–13  $\mu\text{m}$ .

***Cosmarium medioscrobiculatum* W. & G.S. West (Plate 3, Figs. 1–3)**

(Syn.: *Cosmarium medioscrobiculatum* var. *egranulatum* Gutwinski)

Scott and Prescott 1961. p. 63. Pl. 26, Fig. 3; Yamagishi and Akiyama 1987. 7. 20.

Cell large, slightly longer than broad, median constriction deep, sinus narrowly linear; semicells semicircular to trapeziform, apical margin nearly flat to convex, basal angles broadly rounded, with thickened wall (Plate 3, Fig. 1, arrow), hexagonal in vertical view; cell wall with minute granules and about 20 scrobiculations. Cell length 68–70  $\mu\text{m}$ , breadth 60–65  $\mu\text{m}$ , isthmus 24–26  $\mu\text{m}$ . Our isolates much larger than type specimen.

***Cosmarium ocellatum* var. *glabrum* Hinode (Plate 2, Figs. 8–10)**

Yamagishi and Akiyama 1984. 2. 15.

Cell small, as long as broad, median constriction deep, sinus linear, rounded at extremity; semicells semielliptic or semicircular, basal angle rounded, apex scarcely flattened, elliptic with poles broadly rounded in vertical view, circular in lateral view; cell wall smooth or finely punctuate, without central scrobiculation. Cell length 25–27  $\mu\text{m}$ , breadth 23–25  $\mu\text{m}$ , isthmus 5–6  $\mu\text{m}$ .

***Cosmarium ocellatum* var. *notatum* (Nordstedt) Krieger & Gerloff (Plate 2, Figs. 11–13)**

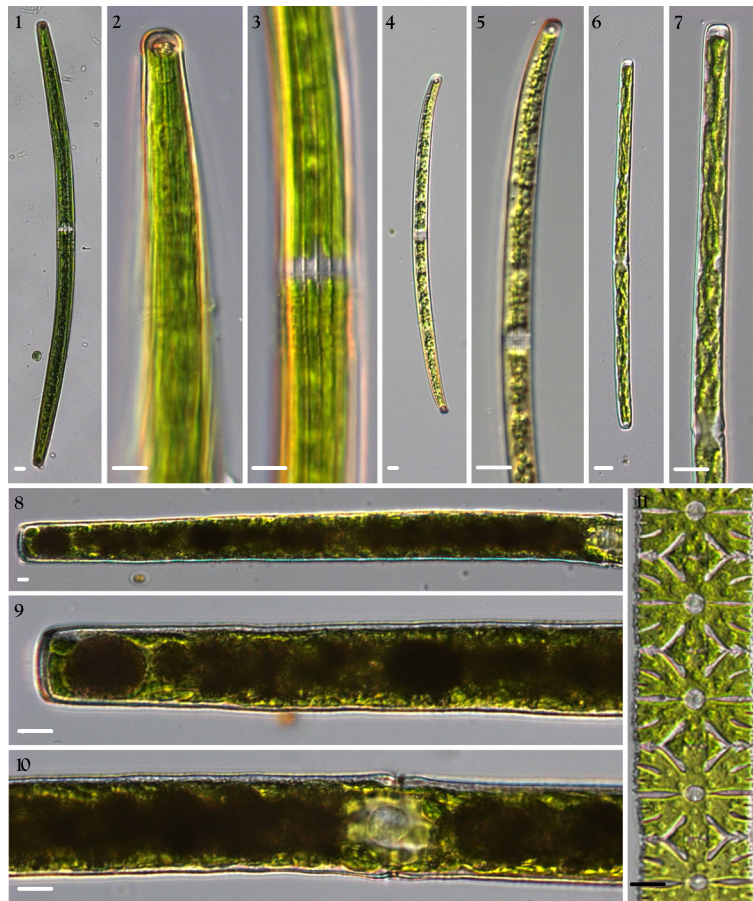
(Syn.: *Cosmarium notatum* (Grönblad) Coesel)

West and West 1912, p. 3, Pl. 117, Figs. 6–10; Coesel and Meesters K(J). 2007, p. 128, Pl. 76, Figs. 4 and 5.

Cell small, slightly longer than broad, median constriction deep, sinus linear, apex dilated; semicells subsemicircular, basal angle rounded, elliptic with poles broadly rounded in vertical view, circular in lateral view; cell wall fine punctuate, with central scrobiculation (Plate 2, Fig. 11, arrow), wall in midregion strongly thickened and often brown (Plate 2, Fig. 12, arrow). Cell length 24–25  $\mu\text{m}$ , breadth 21–23  $\mu\text{m}$ , isthmus 4–5  $\mu\text{m}$ .

***Cosmarium pseudoornatum* Eichler & Gutwinski (Plate 2, Figs. 16–18)**

Prescott et al. 1981. p. 239. Pl. 256, Fig. 6.



**Plate 5** Figs. 1–3 *Closterium angustatum*. 4, 5 *Closterium juncidum*. 6, 7 *Haplotaenium minutum* var. *elongatum*. 8–10 *Pleurotaenium simplicissimum*. 11 *Micrasterias foliacea*

Cell small, as long as broad, median constriction deep, sinus narrowly linear, slightly open at extremity; semi-cells elliptic, lateral margins convex, basal angle rounded, apex flat to slightly convex, margins granular-undulate, elliptic with 3 large granules in middle of each side in vertical view, subcircular in lateral view; cell wall ornamented with 5 to 6 vertical series of emarginated granules, protruded midregion with 3 vertical series of 3–4 granules per row. Cell length 25–28  $\mu\text{m}$ , breadth 25–28  $\mu\text{m}$ , isthmus 6–7  $\mu\text{m}$ .

***Cosmarium reniforme* var. *elevatum* W. & G.S. West (Plate 3, Figs. 15–17)**

Prescott et al. 1981. p. 277. Pl. 259, Fig. 1; Yamagishi and Akiyama 1985, 4: 27.

Cell medium in size, about 1.5 times longer than broad, median constriction deep, sinus narrow linear, slightly dilated extremity; semi-cells reniform, apex elevated, basal angles rectangular-rounded, lateral margins slightly convex, ellipsoid in lateral view, broadly elliptic in vertical view; cell wall with coarse granules arranged

in regular, longitudinal rows. Cell length 50–52  $\mu\text{m}$ , breadth 30–32  $\mu\text{m}$ , isthmus 10–11  $\mu\text{m}$ .

***Cosmarium stigmosum* (Nordstedt) Krieger (Plate 3, Figs. 18 and 19)**

Krieger and Gerloff 1969, p. 169, Pl. 35, Fig. 1; Yamagishi and Akiyama 1987. 6, 27.

Cell medium in size, about 1.2 times longer than broad, median constriction deep, sinus narrow, open outward; Semicells trapeziform, basal angle rounded, apex flat to slightly convex, lateral margin convex, apical angles broadly rounded; hexagonal-elliptic with poles broadly rounded in vertical view; subcircular in lateral view; cell wall with fine granules. Cell length 39–41  $\mu\text{m}$ , breadth 32–34  $\mu\text{m}$ , isthmus 14–15  $\mu\text{m}$ .

***Xanthidium cristatum* var. *papilliferum* Irénée-Marie (Plate 1, Figs. 6–9)**

Prescott et al. 1982. p. 65. Pl. 321, Fig. 1.

Cell large, slightly longer than broad (excluding spines), median constriction deep, sinus narrowly linear, slightly open extremity; semi-cells subpyramidal, apices truncate,



**Plate 6 Fig. 1** *Triploceras gracile*. **2** *Onychonema filiforme*. **3** *Lagynion triangulare*. **4** *Epipyxis ramosa*

lateral margins concave, lateral and apical angles with pairs of spines upwardly directed, basal angles with a spine horizontally directed and a single wart (Plate 1, Fig. 6, arrow), midregion protuberance bearing a ring of 8–12 pits surrounding a series of 2–3 pores, elliptic with a small protuberance at midregion on each side and 3 divergent spines at each pole in vertical view, circular with a small midregion protuberance on each side and a pair of divergent spines at apical margin in lateral view. Cell length 45–48  $\mu\text{m}$  excluding spines, 61–65  $\mu\text{m}$  including spines, breadth 42–45  $\mu\text{m}$  excluding spines, isthmus 10–11  $\mu\text{m}$ , spine length 7–10  $\mu\text{m}$ .

***Xanthidium octocorne* Ralfs (Plate 4, Figs. 1 and 2)**

West and West 1912, p. 3, Pl. 117, Figs. 6–10; Coesel and Meesters K(J). 2007, p. 155, Pl. 85, Figs. 9–11.

Cell small, about 1.3 longer than broad (excluding spines), median constriction deep, sinus wide, almost semi-circular excavation; semicells transversely trapeziform-rectangular, basal margins slightly concave or straight, sides concave, basal and upper angles rectangularly rounded and with long, acute, straight spines; spines of basal angles parallel to slightly divergent, spines of upper angles divergent, apical margin distinctly concave than the lateral margins, subcircular to ovate in lateral view, elliptic with angles rounded and a straight spine in vertical view. Cell length

17–20  $\mu\text{m}$  excluding spines, 22–24  $\mu\text{m}$  including spines, breadth 11–13  $\mu\text{m}$  excluding spines, isthmus 4–5  $\mu\text{m}$ , spine length 5–7  $\mu\text{m}$ .

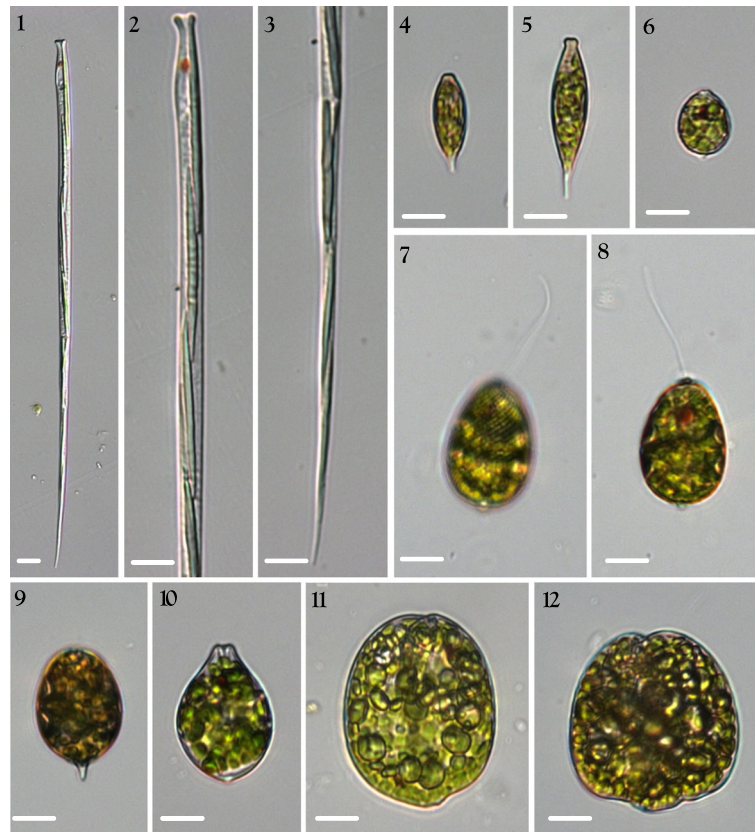
***Staurastrum arachne* Ralfs (Plate 4, Figs. 5–8)**

Hirano 1959, p. 366, Pl. 47, Fig. 10; Prescott et al. 1982, p. 127, Pl. 429, Fig. 5; Pl. 432, Figs. 3 and 9; Coesel and Meesters K(J). 2007, p. 174, Pl. 107, Figs. 1–3.

Cell small, about two times as long as broad with processes, median constriction deep, sinus an acute notch, open toward apex, isthmus narrow; semicells cup-shaped, apical margins slightly convex, lateral angles extended into relatively slender horizontal process terminated by 3 min spines; dorsal margin crenulate, ventral margin smooth, arms horizontal, with 4 series of minute encircling denticulations and with a horizontal series of minute spines above the isthmus, 5-radiate, sides concave, internal region of sides with one minute sharp spine, central area smooth, angles with processes tipped with 3 min teeth in vertical view. Cell length 20–22  $\mu\text{m}$ , breadth 36–40  $\mu\text{m}$  with processes, isthmus 9–11  $\mu\text{m}$ .

***Staurastrum cyrtoceram* var. *inflexum* Coesel & Meesters (Plate 4, Figs. 3 and 4)**

Coesel and Meesters K(J). 2013, p. 89, Pl. 78, Figs. 3–12.



**Plate 7 Figs. 1-3** *Cyclidiopsis acus*. **4** *Lepocinclis acicularis*. **5** *L. marssonii* var. *sinensis*. **6** *L. fusiformis* var. *minor*. **7, 8** *L. ovum* var. *palatina*. **9** *L. pseudoovum*. **10** *L. fusiformis* var. *amphirhynchus*. **11** *Phacus brevicaudatus*. **12** *P. lefevrei*

Cell small, including processes about 1.35 times broader than long, median constriction deep, sinus an acute notch, broadly open, isthmus relatively broad; semicells subcuneate, apical margin slightly convex, ventral margins concave, processes relatively long and nearly horizontal or strongly downturned, with series of 4 transverse granules, tipped with 2–3 short teeth, triangular with slightly concave margins, truncate processes, margins undulate-granular, smooth in median region of cell in vertical view. Cell length 17–20 μm, breadth 27–30 μm with processes, isthmus 4–5 μm.

***Staurostrum sexangulare* var. *productum* Nordstedt (Plate 4, Figs. 13–15)**

Scott and Prescott 1961. p. 107. Pl. 46, Fig. 4.

Cell medium in size, including protuberance about 1.5 times broader than long, median constriction deep, sinus broad and U-shaped, acutely open at the extremity; semicells bowl-shaped, basal margins slightly concave, apical margin convex, lateral margins forming a processes divided into two whorls of subprocesses, lower whorl of subprocesses horizontal or slightly convergent, upper one divergent, each process with 2–3 series denticulations at

**Table 2** Morphological characteristics of *Cosmarium hexagonum* sp. nov. and related taxa

	<i>C. hexagonum</i> sp. nov.	<i>C. praecisum</i>	<i>C. polygonatum</i>	<i>C. polygonum</i> f. <i>rectum</i>	<i>C. polygonatum</i> var. <i>hexagonum</i>
Semicell shape in front view	Rhomboid	Transversely hexagonal	Hexagonal	Hexagonal	Broadly hexagonal
Semicell shape in vertical view	Octagonal	Ellipsoid	Ellipsoid	Ellipsoid	Ellipsoid
Wall scrobiculation	Median conical tubercles	Median tubercles	Median tubercles	Median conical tumor	Median tumor and one small granule at each angles
Cell length	25–27 μm	13–18 μm	8–14 μm	14 μm	9.2–9.9 μm
Cell broad	24–25 μm	13–19 μm	9–17 μm	12.5 μm	9.2 μm
Isthmus	5–6 μm	3–6 μm	3.5–5 μm	4 μm	2.5 μm

the side and 3–4 spines at the extremity, 5-radiate, angles produced to form the long tapering processes, upper whorl of subprocesses from base of lower one, sides concave and with two pairs of small granules at base of each processes, midregion smooth in vertical view. Cell length 35–37  $\mu\text{m}$ , breadth 55–58  $\mu\text{m}$  with processes, isthmus 9–10  $\mu\text{m}$ . This variety differs from type species by a pair of granules between processes, and two pairs of minute granules at base of each processes.

***Staurastrum sinense* Lütkenmüller (Plate 4, Figs. 9–12)**

Prescott et al. 1982. p. 190, Pl. 340, Figs. 1 and 2; Coesel and Meesters K(J). 2013, p. 149, Pl. 54, Figs. 11 and 12.

Cell small, about as long as broad with processes, median constriction deep, sinus a broad U-shaped, widely open; semicells broadly cuneiform, apical margin truncate or nearly straight, apical angles produced to form cylindrical processes, with 4–5 or more concentric series of fine granules, 4-radiate, sides concave, pronounced, broadly rounded to truncate angles, central area smooth in vertical view. Cell length 20–25  $\mu\text{m}$ , breadth 20–25  $\mu\text{m}$  with processes, isthmus 8–10  $\mu\text{m}$ .

***Desmidium baileyi* var. *caelatum* (Kirchn.) Nordstedt (Plate 1, Figs. 10–12)**

Coesel and Meesters K(J). 2007, p. 210, Pl. 123, Figs. 1–4.

Cell slightly broader than long, median constriction very shallow, widely open; semicells rectangular, lateral margins parallel, apical margin markedly concave, 3 or 4 angular sides with rounded angles, straight or slightly concave in vertical view; filaments slightly twisted or not twisted. Cell length 17–20  $\mu\text{m}$ , breadth 20–25  $\mu\text{m}$ .

***Onychonema filiforme* (Ralfs) Roy & Bisset (Plate 6, Fig. 2) (Syn.: *Sphaerosma filiforme* Ralfs)**

Coesel and Meesters K(J). 2007, p. 207, Pl. 120, Figs. 5–7; Dillard 1993, p. 122, Pl. 35, Fig. 1. John et al. 2011, p. 739, Pl. 179, Fig. D.

Cell as long as broad or slightly broader than long; median constriction deep, sinus narrow linear; semicells ellipsoid or semicircular, apical margin slightly convex; apical processes about 1/2 of semicell length, widely spaced and disposed asymmetrically, one overlapping adjacent cell in front, the other behind; wall smooth. Cell length 10–13  $\mu\text{m}$ , breadth 13–14  $\mu\text{m}$ , isthmus 4–5  $\mu\text{m}$ . This species was reported by Chung et al. at Han River in 1968, and illustrated as *O. filiformis* in *Illustrated Encyclopedia of Fauna and Flora of Korea* (Chung 1968), but cell shape of that specimen differs considerably from type species.

***Micrasterias foliacea* Bailey ex Ralfs (Plate 5, Fig. 11)**  
Prescott et al. 1977. p. 158. Pl. 139, Figs. 3–8.

This species reported by Chung et al. only as list at Seoul and Chuncheon in 1965 and 1968, respectively, but it has not been reported in Korean peninsula until observed at very shallow wetland of Jeju Island by Kim (2014a).

***Triploceras gralile* Bailey ex Ralfs (Plate 6, Fig. 1)**

Prescott et al. 1975. p. 143. Pl. 51, Figs. 7–14; Dillard 1990, p. 140, Pl. 49, Fig. 6.

Reported by Kim (2014b) in a very shallow wetland on Jeju Island, but very rare and new to Korean peninsula.

**Euglenophyta**

I identified 49 taxa in the Euglenophyta, 9 of which are new to Korea.

***Cyclidiopsis acus* Korshikov (Plate 7, Figs. 1–3)**

Huber-Pestalozzi 1955, p. 405, Pl. 83, Fig. 869; Yamagishi and Akiyama 1995. 14:19.

Cell colorless, free-swimming, osmotrophic, elongated, tapering, rigid, slight bending, no euglenoid movement; similar to *Euglena acus* except for apical canal opening. Cell length 130–190  $\mu\text{m}$ , breadth 6–13  $\mu\text{m}$ .

***Lepocinclis acicularis* Francé 1893 (Plate 7, Fig. 4)**

Yamagishi and Akiyama 1989. 10. 40.

Cell fusiform; anterior end narrow and truncate; posterior end narrowly produced into short, straight cauda; lateral sides slightly convex; periplasts oblique-spirally striated; paramylon two, ring-like plate. Cell length 17–23  $\mu\text{m}$ , breadth 8–10  $\mu\text{m}$ .

***Lepocinclis fusiformis* var. *amphirhynchus* Nygaard (Plate 7, Fig. 10)**

Yamagishi and Akiyama 1998. 20. 42.

Cells broad and fusiform; anterior end conically narrowed, produced into a truncately rounded and shallowly bilobed apex; posterior end conically produced into a short caudal process; lateral sides roundly swelled; periplasts spirally striated; paramylon two, ring-like plate. Cell length 25–28  $\mu\text{m}$ , breadth 20–23  $\mu\text{m}$ .

***Lepocinclis fusiformis* var. *minor* Chu (Plate 7, Fig. 6)**

Yamagishi and Akiyama 1994. 13. 24.

Cell small, broad and fusiform; anterior end narrow and truncate; posterior end bluntly rounded and slightly pronounced, with a small nipple-like process; lateral sides broadly convex; periplasts spirally striated; paramylon two, ring-like plate. Cell length 16–18  $\mu\text{m}$ , breadth 12–14  $\mu\text{m}$ .

***Lepocinclis marssonii* var. *sinensis* Popova (Plate 7, Fig. 5)**  
Yamagishi and Akiyama 1989. 10. 40.

Cell long and fusiform; anterior end narrowly produced, with neck-like constriction and truncate, slightly bipapillated; posterior end gradually narrow and projected into a straight cauda, with a distinct nodulation at base; lateral sides convex; periplasts longitudinally striated; paramylon two, ring-like plate. Cell length 35–42  $\mu\text{m}$ , breadth 9–11  $\mu\text{m}$ .

***Lepocinclis ovum* var. *palatina* Lemmermann (Plate 7, Figs. 7 and 8)**

Yamagishi and Akiyama 1997. 19. 33.

Cell broad ovoid, broadest at posterior end; anterior end gradually narrowed, rounded, shallowly bilobed; posterior end broad truncately rounded, with a small papillate cauda; periplasts spirally striated; paramylon two, ring-like plate. Cell length 30–33  $\mu\text{m}$ , breadth 20–25  $\mu\text{m}$ .

***Lepocinclis pseudoovum* Conrad (Plate 7, Fig. 9)**

Yamagishi and Akiyama 1989. 10. 48.

Cell ovoid to broad ellipsoid; anterior end broadly rounded or slightly truncate; posterior end broad rounded, with a short, straight cauda; periplasts spirally striated; paramylon two, ring-like plate. Cell length 30–33  $\mu\text{m}$ , breadth 20–22  $\mu\text{m}$ , cauda 3–4  $\mu\text{m}$ .

***Phacus brevicaudatus* (Klebs) Lemmermann (Plate 7, Fig. 11)**

Yamagishi and Akiyama 1994. 13. 40.

Cell large, thick, broad ovoid, nearly suborbicular in face view; dorsal surface with a longitudinal, deep furrow extending the full length of the cell; thin ellipsoid with a concave absence at one side in vertical view; anterior end narrowly rounded and shallowly bilobed; posterior end broadly rounded, with an abbreviated obtuse cauda-like projection; lateral sides broadly swelled; periplasts roughly and longitudinally striated; paramylon one or two, large, ring-like or circular plate. Cell length 45–50  $\mu\text{m}$ , breadth 30–32  $\mu\text{m}$ .

***Phacus lefevrei* Bourrelly (Plate 7, Fig. 12)**

Yamagishi and Akiyama 1987. 7. 50.

Cell large, broad ovoid to subcircular; anterior end slightly narrow and rounded, shallowly bilobed by a dorsal furrow; posterior end broadly rounded with a short round projection; lateral sides broadly rounded with periplasts, roughly and longitudinally striated; paramylon a single large circular plate. Cell length 44–47  $\mu\text{m}$ , breadth 42–45  $\mu\text{m}$ .

**Chrysophyta**

I identified 53 taxa in the Chrysophyta, 3 of which are new to Korea.

***Tetraedriella polychloris* Skuja (Plate 1, Fig. 3)**

John et al. 2011, p. 332, Pl. 85, Fig. D.

Cells free-floating, tetrahedral, with slightly convex to concave sides and broadly rounded angles, rounded corners without spines; cell wall fairly thick and ornamented with coarse punctate; chloroplast numerous, small discoid, without pyrenoid; Cell diameter 25–30  $\mu\text{m}$ .

***Epipyxis ramosa* (Lauterborn) Hilliard & Asmund (Plate 6, Fig. 4)**

(Syn.: *Hyalobryon ramosum* Lauterborn)

Yamagishi and Akiyama 1985. 4. 41; John et al. 2011. p. 297. Pl. 77. Fig. K.

Thallus epiphytic, dendroid colony; lorica long and cylindrical, slightly curved or twisted, base conically rounded, margins parallel. Cell length 40–50  $\mu\text{m}$ , breadth 3.5–6.5  $\mu\text{m}$ .

***Lagynion triangulare* (Stokes) Pascher (Plate 6, Fig. 3)**

Dillard 2007. p. 9. Pl. 1, Fig. 13.

Thallus epiphytic, unicellular; lorica flask-shaped with angular corner and base flattened against substrate; neck long and cylindrical; one or two small discoid chromatophores. Lorica diameter 16–18  $\mu\text{m}$ , height 11–12  $\mu\text{m}$ ; neck length 4–5  $\mu\text{m}$ , diameter 2–2.5  $\mu\text{m}$ .

**Discussion**

Previous studies have reported about 2450 taxa of freshwater algae in Korea excluding diatoms (Kim 2015; Lee and Kim 2015a, 2015b; Lee and Kim 2015a, 2015b; Kim 2017; Kim and Kim 2017; Jung et al. 2017). We identified one new species—*Cosmariium hexagonum* sp. nov.—and provide the first report of 44 phytoplankton taxa in Korea.

The phytoplankton community of Cheonjin Lake has high species diversity, especially desmids, and the number of species was greatest during the autumn. Previous investigations in swamps or in old and shallow reservoirs of Korea have reported similar results (Kim and Chung 1993a, 1993b; Kim 2001). Cheonjin Lake appeared to have a greater abundance of phytoplankton than other brackish lagoons in Korea. Several previous studies have examined phytoplankton flora in lagoons of Korea. In particular, the phytoplankton communities of these lagoons had 15 to 164 taxa, with a high abundance of diatoms (Cho et al. 1975; Mizuno and Cho 1980; Lee et al. 2000; Moon and Lee 2002; Heo et al. 2004; Kwon et al. 2005). However, the phytoplankton flora in Cheonjin Lake, which recently changed to freshwater, were characterized by a high abundance of desmids and chlorococcal green algae and relatively low abundance of diatoms, in contrast to the previously surveyed brackish lagoons, lakes, reservoirs, and swamps in Korea. In fact, the phytoplankton community of Cheonjin Lake was very similar to that of shallow reservoirs and swamps at inland locations, in that there

was a high species diversity and many species of desmids, but few taxa in the Euglenaceae (Kim and Chung 1993a, 1993b). In addition, this lake has 44 taxa, including one new species, that are new to Korea.

In conclusion, this study of changes in a phytoplankton community in a region that changed from lagoon to brackish water and then to freshwater provides important new information about ecological succession in an aquatic community.

## Conclusion

In this study, a total 376 taxa of 148 desmids (Charophyceae), Chlorophyceae (103 taxa), Chrysophyta (53 taxa), Euglenophyta (49 taxa), Cyanophyta (13 taxa), Dinophyta (8 taxa), and Chryptophyta (2 taxa) were identified from Cheonjin Lake. Twenty-eight taxa of desmids including a new species (*Cosmarium hexagonum* sp. nov.), 9 taxa of Euglenophyceae, 4 taxa of Chlorophyceae, 2 taxa of Chrysophyceae, and 1 taxon of Xanthophyceae were newly recorded in Korea.

## Abbreviations

Fig.: Figure; Pl.: Plate; Syn.: Synonym

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## Availability of data and materials

Not applicable

## Author's contributions

The author conceived the study, collected the data, interpreted the results, and wrote the manuscript. The author read and approved the final manuscript.

## Ethics approval and consent to participate

Not applicable

## Consent for publication

Not applicable

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