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Silica-scaled chrysophytes in large tributaries of Lake Baikal

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Abstract – High diversity of silica-scaled chrysophytes was recorded in the Barguzin River mouth and the Selenga River delta. Their flora was represented by 66 species and intra-specific taxa: *Chrysosphaerella* – 2, *Paraphysomonas* – 8, *Clathromonas* – 5, *Spiniferomonas* – 8, *Mallomonas* – 29, and *Synura* – 14. Eight taxa of silica-scaled chrysophytes were observed for the first time in Russia: *Chrysosphaerella rotundata*, *Mallomonas doignonii*, *M. trummensis*, *M. corymbosa*, *Clathromonas poteriophora*, *Paraphysomonas acuminata acuminata*, *P. vulgaris*, and *Synura laticarina*. In May, we found scales of *Mallomonas striata* with morphologically changed structure in the mouth of the Barguzin River and Srednyaya Channel of the Selenga River delta. The flora of silica-scaled chrysophytes studied differs from one tributary to another. We observed only 52 species in the Selenga River delta, whereas in the Barguzin River mouth we identified 35 species. These large rivers affect the flora of Lake Baikal diversifying silica-scaled chrysophytes in its southern and central basins. The total list of species and intra-specific taxa in the Selenga River delta, Barguzin River mouth, and in Lake Baikal includes 72 taxa. Therefore, this area may be considered as a "hotspot" of silica-scaled chrysophytes together with three hotspots observed worldwide earlier.

Silica-scaled chrysophytes / hotspot / Selenga River / Barguzin River / Lake Baikal

INTRODUCTION

A biogeographic area which is rich in high species diversity of silica-scaled chrysophytes is called a "hotspot" (Němcová *et al.*, 2012). High diversity of chrysophytes is a rare phenomenon and until present it has been recorded only at three sites of the world: in Bolshezemelskaya and Vorkuta tundras (75 species) (Siver *et al.*, 2005), in waterbodies of Finland (73 species) (Hallfors & Hallfors, 1988), and in waterbodies of Aquitania (France) (58 species) (Němcová *et al.*, 2012). According to Němcová *et al.* (2012), high species richness may be attributed to diverse habitat conditions in these regions: trophic status (from oligotrophic to mesotrophic), origin, and physical, chemical and hydrological characteristics. Thus, a high diversity of chrysophytes is observed in the vast Bolshezemelskaya Tundra region of Russia, which abounds in water bodies differing in origin and fed from different sources (Siver *et al.*, 2005). In Finland, a rich species composition of scaled chrysophytes has been revealed in the course of 4-year research on 141 lakes, with

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samples from large lakes having been taken four times a year (Hallfors & Hallfors, 1988). The region of Aquitaine (France) bordering the Atlantic Ocean is the smallest among the regions considered, but its water bodies are also diverse in terms of origin and formation conditions (Němcová *et al.*, 2012). Moreover, the diversity of environment in river deltas and mouths provides conditions for a high abundance of chrysophyte species, and these habitats may be regarded as "hot spots" in this respect. The aim of this study is to determine diversity of silica-scaled chrysophytes in the channels of the Selenga River delta and in the Barguzin River mouth, main tributaries of Lake Baikal, and to assess possible impact of these rivers on the algal flora of Lake Baikal.

MATERIAL AND METHODS

The water was sampled in 2016 in different hydrological phases (low-water level in winter, spring flood, and low-water level in autumn) in the lower reaches of the main tributaries of Lake Baikal – Selenga River, channels of its delta, and in the Barguzin River mouth (Fig. 1). Sixty-three samples were collected with a 1.3 L water sampler from the surface water layer (0 m) on March 12-18, May 3-10, July 12-20, and September 11-19 of 2016.

For chemical analysis, water samples were filtered through a membrane filter with a pore diameter of 0.45 µm. Conductivity was measured at 25°C with a conductometer DS-12 (Horiba, Japan). Colorimetric and potentiometric methods were used for measuring silicon and total phosphorus, respectively (Wetzel & Likens, 1991). Reliability of the results obtained was proved by regular control of the analysis quality within the International EANET Program for testing reference samples of surface waters.

To analyze chrysophytes in phytoplankton, samples were fixed in the Lugol solution and then settled (Kuzmin, 1975). We collected simultaneously water samples (11-15 ml) for filtering them through a Whatman filter with a diameter of 13 mm and a pore diameter of 1 µm, dried at room temperature, coated with gold and examined on a scanning electron microscope Philips SEM 525M. For transmission electron microscopy (TEM), we centrifuged a 1 ml sample in an Eppendorf. Settled sediments were dropped onto formvar coated grids and observed using a Zeiss LEO 960E.

RESULTS

Hydrochemical parameters

Water in the Selenga and Barguzin rivers is of low mineralization, bicarbonates and calcium group. Depending on the water level in 2016, the water conductivity varied from 143 mS/m in May to 245 mS/m in winter in the lower reaches of the Selenga River (sites 2 and 3) and in large channels of its delta (sites 4, 9 and 10) (Table 1). During the free-ice period, conductivity in large channels of the Selenga River delta (sites 4, 9 and 10), its small channels (sites 6 and 5) and in the small Lake Zavernyaikha (site 7) was similar. Differences were recorded in winter when small channels froze in their middle part and their mouths were fed by

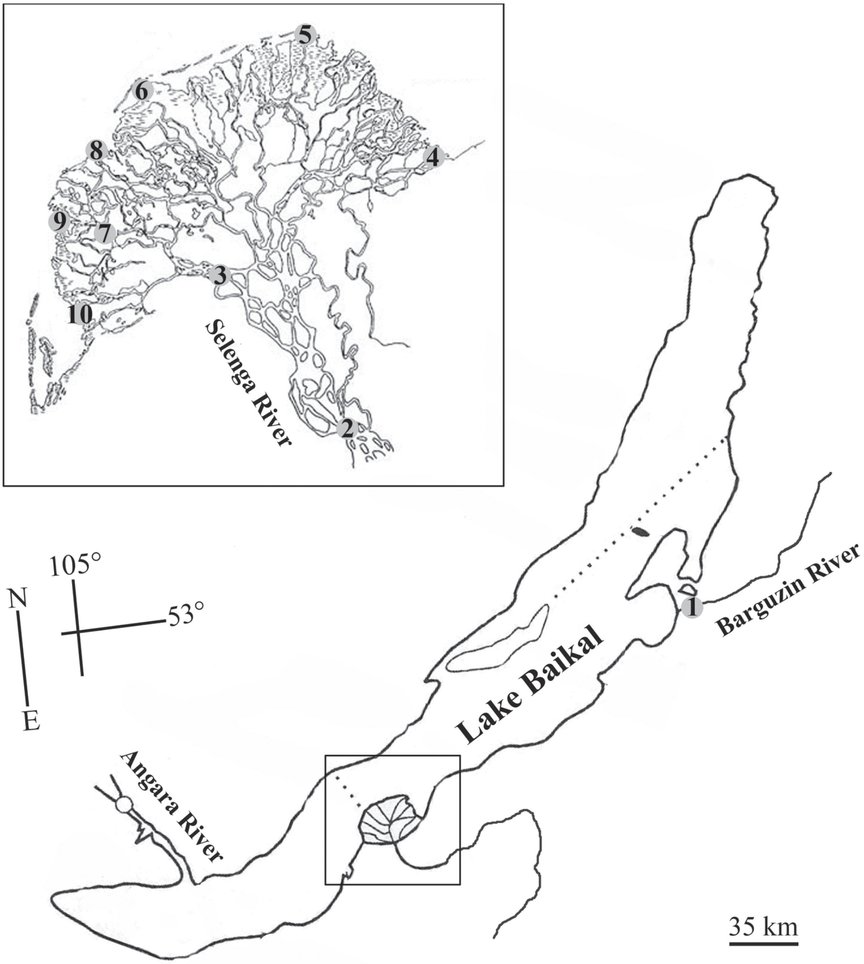


Fig. 1. Schematic map of the study region and locations of sampling sites. A dashed line divides the lake into southern, central, and northern basins.
1. Barguzin River mouth; **2.** Selenga River, settlement of Kabansk; **3.** Selenga River, settlement of Murzino; **4.** Mouth of Lobanovskaya Channel; **5.** Mouth of Severnaya Channel; **6.** Mouth of Srednyaya Channel; **7.** Lake Zavernyaikha; **8.** Mouth of Galutai Channel; **9.** mouth of Kharauz Channel; **10.** Mouth of Levoberezhnaya Channel.

underground waters of lower mineralization. As a result, conductivity in March at sites 6 and 7 was 1144 mS/m and 5 mS/m respectively. Conductivity at site 5 in 2016 compared to 2003-2004 (307-457 mS/m) decreased up to 241 mS/m and was close to that at site 9 (240 mS/m). These changes show that the channel in the upper reaches did not freeze, and chemical composition of its water was affected by the water of the Selenga River. Conductivity in the Barguzin River mouth (site 1) varied during a year from 151 to 212 mS/m. The pH in the studied water bodies in winter was close to neutral (6.95-7.44). In spring and summer, pH values increased up to 8.13 because of the decrease of carbon dioxide concentration (Table 1). The content of dissolved oxygen in the water of these water bodies did not lower to 6 mg/L being

Table 1. Physicochemical parameters of Barguzin and Selenga rivers and channels of the Selenga delta in different months, 2016 (site numbers in Fig. 1)

St. number	Location / Month Year	pH				T, °C				O_2, mg/L				Si, mg/L				P_{total}, µg/L				Conductivity, mS/m			
		III	V	VII	IX	III	V	VII	IX	III	V	VII	IX	III	V	VII	IX	III	V	VII	IX	III	V	VII	IX
1.	Barguzin River (mouth)	7.44	7.83	–	8.03	0.4	10	–	3.8	6.3	–	–	–	4.30	3.3	–	3.7	50	96	–	21	212	151	–	183
2.	Selenga River (Kabansk)	7.00	7.98	7.31	8.15	0.4	13.4	–	3.2	7.6	13.7	–	12.2	4.46	3.38	4.77	4.4	43	76	31	72	233	144	197	200
3.	Selenga River (Murzino)	7.05	8.13	–	8.14	0.4	14	–	3.4	7.3	9.9	–	12.1	4.4	3.2	–	4.2	48	67	–	56	234	145	–	201
4.	Lobanovskaya Channel	7.14	7.85	–	8.09	0.4	14	–	5.9	6.6	–	–	–	4.7	3.4	–	4.2	44	91	–	36	245	151	–	201
5.	Severnaya Channel	7.32	–	–	8.06	0.4	–	–	4.4	9.7	–	–	12	3.9	–	–	4.1	38	–	–	57	241	–	–	202
6.	Srednyaya Channel	6.95	8.03	–	7.95	0.4	16	–	4.6	3.6	11	–	12	10.5	2.9	–	3.8	387	67	–	26	1144	146	–	204
7.	Lake Zavernyaikha	6.97	8.01	–	7.7	0.4	11	–	3.2	1.0	11	–	11	6.1	2.4	–	3.4	48	62	–	41	518	166	–	220
8.	Galutai Channel	–	7.92	–		–	13	–		–	9.4	–		–	3.4	–		–	72	–		–	144	–	
9.	Kharauz Channel	7.18	7.99	–	8.15	0.4	12	–	4.0	8.0	9.9	–	12.2	5.1	3.2	–	4.2	36	76	–	43	240	143	–	201
10.	Levoberezhnaya Channel	7.23	7.99	–	8.13	0.4	14	–	4.0	7.0	9.8	–	13	4.5	3.3	–	4.2	36	81	–	48	240	146	–	202

(–) no data.

favorable for hydrobionts (Table 1). The Srednyaya Channel (site 6) and Lake Zavernyaikha (site 7) were an exception: oxygen concentration in winter was low (3.6 and 1.0 mg/L respectively).

Maximal concentrations of silicon in the Barguzin and Selenga rivers and in large channels of the Selenga delta were recorded in winter, likely due to lower runoff and minimal development of algae (Table 1). The increase of water level in spring, floods in summer, and intense development of algae cause the decrease of silicon concentrations (Sinyukovich *et al.*, 2010; Sorokovikova *et al.*, 2015). Higher concentrations of silicon were recorded at site 6 (10.5 mg/L) and at site 7 (6.1 mg/L), which is likely attributed to the seepage of ground waters with high silicon content, whilst at site 5 the lowest silicon concentrations were registered in winter (3.9 mg/L).

Special attention is paid to the content of phosphorus in the water of the Baikal tributaries, which is the main stimulator of phytoplankton growth and eutrophication of aquatic ecosystems. In 2016, concentrations of total phosphorus in the Selenga River and channels of its delta varied from 36 to 91 μg P/L. Minimal concentrations were recorded in winter and maximal values in spring during floods when high amount of contaminants was brought from the catchment area. The exception was site 6 where unlike other water bodies maximal concentrations of total phosphorus in water were registered in winter (387 μg P/L). In spring, its concentration decreased, and in autumn it was lower than in the Selenga River and other channels (Table 1). In the Barguzin River water (site 1), concentrations of total phosphorus varied from 21 to 96 μg P/L with its minimum in autumn. As is seen from the results obtained at this site, its elevated concentrations were recorded in winter and during floods. This is likely attributed to the impact of sewage from the settlement of Ust-Barguzin. Moreover, in the flood plain of the river there are bogs whose waters flow through the channels to the Barguzin River and can affect chemical composition of its water (Drucker *et al.*, 1997).

The results obtained show high concentrations of P_{total} in the Barguzin and Selenga rivers and channels of the Selenga delta. The critical level of P_{total} is 25 μg P/L indicating the transition of the water body to a eutrophic state (Vollenweider *et al.*, 1980). Judging by this value, the Baikal channels under study can be referred to highly eutrophic environments.

Silica-scaled chrysophytes

We recorded 66 species and intra-specific taxa in the Selenga River delta and Barguzin River mouth: *Chrysosphaerella* – 2, *Paraphysomonas* – 8, *Clathromonas* – 5, *Spiniferomonas* – 8, *Mallomonas* – 29, and *Synura* – 14. (Table 2, Figs 2-79). The most common taxa in these areas were *Chrysosphaerella brevispina*, *Mallomonas acaroides*, *M. corymbosa*, *M. striata*, *M. tonsurata*, and *Synura glabra*. Eight taxa of silica-scaled chrysophytes were observed for the first time in Russia: *Chrysosphaerella rotundata*, *Mallomonas doignonii*, *M. trummensis*, *M. corymbosa*, *Clathromonas poteriophora*, *Paraphysomonas acuminata acuminata*, *P. vulgaris*, and *Synura laticarina*. The number of taxa in samples varied from 2 to 35.

In the samples collected in March 2016, no silica-scaled chrysophytes were recorded at all sites. In May, July and September these algae were not registered at three sites – Murzino at the Selenga River (site 3), mouth of the Kharauz Channel (site 9) and mouth of the Levoberezhnaya Channel (site 10). However, physicochemical parameters at these sites were similar to those at other stations where chrysophytes were recorded (Table 1).

Table 2. List of chrysophytes and their distribution in the Barguzin River mouth and Selenga River delta in different months (2016). Site numbers correspond to those in Fig. 1 and Table 1. “*” – species found in Russia for the first time. Taxa detected in Lake Baikal are in bold

No.	*Species*	*Months and sites*																	
		May							*July*					*September*					
		1	*2*	*4*	*5*	*6*	*7*	*8*	*1*	*2*	*4*	*5*	*7*	*1*	*2*	*4*	*5*	*6*	*7*
1.	***Chrysosphaerella brevispina*** Korshikov	+	+	+		+	+	+	+	+	+		+	+		+			
2.	*Chrysosphaerella rotundata* Škaloudová & Škaloud			+															
3.	***Paraphysomonas acuminata acuminata*** Scoble & Cavalier-Smith*	+		+				+					+						+
4.	*P.* sf. *bandaiensis Takahashi*	+						+	+	+			+	+	+				+
5.	*Paraphysomonas caelifrica* Preisig & Hibberd	+																	
6.	*P. corynephora* Preisig & Hibberd	+							+					+					
7.	***P. gladiata*** Preisig & Hibberd	+							+					+					
8.	*P. punctata* Preisig & D.J.Hibberd	+																	
9.	*P. uniformis hemiradia* Scoble & Cavalier-Smith	+		+															
10.	*P. vulgaris* Scoble *et* Cavalier-Smith*	+	+	+	+		+		+	+		+		+	+		+		
11.	*Clathromonas butcheri* (Pennick & Clarke) J.M.Scoble & T.Cavalier-Smith	+			+							+					+		
12.	*C.* cf. *diademifera* (Takahashi) J.M.Scoble & T.Cavalier-Smith	+																	
13.	*C. homolepis* (Preisig & Hibberd) J.M.Scoble & T.Cavalier-Smith						+												
14.	*C. poteriophora* (Moestrup & Kristiansen) J.M.Scoble & T.Cavalier-Smith*				+														
15.	*C. subrotacea* (Thomsen) J.M.Scoble & T.Cavalier-Smith	+																	
16.	*Spiniferomonas abei* Takahashi				+														
17.	***S. abrupta*** Nielsen	+						+											
18.	*S. bilacunosa* Takahashi						+						+						
19.	***S. bourrellyi*** Takahashi			+	+														
20.	***S. cornuta*** Balonov			+	+		+					+					+		
21.	*S. silverensis* Nicholls			+															

No.	Species	*Months and sites*																	
		May							*July*					*September*					
		1	*2*	*4*	*5*	*6*	*7*	*8*	*1*	*2*	*4*	*5*	*7*	*1*	*2*	*4*	*5*	*6*	*7*
22.	***S. trioralis*** f. ***trioralis*** Takahashi			+	+	+	+					+					+	+	
23.	***S. trioralis*** f. ***cuspidata*** Balonov			+			+	+			+		+			+			+
24.	***Mallomonas acaroides*** Perty	+	+	+	+				+	+	+			+	+	+			
25.	*M. akrokomos* Ruttner		+	+	+	+		+										+	
26.	*M. alata* Asmund, Cronberg & Dürrschmidt	+		+	+			+	+		+			+		+			
27.	***M. alpina*** Pascher & Ruttner	+		+		+		+	+					+					
28.	*M. annulata* (D.E.Bradley) K.Harris			+	+	+		+			+					+			
29.	*M. doignonii* Bourrelly*	+																	
30.	*M. calceolus* Bradley	+																	
31.	*M. caudata* Iwanoff								+					+					
32.	*M. corymbosa* Asmund*	+	+	+		+	+		+		+		+	+		+			+
33.	*M. costata* Dürrschmidt					+							+						+
34.	***M. crassisquama* var. *crassisquama*** (Asmund) Fott	+			+	+	+		+				+	+					+
35.	*M. crassisquama* var. *papillosa* Siver & Skogstad			+															
36.	*M. cratis* Harris & Bradley			+		+	+	+	+			+		+			+		
37.	*M. eoa* E.Takahashi	+		+		+	+												
38.	*M. insignis* Penard										+								
39.	***M. mangofera*** Harris & Bradley						+						+						+
40.	*M. multiunca* Asmund	+					+		+				+	+					+
41.	*M. oviformis* Nygaard				+														
42.	*M. papillosa* Harris & Bradley	+					+	+					+						+
43.	*M. pseudocoronata* Prescott	+				+													
44.	*M. pugio* Bradley		+	+															

No.	*Species*	*Months and sites*																	
		May							*July*					*September*					
		1	*2*	*4*	*5*	*6*	*7*	*8*	*1*	*2*	*4*	*5*	*7*	*1*	*2*	*4*	*5*	*6*	*7*
45.	*M. punctifera* Korshikov		+			+	+			+									
46.	***M. striata*** Asmund	+	+	+		+	+	+	+		+			+		+			
47.	***M. tonsurata*** Teiling	+	+			+		+	+	+		+		+	+		+	+	
48.	*M. torquata* Asmund & Cronberg				+	+		+											
49.	*M. trummensis* Cronberg*			+	+		+	+											
50.	***M. vannigera*** Asmund	+																	
51.	*M.* sp. 1	+				+												+	
52.	*M.* sp. 2		+																
53.	*Synura asmundiae* (Cronberg & Kristiansen) Škaloud, Kristiansen & Škaloudová	+																	
54.	*S. biseriata* Balonov	+							+										
55.	*S. echinulata* Korshikov					+	+												
56.	***S. glabra*** Korshikov		+	+	+	+	+	+				+	+				+		+
57.	***S. heteropora*** Skaloud, Skaloudová & Procházková in Skaloud *et al.*	+			+	+		+	+			+		+			+		
58.	*S. laticarina* Skaloud, Skaloudová, Procházková & Nemcová*							+											
59.	*S. macropora* Skaloud, Skaloudová, Procházková & Nemcová	+	+	+				+	+	+				+	+				
60.	*S. multidentata* (Balonov & Kuzmin) Péterfi & Momeu	+							+					+					
61.	*S.* cf. *nygaardii* (Petersen & Hansen) Kristiansen						+						+						
62.	***S. petersenii*** Korshikov	+			+	+													
63.	*S. punctulosa* Balonov	+	+					+	+	+				+	+				
64.	*S. spinosa* Korshikov				+	+	+						+						+
65.	*S. truttae* (Siver) Skaloud & Kynclová		+	+	+		+	+		+			+		+				+
66.	***S. uvella*** Ehrenberg							+											
	Total	**35**	**14**	**25**	**20**	**21**	**23**	**22**	**20**	**9**	**8**	**5**	**15**	**19**	**7**	**7**	**8**	**6**	**12**

DISCUSSION

Biogeographic distribution of silica-scaled chrysophytes

Rare species of the genera *Chrysosphaerella, Paraphysomonas, Clathromonas, Mallomonas,* and *Synura,* which show a scattered distribution in the world's water bodies, have been recorded in the study region.

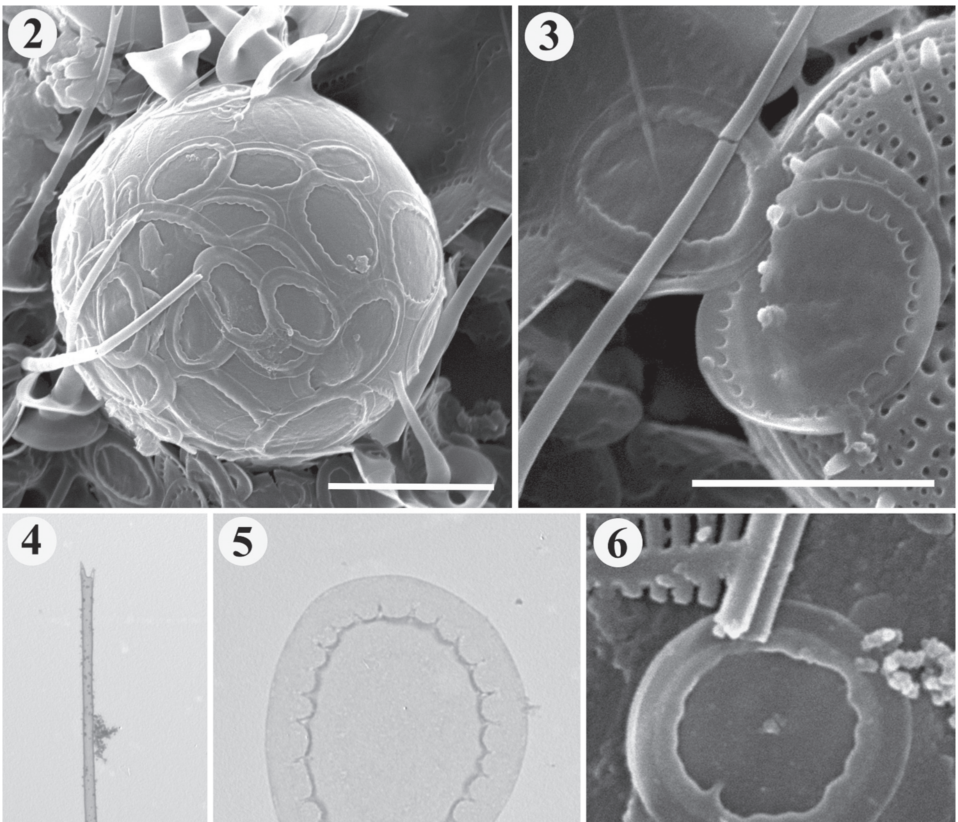
In May in the Lobanovskaya Channel (site 4) we found a rare species of the genus *Chrysosphaerella* – *Chrysosphaerella rotundata* (Figs 2-6) described previously in a small lake in Finland (Škaloudová & Škaloud, 2013). By morphology *C. rotundata* is similar to *C. brevispina*, however a main outstanding feature of *C. rotundata* are three types of scales (large and small oval, and large round scales), which cover the cell (Škaloudová & Škaloud, 2013). It is noteworthy that some of the round scales were larger than it is given in the description (3.0-3.5 × 2.2-3.1 µm) (Škaloudová & Škaloud, 2013), they reached approximately 3.75-4 µm.

A scattered distribution is characteristic of eight species of the genus *Synura*. In Russia, the rare species *S. punctulosa* has been reported from the Rybinsk and Kama reservoirs (Balonov, 1976) and small lakes of the Lower Yenisei basin (Bessudova *et al.*, 2018). This species has also been found in water bodies of Finland (Kristiansen & Preisig, 2007). The species *S. biseriata* was described from the Rybinsk reservoir (Balonov, 1976), the scale of this species indicated as *Synura* species was first discovered and described from the water pond of Alaska (Napaskiak) (Asmund, 1968). *S. biseriata* and *S. multidentata* have been recorded only in the Barguzin River (site 1). After the recent revision of the Synura section Peterseniae (Škaloud *et al.*, 2012; Škaloud *et al.*, 2013a), using molecular and morphometric evidence, several forms belonging to *Synura petersenii* were raised to the rank of species and others referred to as synonyms. Thus, according to taxonomic transformations of the genus *Synura*, the following species were identified in our studies: *S. laticarina* recorded in Russia for the first time and *S. glabra*, *S. macropora* and *S. asmundiae* found earlier in Western Siberia in the Rybinsk reservoir (Balonov, 1976) and Chernaya River (Nizhny Novgorod) (Gusev *et al.*, 2016). *Synura heteropora* and the widespread species *S. petersenii* have also been found previously in Lake Baikal (Bessudova *et al.*, 2017).

The revision of the genus *Paraphysomonas* on the basis of molecular and morphometric data led to taxonomic transformation and, as a result, the genus *Paraphysomonas* includes only those species having spine scales, whereas species with basket scales belong to a new genus *Clathromonas* (Scoble & Cavalier-Smith, 2014). Hence, we report for the first time in Russia one species of the genus *Clathromonas* (*C. poteriophora* (= *Paraphysomonas poteriophora*) and 2 species of the genus *Paraphysomonas* (*P. acuminata acuminata* and *P. vulgaris*). Seven species recorded in this study belong to rare species not only in Russia but also worldwide: *C. butcheri* (= *P. butcheri*), *C. homolepis* (= *P. homolepis*), *C.* cf. *diademifera* (= *P. diademifera*), *C. subrotacea* (= *P. subrotacea*), *C. poteriophora*, *P. caelifrica*, *P. corynephora* and *P. punctata*. We found scales having short spines and a ring of flange that was highly curved upwards (Fig. 8). Such features are characteristic only for the species *Paraphysomonas bandaiensis* among all the species of the genera *Paraphysomonas* known until today. However, the scales we found were larger than those described by Takahashi (Takahashi, 1976), they had a diameter of 1-1.6 µm, and we are giving thus this species as *Paraphysomonas* cf. *bandaiensis*.

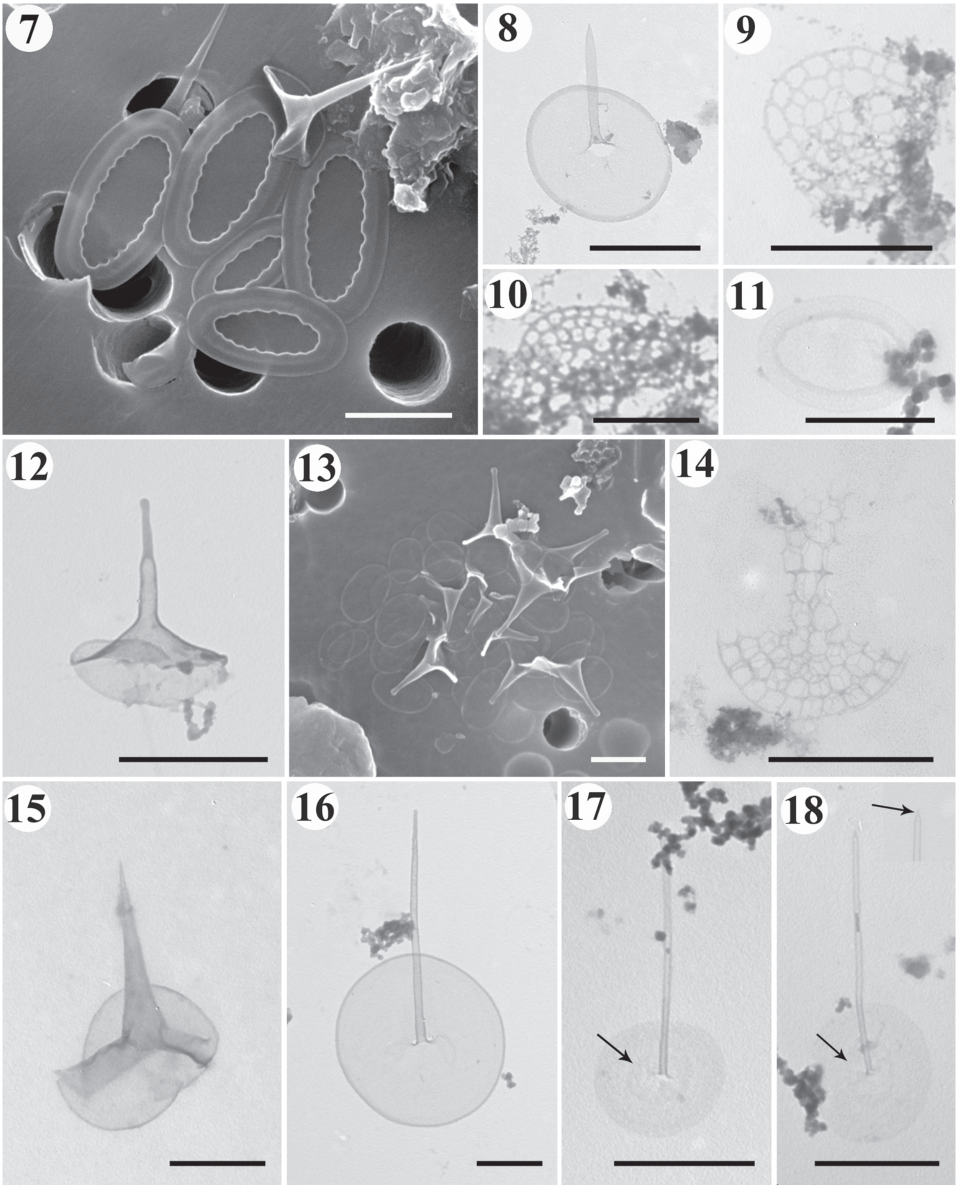
On the basis of the electronic chrysophyte catalog (Škaloud *et al.*, 2013b), the majority of species from the genus *Mallomonas* (16) found by us belong to widespread species. Nine taxa of this genus belong to the species characteristic of midlatitudes of the Northern Hemisphere, Arctic and Subarctic regions: *M. doignonii*, *M. multiunca*, *M. oviformis*, *M. pillulla*, *M. torquata*, *M. pseudocoronata*, *M. crassisquama* var. *papillosa* and *M. pugio*. We observed 3 species (*M. doignonii*, *M. trummensis*, and *M. corymbosa*) found in Russia for the first time.

We were unable to identify *Mallomonas* sp. 1 and *Mallomonas* sp. 2 to the species level. However, a lack of sufficient material (only single scales have been found) does not allow us to classify them as new species. Scales of *Mallomonas* sp. 1 are oval with lateral incurvings. The dome is large and rounded. There are striae on the anterior flanges: three on one flange and five on the other flange. Three



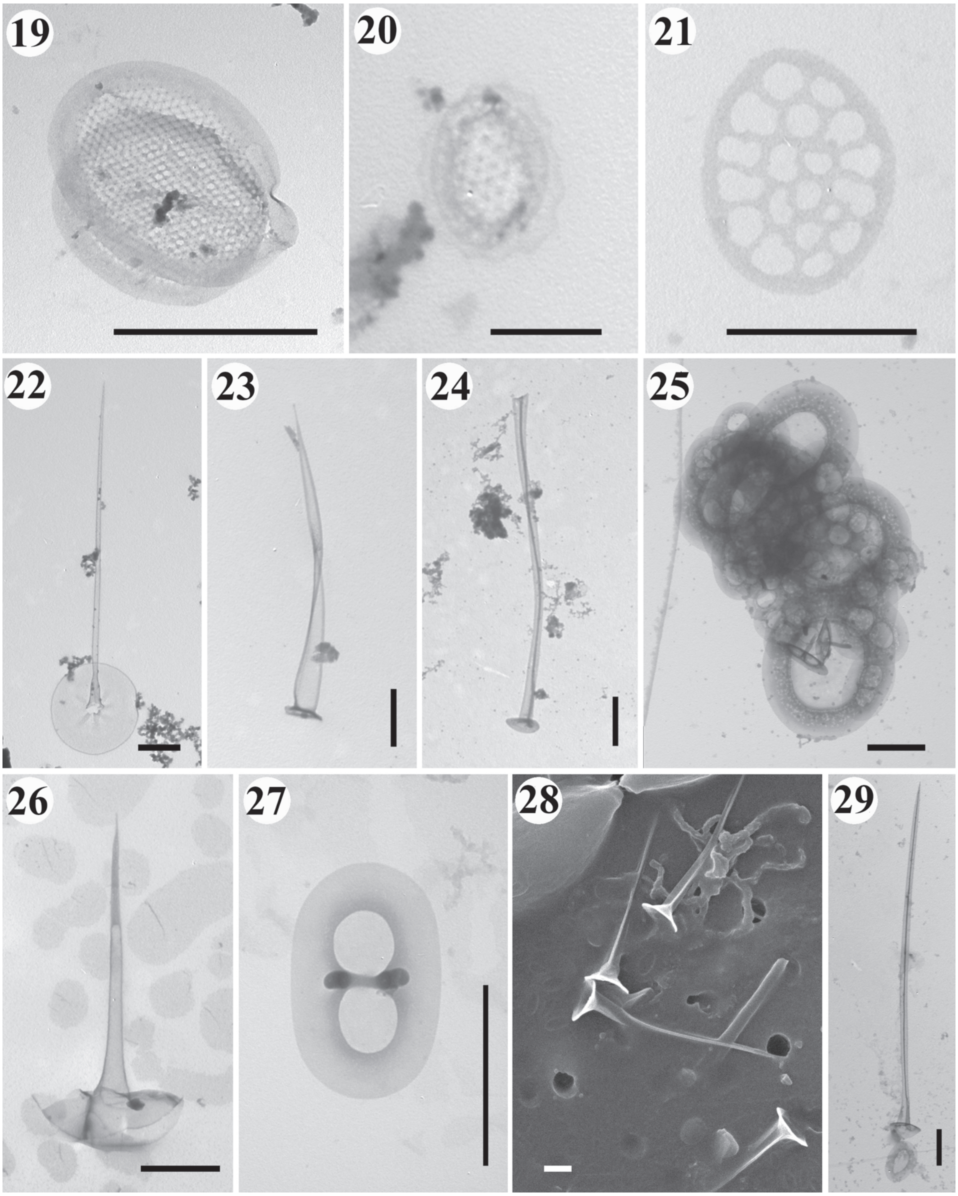
Figs 2-6. Images of *Chrysosphaerella rotundata*: **2.** The three types of scales (large and small oval, and large round scales), which cover the stomatocysts; **3, 5, 6.** The large round scales; **4.** Spine-scales. TEM (4, 5), SEM (2, 3, 6). Scale bars 2, 3 – 4 µm; 4-6 – 2 µm.

large pores are located at the basis of the acute V-rib. The hood is absent. On the shield there are seven longitudinal ribs curved from the dome to the V-rib. Each of them, except the second rib, covers the rib on the posterior flange. Posterior flanges have 18 thick and slightly visible ribs (Fig. 31). The ring of the flange is thin.



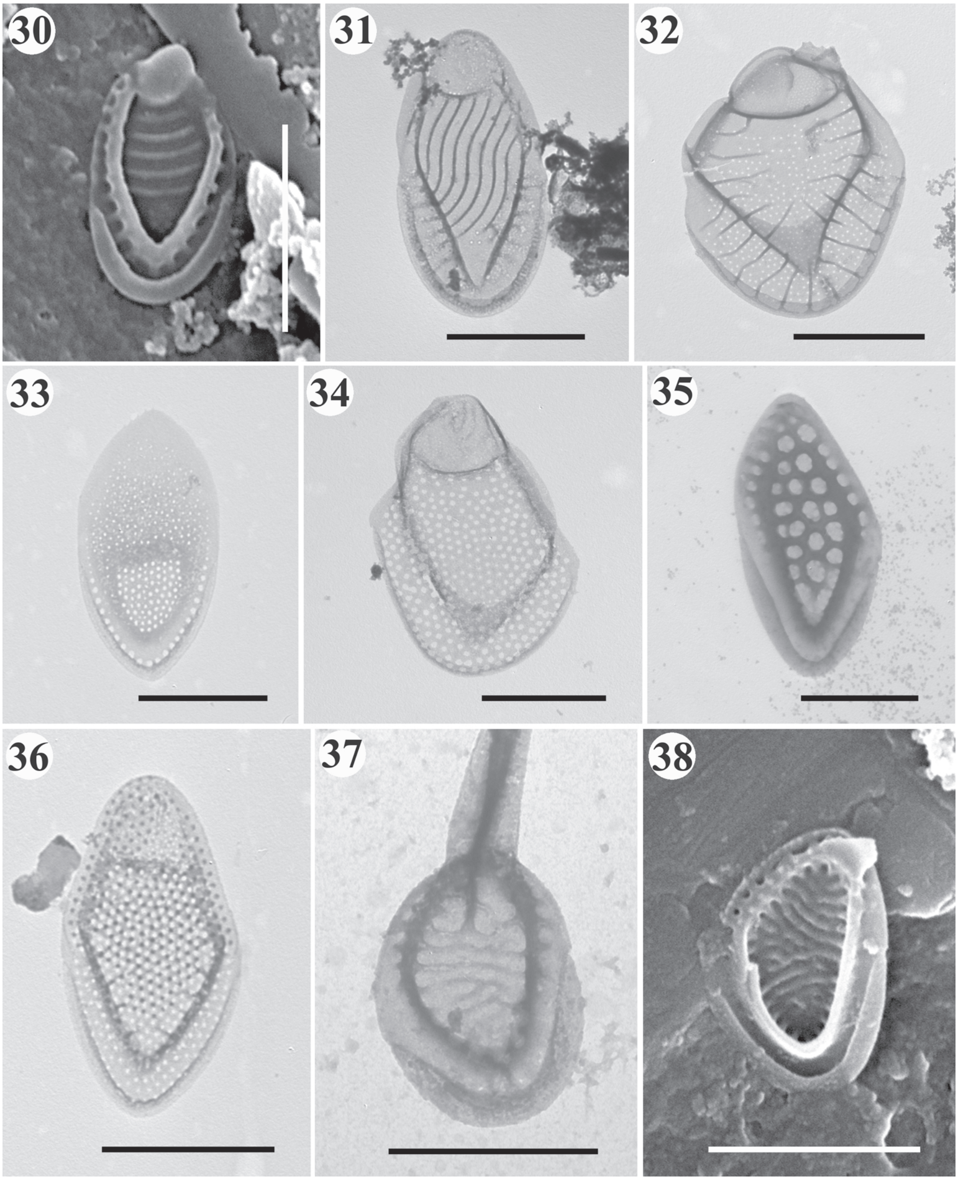
Figs 7-18. Images of *Chrysosphaerella*, *Clathromonas* and *Paraphysomonas*: **7.** *Chrysosphaerella brevispina*; **8.** *Paraphysomonas* sf. *bandaiensis*; **9.** *Clathromonas homolepis*; **10.** *C. butcheri*; **11.** *C.* cf. *diademifera*; **12**, **13.** *P. corynephora*; **14.** *C. poteriophora*; **15.** *P. gladiata*; **16.** *P. vulgaris*; **17**, **18.** *P. acuminata acuminata.* TEM (8-12, 14-18), SEM (7, 13). Scale bars – 1 µm.

Morphological characteristics of the scale such as its shape, the presence of striae on the anterior flange, pores at the basis of the V-rib and striae on the posterior flange are similar to those in *M. striata*. However, *Mallomonas* sp. 1 differs from *M. striata* in the absence of hood and in the presence of longitudinal ribs on the



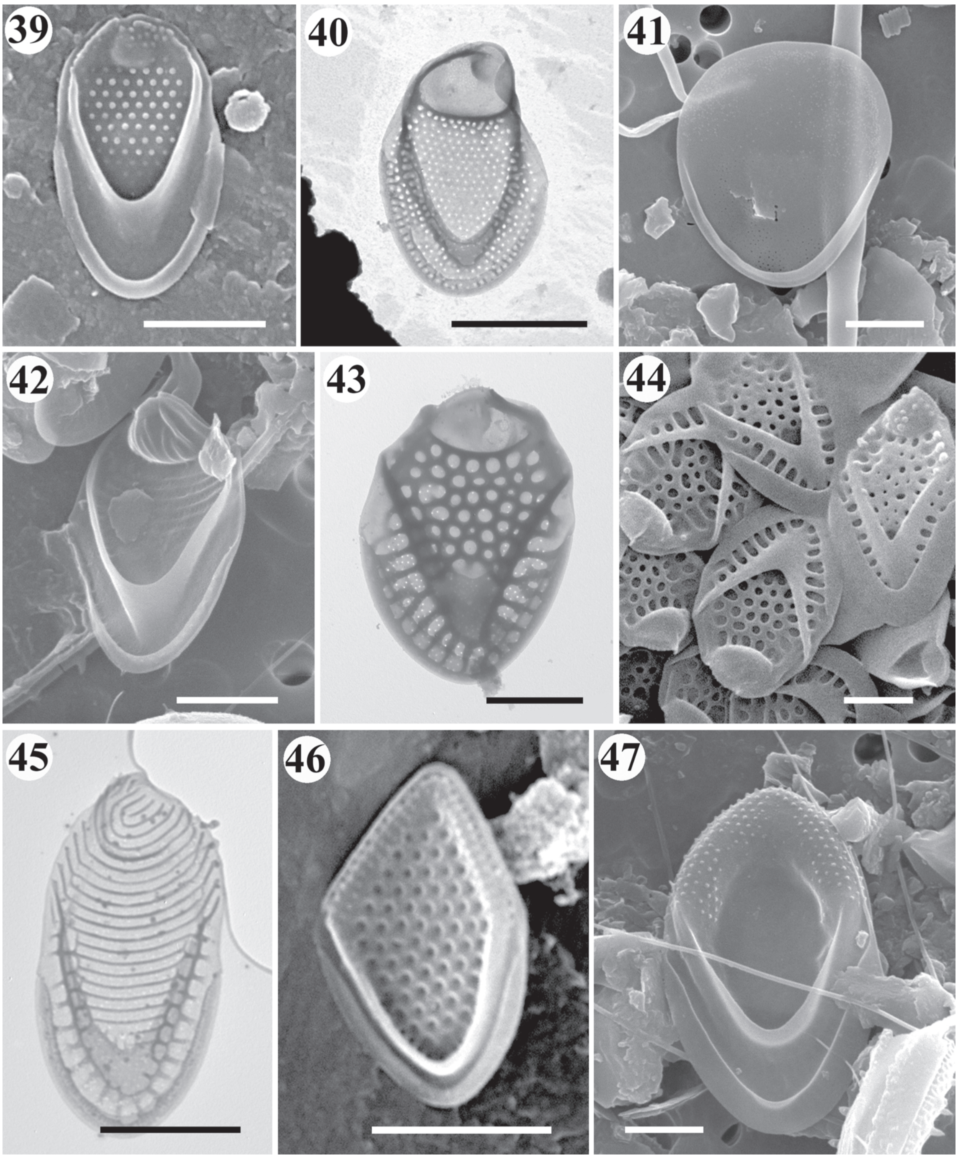
Figs 19-29. Images of *Paraphysomonas*, *Clathromonas* and *Spiniferomonas*: **19.** *P. punctata*; **20.** *P. caelifrica*; **21.** *C. subrotacea*; **22.** *P. uniformis hemiradia*; **23.** *Spiniferomonas abei*; **24.** *S. abrubta*; **25.** *S. bilacunosa*; **26.** *S. bourrellyi*; **27.** *S. cornuta*; **28.** *S. silverensis*; **29.** *S. trioralis* f. *cuspidata*. TEM (19-27, 29), SEM (28). Scale bars 20 – 0.5 µm; 19, 21-29 – 1 µm.

shield, which are curved from the dome to the V-rib, whereas the ribs on the shield of *M. striata* are located radially relative to the V-rib. Scales in *Mallomonas* sp. 2 are oval, and the dome is rounded. There are about 23 thick ribs on the anterior and posterior flanges. The shield bears 5 thick longitudinal ribs. At the basis of the rounded V-rib there are 7 pores: one is in the center and the others form a circle



Figs 30-38. Images of *Mallomonas* species: **30.** *Mallomonas* sp. 2; **31.** *M.* sp. 1; **32.** *M. acaroides*; **33.** *M. akrokomos*; **34.** *M. alpina*; **35.** *M. alata*; **36.** *M. annulata*; **37**, **38.** *M. doignonii*. TEM (31-37), SEM (30, 38). Scale bars: – 2 µm.

around the central pore. The flange ring is wide (Fig. 30). *Mallomonas* sp. 2 is similar to *M. siveri* in shape and size of scales, position of ribs on the shield and pores at the basis of the V-rib. However, despite a number of similarities in the structure, scales of *Mallomonas* sp. 2 differ from those of *M. siveri* in the presence of clearly expressed thick striae on the anterior and posterior flanges, weakly developed dome and wider flange ring.

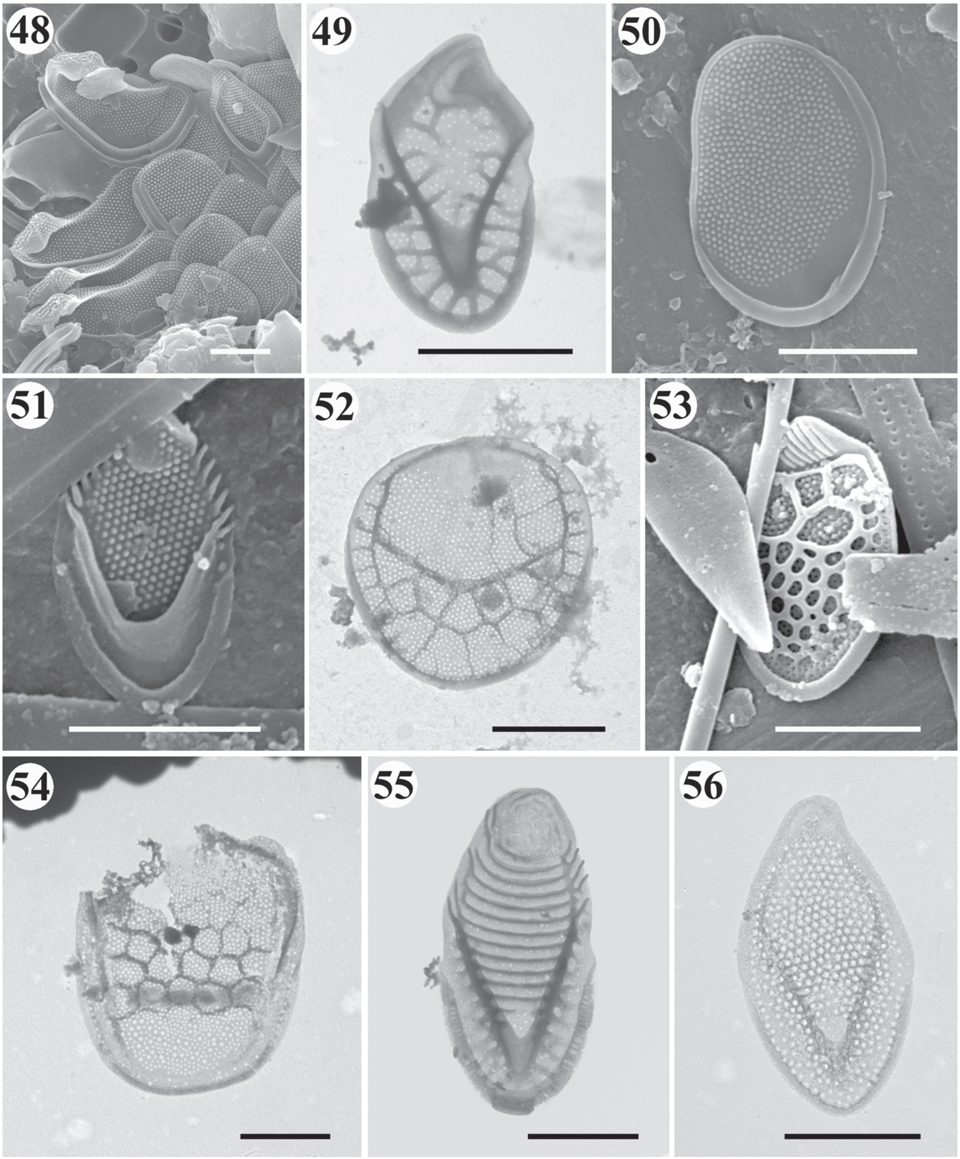


Figs 39-47. Images of *Mallomonas* species: **39.** *M. calceolus*; **40.** *M. corymbosa*; **41.** *M. caudata*; **42.** *M. costata*; **43.** *M. crassisquama* var. *crassisquama*; **44.** *M. crassisquama* var. *papillosa*; **45.** *M. cratis*; **46.** *M. eoa*; **47.** *M. insignis*. TEM (40, 43, 45), SEM (39, 41, 42, 44, 46, 47). Scale bars – 2 µm.

Morphological specific characteristics of *Mallomonas striata*

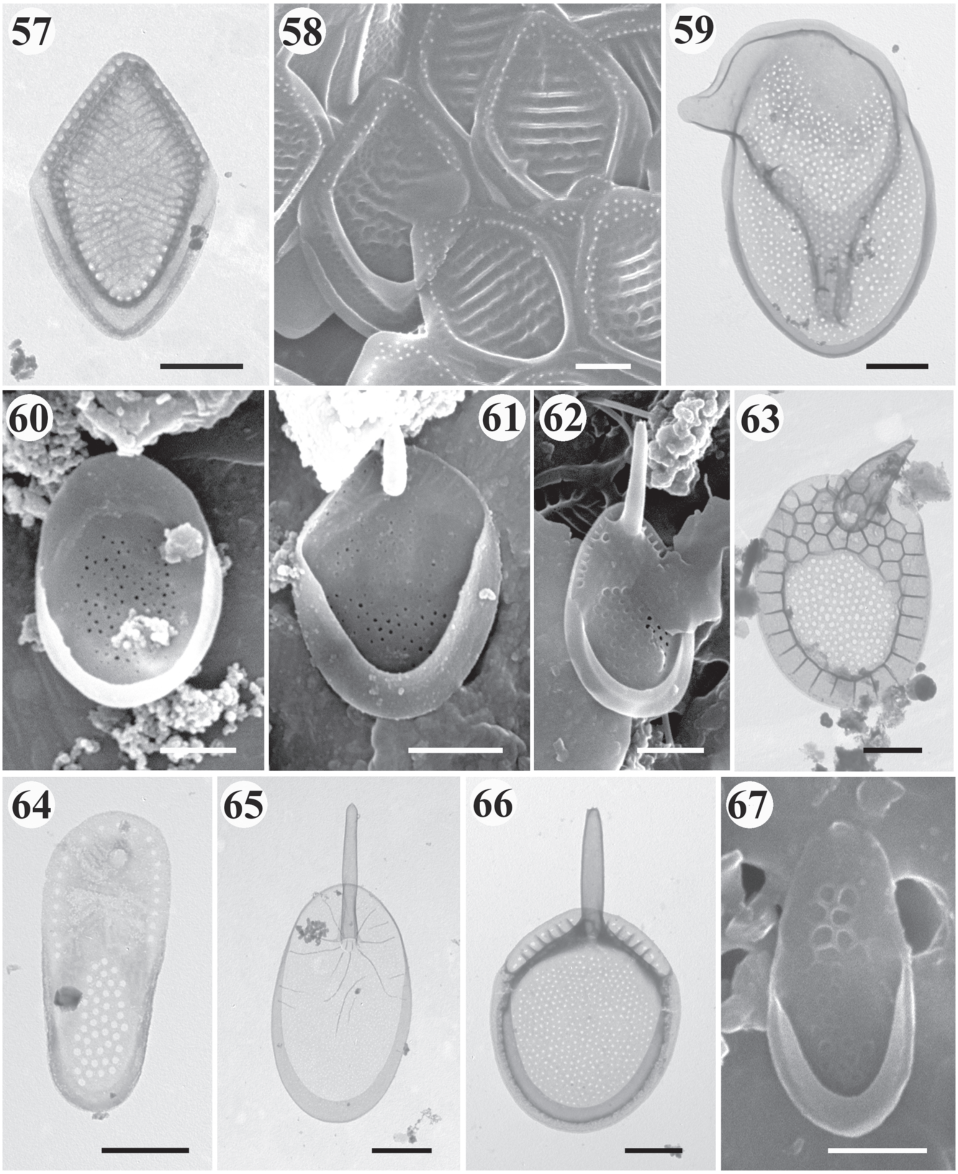
Atypical scales of *M. striata* (Figs 80-88) were observed in the Barguzin River mouth (site 1) and Srednyaya Channel (site 6).

In samples from the Barguzin River, we found typical scales of *M. striata* (Fig. 80) and scales with aberrant or deviating rib patterns (Figs. 80-83). Scales of



Figs 48-56. Images of *Mallomonas* species: **48.** *M. mangofera*; **49.** *M. pseudocoronata*; **50.** *M. oviformis*; **51.** *M. papillosa*; **52.** *M. pugio*; **53.** *M. multiunca*; **54.** *M. punctifera*; **55.** *M. striata*; **56.** *M. tonsurata*. TEM (49, 52, 54-56), SEM (48, 50, 51, 53). Scale bars – 2 µm.

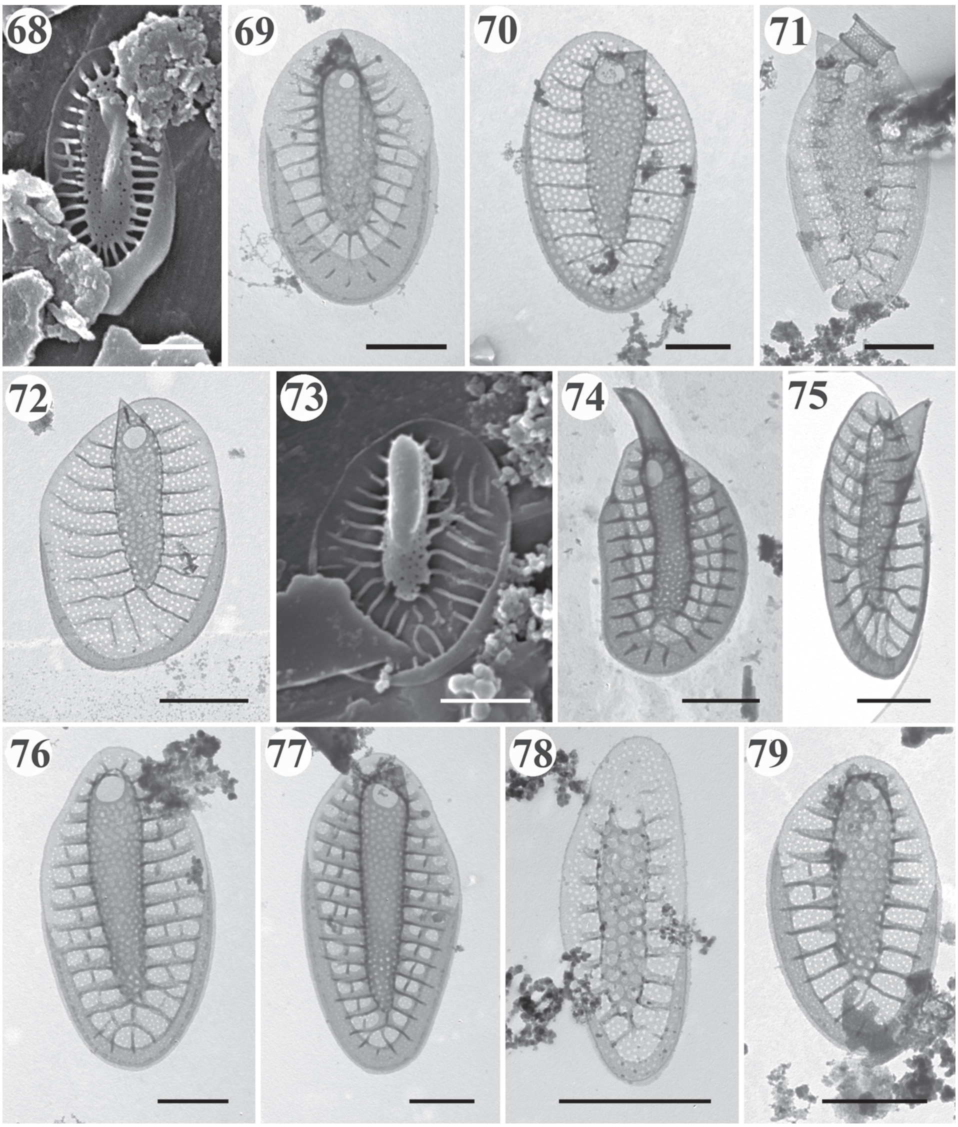
the first type are of irregular shape: anterior submarginal ribs cover the wing-shaped anterior flange from one side, and from another side there are 3 curved ribs on the wing-shaped anterior flange; transverse ribs are tilted on the shield. The dome with 4 radial striae on it is curved (Fig. 81). A distinctive character of the second type of scales is an alteration of transverse ribs: after the sixth transverse rib they are altered



Figs 57-67. Images of *Mallomonas* and *Synura* species: **57.** *M. torquata*; **58.** *M. trummensis*; **59.** *M. vannigera*; **60**, **61.** *Synura biseriata*; **62.** *S. spinosa*; **63.** *S. uvella*; **64.** *S. echinulata*; **65.** *S. punctulosa*; **66.** *S. multidentata*; **67.** *S.* cf. *nygaardii*. TEM (57, 59, 63-66), SEM (58, 60-62, 67). Scale bars – 1 µm.

into 6 vertical ribs (Fig. 82). The third type does not contain ribs on the anterior wing-shaped flange. On the shield, two first ribs and the fourth one are located transversely; the third, fifth and sixth ribs do not have a continuation, and the next six ribs are tilted (Fig. 83).

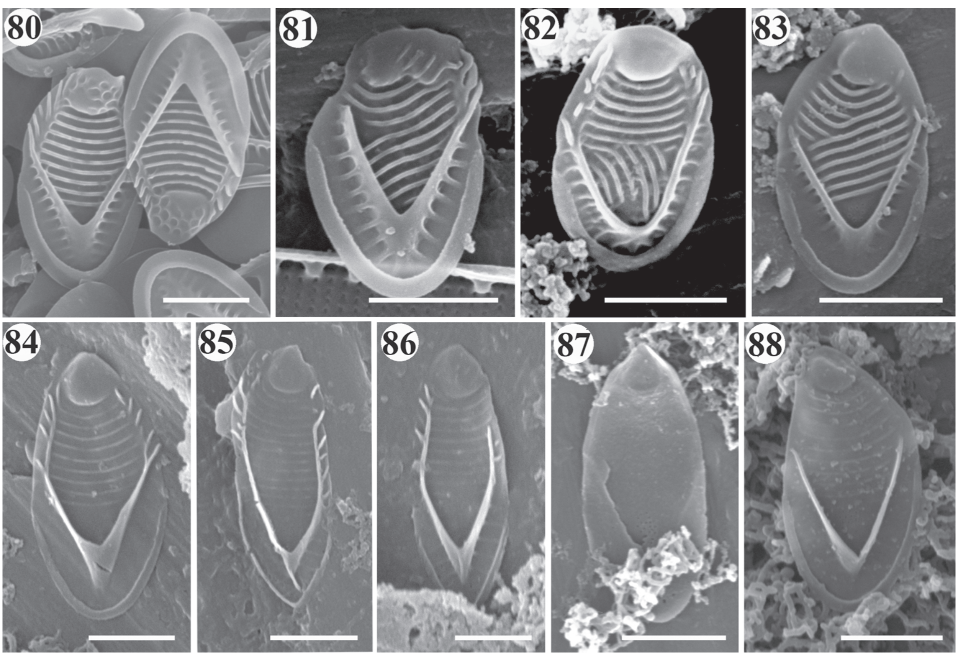
Scales from the Srednyaya Channel (site 6) also have three types of scales (Figs 84-88). The first type is similar to a typical form of *M. striata*, but without ribs on the posterior flange (Fig. 84). The second type differs in size: the scale length



Figs 68-79. Images of *Synura* species: **68**, **69.** *Synura asmundiae*; **70.** *S. macropora*; **71.** *S. laticarina*; **72**, **73.** *S. glabra*; **74**, **75.** *S. truttae*; **76**, **77.** *S. petersenii*; **78**, **79.** *S. heteropora.* TEM (69-72, 74-79), SEM (68, 73). Scale bars – 1 µm.

can reach 9 µm, it is strongly elongated, and a V-rib reaches the hood (Figs 85-87). The third type has no ribs on both anterior and posterior flanges. According to the scale structure, it may belong to *M. siveri* Němcová & Kristiansen (Němcova *et al.*, 2011). However, unlike *M. siveri*, a V-rib in this scale is of acute-angled form characteristic of *M. striata* (Fig. 88). Thus, *M. striata* scales from the Barguzin River mouth and Srednyaya Channel are morphologically different. Scales of *M. striata* from the Barguzin River mouth are of a round shape with a deviating rib pattern, whereas those from the Srednyaya Channel are of a strongly elongated shape.

Earlier studies (Němcová & Pichrtová, 2012) of morphological variability of the cultured *M. striata* scales showed that the increase of morphological plasticity may be caused by ecological stress: the species is affected by pH value changes. However, pH values in the study regions were similar in May at all sites (Table 1). We registered high values of P_{total} (387 µg/L) and conductivity (1144 mS/m) only in March in the Srednyaya Channel. However, in May, these values decreased (Table 1). In the Barguzin River mouth (site 1), we also recorded high concentrations of phosphorus (96 µg/L). The altered shape of scales is likely to be due to higher levels of eutrophication.



Figs 80-88. Variability of *M. striata* from different sites of the study region, May: **80.** A typical standard scale of *M. striata* from the samples of the Lobanovskaya Channel mouth (site 4); **81-83.** Altered scales of *M. striata* from the Barguzin River samples (site 1); **84-88.** Altered scales from the Srednyaya Channel mouth (site 6). SEM. Scale bars – 3 µm.

Specific distribution of silica-scaled chrysophytes in the channels of the Selenga River delta and Barguzin River mouth and their effect on species composition in Lake Baikal

The study of silica-scaled chrysophytes in the channels of the Selenga River delta and Barguzin River mouth demonstrated differences of species composition in these aquatic environments. The highest number of species (35) in one sample was observed in May in the Barguzin River mouth, 13 out of 35 species were not recorded in the channels of the Selenga River mouth. The highest number of species in the Selenga River delta was observed in the Lobanovskaya Channel (site 4, 25 species) and Lake Zavernyaikha (site 7, 23 species) (Table 2). Out of the total number of chrysophytes (52) recorded in the channels of the Selenga River delta 25 species have not previously been reported for the Barguzin River mouth. We suppose that these differences in the species composition are attributed to the specific conditions of the runoff. In the lower reaches of the Barguzin River, there are numerous shallow lakes and bogs connected with a system of channels. Their waters with elevated concentrations of organic matter and decreased pH values (Drucker *et al.*, 1997) are probably inhabited by specific plankton, including chrysophytes that are brought to the Barguzin River and its mouth, thus enriching species diversity. In the Selenga River delta, the channels are not boggy, the reaction of the aquatic environment is close to alkaline, and pH values do not drop below 7.0 (Sorokovikova *et al.*, 2009).

The Selenga and Barguzin rivers are the main tributaries of Lake Baikal. Their runoff into the lake is over 50% and can affect the chemical composition of the lake water and its biodiversity. However, abiotic and biotic factors of the environment change at a distance of 2-4 km from the Selenga River delta and Barguzin River mouth. Chemical composition of the water and species diversity of phytoplankton are similar to those of the open waters of Lake Baikal (Sorokovikova *et al.*, 2012; Tomberg *et al.*, 2014).

Our studies showed that out of 25 silica-scale chrysophytes reported for Lake Baikal (Bessudova *et al.*, 2017), 19 taxa (Table 2) have been observed in the Selenga River delta and Barguzin River mouth, and 47 taxa carried by these large tributaries do not develop in the lake. Species composition of chrysophytes in the open water of the lake is much poorer than in the lake tributaries. This is confirmed by studies of the species diversity of the scaled chrysophytes in lake Frolikha (Gusev, 2016). It is a small lake in the northwest extension of Barguzin range 8 km to the east of the Ayaya Bay (North Baikal). Nine of these ten species occur in the Selenga River channels and the Barguzin River mouth studied. We failed to find the species *Mallomonas kuzminii* Gusev & Kulikovskiy. It is noteworthy that only 4 species of Lake Frolikha may be found in Lake Baikal: *Mallomonas acaroides*, *M. striata*, *Synura petersenii* and *Spiniferomonas trioralis.*

We should note that compared to the water of the open lake, the waters of the tributaries are enriched with organic matter and nutrients. For example, during our observations, the concentration of silicon involved in metabolism of silica-scaled chrysophytes was high (2.4-10.5 mg/L) in the Selenga River delta and Barguzin River mouth (Table 1), while in the mixing zone of the riverine and lacustrine waters it was 0.3-0.8 mg/L at a distance of 5-7 km from the mouths river. Concentrations of total phosphorus in the tributaries was also higher (12-29 mg/L) (Table 1) than in the open Baikal. In the mixing zone, the temperature regime also changes. For instance, the water temperature in the rivers in summer is by 7-13°C higher than in the lake. Thus, the water temperature and chemical composition changes in the mixing zone, i.e. the environment conditions change probable causing the decrease of the number of species coming to Lake Baikal from tributaries' waters. As a result, we observe alteration of species composition and formation of a species assemblage characteristic of cold oligotrophic waters of the lake (Bessudova *et al.*, 2017).

SUMMARY

The investigations performed in the Selenga River delta and Barguzin River mouth revealed high diversity of silica-scaled chrysophytes. The report of rare species of the genera *Chrysosphaerella*, *Paraphysomonas*, *Clathromonas*, *Mallomonas* and *Synura* widens their geography and together with hydrochemical data supplements the knowledge of their autecology. The effect of large tributaries on the flora of silica-scaled chrysophytes of Lake Baikal is limited because of different habitat conditions. Their highest diversity recorded in shallow, well heated aquatic environments rich in nutrients declines significantly (from 66 to 19) while entering the cold oligotrophic lake. It was established that out of 25 species observed in the lake 6 species (*Chrysosphaerella baicalensis*, *C. coronacircumspina*, *Clathromonas takahashii*, *Spiniferomonas septispina*, *S. takahashii* and *Mallomonas striata* var. *getseniae*) have not been reported in the tributaries.

The general list of silica-scaled chrysophytes in Lake Baikal, including channels of the Selenga River delta and Barguzin River mouth, consists of 72 taxa. Therefore, this area may be regarded as a "hotspot" of silica-scaled chrysophytes together with other three hotspots registered earlier in Finland (Hallfors & Hallfors, 1988), Bolshezemelskaya and Vorkuta tundras (Siver *et al.*, 2005) and in Aquitania (France) (Němcová *et al.*, 2012).

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