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New taxonomic records of *Zygnemataceae* (Charophyta) from the Lake Baikal region

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ABSTRACT. *Spirogyra*, *Mougeotia*, and *Zygnema*, the most species-rich genera of green filamentous algae family *Zygnemataceae*, are globally distributed. However, in many regions of the world, including the Lake Baikal region, they remain poorly studied taxonomically. The traditional species identification of zygnemataleans is based on the morphology of asexual and sexual stages of their life cycle. During the study conducted in 2020, we identified 18 taxa of *Spirogyra*, *Mougeotia*, and *Zygnema* from 24 new locations, including Lake Baikal, the Angara River, the Irkut River, and small rivers and water bodies in the lake's surrounding area. Fertile stages were observed only in five *Spirogyra* species, including one variety. *S. circumlineata* is first reported for Lake Baikal. Eight morphotypes of *Spirogyra*, three of *Zygnema*, and two of *Mougeotia* are likely new species for the region. *Spirogyra* is more widespread than *Zygnema* and *Mougeotia* in the region. The taxa of all three genera are dynamic components of periphyton, metaphyton, and aquatic macrophyte communities in the studied area and regularly occur together. Their ability to develop both attached and unattached communities facilitates their distribution, particularly in Lake Baikal's coastal zone.

Keywords: morphotaxonomy, *Spirogyra*, *Mougeotia*, *Zygnema*, Lake Baikal, algal bloom

1. Introduction

Filamentous green algae of the family *Zygnemataceae* (Charophyta), and particularly its most species-rich genera *Spirogyra* (535 valid species), *Zygnema* (210), and *Mougeotia* (173) are globally distributed and abundant in various fresh and brackish waters (Guiry and Guiry, 2020). However, neither family member can be identified at the species level without observations on fertile material, i.e., conjugating filaments and zygospores, whose morphological features are crucial in species delimitation. Thus, in many parts of the world, particularly in Siberia, these algae remain poorly studied taxonomically. Dorogostaisky (1904) first reported eight taxa of *Zygnemataceae*, i.e., three species and one forma of *Mougeotia*, four species of *Spirogyra*, and one species of *Zygnema*, from the Lake Baikal region. Some of them were discovered in several small tributaries of the lake, i.e., Turka, Bolshaya Kotinka, and Chernaya. Meyer (Meyer and Reinhardt, 1925; Meyer, 1927; 1930) was the first who provided records of *Zygnemataceae* from Lake Baikal, including five *Spirogyra*, two *Mougeotia* species, and one *Zygnema* species. These were the only data on *Zygnemataceae* from the lake for an extended period (cf. Volkova et al., 2018). A few additional records appeared as a result of algological studies of the Angara River reservoirs (Zagorenko, 1971; Vorob'eva, 1987), small waterbodies of the Kitoy River, which is a left tributary of the Angara (Egorova et al., 2001), Alla thermal springs (Takhteev et al., 2006), lakes and tributaries of the Selenga River and the Amur River basins in Zabaikalye (Kachaeva, 1974; 1980, Kuklin, 2002; Landscape …, 2002). In total, 30 species of *Zygnemataceae* were reported from the Lake Baikal region, including *Sirogonium sticticum* (Engl. Bot.) Kützing. However, most of the records had no descriptions or pictures of the collected specimens and environmental data on sampling sites. Many other surveys (Votyakova, 1981; Izhboldina, 2007) reported sterile members of *Zygnemataceae* in Lake Baikal and its surrounding area. Over the last decade, filamentous zygnemataleans, especially *Spirogyra*, have become a significant component of the Lake Baikal shallow-water communities (Kravtsova et al., 2014; Timoshkin et al., 2015; Khanaev et al.; 2016; Volkova et al., 2018). Their mass proliferation manifested the serious ecological crisis of the unique shallow-water ecosystem (Timoshkin et al., 2016). In this regard, special studies of the family *Zygnemataceae*, including their taxonomy, peculiarities of their development, and distribution over the lake water area, are relevant.

In our previous work (Volkova et al., 2018), we discovered 15 *Spirogyra* taxa based on thorough

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morphological observations. Eight were new for Lake Baikal and its tributaries, and eight were new for East Siberia. In this paper, we report new records of taxa of the family *Zygnemataceae* in Lake Baikal and its surrounding area based on materials collected during the summer of 2020.

2. Materials and methods

We collected 60 qualitative samples of filamentous zygnemataleans from 26 locations, including Lake Baikal, Lake Bolshoe Eravnoe, the Angara River, the Irkut River, and small rivers and water bodies in the lake's surrounding area during June-September 2020.

List of the studied locations:

1. the bay opposite Bolshoye Goloustnoye village, Lake Baikal, 52°01'36.5"N 105°24'46.8"E;
2. Barguzinskyi Bay, Lake Baikal, opposite Maksimikha village, 53°16'16.2"N 108°45'07.9"E;
3. Listvennichny Bay, Lake Baikal, 51°51'01.5"N 104°52'04.8"E;
4. Cape Berezovy, Lake Baikal, 51°50'78.4"N 104°54'00.8"E;
5. Bolshie Koty Bay, Lake Baikal, 51°54'11.4"N 105°03'84.2"E;
6. Senogda Bay, Lake Baikal, 55°36'48'7"N 109°14'09'1"E;
7. Sakhurta Bay, Maloe More Strait, Lake Baikal, 53°01'08.5"N 106°54'00.7"E;
8. the bay opposite Kultuk village, Lake Baikal, 51°43'01.12"N 103°43'47.5"E;
9. the bay opposite Zarechnoye village, Lake Baikal, 55°35'20'2"N 109°18'19'3"E;
10. Anga Bay, Lake Baikal, 52°46'57.6"N 106°34'29.7"E;
11. the Irkutsk reservoir, the bay near Bolshaya Rechka village, 51°56'31.2"N 104°43'45.5"E;
12. the bay opposite Slyudyanka town, Lake Baikal, 51°39'57.8"N 103°13'09.2"E;
13. Lake Bolshoe Eravnoe, 52°34'13.8"N 111°27'46.9"E;
14. the Egia River, near the Mozhai village, 52°23'58.3"N 110°45'55.0"E;
15. the Medlyanka River, Kultuk village, 51°43'33.1"N 103°43'08.6"E;
16. the Bolshaya Kotinka River, 51°54'12.1"N 105°04'26.8"E;
17. the Malaya Kotinka River, 51°54'20.9"N 105°05'05.7"E;
18. small ponds nearby Solontsovyi Bay of Lake Baikal, 54°13'00.7"N 108°24'43.1"E;
19. swampy ponds nearby the Irkut River, 51°46'57.2"N 102°58'30.9"E;
20. the mouth of the Frolikha River, 55°30'59.5"N 109°52'16.8"E;
21. the Chernaya River, 51°53'29.2"N 105°02'31.6"E;
22. backwater of the Angara River, 52°22'08.6"N 104°13'44.8"E;
23. in the coast of the Angara River, 52°21'50.7"N 104°14'50.7"E;
24. the floodplain of the Angara River, 52°22'16.8"N, 104°13'34.8"E.

The samples were collected at depths up to 1.5-2 m by hands or using a perforated shovel, plankton nets, and knifes. The projective cover (PC) of algae and macrophytes was assessed by eye on a scale in steps of 5%. The water temperature, pH, and electrical conductivity (EC) were measured during sampling using portable device HI 98501 Checktemp (Hanna Instruments Ltd., USA). The samples containing alive specimens were delivered to the laboratory in vials placed in refrigerant. The specimens were further stored in Petri dishes on the north window at a room temperature (20°C) and a natural light source. For the identification and standard morphometric measurements, we used the Olympus CX 21 light microscope equipped with a digital camera and the ToupView 3.7 software. If there was no sexual reproduction, we described sterile filaments, which differed from taxa already reported in the region in at least one of the following characteristics: the type of chloroplast (spiral chloroplast(s) in *Spirogyra*, stellate chloroplast in *Zygnema*, lamellar chloroplast in *Mougeotia*), the number of chloroplasts in a cell, the type of a cell septum, the width and length of the cells. Overall, 357 specimens were analyzed and photographed. In addition, co-occurring macroalgae and aquatic plants were identified. After microscopical observations, the specimens were fixed with 70% ethanol or 4% formalin. The collection of labeled samples and micrographs are stored in the Limnological Institute SB RAS, Irkutsk, Russia. The taxonomic sources on *Zygnemataceae* included Kolkwitz and Krieger (1941), Transeau (1951), Kadlubowska (1984), Rundina (1998), Johnson (2011), Stancheva et al. (2013). The nomenclature of the studied taxa is according to *Algae Base* (Guiry and Guiry, 2020).

3. Results

We identified 18 taxa of the family *Zygnemataceae* in the studied area. Thirteen taxa belong to the genus *Spirogyra*, two – *Mougeotia*, three – *Zygnema*. In total, 23 species and one variety of macroscopic algae (thallus size ≥ 2 mm) and three species of higher aquatic plants belonging to 11 genera, 9 families, 7 orders were identified in plant-aggregations with zygnemataleans. Here, we provide morphological accounts of the discovered members of the family *Zygnemataceae*, new geographical locations together with environmental characteristics, co-occurring macrophytes and algae.

Phylum CHAROPHYTA Migula
Class *Zygnematophyceae* Round ex Guiry
Order *Zygnematales* C.E. Bessey
Family *Zygnemataceae* Kützing
Genus *Spirogyra* Link
***Spirogyra circumlineata* Transeau**
(Fig. 1A, Fig. 1B, Fig. 1C, Fig. 1D)

Vegetative cells 38–49 μm wide, 38–110 μm long; transverse walls plane; chloroplast single with 3–5 turns per cell. Conjugation scalariform, tubes formed by both gametangia. Donor gametangium not inflated, 38–49 μm wide, 32–114 μm long; recipient gametangium slightly inflated, 44–50 μm wide, 65–140 μm long; cells without conjugation pair not inflated or somehow inflated, 46–54 μm wide, 73–128 μm long. Zygospores ellipsoid, 39–48 μm wide, 47–90 μm long; mesospore yellow-brown, smooth.

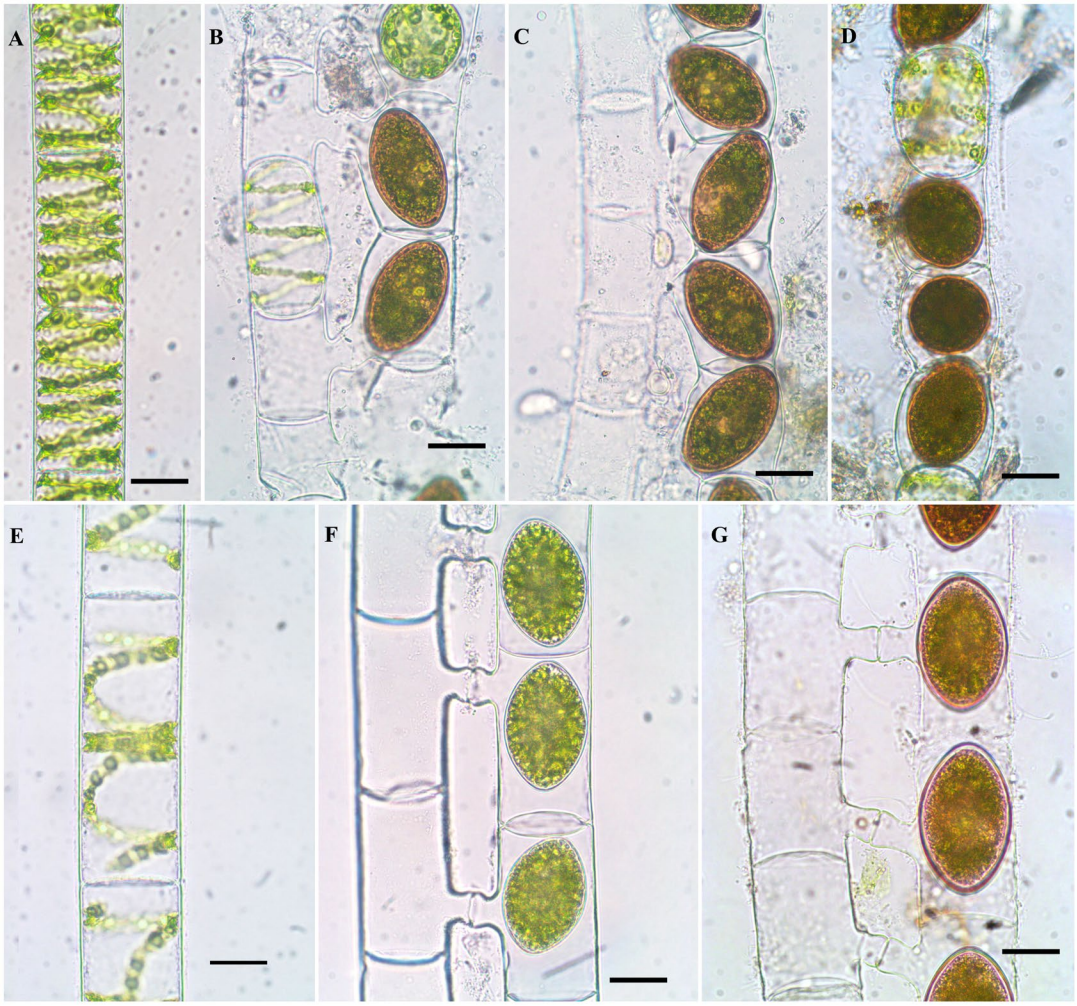

Fig.1. Light microscopic images of *Spirogyra* species from the Lake Baikal region: (A, B, C, D) *S. circumlineata*; (E, F, G) *S. condensata*. Scale bar, 30 μm.

Fertile thalli of *S. circumlineata* have been encountered in 2 new locations: **1** - June 2020, in the water column, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata* (F. Weber & Mohr) Kützing, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5); **2** - June 2020, on the water surface, water temperature 19°C, pH 7.6, synusia of unattached free-floating algae, metaphyton (*Spirogyra* spp. ster., *S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp. ster. 8, *Mougeotia* sp. ster. 1) (PC 5-10%) in macrophyte communities dominated by *Elodea canadensis* Michx. (40%) + *Myriophyllum spicatum* L. (30%) + *Potamogeton* sp. (10%).

Rare species in Europe, Asia, and North America (Transeau, 1951; Kadlubowska, 1984; Rundina, 1998). Previously, we discovered this species in the Bolshaya Kotinka River (Volkova et al., 2018). This is the first report of this species for Lake Baikal. *S. circumlineata* is morphologically similar to *S. varians* (Hassall) Kützing, however differs in larger cell size, constancy of the conjugation form and zygospores, and a lower degree of swelling of the cells without conjugating pair.

***Spirogyra condensata* (Vaucher) Dumortier**
(Fig. 1E, Fig. 1F, Fig. 1G)

Vegetative cells 44–55 μm wide, 30–118 μm long; transverse walls plane; chloroplast single with 1.5–4 turns per cell. Conjugation scalariform, tubes formed by both gametangia. Donor gametangium not inflated, 44–60 μm wide, 30–180 μm long; recipient gametangium not inflated, 46–60 μm wide, 46–105 μm long; cells without conjugation pair not inflated; 46.4–62.1 μm wide, 44–160 μm long. Zygospores ellipsoid, often with pointed tops, 41–54 μm wide, 47–96 μm long; exospore thin, smooth; mesospore thick, thick, yellow-brown, smooth.

Fertile thalli of *S. condensata* have been encountered in 5 new locations: **1** - June-July 2020, in the water column, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata*, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5); **2** - June 2020, in the water column and on the water surface, water temperature 18.3°C, pH 7.2, EC 213 μS cm^{-1}, synusia of unattached free-floating algae, or metaphyton (*S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp.

ster. 8, *Mougeotia* sp. ster. 1) (5-15%) in macrophytes community dominated by *Elodea canadensis* (40%) + *Myriophyllum spicatum* (30%) + *Chara globularis* Thuill. (5-10%); **3** - September 2020, depth < 2 m, stony substrate, water temperature 16°C, pH 7.1, EC 118.7–122.4 μS cm^{-1}, periphyton (*S. fluviatilis*, *S. condensata*, *Ulothrix zonata*, *Tetraspora cylindrica* var. *bullosa* K.I. Meyer, *Didymosphenia* sp.); **4** - September 2020, depth < 2 m, stony substrate, water temperature 16.5°C, pH 7.0, EC 122.4 μS cm^{-1}, periphyton (*S. condensata* ; *Ulothrix zonata*); **5** - June 2020, in the water column and on the water surface, water temperature 17°C, pH 7.2, EC 118.6 μS cm^{-1}, metaphyton (*S. condensata, Ulothrix zonata*, *Cladophora floccosa* K.I. Meyer, *Zygnema* sp. ster. 1, *Mougeotia* sp. ster.1).

Widespread species (Kadlubowska, 1984; Rundina, 1998). In previous surveys, we first identified *S. condensata* from 3 sites of Lake Baikal (Volkova et al., 2018).

Spirogyra decimina var. juergensii (Kützing) O.V. Petlovany (Fig. 2A, Fig. 2B, Fig. 2C)

Vegetative cells 27–34 μm wide, 52–72 μm long; transverse walls plane; chloroplast single, 2–4 turns per cell. Conjugation scalariform, tubes formed by both gametangia with slight predominance by the male gametangium. Donor gametangium not inflated, 30–33 μm wide, 37–67 μm long; recipient gametangium not inflated or slightly inflated on the conjugating side, 27–30 μm wide, 66–97 μm long. Zygospores ellipsoid, sometimes with rounded tops, 26–32 μm wide, 57–72 μm long; mesospore yellow-brown, smooth.

Fertile thalli of *S. decimina* var. *juergensii* have been encountered in 2 new locations: **1** - June 2020, in the water column, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata*, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5); **11** - July 2020, depth < 0.5 m, sand, water temperature 24.1°C, pH 7.3, EC 167 μS cm^{-1}, periphyton (*S. decimina* var. *juergensii* , *Ulothrix zonata*).

Widespread species and variety (Kadlubowska, 1984; Rundina, 1998). In Lake Baikal, it was first found by Meyer and Reinhardt (1925) in Istoksky Bay. In previous surveys, we identified *S. decimina* var. *juergensii* from 6 other sites of Lake Baikal (Volkova et al., 2018).

Spirogyra fluviatilis Hilse (Fig 2D, Fig 2F, Fig 2G)

Vegetative cells 34–47 μm wide, 84–285 μm long; transverse walls plane; 3–4 chloroplasts with 5–14 turns per cell. Vegetative filaments often with multicellular branched rhizoids. Conjugation scalariform, tubes formed by both gametangia, sometimes predominantly by male gametangia. Donor gametangium not inflated or slightly cylindrically inflated, 35–45 μm wide, 66–225 μm long; recipient gametangium more or less inflated mainly on conjugation side or both sides, 33–60 μm wide, 70–194 μm long; cells without conjugation pair not swollen, rarely slightly cylindrically inflated, sometimes form rhizoids. Zygospores ellipsoid, 44–70 μm wide, 68–180 μm long; exospore smooth, colorless; mesospore brown, thick, distinctly multilayered, reticulate, sometimes wrinkled.

Fertile thalli of *S. fluviatilis* have been encountered in a single location: **7** - June 2020, depth 1.5-2 m, stony substrate, water temperature 16.2°C, pH 6.9, periphyton (*Ulothrix zonata*, *Tetraspora cylindrica* var. *bullosa, Draparnaldioides simplex* (K.I. Meyer) Vishnyakov, *S. fluviatilis*).

Widespread species (Kadlubowska, 1984; Rundina, 1998; Stancheva et al., 2013; Sherwood et al., 2018). In previous surveys, we first identified *S. fluviatilis* from 25 sites of Lake Baikal and in the Angara River (Volkova et al., 2018).

Spirogyra varians (Hassall) Kützing (Fig. 2H, Fig. 2I, Fig. 2J)

Vegetative cells 38–41 μm wide, 63–78 μm long; transverse walls plane; chloroplast single with 1.5–3.5 turns per cell. Conjugation scalariform, tubes formed by both gametangia with predominance by the male gametangium; conjugation often occurs among three filaments. Donor gametangium sometimes inflated, 41–50 μm wide, 38–82 μm long; recipient gametangium strongly inflated on the conjugating side, 41–50 μm wide, 49–75 μm long; cells without conjugating pair swollen, 53–64 μm wide, 60–90 μm long. Zygospores ellipsoid, 45–57 μm wide, 50–81 μm long; mesospore yellow-brown, thick, smooth.

Fertile thalli of *S. varians* have been encountered in 3 new locations: **1** - June-July 2020, in the water column, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata*, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5); **2** - June 2020, depth < 2 m and on the water surface, water temperature 18.3-19°C, pH 7.2, EC 213 μS cm^{-1}, synusia of unattached algae, or metaphyton (*S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp. ster. 8, *Mougeotia* sp. ster. 1) (5-15%) in macrophytes community dominated by *Elodea canadensis* (40%) + *Myriophyllum spicatum* (30%) + *Chara globularis* (5-10%); **6** - June 2020, in the water column and on the water surface, water temperature 18°C, pH 7.3, EC 184 μS cm^{-1}, metaphyton (*Spirogyra varians*, *Ulothrix zonata*).

The first findings of this species were reported from two sites of Lake Baikal and two of its tributaries (Volkova et al., 2018). *S. varians* is among the commonest in Lake Baikal and its surroundings, which corresponds to the cosmopolitan status of the species (Transeau, 1951; Kadlubowska, 1984; Rundina, 1998; Stancheva et al., 2013; Sherwood et al., 2018).

Spirogyra sp. ster. 1 (Fig. 3A)

Vegetative cells 54-67 μm wide, 132-340 μm long; transverse walls plane; 5-6 chloroplasts with 6-12 turns per cell.

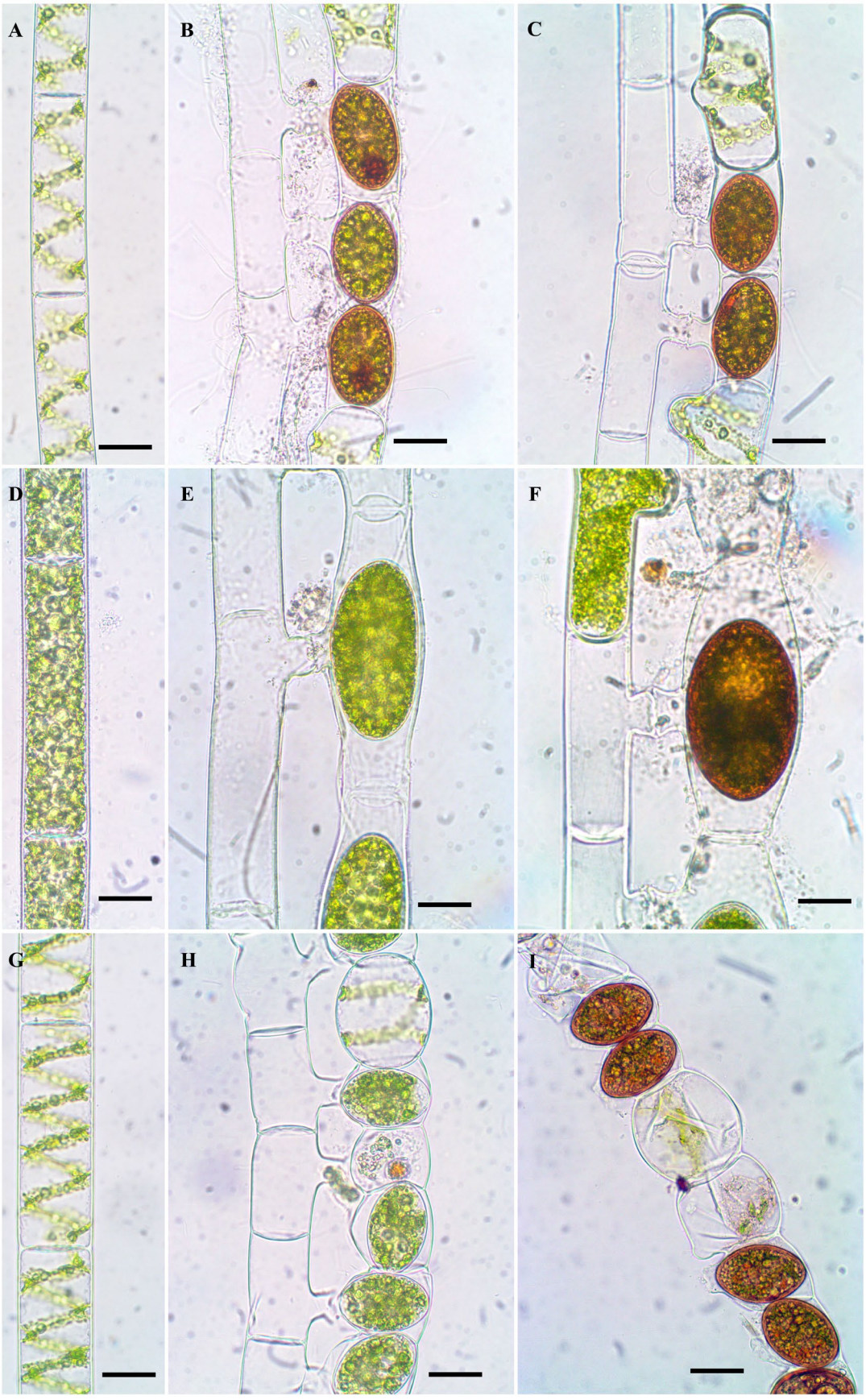

Fig.2. Light microscopic images of *Spirogyra* species from the Lake Baikal region: (A, B, C) *S. decimina* var. *juergensii*; (D, E, F) *S. fluviatilis*; (G, H, I) *S. varians*. Scale bar, 30 μm.

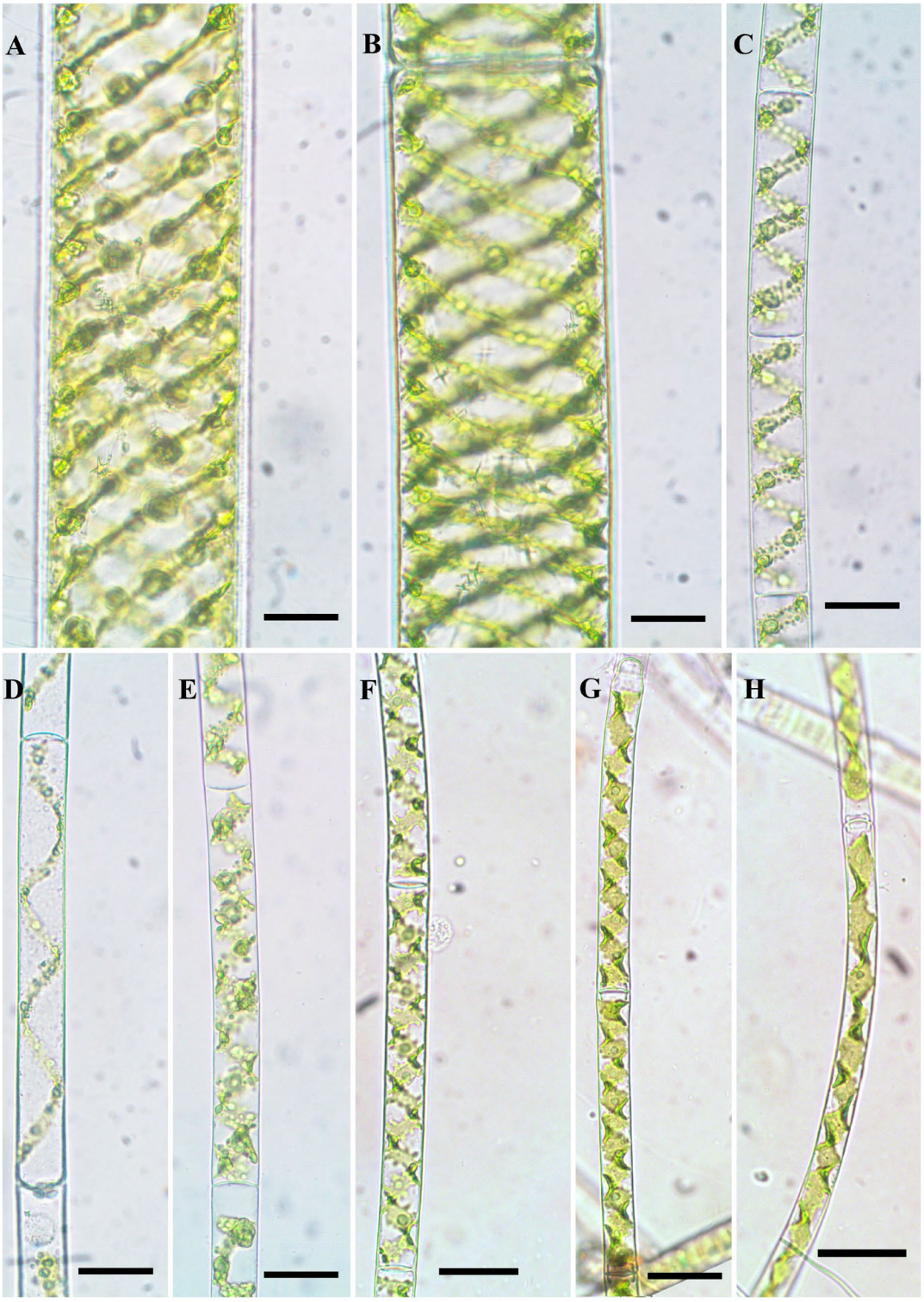

Fig.3. Light microscopic images of *Spirogyra* morphotypes from the Lake Baikal region: (A) *Spirogyra* sp. ster. 1; (B) *Spirogyra* sp. ster. 2; (C) *Spirogyra* sp. ster. 3; (D) *Spirogyra* sp. ster.4; (E) *Spirogyra* sp. ster. 5; (F) *Spirogyra* sp. ster. 6; (G) *Spirogyra* sp. ster. 7; (H) *Spirogyra* sp. ster. 8. Scale bar, 30 μm.

This is the first report of this *Spirogyra* morphotype for the region. *Spirogyra* sp. ster. 1 has been first encountered in 7 locations: **1** - June-July 2020, in the water column and on the water surface, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata*, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5); **2** - June 2020, depth < 2 m and on the water surface, water temperature 18.3-19°C, pH 7.2, EC 213 μS cm^{-1}, synusia of unattached algae, or metaphyton (*S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp. ster. 8, *Mougeotia* sp. ster. 1) (5-15%) in macrophytes community dominated by *Elodea canadensis* (40%) + *Myriophyllum spicatum* (30%) + *Chara globularis* (5-10%); **3** - September 2020, depth ≥ 1.5-2 m, stony substrate, water temperature 9-16°C, pH 7.1, EC 118.7–122.4 μS cm^{-1}, periphyton

(*S. fluviatilis*, *S. condensata*, *Ulothrix zonata*, *Tetraspora cylindrica* var. *bullosa* K.I. Meyer, *Didymosphenia* sp.); **8** - June-July 2020, on the water surface an in the water column, water temperature 18-19°C, EC 224 μS cm^{-1}, metaphyton (*Spirogyra* sp. ster. 1., *Mougeotia* sp. ster. 1); **9** - June 2020, in the water column and on the water surface, water temperature 19.4-20°C, EC 210 μS cm^{-1}, metaphyton (*Spirogyra* sp. ster. 1, *Mougeotia* sp. ster. 1); **12** - June-July 2020, depth ~ 2 m, stones, water temperature 13°C, metaphyton (*Ulothrix zonata*, *Spirogyra* sp. ster. 1); **13** - July 2020, algal accumulations on the shore, water temperature 19.2°C, EC 403 μS cm^{-1}, synusia of *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2.

***Spirogyra* sp. ster. 2 (Fig. 3B)**

Vegetative cells 86-91 μm wide, 200-520 μm long; transverse walls plane; 4-5 chloroplasts with 6-12 turns per cell.

This is the first report of this *Spirogyra* morphotype for the region. *Spirogyra* sp. ster. 2 has been first encountered in 4 locations: **2** - June 2020, depth < 2 m and on the water surface, water temperature 18.3-19°C, pH 7.2, EC 213 μS cm^{-1}, synusia of unattached algae, or metaphyton (*S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp. ster. 8, *Mougeotia* sp. ster. 1) (5-15%) in macrophytes community dominated by *Elodea canadensis* (40%) + *Myriophyllum spicatum* (30%) + *Chara globularis* (5-10%); **13** - July 2020, algal accumulations on the shore, water temperature 19.2°C, EC 403 μS cm^{-1}, synusia of *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2; **14** - July 2020, water temperature 21.5°C, EC 944 μS cm^{-1}, metaphyton (*Spirogyra* sp.ster.2); **15** – August, 2020, water temperature 8.2°C, EC 102 μS cm^{-1}, metaphyton (*Spirogyra* sp. ster.2).

***Spirogyra* sp. ster. 3 (Fig. 3C)**

Vegetative cells 23-24 μm wide, 101-120 μm long; transverse walls plane; 1 chloroplast with 4 turns per cell.

This is the first report of this *Spirogyra* morphotype for the region. *Spirogyra* sp. ster. 3 has been first encountered in a single location: **1** - June-July 2020, in the water column and on the water surface, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata*, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5).

***Spirogyra* sp. ster. 4 (Fig. 3D)**

Vegetative cells 19-20 μm wide, 190-199 μm long; transverse walls plane; 1 chloroplast with 3-3.5 turns per cell.

This is the first report of this *Spirogyra* morphotype for the region. *Spirogyra* sp. ster. 4 has been first encountered in a single location: **1** - June-July 2020, in the water column and on the water surface, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata*, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5).

***Spirogyra* sp. ster. 5 (Fig. 3E)**

Vegetative cells 18-19 μm wide, 190-199 μm long; transverse walls plane; 1 chloroplast with 3-3.5 turns per cell.

This is the first report of this *Spirogyra* morphotype for the region. *Spirogyra* sp. ster. 5 has been first encountered in a single location: **1** - June-July 2020, in the water column and on the water surface, water temperature 14.0-15.2°C, pH 7.6, EC 129.3 μS cm^{-1}, metaphyton (*Ulothrix zonata* (*Ulothrix zonata*, *S. fluviatilis*, *S. condensata*, *S. decimina* var. *juergensii*, *S. circumlineata*, *S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Spirogyra* sp. ster. 4, *Spirogyra* sp. ster. 5).

***Spirogyra* sp. ster. 6 (Fig. 3F)**

Vegetative cells 14-16 μm wide, 112-195 μm long; transverse walls plane; 1 chloroplast with 2-12 turns per cell.

This is the first report of this *Spirogyra* morphotype for the region. *Spirogyra* sp. ster. 6 has been first encountered 3 locations: **2** - June 2020, depth < 2 m and on the water surface, water temperature 18.3-19°C, pH 7.2, EC 213 μS cm^{-1}, synusia of unattached algae, or metaphyton (*Spirogyra* spp. ster., *S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp. ster. 8, *Mougeotia* sp. ster. 1) (5-15%) in macrophytes community dominated by *Elodea canadensis* (40%) + *Myriophyllum spicatum* (30%) + *Chara globularis* (5-10%); **3** - September 2020, at depth ≥ 1.5-2 m, stony substrate, water temperature 9-16°C, pH 7.1, EC 118.7–122.4 μS cm^{-1}, metaphyton (*S. fluviatilis*, *S. condensata*, *Ulothrix zonata*, *Tetraspora cylindrica* var. *bullosa*, *Didymosphenia* sp., *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster.6, *Zygnema* sp.ster.1); **6** - June 2020, in the water column and on the water surface, water temperature 18°C, pH 7.3, EC 184 μS cm^{-1}, metaphyton (*Spirogyra varians*; *Spirogyra* sp. ster. 2).

***Spirogyra* sp. ster. 7 (Fig. 3G)**

Vegetative cells 12.5-13 μm wide, 104-125 μm long; transverse walls replicate; 1 chloroplast with 5-6 turns per cell.

First encountered in a single location: **2** - June 2020, depth < 2 m and on the water surface, water temperature 18.3-19°C, pH 7.2, EC 213 μS cm^{-1}, synusia of unattached algae, or metaphyton (*Spirogyra* spp. ster., *S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp. ster. 8, *Mougeotia* sp. ster. 1) (5-15%) in macrophytes community dominated by *Elodea canadensis* (40%) + *Myriophyllum spicatum* (30%) + *Chara globularis* (5-10%).

***Spirogyra* sp. ster. 8 (Fig. 3H)**

Vegetative cells 10-11 μm wide, 199-204 μm long; transverse walls replicate; 1 chloroplast with 8-12 turns per cell.

First encountered in a single location: **2** - June 2020, depth < 2 m and on the water surface, water temperature 18.3-19°C, pH 7.2, EC 213 μS cm^{-1}, synusia of unattached algae, or metaphyton (*Spirogyra* spp. ster., *S. fluviatilis*, *S. condensata, S. varians*, *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 6, *Spirogyra* sp. ster. 7, *Spirogyra* sp. ster. 8, *Mougeotia* sp. ster. 1) (5-15%) in macrophytes community dominated by *Elodea canadensis* (40%) + *Myriophyllum spicatum* (30%) + *Chara globularis* (5-10%).

Genus *Mougeotia* C. Agardh

***Mougeotia* sp. ster. 1 (Fig. 4A)**

Filaments without rhizoids. Vegetative cells 18-23 μm wide, 40-270 μm long; transverse walls plane, with 1 axial lamellar chloroplast.

This is the first report of this *Mougeotia* morphotype for the region. *Mougeotia* sp. ster. 1 has been first encountered in 8 locations: **5** - June 2020, in the water column and on the water surface, water temperature 17°C, pH 7.2, EC 118.6 μS cm^{-1}, metaphyton (*S. condensata, Ulothrix zonata*, *Cladophora floccosa* K.I. Meyer, *Zygnema* sp. ster. 1, *Mougeotia* sp. ster.1); **8** - June-July 2020, on the water surface and in the water column, water temperature 18-18-19°C, EC 224 μS cm^{-1}, metaphyton (*Spirogyra* sp. ster. 1., *Mougeotia* sp. ster. 1); **9** - June 2020, in the water column and on the water surface, water temperature 19.4-20°C, EC 210 μS cm^{-1}, metaphyton (*Mougeotia* sp. ster. 1); **10** - June 2020, sandy substrate, water temperature 17°C EC 124 μS cm^{-1}, synusia of unattached algae, metaphyton (*Zygnema* sp. ster. 1, *Mougeotia* sp. ster. 1) (15%) in macrophytes community dominated by *Myriophyllum sibiricum* Kom. (30%) + *Elodea canadensis* (20%) + *Potamogeton* spp. (10%) + *Chara* sp. (10%); **16** - June 2020, depth < 0.5m, stony substrate, water temperature 16.5-17.5°C, pH 7.1, metaphyton (*Zygnema* sp. ster. 1, *Zygnema* sp. ster. 3, *Mougeotia* sp. ster.1); **17** - June 2020, depth < 0.5 m, sandy substrate, water temperature 15-25°C, pH 6.8, metaphyton (*Zygnema* sp. ster. 1, *Mougeotia* sp. ster. 1); **18** - July 2020, water temperature 15-23°C, synusia of *Mougeotia* sp. ster. 1. in macrophytes community dominated by *Potamogeton* sp. and *Myriophyllum* sp.; **19** - July 2020, water temperature 26.5°C, EC 334 μS cm^{-1}, algal mats (*Mougeotia* sp. ster. 1, *Zygnema* sp. ster.1).

***Mougeotia* sp. ster. 2 (Fig. 4B)**

Filaments without rhizoids. Vegetative cells 15-19 μm wide, 30-200 μm long; transverse walls plane, with 1 axial lamellar chloroplast.

This is the first report of this *Mougeotia* morphotype for the region. *Mougeotia* sp. ster. 2 has been first encountered in 4 locations: **19** - July 2020, sandy substrate, water temperature 11.5°C, EC 375 μS cm^{-1}, metaphyton (*Mougeotia* sp. ster. 2); **20** - June 2020, at depth < 0.5 m, sandy substrate, water temperature 12°C, metaphyton of *Mougeotia* sp. ster. 2, (15%) in macrophytes community dominated by *Potamogeton* sp. (30%) + *Myriophyllum* sp. (20%); **22** - July 2020, sandy substrate, water temperature 24.4°C, EC 603 μS cm^{-1}, in a large accumulation of filamentous algae on a flooded meadow, in shallow water in the flooded grass; **23** - July 2020, sandy substrate, water temperature 27.1°C, EC 555 cm^{-1}, metaphyton (*Mougeotia* sp. ster. 2).

Mougeotia sp. ster. found in Angaro-Kicherskoye Bay (Lake Baikal) (Meyer, 1930), Davsha Bay, Kotelnokovskyi Cape (Lake Baikal) (Izhboldina, 2007), the delta of the Selenga River (Votyakova, 1981), the Peremennaya River, and Krivoye Lake (Izhboldina, 2007). *Mougeotia genuflexa* (Dillw.) Ag. was found in Anga Bay, Proval Bay, Nizhneangarsky Bay (Lake Baikal) (Meyer, 1930). *M. laetevirens* (A. Br.) Wittr. was found in Anga Bay (Meyer, 1930).

Genus *Zygnema* C. Agardh (Fig. 4C)

***Zygnema* sp. ster. 1**

Filaments without basal rhizoids. Vegetative

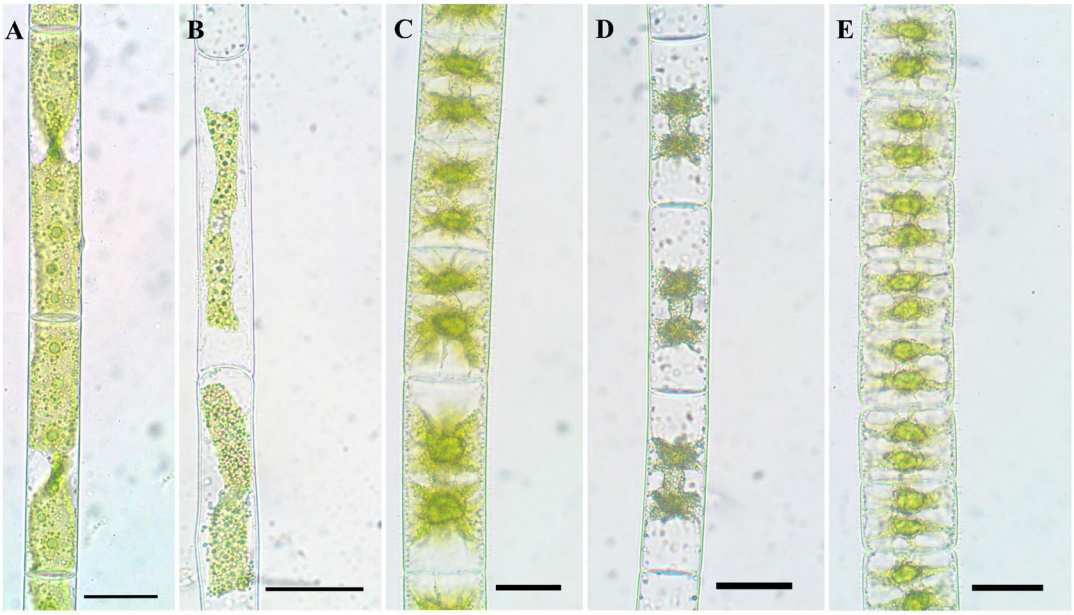

Fig.4. Light microscopic images of *Mougeotia* and *Zygnema* morphotypes from the Lake Baikal region: (A) *Mougeotia* sp. ster. 1; (B) *Mougeotia* sp. ster. 2; (C) *Zygnema* sp. ster. 1; *Zygnema* sp. ster. 2; *Zygnema* sp. ster. 3. Scale bar, 30 μm.

cells 32-38 μm wide, 35-98 μm long; transverse walls plane, 2 stellate chloroplasts in each cell.

This is the first report of this *Zygnema* morphotype for the region. *Zygnema* sp. ster. 1 has been first encountered in 6 locations: **3** - September 2020, depth ≥ 2 m, stony substrate, water temperature 9-14°C, pH 7.1, EC 118.7–122.4 μS cm^{-1}, metaphyton (*S. fluviatilis*, *S. condensata*, *Ulothrix zonata*, *Tetraspora cylindrica* var. *bullosa*, *Didymosphenia* sp., *Spirogyra* sp. ster. 1, *Spirogyra* sp. ster.6, *Zygnema* sp.ster.1); **5** - September 2020, depth < 1-1,5 m, in the water column and on the water surface, water temperature 17°C, pH 7.2, EC 118.6 μS cm^{-1}, metaphyton (*S. condensata, Ulothrix zonata*, *Cladophora floccosa* K.I. Meyer, *Zygnema* sp. ster. 1, *Mougeotia* sp. ster.1); **10** - June 2020, depth < 0.5 m, sandy substrate, water temperature 17°C, EC 124 μS cm^{-1}, among of unattached free-floating algae, or metaphyton (*Zygnema* sp. ster. 1, *Mougeotia* sp. ster. 1) (15%) in macrophytes community dominated by *Myriophyllum sibiricum* (30%) + *Elodea canadensis* (20%) + *Potamogeton* spp. (10%) + *Chara* sp. (10%); **16** - June 2020, depth < 0.5m, stony substrate, water temperature 16.5°C, pH 7.1, metaphyton (*Zygnema* sp. ster. 1, *Zygnema* sp. ster. 3, *Mougeotia* sp. ster.1); **17** - June 2020, depth < 0.5 m, sandy substrate, water temperature 15-25°C, pH 6.8, metaphyton (*Zygnema* sp. ster. 1, *Mougeotia* sp. ster. 1); **21** - June 2020, depth < 0.5 m, sandy substrate, in water column, water temperature 15°C, pH 7.2, among of unattached free-floating algae, or metaphyton (*Zygnema* sp. ster, *Mougeotia* sp. ster.1);

***Zygnema* sp. ster. 2 (Fig. 4D)**

Filaments without basal rhizoids. Vegetative cells 23-24 μm wide, 68-78 μm long; transverse walls plane, 2 stellate chloroplasts in each cell.

This is the first report of this *Zygnema* morphotype for the region. *Zygnema* sp. ster. 2 has been first encountered in the quarry lake in a single location: **24** - July 2020, in a large accumulation of filamentous algae on a flooded meadow, in shallow water in the flooded grass, water temperature 27.1˚C, EC 555 μS cm^{-1}.

***Zygnema* sp. ster. 3 (Fig. 4E)**

Filaments without basal rhizoids. Vegetative cells 40-43 μm wide, 31-40 μm long; transverse walls plane, 2 stellate chloroplasts in each cell.

This is the first report of this *Zygnema* morphotype for the region. *Zygnema* sp. ster. 3 has been first encountered in a single location: **16** - August 2020, depth < 0.5m, stony substrate, water temperature 16.5°C, pH 7.1, metaphyton (*Zygnema* sp. ster. 1, *Zygnema* sp. ster. 3, *Mougeotia* sp. ster.1).

In Lake Baikal, one *Zygnema* species was found in Istoksky Bay (Meyer, 1930). Filaments of *Zygnema* sp. ster. were found in Maloe More Bay, Lake Baikal (Izhboldina, 2007). In the Lake Baikal surrounding area, *Zygnema* sp. ster. were observed in the Osinovka River and in some small freshwater lakes (Izhboldina, 2007).

4. Discussion

Reliable taxonomic reports of *Zygnemataceae* are scarce, being commonly reduced to simply mentioning a generic name without the description of specimens. This because sexual reproduction, or conjugation, is a rarely observed phenomenon in nature. According to different estimates, fertile specimens may occur only in 10-20% of a large-scale field collection (McCourt and Hoshaw, 1986; Novis, 2004; Hainz et al., 2009; Stancheva et al., 2012; 2013; Volkova et al., 2018). Nevertheless, we believe it is essential not only to name the taxa but also to provide morphological descriptions, although not enough for precise identifications, even if fertile filaments were not found. Such an approach would make taxonomic surveys dealing with sterile zygnemataleans as biologically meaningful as possible and a practical basis for further studies. Detailed information on these algae would help assess their bio-indicating role and proliferation degree to respond to water pollution (Hainz et al., 2009) or trace the species origin (Volkova et al., 2018). For instance, when the massive proliferation of *Spirogyra* occurred in Lake Baikal ten years ago, it was uncertain whether native or invasive species caused it (Grachev, 2016). That was primarily since most of the records that mentioned zygnemataleans from this region earlier were not focused on describing either fertile or, even less, sterile filaments. Thus, in the case of the blooming of uncommon zygnemataleans in Lake Baikal, not only their precise identification was challenging, but also understanding their origin and life history. In addition, the description of morphology combined with DNA barcoding might help reveal the hot spots of their diversity and estimate the species' morphological plasticity. It is relevant, especially given the problems inherent in the existing species concept in *Zygnemataceae* (McCourt and Hoshaw, 1990).

In this survey, 18 taxa were identified using morphological characters and classified into three genera, *Spirogyra*, *Mougeotia*, and *Zygnema*. *Spirogyra* was the most diverse genus with thirteen taxa. Two and three taxa belong to *Mougeotia* and *Zygnema* genera, respectively. Fertile stages were in five *Spirogyra* species, including one variety. *S. circumlineata* is reported for Lake Baikal for the first time. Previously, this species was found only in the Bolshaya Kotinka River, one of the lake's southern tributaries (Volkova et al., 2018). Eight new morphotypes of *Spirogyra* were first discovered in the studied area. These do not correspond to descriptions of the already known species and likely represent eight species new for the region. We observed only sterile filaments of *Mougeotia* and *Zygnema*. The *Mougeotia* and *Zygnema* morphotypes we discovered are first reported for the region. The cell dimensions of *Mougeotia* sp. ster. 1, *Mougeotia* sp. ster. 2, and *Zygnema* sp. ster. 1, *Zygnema* sp. ster. 2 are close to those in *Mougeotia genuflexa*, *M. laetevirens*, and *Z. cruciatum*, the species already known from Lake Baikal (Izhboldina, 2007). However, these may also represent previously unknown species since the morphology of sterile filaments overlaps considerably in various taxa (Rundina, 1998). Nevertheless, as in *Spirogyra*, the lack

of conjugation or resting stages in the studied taxa of *Mougeotia* and *Zygnema* prevents their identification at the species level.

Based on presented data and previous taxonomic surveys (Meyer, 1930; Rundina, 1998; Volkova et al., 2018), *Spirogyra* appears more widely distributed than *Mougeotia* or *Zygnema* among the sites investigated. In this study, *Spirogyra*, *Mougeotia*, and *Zygnema* were found in 14, 12, and 7 out of 24 locations, respectively. The distributions of the taxa are likely broader than reported here since most of the species of all three genera are cosmopolitan (Kadlubowska, 1984; Rundina, 1998). Nevertheless, considering the ancientness and specific environmental features of Lake Baikal resulted in its exceptional biodiversity, one could also expect endemic or rare zygnemataleans, as in other unique regions of our planet (Novis, 2004; Sherwood et al., 2018).

Algae of the family *Zygnemataceae* often dominate periphyton or metaphyton assemblages (Hoshaw, 1968; Simons and Van Beem, 1990; Rundina, 1998). Furthermore, they can be a regular part of plant communities or act as an optional component, namely seasonal synusia (Sviridenko et al., 2012). In this study, zygnemataleans were part of 4 attached (periphyton) and 16 free-floating (metaphyton) algal communities. The first ones were observed in Lake Baikal and also consisted of green algae, such as *Ulothrix zonata*, *Tetraspora cylindrica* var. *bullosa*, *Draparnaldioides simplex*, and diatom *Didymosphenia* sp. These are typical species for the lake's open littoral zone with an active hydrodynamic regime (Izhboldina, 2007). The composition of metaphyton varied depending on location and biotope. In four investigated sites (Anga Bay, Barguzinskyi Bay, the Frolikha River's mouth, ponds near the Solontsoviy Cape of Lake Baikal), free-floating synusia of *Spirogyra*, *Zygnema*, and *Mougeotia* with the PC of 5–15% were part of macrophytes communities dominated by *Myriophyllum sibiricum*, *M. spicatum*, *Elodea canadensis*, *Potamogeton* spp., and *Chara globularis*. In seven Lake Baikal's sites (the bay opposite Bolhoye Goloustnoye village, Bolshiye Koty Bay, the bay opposite Kultuk, Listvennochniy Bay, Senogda Bay, the bay opposite Slyudyanka town, the bay opposite Zarechnoye village) and in the shallow, warmed-up areas of the studied rivers (the Chernaya River, the Bolshaya Kotinka River, the Malaya Kotinka River, the Angara River, the Irkut River, the Egia River, the Medlyanka River), metaphyton consisted of *Spirogyra* and/or *Mougeotia*, *Zygnema*, and occasionally included other green filamentous algae, *Ulothrix zonata*, and *Cladophora floccosa*.

5. Conclusion

This study is a new taxonomic report on *Zygnemataceae* from the Lake Baikal region with morphological descriptions of the discovered taxa, characteristics of their environment, and accounts of the co-occurring macrophytes and algae. We identified 18 taxa of the genera *Spirogyra*, *Zygnema*, and *Mougeotia* from 26 new locations, including the Angara River, the Irkut River, Lake Baikal, the five tributaries of the lake (the Chernaya River, the Bolshaya Kotinka River, the Malaya Kotinka River, the Frolikha River, the Medlyanka River), and the small ponds and swamps in the lake surrounding area. In addition to 19 taxa of the family already known from the area, we described thirteen potentially new species. *Spirogyra* is more diverse and widespread than *Zygnema* and *Mougeotia* in the Lake Baikal region. However, the taxa of all three genera regularly present in the communities. The predomination of sterile specimens complicates their precise taxonomic identification; however, it indicates optimal conditions for the vegetation of zygnemataleans and their biomass growth. The members of the family *Zygnemataceae* represent a dynamic component of periphyton, metaphyton, and aquatic macrophyte communities in the studied area. This, on the one hand, reveals them as a significant yet optional component of plant communities. On the other hand, this contributes to their actual distribution, in particular, in the littoral zone of Lake Baikal.

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Conflicts of Interest

The authors declare no conflicts of interest.

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