ABS ACTA BIOLOGICA SIBIRICA
A journal on the biodiversity of Siberia and the adjacent lands

Acta Biologica Sibirica 11: 1311–1329 (2025)
doi: 10.5281/zenodo.17699890
http://journal.asu.ru

RESEARCH ARTICLE

Current state of spring phytoplankton of the Bratsk and Ust-Ilimsk reservoirs of the Angara Cascade

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Academic editor: R. Yakovlev | Received 9 September 2025 | Accepted 20 November 2025 | Published 27 November 2025

http://zoobank.org/9C943DFA-A7E2-471D-9EFE-8A5BB3367A4E

Citation: Firsova AD, Galachyants YuP, Bessudova AY, Buzevich (Buvaeva) VV, Shirshova VK, Marchenkov AM, Tanichev AI, Vorobyova SS, Likhoshway YeV (2025) Current state of spring phytoplankton of the Bratsk and Ust-Ilimsk reservoirs of the Angara Cascade. Acta Biologica Sibirica 11: 1311–1329. https://doi.org/10.5281/zenodo.17699890

Abstract

Continental reservoirs are sources of fresh water, but they are currently experiencing increasing anthropogenic stress. Reservoirs are among the most important water bodies for the needs of the population, and they require regular monitoring. However, some of these reservoirs have not been monitored for decades. The aim of this study was to assess the species richness, structure and density of spring phytoplankton of the Bratsk and Ust-Ilimsk reservoirs in the modern period. As a result of studies of these reservoirs, 62 taxa of planktonic algae were identified in phytoplankton in the spring season of 2024, of which diatoms and chrysophytes predominated in species richness. The dominant complex included the diatoms *Aulacoseira islandica*, *Nitzschia graciliformis*, *Asterionella formosa*, *Fragilaria radians*, and *Stephanodiscus minutulus*, the proportion of which in the total abundance and biomass varied between stations and reservoirs. The most significant predictors of phytoplankton community structure were nitrate and phosphate; conductivity, transparency and temperature were also important. Maximum values of total abundance and total biomass of phytoplankton were observed in the Bratsk Reservoir – 1119 thousand cells/L and 579 mg/m^3, in the Ust-Ilimsk – 577 thousand cells/L and 274 mg/m^3 respectively. These values do not exceed the indicators of previous years of observaions.

The values of phytoplankton biomass characterize the studied areas of the Bratsk and Ust-Ilimsk reservoirs in June 2024 as oligotrophic.

Keywords
Phytoplankton, reservoirs, abundance, biomass

Introduction

Phytoplankton as a primary producer is one of the most important factors reflecting the state of ecosystems. Regulation of rivers leads to widening of the riverbed and many hydrophysical and hydrochemical changes, which, in turn, affect the species structure and density of aquatic organisms. Despite the introduction of new research methods, traditional microscopy methods, which are used to determine the species composition and quantitative indicators of phytoplankton, remain relevant for assessing the current state of water bodies (Kavagutti et al. 2023). For oligotrophic lakes located in northern and temperate latitudes, the assessment of spring phytoplankton is especially important, since this period is the most productive.

As a result of the construction of hydroelectric power stations (HPS) on the Angara River, four reservoirs were created. The filling of the Bratsk Reservoir, the second from Baikal and one of the largest in the world by volume, was completed in 1967. The filling of the third of the cascade of reservoirs, Ust-Ilimsk, reached the design level in 1977. Regulation of the Angara flow led to a change in hydrological conditions and, accordingly, a change in the species composition of hydrobionts. Previous studies have shown that after their formation, the Angara reservoirs were characterized by low mineralization, but in subsequent years there was an increase in both mineralization, organic matter, biogenic elements, changes in water flow, transparency and temperature conditions (Kobanova 1980, Vorobyova 1997).

Most of the studies on phytoplankton in reservoirs of the reservoirs of the Angara Cascade of Hydroelectric Power Stations were carried out in the 70–90s of the last century (Kozhova 1970, Kobanova 1980, Vorobyova 1987, 1995, 1997). It was shown that phytoplankton of the reservoirs of the Angara Cascade is characterized by two peaks of seasonal growth – spring and summer (Vorobyova 1995). In the spring season, in the period 1972–1987, the mean abundance of phytoplankton in the Bratsk Reservoir varied in wide interannual ranges from 1 million to 28.6 million cells/L. Diatoms formed up to 99% of the phytoplankton biomass. Cryptophytes and dinoflagellates acted as subdominants. During the entire observation period of this reservoir from 1972 to 1987, the total species richness of planktonic algae in the spring season reached 160 taxa (Vorobyova 1995).

Spring season 1972–1974 in the Angara River, in the place of the future Ust-Ilimsk Reservoir, was also characterized by a change in the abundance of phytoplankton in wide interannual ranges from 0.05 to 2.2 million cells/L. The basis of the phytoplankton biomass was made up of diatoms (up to 89%). Subdominants, as in the Bratsk Reservoir, were cryptophytes and dinophytes. In the Ust-Ilimsk Reservoir in the spring of 1975–1987, the species richness increased to 210 over the entire observation period, and the average abundance of phytoplankton cells varied within 0.1–10.3 million cells/L, with the dominance of diatoms, which made up 61–87% of the total biomass (Vorobyova 1987, 1995, 1997).

The aim of this study was to assess the species richness, structure and density of spring phytoplankton of the Bratsk and Ust-Ilimsk reservoirs in the modern period.

Materials and methods

Research objects. The Bratsk Reservoir is one of the largest reservoirs in the world. It has a complex morphological structure, where lake-like expansions alternate with narrow river sites. The dam at the Bratsk Hydroelectric Power Station was built in 1961, the filling of the reservoir was completed in 1967. The height above sea level is 392–403 m. The reservoir is divided into two branches – Angara and Okinskaya. It stretches 520 km along the length of the Angara River. Its area reaches 5.470 km^2, the maximum depth is 150 m, and the length of the coastline is 6 thousand km. The coastline in many areas is very winding and forms many small bays (Fig. 1). The Bratsk Reservoir is classified as a slow-flowing reservoir (Vorobyova 1995).

The Ust-Ilimsk Reservoir was filled in 1974–1977. This is the third reservoir of the Angara Cascade. The Angara branch is 300 km long. The length of the coastline is 2.500 km, the greatest width is 12 km, the maximum depth is 94 m, the height above sea level is 294.5–296.0 m (Fig. 1). The reservoir is divided into two branches – Angara and Ilim. The Ust-Ilimsk Reservoir extends along the river up to the Ust-Ilimsk Hydroelectric Power Station dam and is characterized by an insignificant, one and a half meter change in water level during the year (Kobanova 1980, Vorobyova 1995).

Sampling and analysis. In this study, water samples and phytoplankton samples were collected from 1 to 14 June 2024 at 18 stations of the Bratsk and Ust-Ilimsk reservoirs (Fig. 1, Table 1).

Water transparency (S) was measured using a Secchi disk. Water samples were collected using a 5-liter Niskin bathometer (OOO Volta, Moscow, Russia). Water temperature and pH were measured using a pH-410 field instrument (OOO Akvilon, Moscow, Russia) at each sampling depth. The values for each depth were then averaged. Integral samples of 1.2 L volume were obtained by combining equal volumes of water (400 mL from each layer) collected from depths of 0, 5 and 10 m. For microscopy, 1.2 L of each combined sample was filtered through an analytical track membrane with a pore size of 3 μm (Reatrek, Russia) using a PVF-47/3 NB filtration system (BMT, Vladimir, Russia). The sediment was collected and fixed with 50 mL formaldehyde to a final concentration of 3.7% (45 mL sample + 5 mL 37% formaldehyde). Phytoplankton samples were analyzed using light and scanning electron microscopy (LM and SEM) (Fig. 2) according to a previously published method (Firsova et al. 2023). The coefficient of commonality (similarity) of species composition was determined according to Sorensen (Sadchikov 2003).

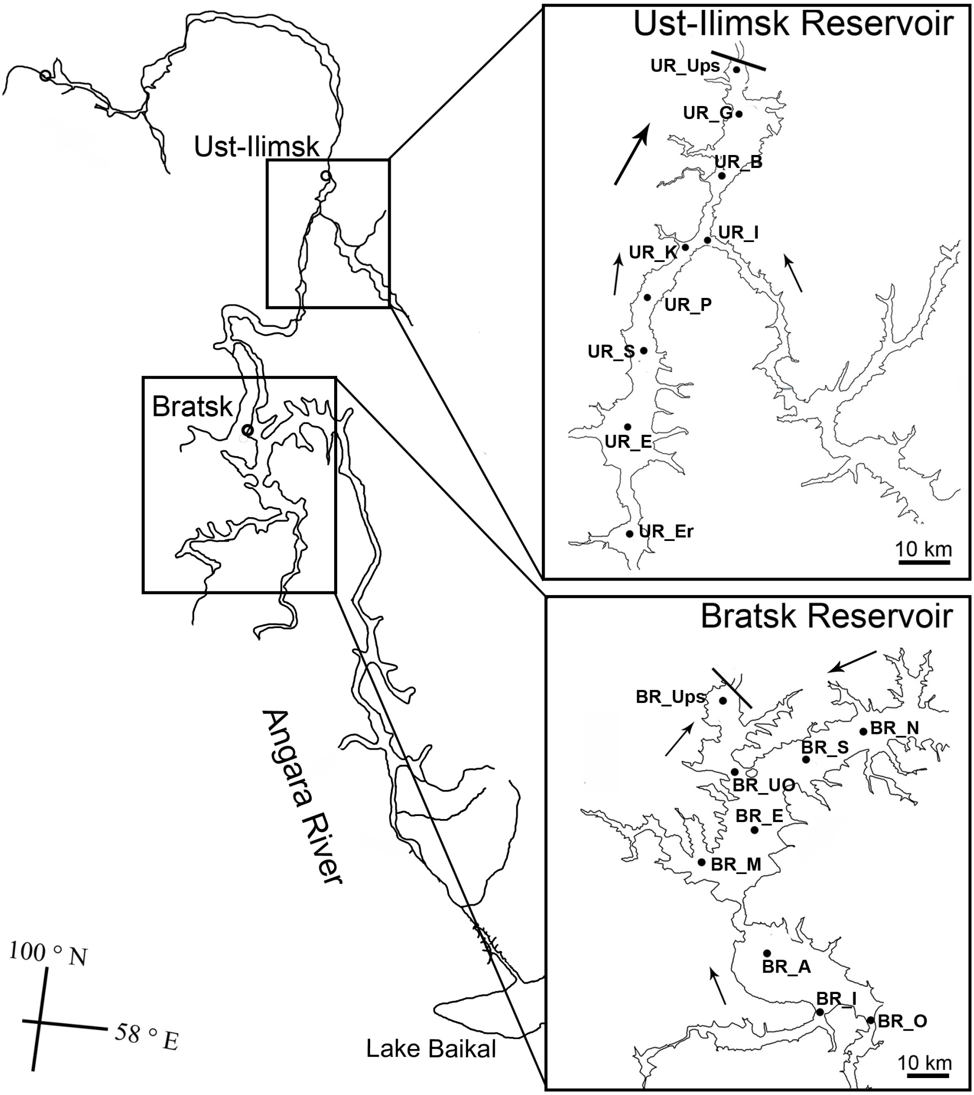

Figure 1. Sampling locations in the Bratsk and Ust-Ilimsk reservoirs in June 2024 (arrows indicate the direction of currents).

Table 1. Sampling sites in the Bratsk and Ust-Ilimsk reservoirs and their water parameters in June 2024 (location and designation of stations according to Fig. 1; temperature values exceeding 9 °C are highlighted in bold).

	Station locations	Station designation	Coordinates, N/E	Date of sampling dd.mm.yy	Secchi disk (S), m	pH	T, °C	EC, mS/m
Bratsk Reservoir	The center of the site opposite the village of Naratai	BR_N	56.17366 / 102.30780	04.06.24	7.0	7.64	4.36	146
	The center opposite the Sudovka Bay	BR_S	56.11156 / 102.08168	04.06.24	4.0	7.97	6.60	145
	The center of the site opposite the Ermakovka Bay	BR_E	55.944523 / 101.87751	03.06.24	4.5	8.29	7.50	131
	The center of the site opposite the Malaya Bay	BR_M	55.86896 / 101.67643	04.06.24	4.0	7.87	5.80	143
	The center of the site is opposite the Gulf of Artum	BR_A	55.62689 / 102.03250	03.06.24	4.0	8.48	**9.10**	137
	Oka River	BR_O	55.51542 / 102.35615	03.06.24	2.5	8.47	**10.40**	140
	Iya River	BR_I	55.52059 / 102.14290	03.06.24	2.0	8.24	**9.40**	145
	The center of the site opposite Ust-Okskaya Island	BR_UO	56.07210 / 101.80705	03.06.24	4.0	7.96	5.90	140
	Upper pool of the Bratsk Hydroelectric Power Station	BR_ Ups	56.25035 / 101.76145	04.06.24	6.5	8.14	7.60	145
Ust-Ilimsk Reservoir	The center of the site opposite the Ershovsky Bay	UR_Er	57.14927 / 102.33867	07.06.24	5.5	8.01	**9.40**	154
	The center of the site is the Educhansky Bay – the middle bay	UR_E	57.33838 / 102.34039	07.06.24	5.5	7.95	7.26	154
	The center of the site opposite Sukhoi Bay	UR_S	57.47301 / 102.39051	07.06.24	6.0	7.68	5.70	155
	Center of the site of the river Pyataya – the river Shcherbakovka	UR_P	57.56345 / 102.40081	06.06.24	7.0	7.64	5.50	154
	The center of the site opposite the Kamenny Bay	UR_K	57.64466 / 102.51668	06.06.24	8.0	7.57	5.23	155
	Ilim River	UR_I	57.65917 / 102.60028	06.06.24	6.5	7.56	6.20	158
	The center of the site opposite the Badarma River	UR_B	57.76060 / 102.62620	06.06.24	7.0	7.49	5.23	155
	The center of the site opposite the island of Nadezhda (Deep)	UR_G	57.86712 / 102.67375	06.06.24	6.0	7.59	4.90	151
	Upper pool of the Ust-Ilimsk Hydroelectric Power Station	UR_ Ups	57.95228 / 102.68084	06.06.24	6.0	7.31	4.80	158

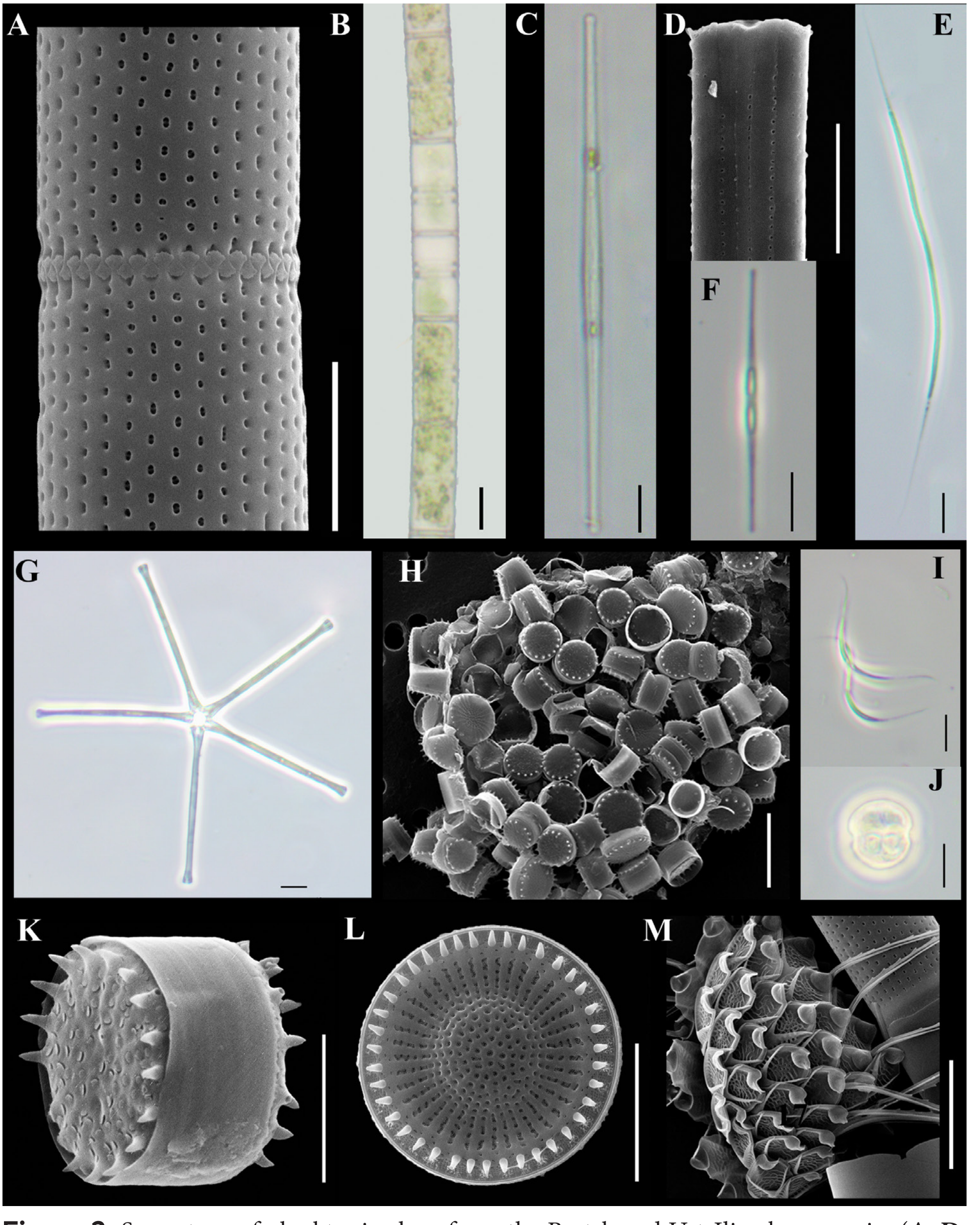

Figure 2. Some taxa of planktonic algae from the Bratsk and Ust-Ilimsk reservoirs (**A**, **D**, **H**, **K**–**M** – SEM; **B**, **C**, **E**–**G**, **I**, **J** – LM): **A**, **B** – *Aulacoseira islandica*; **C**, **D** – *Fragilaria radians*/*Ulnaria acus*; **E** – *Koliella longiseta*; **F** – *Nitzschia graciliformis*; **G** – *Asterionella formosa*; **H**, **K** – *Stephanodiscus minutulus*; **I** – *Monoraphidium contortum*; **J** – *Glenodinium* sp.; **L** – *Stephanodiscus alpinus*; **M** – *Mallomonas acaroides* forma. Scale: **A**–**C**, **E**–**J**, **L**, **M** – 10 μm; **D**, **K** – 3 μm.

Hellinger-transformed species abundance matrix was subjected to principal component analysis (PCA) in the vegan package v.2.5-6 (Oksanen et al. 2022). Environmental variables were centered and scaled to have zero means and standard deviation of one. The significance of environmental variables was assessed by fitting them onto the ordination using envfit with 999 permutations. The R package apcluster (Bodenhofer et al. 2011) was used for beta-diversity cluster analysis. The pairwise distance matrix was computed using the Bray–Curtis similarity index, and clusters were generated using affinity propagation, followed by exemplar-based agglomerative clustering. In addition to the data presented in Table 1, data on the concentrations of dissolved silicon (0.8–1.8 mg/L), orthophosphate (PO_4^{3-}) (0.003–0.028 mg/L), nitrite (0.002–0.005 mg/L), ammonium (0–0.015 mg/L), and nitrate (NO_3^-) (0.12–0.26 mg/L), determined in the work (Galachyants et al. in press), were used for PCA and cluster analysis.

Results

Hydrochemical and hydrophysical parameters of reservoir water

The water temperature during the hydrological spring season in the Bratsk Reservoir varied widely, from 4.36 to 10.40 °C (Fig. 3A). The pH of the water corresponded to a slightly alkaline reaction (7.64–8.48). The water transparency varied from 2.0 to 7.0 m, EC from 131 to 146 mS/m (Table 1). The water temperature in the Ust-Ilimsk Reservoir varied from 4.80 to 9.40 °C. The pH of the water was lower than in the Bratsk Reservoir (7.31–8.01), but it also had a slightly alkaline reaction. The transparency of the water was higher than in the Bratsk Reservoir, at 5.5–8.0 m, EC values were also higher than in the Bratsk Reservoir and varied slightly – from 151 to 158 mS/m (Table 1).

Phytoplankton of the Bratsk Reservoir

In the spring season, 56 taxa of planktonic algae belonging to 8 phyla were identified in the Bratsk Reservoir: Bacillariophyta (18 taxa), Chlorophyta (8), Cyanophyta (2), Chrysophyta (17), Dinophyta (4), Cryptophyta (4), Charophyta (2) and Haptophyta (1) (Table 2).

Individual scales of scaled chrysophytes were identified, which were not included in the calculation of abundance and biomass. These are *Spiniferomonas bourrellyi*, *S. cuspidata*, *S. trioralis*, *Lepidochromonas takahashii*, *Mallomonas acaroides*, *M. akrokomos*, and *M. alpina* (Table 2).

The total abundance of phytoplankton, including of benthic forms, in the Bratsk Reservoir varied from 366 to 1.119 thousand cells/L, total biomass from 69 to 579 mg/m^3 (Fig. 3B). Diatoms dominated at all stations, accounting for 80 to 95% of the total abundance. The composition of the dominant species was heterogeneous and changed along the current (Fig. 3C). In the Naratai site of the Angara branch, at station BR_S, diatom *Nitzschia graciliformis* (Fig. 2F) was the most abundant, while at station BR_N it was a subdominant. At these two stations, the subdominants also included the chrlorophyta *Monoraphidium contortum* (Fig. 2I) (about 15%), diatoms *Aulacoseira islandica* (Fig. 2A, C), *Stephanodiscus minutulus* (Fig. 2H, K), and the haptophyte *Chrysochromulina parva* (Fig. 3C). The biomass (Fig. 3D) was mainly formed by large diatoms species – *N. graciliformis* and *A. islandica*. At stations BR_E–BR_O, a change in the species structure was observed. At all stations except BR_I, *A. islandica* dominated in terms of abundance and biomass, with large diatom species *Asterionella formosa* (Fig. 2G) and *Fragilaria radians*/*Ulnaria acus* (Fig. 2C, D) subdominant. Small centric diatom *S. minutulus* made a significant contribution to the abundance at stations BR_A and BR_O. Only in the Iya branch (BR_I) did *A. formosa* dominate (Fig. 2C). Further, at stations near the upper pool (BR_UO and BR_Ups), phytoplankton consisted of 75–80% by abundance and 90–95% by biomass of *A. islandica* (Fig. 3C, D). The remaining algae groups were represented insignificantly and their abundance were not high, or they were encountered singly. The biomass at almost all stations, with the exception of BR_S and BR_N, was formed by large-celled species, among which *A. islandica* predominated (Fig. 3D).

Phytoplankton of the Ust-Ilimsk Reservoir

In the spring season, 32 taxa of planktonic algae belonging to 6 phyla were identified in the Ust-Ilimsk Reservoir: Bacillariophyta (12 taxa), Chlorophyta (7), Cyanophyta (3), Chrysophyta (4), Dinophyta (5) and Cryptophyta (1) (Table 2).

The scales of scaled chrysophytes were identified that were not included in the abundance and biomass calculations. These are *Spiniferomonas bourrellyi* and *Mallomonas alpina* (Table 2).

The total abundance and biomass, including of benthic forms, varied within 104–577 thousand cells/L and 41–274 mg/m^3, respectively (Fig. 3B). At the stations (UR_Er, UR_E) of the upper site of the Angara branch, influenced by the runoff of the Bratsk Reservoir, 63–75% of the total abundance (Fig. 3C) and 85–95% of the total biomass (Fig. 3D) of phytoplankton was diatom *A. islandica*. At the remaining stations, the small centric diatoms *S. minutulus* were predominant in abundance (from 65 to 80% of total abundance), with chrlorophyta *Monoraphidium contortum*, dinoflagellate *Glenodinium* sp. (Fig. 2I), diatoms *A. formosa*, and *F. radians* were subdominants (Fig. 3C). In terms of biomass, diatom *A. islandica* was predominant (up to 40% of the total biomass), the proportion of which decreased towards the upper pool, and the dinoflagellate *Scrippsiella* sp., the proportion of which, on the contrary, increased towards the upper pool up to 35% (Fig. 3D).

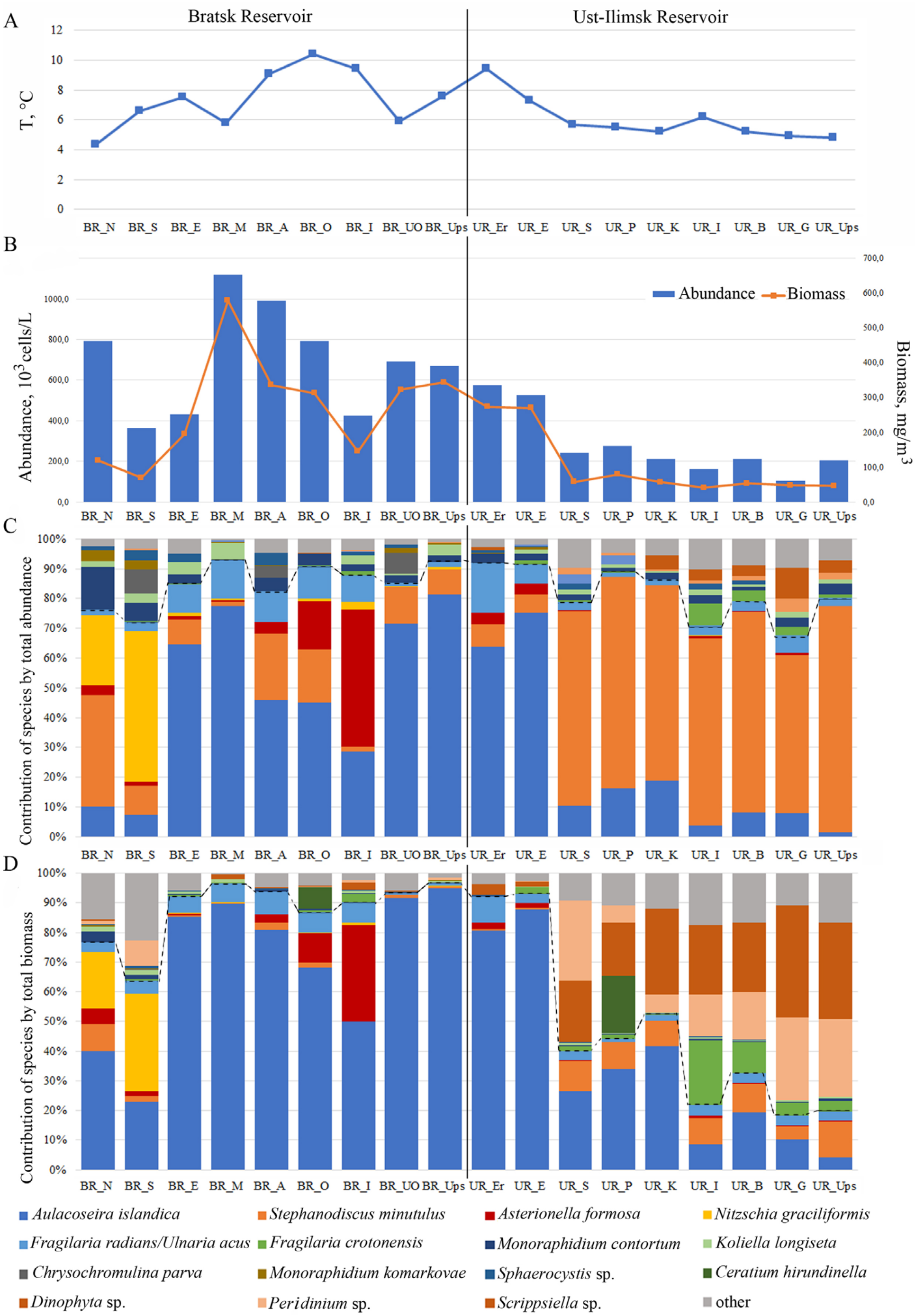

Figure 3. Quantitative and qualitative characteristics of phytoplankton of the Bratsk and Ust-Ilimsk reservoirs on June 1–14, 2024. **A** – water temperature; **B** – total abundance and biomass of phytoplankton; **C** – contribution of dominant species to total abundance; **D** – to total biomass. In **C** and **D**, the dotted line separates diatoms from other algae.

Table 2. Species composition of planktonic algae of the Bratsk and Ust-Ilimsk reservoirs in June 2024

No	Taxa	Bratsk Reservoir	Ust-Ilimsk Reservoir
	Cyanophyta		
1	*Anabaena* sp.	+	+
2	*Cyanodictyon planctonicum* B.A. Mayer	+	-
3	*Dolichospermum scheremetieviae* (Elenkin) Wacklin, L. Hoffmann & Komárek	-	+
4	*Microcystis pulverea* (H.C. Wood) Forti	-	+
	Cryptophyta		
5	*Cryptomonas marssonii* Skuja	+	-
6	*Cryptomonas ovata* Ehrenberg	+	-
7	*Komma caudata* (L. Geitler) D.R.A. Hill	+	-
8	*Rhodomonas lens* Pascher & Ruttner	+	-
9	*Rhodomonas pusilla* (H.Bachmann) Javornický	-	+
	Dinophyta		
10	*Ceratium hirundinella* (O.F. Müller) Dujardin	+	+
11	*Dinophyta* sp.	+	+
12	*Glenodinium* sp.	-	+
13	*Gyrodinium helveticum* (Penard) Y. Takano & T. Horiguchi	+	-
14	*Peridinium* sp.	+	+
15	*Scrippsiella* sp.	-	+
	Haptophyta		
16	*Chrysochromulina parva* Lackey	+	-
	Chrysophyta		
17	*Chrysolykos planctonicus* B. Mack	+	-
18	*Dinobryon cylindricum* O.E. Imhof	+	-
19	*Dinobryon divergens* O.E. Imhof	+	+
20	*Dinobryon sociale* (Ehrenberg) Ehrenberg	+	-
21	*Dinobryon sociale* var. *americanum* (Brunnthaler) Bachmann	+	+
22	*Kephyrion elegans* (D.K.Hilliard) Starmach	+	-
23	*Kephyrion ovale* (Lackey) Huber-Pestalozzi	+	-
24	*Kephyrion inconstans* (Gerlinde Schmid) Bourrelly	+	-
25	*Kephyrion moniliferum* (Gerlinde Schmid) Bourrelly	+	-
26	*Kephyrion spirale* (Lackey) Conrad	+	-
27	*Spiniferomonas bourrellyi* Takahashi	+	+
28	*S. cuspidata* (Balonov) Kapustin	+	-
29	*S. trioralis* Takahashi	+	-

No	Taxa	Bratsk Reservoir	Ust-Ilimsk Reservoir
30	*Lepidochromonas takahashii* (Cronberg & Kristiansen) Kapustin & Guiry	+	-
31	*Mallomonas acaroides* forma Perty	+	-
32	*M. akrokomos* Ruttner	+	-
33	*M. alpina* Pascher & Ruttner	+	+
	Bacillariophyta		
34	*Acanthoceras zachariasii* (Brun) Simonsen	+	-
35	*Asterionella formosa* Hassall	+	+
36	*Aulacoseira granulata* (Ehrenberg) Simonsen	+	-
37	*Aulacoseira islandica* (O.Müller) Simonsen	+	+
38	*Aulacoseira ambigua* (Grunow) Simonsen	+	+
39	*Cyclostephanos dubius* (Hustedt) Round	+	-
40	*Discostella pseudostelligera* (Hustedt) Houk & Klee	+	-
41	*Fragilaria crotonensis* Kitton	+	+
42	*Fragilaria radians* (Kützing) D.M. Williams & Round	+	+
43	*Lindavia minuta* (Skvortzov) T. Nakov et al.	+	+
44	*Lindavia* sp.	+	-
45	*Nitzschia graciliformis* Lange-Bertalot & Simonsen	+	+
46	*Stephanodiscus meyeri* Genkal & Popovskaya	+	+
47	*Stephanodiscus alpinus* Hustedt	+	+
48	*Ulnaria acus* (Kützing) Aboal	+	+
49	*Stephanodiscus hantzschii* Grunow	+	+
50	*Stephanodiscus minutulus* (Kützing) Cleve & Möller	+	+
51	*Ulnaria danica* (Kützing) Compère & Bukhtiyarova	+	-
	Chlorophyta		
52	*Ankistrodesmus arcuatus* Korshikov	+	-
53	*Crucigenia quadrata* Morren	+	-
54	*Lagerheimia genevensis* (Chodat) Chodat	+	+
55	*Koliella longiseta* (Vischer) Hindák	+	+
56	*Monoraphidium contortum* (Thuret) Komárková-Legnerová	+	+
57	*Monoraphidium komarkovae* Nygaard	+	+
58	*Pandorina morum* (O.F. Müller) Bory	+	+
59	*Sphaerocystis* sp.	+	+
60	*Franceia ovalis* (Francé) Lemmermann	-	+
	Charophyta		
61	*Elakatothrix genevensis* (Reverdin) Hindák	+	-
62	*Staurastrum* sp.	+	-
	Total	56	32

Comparison of diversity and structure of phytoplankton communities of the Bratsk and Ust-Ilimsk reservoirs

All diversity indices in the Ust-Ilimsk Reservoir (UR) were systematically lower than in the Bratsk Reservoir (BR) (Fig. 4). However, the differences did not reach statistical significance after correction for multiple comparisons (Wilcoxon test, FDR-p > 0.3). For richness, a near-significant decreasing trend was observed (p = 0.055).

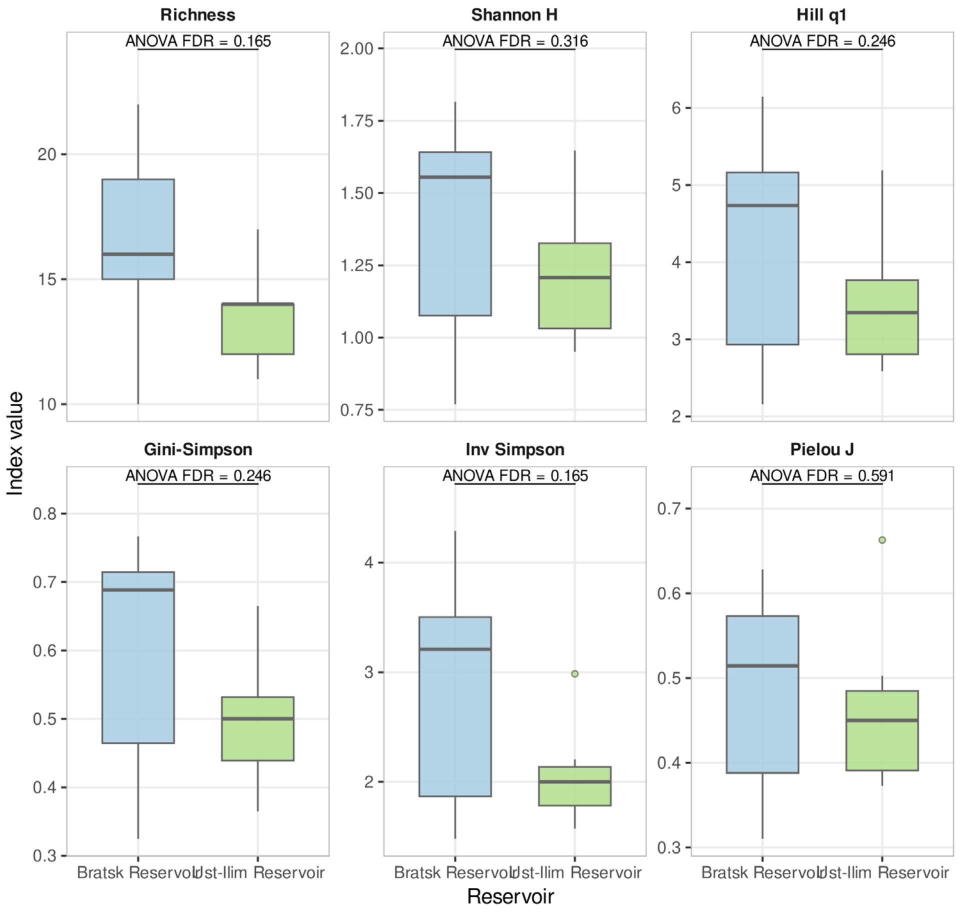

Figure 4. Alpha diversity indices in the Bratsk and Ust-Ilimsk reservoirs in June 2024.

Cluster analysis (Fig. 5A) divided the stations into two principal groups: (1) stations of the Bratsk Reservoir and the upper sites of Ust-Ilimsk (UR_Er, UR_E), with BR_I being the most isolated; (2) the main part of the Ust-Ilimsk stations, together with the Angara-mainstem stations BR_N and BR_S. Station BR_M occupied an intermediate position.

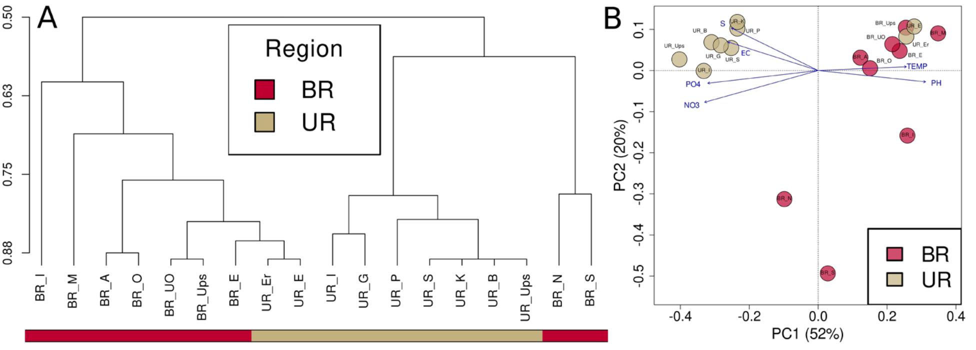

Figure 5. Exploratory analysis of the community similarity patterns. (**A**) Cluster analysis using affinity propagation; the color bar below the dendrogram indicates the regional affiliation of profiles. (**B**) Principal Component Analysis (PCA) of species abundance data. Colors denote regional affiliation; arrows indicate significant environmental variables fitted with envfit (FDR $p_{adj} \leq 0.01$).

Principal component analysis (PCA) (Fig. 5B) revealed that PC1 (52% of variance) clearly separated Bratsk and Ust-Ilimsk profiles, with two upstream Ust-Ilimsk stations (UR_Er and UR_E) clustering on the Bratsk side. PC2 (20%) further isolated the Bratsk Angara mainstem sites upstream of the tributary confluences, with BR_N and BR_S projecting away from both the Bratsk bay/confluence group and the Ust-Ilimsk sites.

Discussion

Comparison of the species structure of phytoplankton with data from previous years

In total, 62 taxa of planktonic algae, were identified in the reservoirs we studied in June 2024, of which 56 were in the Bratsk Reservoir and 32 in the Ust-Ilimsk Reservoir. Earlier, in the spring season, in the period 1972–1978, the species richness of planktonic algae in the Bratsk Reservoir ranged from 50–66 taxa (Vorobyova et al. 1981, p. 21). During the spring season in the Ust-Ilimsky Reservoir during the observation period of 1972–1987, the species richness of planktonic algae ranged from 48–79 taxa (Vorobyova et al. 1987, p. 51).

Previously, it was believed that the Bratsk and Ust-Ilimsk reservoirs had the highest similarity coefficient among the reservoirs of the Angara Cascade – 0.85 according to the Sørensen coefficient (Sadchikov 2003) (Vorobyova 1995). We showed that the spring phytoplankton of the Bratsk and Ust-Ilimsk reservoirs in 2024 had both similarities and differences. Phytoplankton communities in the Ust-Ilimsk Reservoir in June 2024 were characterized by lower diversity, which reflects its decrease down the cascade with faster flow and less mosaic environment. The main ordination axis (PC1) (Fig. 5) reflects regional differences between Bratsk and Ust-Ilimsk Reservoirs, with the upper stations UR_Er and UR_E retaining the “imprint” of communities formed in the Bratsk Reservoir bays. The second axis (PC2) indicates lateral heterogeneity in Bratsk Reservoir, where the oligotrophic Angara riverbed (BR_N, BR_S) contrasts with the bays in environmental parameters.

It was previously shown that in the period from 1972 to 1987, in the spring, when solar radiation increases, the basis of the plankton of the Angara branch of the Bratsk Reservoir was occupied by diatoms (83–99% of the total biomass). The water temperature in previous years did not exceed 7.2 °C (Vorobyova 1995). In spring, representatives of the genus *Stephanodiscus* dominated, and species such as *Aulacoseira islandica*, *Fragilaria radians*, *Stephanodiscus minutulus*, and *Nitzschia graciliformis* were represented to a lesser extent (Vorobyova 1995). In our study in the Bratsk Reservoir, Stephanodiscus minutulus was the main subdominant and dominated only at one station (BR_N).

It was previously shown that in the spring season in Ust-Ilimsk (1975, 1977, 1980, 1981–1987) diatoms constituted 61–97% of the total biomass (Vorobyova 1995), in June 2024 they accounted for 80–95% of the total abundance and from 40 to 90% of the total biomass. Phytoplankton was characterized by an extremely uneven distribution along the river. In the lower pool of the Ust-Ilimsk Reservoir, high concentrations of *S. minutulus* were noted (Sheveleva and Vorobyova 2009). In our study, a similar picture was observed (Fig. 3). During our observation period, in contrast to 1975–1987 (Vorobyova 1995, 1997), in addition to the species that previously constituted the main background of phytoplankton: *Stephanodiscus minutulus*, *Asterionella formosa*, *Fragilaria radians*, at the first two stations, which were under the influence of the waters of the Bratsk Reservoir, *Aulacoseira islandica* dominated, making up 65–75% of the total abundance. This species was not part of the dominant complex in 1975–1987. Among the dinophytes, the large-celled *Scrippsiella* sp. stood out in terms of biomass indicators; despite its low abundance (11 thousand cells/L), it reached a high proportion in the biomass (up to 35%) (Fig. 3).

Cryptophytes, which were previously part of the dominant complex (Kobanova 1980, Vorobyova 1995, 1997), growth poorly in the Ust-Ilimsk Reservoir in June 2024 and were practically never included in the subdominant species.

It is important to note that, as in previous years, we did not record the growth of cyanobacteria in the Bratsk and Ust-Ilimsk reservoirs. Unlike, for example, the Volga Reservoirs, in which, as the reservoirs mature, diatoms give way to cyanobacteria (Korneva 2015).

Habitat parameters and community structure

The species structure of phytoplankton communities of the studied reservoirs can be influenced by several factors and/or their sum.

Figures 3C and B show that stations BR_N and BR_S have a significant difference from other stations in terms of community structure. Here, both in terms of abundance and biomass, the diatom *Nitzschia graciliformis* dominates, and the chrlorophyta *Monoraphidium komarkovae* is a subdominant. Both of these species are minor at other stations of the Bratsk Reservoir. According to our unpublished data on the structure of phytoplankton in 2024 near the source of the Angara River (3 km from Listvyanka), the Irkutsk Reservoir (lower and upper pools) and the Angara River near city Svirsk, *N. graciliformis* and *M. komarkovae* are among the dominant species, and they were probably brought to the Bratsk Reservoir with the flow of water masses of the Angara River, and further downstream they grew and/or did not grow.

The dominant species of phytoplankton at the station before the upper pool of the Bratsk Reservoir and the first stations of the Ust-Ilimsk Reservoir (BR_UO, BR_Ups, UR_Er, UR_E) have a similar species composition (Fig. 3B). According to the PCA (Fig. 5B), the composition of phytoplankton at these stations is affected by water temperature, but at these stations it varied widely – from 5.9 to 9.4 °C. It can be assumed that locally the composition of phytoplankton is affected by river tributaries, for example the Oka River (BR_O) and the Iya River (BR_I) opposite Artum Bay (BR_A), but such a phenomenon is not observed in the Ust-Ilimsk Reservoir, since changes in composition occur at the station opposite Sukhoi Bay (UR_S), and this is more than 20 km from the mouth of the Ilim River (UR_I) (Fig. 1).

It should be noted that, in contrast to previously published data, at two stations of the Bratsk Reservoir (BR_O, BR_I), we observed a noticeable growth of *A. formosa*, which is typical for the summer period of Lake Baikal and the Angara reservoirs. This may be due to a higher water temperature (9.4–10.4 °C) compared to other stations. Previously, this species was not part of the spring dominant complex, which may be the result of a shift in the warm period to an earlier date and the creation of more favorable conditions for the growth of this species. For example, long-term studies of the Mozhaisk Reservoir have shown that summer vertical stratification occurs 9 days earlier than in the 1980s, and spring homothermy – 5 days earlier. The duration of summer stratification has increased by 18 days, and spring homothermy has decreased by 4 days. Changes in the timing of hydrometeorological and hydrochemical processes affected the timing and degree of growth of aquatic organisms (Goncharov et al. 2022).

Quantitative indicators of modern phytoplankton of the Bratsk and Ust-Ilimsk reservoirs

Quantitative indicators of phytoplankton growth in the Bratsk Reservoir in June 2024 were not high and were within the range of interannual fluctuations. Thus, at different stations of the Bratsk Reservoir we established variations in the abundance from 366 to 1,119 thousand cells/L and total biomass from 69 to 579 mg/m^3 against those previously reported for the spring period (May-June) of 1972–1987 – from 1 million to 28.6 million cells/L and from 0.42 to 13.5 g/m^3, respectively (Vorobyova et al. 1981, Vorobyova 1997).

Quantitative indicators of phytoplankton growth in the Ust-Ilimsk Reservoir were lower than in the Bratsk Reservoir. Thus, in June 2024, the abundance and biomass varied from 104 to 577 thousand cells/L and from 41 to 274 mg/m^3, respectively, and earlier (1975–1987) indicated values of 0.1–10.3 million cells/L and 0.03–3.2 g/m^3) (Vorobyova 1997).

According to the average vegetation biomass of phytoplankton, the Ust-Ilimsk Reservoir in the 1970s, according to the classification of trophic statuses of reservoirs (Mikheeva 1975, Milius and Kyvask 1979, Trifonova 1993, Kitaev 1984) (Table 3), could be classified as oligotrophic, and in the 1980s – as mesotrophic.

In the 1990s, an increase in water level and transparency and a decrease in biogens led to a decrease in quantitative indicators and a shift in status towards oligotrophy. At that time, according to Vorobyova (1995), the phytoplankton of this reservoir entered a stage of relative stabilization. Our research showed that in June 2024 the studied area of the reservoir has an oligotrophic status.

In 1972–1987, Bratsk Reservoir was characterized by a mesotrophic status (Vorobyova 1995). Based on the classification of trophic statuses of water bodies (Mikheeva 1975, Milius and Kyvask 1979, Trifonova 1993, Kitaev 1984), we believe that in the spring of 2024, these areas of the reservoir, in terms of quantitative indicators of phytoplankton, as well as the studied areas of the Ust-Ilimsk Reservoir, have an oligotrophic status (Table 3).

Table 3. Classification of water body types by phytoplankton biomass (g/m^3)

References	Trophic status		
	Oligotrophic	**Mesotrophic**	**Eutrophic**
Mikheeva 1975	<1.5	1.5–2.0	>2
Milius and Kyvask 1979	<1	1–3	3–7
Trifonova 1993	<1	1.3	3–10
Kitaev 1984	<0.5–1.0	1–4	4–16
This study Bratsk Reservoir	0.069–0.579	–	–
This study Ust-Ilimsk Reservoir	0.041–0.274	–	–

During the formation of reservoirs, plankton goes through several stages of formation: destruction of existing cenoses, formation of new ones, relative stabilization (Kuzmin 1974, Kozhova 1978, Vorobyova 1997, Korneva 2015). The period of maturity of the reservoir is characterized by relative stabilization of the phytoplankton community. Over the past years, the Bratsk and Ust-Ilimsk reservoirs have experienced a characteristic decrease in species diversity. Due to changing habitat conditions, some species have dropped out of the plankton, and a permanent dominant complex has formed. The main role in the formation of phytoplankton biomass in the spring, as before, in 2024 belonged to diatoms (species of the genera *Fragilaria*, *Stephanodiscus*, *Aulacoseira*, *Asterionella*). Common to both reservoirs was the growth of *Aulacoseira islandica*, which prevailed at most stations.

Conclusions

An analysis of the structure of spring phytoplankton communities in June 2024 showed that, as in previous years, the phytoplankton of the Bratsk and Ust-Ilimsk reservoirs was characterized by the dominance of diatoms. Based on quantitative indicators of the total phytoplankton biomass, the studied areas of the Bratsk and Ust-Ilimsk reservoirs in June 2024 can be classified as oligotrophic. Since global warming may affect phytoplankton given the presence of settlements along the reservoir shores, continuous monitoring of water quality in seasonal and interannual dynamics is necessary.

Acknowledgements

The authors express their gratitude to the captains of the vessels that worked in the Bratsk and Ust-Ilimsk reservoirs: K.V. Stolyarov (in Bratsk) and V.T. Shalimov (in Ust-Ilimsk), A.P. Fedotov – for useful comments on the text of the manuscript. Microscopic studies were carried out at the Electron Microscopy instrument center of the Shared Research Facilities for Physical and Chemical Ultramicroanalysis LIN SB RAS with the assistance of V.I. Egorov, M.M. Maslennikova and A.P. Lopatin.

The work was carried out with the financial support of the Russian Science Foundation, project No. 23-14-00028, https://rscf.ru/project/23-14-00028/.

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