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RESEARCH ARTICLE

Recent observation of seasonal variability of plankton in Maloe More Strait (Lake Baikal)

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Abstract

In this paper, we describe the structure and quantitative characteristics of phyto- and zooplankton from Maloe More Strait of Lake Baikal studied in June-October, 2024. Maloe More is a popular recreational zone facing higher anthropogenic stress. In summer, phytoplankton in the littoral area of the strait showed continuous biomass maximum, starting from July until late August during cyanobacterial blooms. Two smaller maxima were observed in the strait pelagic zone, the first by the end of spring vegetation of phytoplankton, and second during excessive cyanobacterial growth in August. Elevated water temperatures resulted in prolonged cyanobacterial vegetation with a change of dominants. Restructuring of food resources and temperature fluctuations entailed transformations in the zooplankton structure. In June, the pelagic plankton was dominated by *Epischura*, a Baikal endemic. As the water temperature rose, the dominant position was occupied by *Cyclops kolensis*, the population of which was represented by mature specimens and nauplii. In summer, *Cladocera* reached its abundance peak in the nearshore. The highest number of rotifers was documented during maximal rise of nanoplanktonic flagellate concentrations in autumn.

Keywords

Lake Baikal, intensive cyanobacterial vegetation, phytoplankton, seasonal dynamics, structural changes, temperature, trophic state, zooplankton

Introduction

Insights into community structures affected by changing environments is one of the basic concerns of ecological scientists. Phyto- and zooplankton play a critical role in linking aquatic food webs, involved in biogeochemical cycles of water bodies. Meanwhile, available knowledge on environmental variables governing their seasonal dynamics requires further improvement, especially with regard to coastal ecosystems (Maberly et al. 2022). It is generally accepted that phytoplankton successions in lakes depend on water temperature, water transparency, light intensity and nutrient availability. However, temperature and phytoplankton (Moore 1982; Riv'er 2012; Dong et al. 2022; and others) are considered critical factors shaping the composition and growth intensity of zooplankton.

Detailed investigations of phyto- and zooplankton of Maloe More Strait were undertaken in 1950s (Kozhova 1959; Vilisova 1959). The authors identified the species composition of plankton and described its seasonal and interannual dynamics. In 1980s, G.I. Popovskaya (1989, 1991) documented first changes in phytoplankton of Maloe More Strait registering excessive growth of cyanobacteria not only in the nearshore of the strait but in its open part in summer. Biomass of phytoplankton increased several times in contrast to the 1950s, which brought the author (Popovskaya 1991) to a conclusion that it was induced by escalating anthropogenic load in this region of Lake Baikal. At present, climate changes and high anthropogenic stress in many freshwater ecosystems, including Lake Baikal, caused structural transformations in aquatic communities and species richness (Izmest'eva et al. 2016; Timoshkin et al. 2016; Sheveleva, Penkova 2020; and others). In Lake Baikal phytoplankton, the structure of the dominant species was changed and number of small mixotrophic flagellates was sharply increased (Bondarenko et al. 2022, 2023). The zooplankton number was increased as well due to the rotifer abundance (Sheveleva, Penkova 2020; Bondarenko et al. 2023).

The present work is aimed at estimating the current diversity and variability of the abundance of plankton from Maloe More Strait studied in June-October 2024. Understanding plankton dynamics is important for appreciating their role in ecosystem health. Plankton promptly responds to environmental challenges due to its short life cycle, hence, the species composition and dynamics most readily reflect changes in their habitat that made us address variations in the trophic state of the strait using phyto- and zooplankton indicators.

Materials and methods

Site description

Lake Baikal is the deepest (1642 m), most ancient reservoir on Earth, over 30 million years old, and contains 20% of the world's surface freshwater. The Maloe More strait is located between the western shore of Lake Baikal and Olkhon Island. It is 75 km long, including the Mukhor Bay, which is 18 km in the widest part and 4 km in the shortest part. Its area is about one thousand km^2 and its depth is up to 200 m (Kozhov 1963). This part of Lake Baikal is subject to intense anthropogenic load.

We conducted five surveys: one at the end of spring phytoplankton vegetation in June, three in summer (first decade of July, late July and August) and one in early October 2024. Plankton was sampled at two nearshore sites in Mukhor Bay and two sites in the pelagic zone of Maloe More Strait (Fig. 1). To assess the current state of plankton in the strait, we compared original records with the published data.

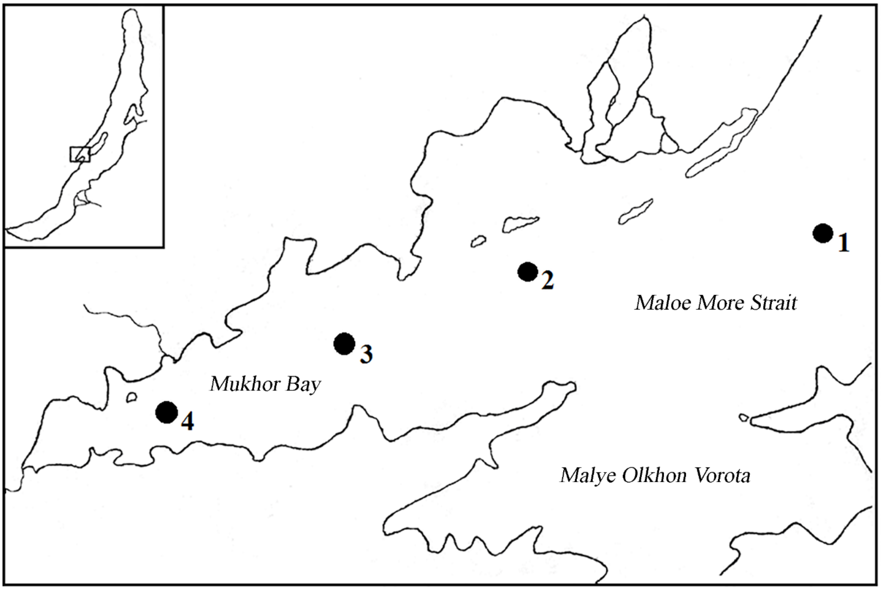

Figure 1. Map of the study area. 1, 2 – pelagic zone; 3, 4 – Mukhor Bay.

Collection and processing of phytoplankton samples. 1 L samples were collected from a 0–1 m water layer by Ruttner water sampler and fixed in Utermóhl's solution and concentrated by sedimentation. The 0.1 ml concentrate was examined by triple counting using a light microscope Peraval (Carl Zeiss). Net- and nanoplankton were counted and identified at ×720 magnification. Biomass of algae was assessed with account of individual volumes of their cells (Makarova, Pichkily 1970). Species with maximal contribution to the total biomass were specified as dominant. The species diversity was estimated according to Shannon's index (H) calculated by the biomass. Algae were identified following Starmash 1985; Komarek, Anagnostidis 1998; Genkal et al. 2020; and others.

Collection and processing of zooplankton samples. Juday plankton net (diameter 37.5 cm, mesh size 100 μm) was used for sampling in the upper 25-m pelagic layer and surface-to-bottom littoral layer. The laboratory processing was carried out using the standard method, the individual weights of the Baikal organisms were used to calculate the biomass (Kozhova, Melnik 1978). Average abundance, N_{total} (thousand individuals/m^3), abundance of three main taxonomic groups (rotifers, cladocerans, and copepods), and the total biomass (B_{total}, mg/m^3) were calculated. The species diversity was estimated according to Shannon's index (H), calculated by the abundance and biomass. Each taxonomic group included species with relative abundance and biomass ≥ 5% that were considered dominant (Lazareva et al. 2001). For species identification, we used guides and keys (Kutikova 1970; Einsle 1996; Korovchinsky et al. 2023).

The trophic state was assessed by determination of the number of species indicators of eutrophication (SE); biomass ratios of crustaceans and rotifers *Bcr/Brot*, as well as cyclopoid and calanoid copepods *Bcycl/Bcal*; number of cladocerans and copepods *Nclad/Ncop*, crustaceans and rotifers *Ncr/Nrot*; $w_{average}$ (B_{total}/N_{total}) – average individual weight of a specimen in the community; B_{zoo}/B_{phyto} – biomass ratio of consumers and producers. The trophic state was determined according to the Mäemets trophic coefficient E = K (x+1)/(A+V) (y+1) (Andronikova, 1996), where K – number of Rotifera species, A – number of Copepoda species, V – number of Cladocera species, x – number of meso-eutrophic species, y – number of oligo-mesotrophic species (Andronikova 1996).

Results

Temperature. In the first decade of June, the nearshore water was well warmed, whereas the temperature in the pelagic zone was low (Fig. 2). Higher values were observed both in the nearshore and pelagic zones of the Strait in the first decade of July with their maxima registered in Mukhor Bay, 21.5–22.5° C. Temperatures remained elevated at all sampling sites until late August, and in early October they dropped to 12.8–14.6° C.

Phytoplankton. In the end of spring vegetation in June, the phytoplankton of the pelagic zone of the Strait was represented by common species recently observed in Lake Baikal: dominant green *Koliella longiseta* (Vischer) Hind, 173.4–280.8 thousand cells/L, and diatom *Ulnaria acus* (Kützing) M. Aboal, number of which ranged from 21.6 to 88.9 thousand cells/L. Nanoplanktonic dinoflagellates, *Biecheleria* sp. and *Woloszynskia* cf. *pascheri*, are plentiful, 22.2–31.2 thousand cells/L. The total biomass amounted to 301–404 mg/m^3 (Fig. 3). In Mukhor Bay, the biomass was 214–418 mg/m^3, the microplanktonic forms were scanty dominated by the diatom *Nitzschia graciliformis* Lange-Bertalot et Simonsen emend Genkal et Popovskaya (11–110 thousand cells /L). Nanoplanktonic flagellates, represented by haptophyte *Chrysochromulina parva* Lackey (25.4–1227.6 thousand cells/L) and cryptophyte *Rhodomonas pusilla* (Bachm.) Javorn. (33.9–135.2 thousand cells/L), reached high concentrations.

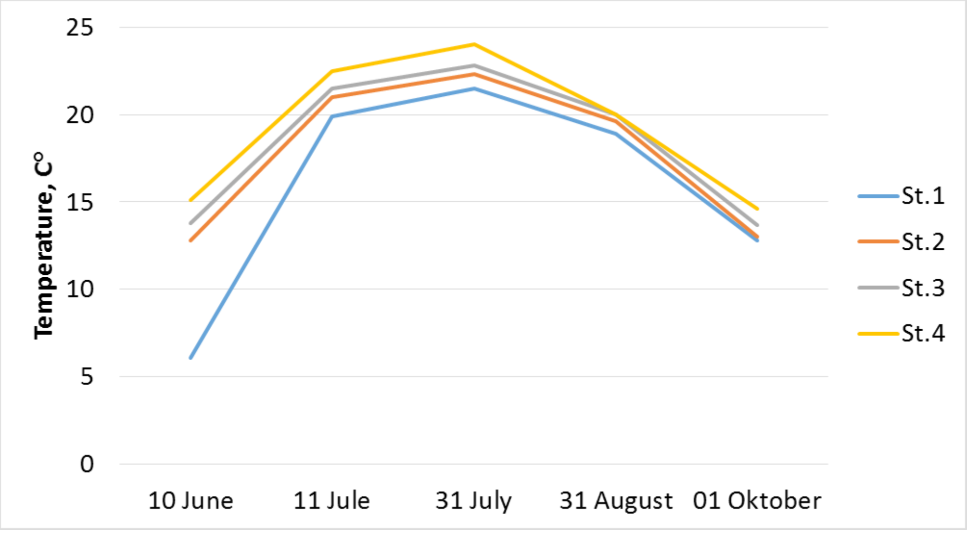

Figure 2. Changes in water temperature during the study period, 2024.

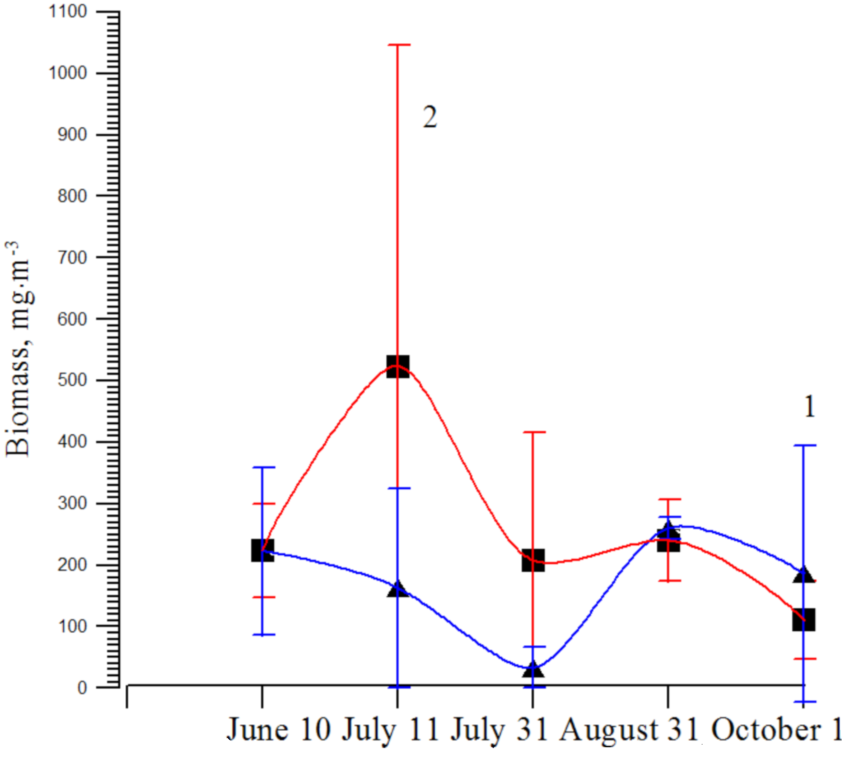

Figure 3. Dynamics of phytoplankton biomass, 2024: 1 – pelagic zone; 2 – Mukhor Bay.

Summer vegetation started with warming up of the upper water layers in July. Blooming spots visible to the naked eye were reported in Mukhor Bay: cyanobacteria developed, first of all, *Dolichospermum lemmermannii* (P.G.Richt.) Wacklin, L. Hoffm. & Komárek, the number of which was estimated to 1401.1 thousand cells/L. Other cyanobacteria were also registered in noticeable concentrations, such as: *D. flos-aquae* (Bornet & Flahault) P. Wacklin, L. Hoffmann & Komárek, *D. scheremetieviae* (Elenkin) Wacklin, L. Hoffmann & Komárek and *Trichormus variabilis* (Kützing ex Bornet & Flahault) Komárek & Anagnostidis, 404.6–612.1 thousand cells/L. In July, pelagic plankton was few in number, represented by negligible concentrations of nanoplanktonic flagellates. In water areas close to Mukhor Bay, we observed onset of cyanobacterial vegetation, the total number of which exceeded 600 thousand cells/L. Elevated concentrations of cyanobacteria persisted until late August in this area. In August, pelagic Baikal phytoplankton basically consists of picoplankton forms (Bondarenko, Guselnikova 1989; Popovskaya 1991; Belykh et al. 2006), the number of which reached more than 220 million cells/L. In August 2024, microphytoplankton was represented by the chrysophyte *Dinobryon sociale* (Ehrenb.) Ehrenb. 2.5 to 41.4 thousand cells/L and green *Monoraphidium contortum* (Thur.) Komarkova-Legnerova 1.5 to 10.1 thousand cells/L. *M. contortum* was the only species among thirteen species found in the plankton at that time and not related to the flagellate forms. The total number of nanoplanktonic phytoflagellates varied from 68 to 240 thousand cells/L. Cyanobacteria continued to vegetate in the nearshore zone by increasing their species number and changing dominants. The highest number was documented in *Dolichospermum spiroides* (Kleb.) Wacklin, L. Hoffm. & Komárek), up to 540 thousand cells/L. *Chroococcus limneticus* Lemm., 52.4 thousand cells/L, and *D. affine* (Lemm.) Wacklin, L. Hoffmann & Komárek, 34 thousand cells/L, appeared in plankton.

In the beginning of October, we observed only small algae in the pelagic zone, dominated by *Chrysochromulina parva* (37.6–378.3 thousand cells/L) and *Rhodomonas pusilla* (30.7–145.2 thousand cells/L). The amount of nanoplanktonic dinoflagellates was 13–41 thousand cells/L. Their biomass varied along the Strait water area from 61 to 398 mg/m^3. Phytoplankton in Mukhor Bay was distinguished from phytoplankton in the pelagic zone by a small number of large-celled algae: the dinoflagellate *Ceratium hirundinella* (O.F.Müller) Dujardin (1.5–6.4 thousand cells/L) and diatom *Asterionella formosa* Hass. (3.8–5.8 thousand cells/L). The samples also included semi-decomposed colonies or small fragments of cyanobacteria of the genus *Dolichospermum* (Ralfs ex Bornet & Flahault) P. Wacklin, L. Hoffmann & J. Komárek (*D. lemmermannii*, *D. spiroides*), the number of which ranged within 13.4–72.5 thousand cells/L, their biomass varying from 92 to 188 mg/m3. During our observations maximal biomass values were registered in the littoral zone in July, and two insignificant rises in the pelagic zone in June and October (Fig. 3).

It is considered that the species diversity indices measured during seasonal succession are evidently correlated to the structural transformations in the plankton community. The species diversity in early spring succession is fast growing, then it stabilizes and decreases dramatically in autumn and winter (Andronikova 1996). Similar pattern is generally reported in the pelagic zone where maximum Shannon indices derived for phytoplankton in June (1.88) remain relatively stable in summer (1.70–1.77), dropping in autumn to (1.58). The situation in Mukhor Bay is opposite: maximal indices (2.0) were estimated at the end of spring vegetation, in June and August at the cyanobacterial blooms.

Zooplankton. In 2024, studies were initiated in the first decade of June, when the surface water layer warmed up to 6.4° C in the pelagic zone. Endemic *Epischura baikalensis* Sars and single specimens of rotifers *Synchaeta pachypoda* Kutikova et Vassiljeva, and *Notholca grandis* Voronkov were registered there. In the first decade of July, the temperature of the pelagic water rose to 20° C, remaining constant until late August (Fig. 2). Higher water temperature induced *Epischura* migration to the hypolimnion, and the dominant position was occupied by *Cyclops kolensis* Lilljeborg (56 – 96%), the population of which was represented by mature individuals and nauplii.

In the period from late July to early October with abundant algae resources, the community was dominated by cladocerans, *D. galeata* (22–86%) and *B. longirostris* (6–78 %), attributed by Gutelmacher (Gutelmacher et al. 1988) to macrofiltrators. A dominant complex of rotifers is represented by 1–4 species, the leading position among which belonged to polyphagous *A. priodonta*, from 43 to 96% (Table 1). The species dominating a taxonomic group of rotifers the number of which exceeded 5%, were *K. longispina*, *F. terminalis* and *K. quadrata* (Table 1). Quantitative indices of zooplankton reached two peaks in June – October: maximal abundance and biomass in the middle of June owing to *E. baikalensis* growth, abundance maximum in late August on account of *C. kolensis* and *D. galeata*, and biomass due to plentiful *Daphnia*. The average abundance during the study period amounted to 4.3±1.7 thousand specimens/m^3 and the biomass –100±94 mg/m3.

Observations in Mukhor Bay started when the surface water temperature was 15.1° C. The plankton fauna was characterized by a high species diversity – 25 species, 15 crustaceans, 10 of which were cladocerans. Two rare species were encountered in the Bay – *Daphnia cristata* Sars and *Diaphanosoma brachyurum* (Lievin). The complex of dominants included from 5 to 9 species (Table 1). Permanent constituent of the dominating core were *D. galeata*, *E. graciloides* and *A. priodonta*. Copepods dominated in abundance in the middle of June on account of *C. kolensis* population, and in late July owing to thermophilic cyclopoid copepods, *Th. crassus* + *M. leuckarti*, attaining high abundance. Just in late July we registered abundance maximum of this taxonomic group (Fig. 4).

The development of Cladocerans was characterized by two peaks, the highest observed in late August. It should be noted that *D. galeata* outnumbered *B. longirostris* from 2.5 to 9 times. Being relatively diverse, the rotifers were inferior to the crustaceans in abundance (Table 1). A group of foraging dominants (Monakov 1998; Lazareva 2004) included predators *A. priodonta*, *B. hudsoni*, *S. stylata*, and filter-feeders – phytophagous *K. longispina*, *P. dolichoptera*, *K. quadrata*, *E. dilatata*, *F. terminalis* (Table 1). The highest abundance of rotifers was observed in early October (Fig. 4). The open water period was characterized by two peaks in zooplankton abundance with the highest value (53.0 thousand specimens/m^3) registered in late August that coincided with the maximal biomass (3.76 g/m^3).

Table 1. Structure of a dominant zooplankton complex (% of the taxonomic group number) in Maloe More Strait (June-August 2024)

Date	Pelagic zone	Mukhor Bay
10 June	*E. baikalensis* (96); *S. pachypoda* (98)	*C. kolensis* (75); *Eudiaptomus graciloides* (Lilljeborg) (10); *D. galeata* (57); *B. longirostris* (12); *A. priodonta* (58); *K. longispina* (12); *Polyarthra dolichoptera* Idelson (9)
11 July	*E. baikalensis* (44); *C. kolensis* (56)	*Mesocyclops leuckarti* (Claus) + *Thermocyclops crassus* (Fischer) (95); *E. graciloides* (5); *D. galeata* (42); *B. longirostris* (22); *A. priodonta* (74); *K. quadrata* (7); *Bipalpus hudsoni* (Imhof) (7)
31 July	*C. kolensis* (42); *Asplanchna priodonta* Gosse (43); *Kellicottia longispina* Kellicott (7); *Filinia terminalis* (Plate) (7); *Keratella quadrata* (Müller) (14); *Daphnia galeata* Sars (44); *Bosmina longirostris* (Müller) (11)	*M. leuckarti* + *Th. crassus* (93); *E. graciloides* (7); *D. galeata* (93); *Leptodora kindtii* (Focke) (5); *A. priodonta* (30); *K. quadrata* (40); *K. longispina* (30)
31 August	*C. kolensis* (96); *D. galeata* (86); *B. longirostris* (6); *A. priodonta* (96)	*M. leuckarti* + *Th. crassus* (62); *E. graciloides* (38); *D. galeata* (97); *A. priodonta* (58); *Euchlanis. dilatata* Ehrenberg (38)
1 October	*E. baikalensis* (57); *C. kolensis* (43); *B. longirostris* (78); *D. galeata* (22); *K. quadrata* (49); *A. priodonta* (23); *K. longispina* (15)	*C. kolensis* (92); *E. graciloides* (5); *D. galeata* (76); *B. longirostris* (24); *A. priodonta* (56); *K. longispina* (19); *Synchaeta stylata* Wierzejski (11); *K. quadrata* (7)

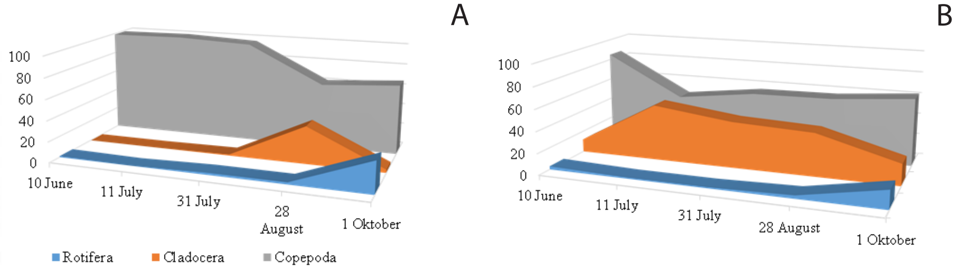

Figure 4. Relative abundance (proportion of taxonomic group in total abundance, %) of zooplankton, **A** – pelagic zone; **B** – Mukhor Bay.

Trophic state of Maloe More Strait. To gain a better understanding of the present trophic state of the Strait, the authors used different structural coefficients (Table 2), however, the results obtained were ambiguous and inconsistent. Due to the dominance of small-sized forms, biomass of the pelagic phytoplankton remained within the limits of the oligotrophic status. Oligotrophy of Maloe More pelagic zone is also confirmed by dominant *E. baikalensis* and *C. kolensis* species, zooplankton biomass (0.015–0.240 mg/m^3) and the following informative coefficients (Table 2): dominance (abundance and biomass in the taxonomic group) of copepods compared to cladocerans and rotifers (R:Cl:Cop); biomass ratio of crustaceans and rotifers (B crus/B rot); low value of cladoceran number compared to copepods N clad/N cop; w – mean individual weight of zooplankton organisms dominated by crustaceans. In oligotrophic lakes, phytoplankton biomass is sometimes lower than the biomass of zooplankton, in eutrophic waters it is higher, and similar in mesotrophic water bodies (Andronikova 1996). According to this criterion and based on average values measured during three seasons, the pelagic part of the strait may be referred to as an oligotrophic zone only in June when the zooplankton is mainly represented by *Epischura*.

Because of biomass is a trophic parameter of water-reservoirs, Shannon's index ranges based on the zooplankton biomass was proposed to characterize different aquatic objects (Andronnikova, 1996). Based on the zooplankton productivity indices, the water bodies were rated as follows: 2.6-4.0 – oligotrophic; 2.1-2.5 – mesotrophic; 1.0-2.0 – eutrophic. All the indices we obtained for Mukhor Bay were belonged to the eutrophic type, the pelagic zone of Maloe More Strait is an area of extreme conditions. So Shannon's index is inappropriate to describe the pelagic zone of Lake Baikal.

In Mukhor Bay, zooplankton biomass is higher even during intense proliferation of cyanobacteria when the total biomass of phytoplankton reaches or exceeds 1 g/m^3. This is typical for oligotrophic waters, and it is only in June that the biomass of phyto- and zooplankton is comparable, as in mesotrophic lakes. The majority of structural characteristics of zooplankton from Mukhor Bay are consistent with those typical for mesotrophic and eutrophic water bodies: abundance/biomass ratio of taxonomic groups (R:Cl:Cop based on N and B, %), the biomass ratio of predator/filter feeders (B_3/B_2), ratio of Cladocera and Copepoda numbers (N clad/ N cop), as well as Shannon's index based on the biomass (H_B) and trophic state index (E). Moreover, dominant complexes included indicator species of eutrophic waters (Andronikova 1996): *K. quadrata*, *F. terminalis*, *C. kolensis*, *B. longirostris*, *Th. crassus*. Average seasonal zooplankton biomass amounted to 1450±571 mg/m^3, which, following S.P. Kitaev's classification (2007), complies with the mesotrophic status of the strait. Non-informative parameters describing the strait were as follows: biomass ratio of cyclopoid and calanoid copepods and (Bcycl/Bca), mean seasonal zooplankton biomass 1450±571 mg/m^3) and ratio of crustaceans and rotifers (Bcr/Brot), the latter is indicative of large-sized species dominance of the strait plankton community.

Table 2. Trophic indexes of plankton in Maloe More Strait

Parameters	Andronikova 1996			Authors' data									
				Mukhor Bay					Pelagic zone				
	oligotrophic state	**mesotrophic state**	**eutrophic state**	**10.06**	**11.07**	**31.07**	**28.08**	**1.10**	**10.06**	**11.07**	**31.07**	**28.08**	**1.10**
R:Cl:Cop (% Ntot)	32:38:58	30:47:43	46:52:35	2:8:92	1:57:42	0:43:57	2:83:15	16:20:64	1:0:99	0:06:100	1:1:98	2:36:62	27:3:70
R:Cl:Cop (% Btot)	7:26:45	8:32:40	13:48:27	3:24:73	1:82:17	0:77:23	1:96:3	9:62: 29	1:0:99	0:0:100	1: 1:98	1:79:20	1:1:98
w	0.025±0.1	0.0178±0.007	0.0155±0.0047	0.01	0.03	0.03	0.068	0.02	0.02	0.01	0.01	0.03	0
Nclad/Ncop	0.57	0.9	2.0	0.1	0.8	0.76	5.37	0.35	0	0	0.008	0.53	0.04
Bcyc/Bcal	0.1-0.4	0.5-0.8	0.9-1.1	29	2.86	1.8	0.31	5	0.006	93	34	7.5	0.17
B cr/Brot	27	-	82	25	1655	666	16	9	4740	32	125	235	11
B_3/B_2 (%)	38%	-	20%	11	26	21	1	22	0.6	1	30	22	15
Bz/Bph	4.32±1.2	0.78±0.14	0.42±0.07	0.96	2.94	8	15	1.47	1.06	0.2	0.45	0.76	0.29
E	<0.2	0.2-1.0	1.0-4.0	0.4	0.2	0.4	0.3	2.3	1	0	2.0	0.2	1.5
Shannon index, H (B)	2.6-4.0	2.1-2.5	1.0-2.0	0.96	0.8	1.12	0.22	1.1	2.28	0.69	0.28	0.84	0.87
N	$1x10^5$	$3x10^5$	$8x10^5$	15.6	43.34	40.86	53.3	8.3	11.2	2.1	1.16	4.25	2.9
B	<0.5-1.0	1.0-4.0	4.0-16	0.220	1.540	1.660	3.70	0.164	0.240	0.033	0.02	0.160	0.050

Note: R:CL:Cop is the ratio of the main taxonomic group and their contribution (% Ntot); R:Cl:Cop is the same for their contribution (% Btot); w – average individual weight of a specimen in the community; Nclad/Ncop is the ratio of the density cladocerans and copepods; Bcyc/Bcal is the ratio of the biomass of cyclopoid and calanoid copepod; Bcr/Brot is the same for crustaceans and rotifera; B_3/B_2 is the same for predator/filtrater feeders; Bz/Bph is the same for zooplankton and phytoplankton; E – trophic coefficient; H (B) – the species diversity according to Shannon's index by the biomass; N – total density (thous. ind/m3); B – total biomass, g/m^3.

Discussion

According to our research, plankton seasonal changes in the Maloe More straight manifistated as sharp variations of their species and size structures and quantitative parameters. They were caused by species biology and developmental stage, ratios of the taxonomic groups in the biocoenosis, and biotic and abiotic factors. It is well known that seasonal changes of the plankton composition and their abundance depend on the combined influence of the environmental factors and so there is no the only influencing factor. Main factors, light intensity, temperature and biogenic compounds, are generally considered essential contributors to phytoplankton development (Kozhov 1963; Votintsev et al. 1975; Trifonova 1979; Sommer 1986; Talling 1993; Reynolds 2006; Maberly et al. 2022; and others). When studying environmental impacts on seasonal and annual dynamics of Baikal phytoplankton, M.M. Kozhov (1963) arrived at a conclusion that the key factor, initiating spring growth of algae, was increasing illumination in the photosynthesis zone, and the termination of this process was mainly induced by the temperature rise. Multiple consumers that actively graze on algae play an important role in regulating their abundance (Kozhov 1963; Gerasimova, Sadchikov 2024). Studies on deep oligotrophic lakes in the north of Canada (Moore 1981) showed that temperature and light conditions affect initiation of algal bloom and its duration, while nutrient concentrations control only their growth intensity. Summarizing 26-year long observations of phytoplankton in four lake basins of England, J.F. Talling (1993) presented a model correlating seasonal cycles of total phytoplankton abundance and environmental conditions. He assumed that winter minimum of shortwave radiation was critical for the correlation of seasonal cycles and main regular phases of rising phytoplankton numbers occurred at the interphase of time between changes of physical and chemical conditions in such a way that the growth limiting impact of one was compensated by proportional parameters of the other. Every year there are three of such interphases: a) when the incoming shortwave radiation increases in late winter – early spring in terms of sufficient nutrient quantity; b) when the vertical algal cell circulation is strongly reduced and the light availability for each of them is enhanced owing to summer thermal stratification; c) when the biogenic matter arrival into the upper mixed layer is accelerated by its vertical flux during autumn cooling off. Main phases of phytoplankton depletion are observed during increased sedimentation in late spring, late summer, lower growth rates and intense grazing (Talling 1993). Precisely this situation was registered at the termination of spring vegetation in Maloe More Strait in June 2024.

It is reported that higher summer diversity of taxa and their abundance is, first of all, related to warmer water temperatures (Maberly 2022). In our case, the main driver of summer phytoplankton proliferation was warmer water temperatures alongside with complementary influx of nutrients discharged from the tourist camps. Present period is characterized by climate changes leading to 0.5° C surface air temperature rise over the territory of Russian Federation during the last decade

(Third… 2022). Thermal conditions of a hot summer of 2024 enhanced development of planktonic communities. Rise in the proportion of small-celled species was observed in both phyto- and zooplankton of Maloe More Strait. Growth of cyanobacteria, involved in sustaining a long-lasting summer maximum in the seasonal dynamics of the community, contributed to the total phytoplankton abundance increase.

Noticeably lower water temperatures marked the beginning of October. The autumn maximum in the evolution of pelagic phytoplankton, in contrast to spring and summer peaks, was poorly defined. Observations during the same period of the last century showed that phytoplankton was dominated by the diatoms *Cyclotella minuta* Antip. and *Aulacoseira islandica* (O. Müll.) Sim., the golden algae *Dinobryon* and the dinoflagellate *Ceratium hirundinella* (Popovskaya 1989, 1991). Whereas *C. minuta* and the latter two species were encountered by the authors in small quantities in 2024, *A. islandica* was entirely missing in autumn plankton of the strait at present. Phytoplankton data obtained during forty-year observations in Rappbode Reservoir (Germany) showed that seasonal shift in the community was induced by a compromise between small-celled, fast-growing species capable of utilizing available resources (r-strategists) and large-celled species with more complex and efficient mechanisms to use in nutrient-deficient conditions or get access to previously unexploited mineral nutrients (k-strategists) (Wentzky et al. 2020). In summer, the reservoir was poor in nutrients and dominated by k-strategists. During the rest of the year, the amount of nutrients and turbulence were high and the reservoir was dominated by r-strategists demonstrating maximal growth rates. In Maloe More Strait, the mass propagation of mixotrophic flagellates (r-strategists) as previously reported (Bondarenko et al. 2023) was facilitated by higher organic nitrogen and phosphorus concentrations in the water due to decaying colonies of cyanobacteria excessive growth of which occurred usually in summer and early September.

Key factors affecting the composition and growth intensity of zooplankton include: water temperature, oxygen concentration, qualitative and quantitative parameters of food (Moore 1982; Riv'er 2012; Dong et al. 2022). J. Moore (1982) assumed that temperature, among all, was the critical limiting factor for the growth of all main rotifer and crustacean species in large oligotrophic lakes in northern Canada despite of favorable conditions for feeding and illumination. Whereas food resources specified the range but not the timing of explosive growth of abundance of various zooplankton groups. Our observations in Maloe More Strait showed that structural transformations of zooplankton were related to both nutrient level and water temperature. Baikal water is richly oxygenated throughout the entire water column, the saturation never less that 70-80 % even at the bottom of the deepest parts (Votintsev et al. 1975). Therefore, oxygen concentration is not a limiting factor for the growth of zooplankton in Baikal. From mid-June until the first decade of July at the water temperature from 6.4 to 20° C, the pelagic zone is mainly dominated by copepods with absolute predominance of *E. baikalensis* in June. Development of *Epischura* and its habitat layer in Baikal pelagic zone is known to depend significantly on the water temperature (Kozhov 1963; Afanasyeva 1977), the most preferable temperature for crustaceans – 12-15° C. Among copepods, *C. kolensis* (56-96%) becomes the dominant species from mid-July until late August. Published research (Mazepova 1978; Pislegina 2005; Sheveleva et al. 2025) evidences that prolific growth of this cyclopid copepod starts with the water temperature rise.

Relatively high water temperature (from 21° C to 19° C in July and August) and abundant algae food facilitated growth of thermophilic rotifers and cladocerans that constituted the structure-forming core (Table 1). Abundant food stimulates phytophagous rotifers, *K. longispina*, *K. quadrata* and *F. terminalis* (Monakov 1998) to form big clusters (Riv'er 1986). During the whole open water period, *A. priodonta*, was constantly dominant, its abundance rising from July until October (from 0.01 to 0.2 thousand specimens/m^3), that coincided with the phytoplankton peak. All *Asplanchna* are macrophages (Gilyarov 1977), being able to consume and utilize large cells and even whole colonies of algae. In summer 2024, *D. galeata* – coarse mesh filter-feeder able of consuming vegetative 0.32–1.0 µm plankton (Gutelmacher et al. 1988; Monakov 1998), outcompeted cladocerans in abundance in Maloe More Strait (44–86%).

Water cooling to 12° C in early October led to increase of *Epischura* proportion (57%): relatively multiple nauplii of the summer-autumn generation and junior copepodite stages in the plankton. The abundance of *Cyclops kolensis* remained at a high level. The leading position of *D. galeata* in the cladoceran group was occupied by *B. longirostris* (22 and 49%, respectively). During this period, rotifers had three dominant species, relatively large percentage in abundance belonged to *K. quadrata* 49%, *A. priodonta* 23% and *K. longispina* 15%.

There were two peaks in the abundance and biomass of pelagic zooplankton. The first peak was assigned to the growth and abundance of winter-spring *Epischura*, the second peak in late August was related to abundance of thermophilic *C. kolensis* and *D. galeata* species.

Zooplankton, in turn, was capable of regulating algal and cyanobacterial growth. Absence of algal blooms, despite of high nutrient loads, is attributed to intensive zooplankton (filter feeders) grazing (Gerasimova, Sadchikov 2024). Vigorous consumers of algae and cyanobacteria are large-sized *Daphnia*, such as, *Daphnia longispina* O.F. Müller (Gerasimova, Sadchikov 2024). Under high nutrient concentrations, algal blooms are supressed by abundant *Daphnia*. In some cases, colonial algae grow to such an extent that become hard to consume, resistant to herbivorous zooplankton grazing. In such periods, zooplankton is not able to control algal blooms and recover water quality, that was registered in Maloe More Strait in July 2024. By August, cladocerans attained large numbers and the water temperature dropped, diminishing the concentrations of cyanobacteria.

It seems a challenging task to select an indicator representing trophic status of water for such a unique basin as Lake Baikal. The phytoplankton sustains a more distinct tendency for higher trophic levels during intensive cyanobacterial vegetation, first of all, in Mukhor Bay. Following Kitaev's classification (Kitaev 2007), indices estimated for Mukhor Bay are consistent with either eutrophic or mesotrophic (rarely, oligotrophic) type of water bodies in different periods, whereas the strait pelagic zone is described as an oligotrophic zone in spring and August. In July, the trophic status of the pelagic zone is higher. It was earlier stated (Bondarenko et al. 2024) that the trophic state of the pelagic zone becomes higher during years of prolific spring vegetation of psychrophilic Baikal complex as well.

Conclusions

This study was focused on seasonal fluctuations of the species composition and quantitative parameters of phyto- and zooplankton of Maloe More Strait (Lake Baikal) with the account of temperature variations of the environment. The authors collected and analyzed samples from the nearshore and pelagic zones of the strait during 4 months in 2024. It was found out that these indices varied throughout seasons and the strait area. Phytoplankton biomass in the nearshore zone demonstrated maximum during intensive cyanobacterial vegetation in July-August at the water temperature rise up to 21.5–24° C. We also observed two smaller peaks in the pelagic zone of the strait: at the end of spring phytoplankton vegetation and during cyanobacterial blooms in summer. Food resources and temperature range affected the qualitative composition of zooplankton and its quantitative characteristics. During low water temperature periods, the pelagic plankton was dominated by *Epischura*, during cyanobacterial blooms and water warming up we registered abundance maximum of cladocerans. Bursts of cyanobacterial growth in the nearshore zone were accompanied by maximal increase of cladoceran and thermophilic rotifer numbers. In the pelagic and littoral zones the highest numbers of rotifers was registered when nanoplanktonic phytoflagellates reached maximal concentrations.

The majority of structural parameters of plankton from Mukhor Bay obtained during the open water period in 2024, is consistent with the values typical for mesotrophic and eutrophic basins. Based on the quantitative and structural parameters of plankton obtained during surveying the strait pelagic zone in June, August – October, this zone is described as an oligotrophic area. In July, during cyanobacterial blooming the trophic level of the pelagic zone was higher.

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References

Andronikova IN (1996) Structural and functional organization of zooplankton in lacustrine ecosystems. Nauka Publisher, Saint-Petersburg, 190 pp. [In Russian]

Afanas'eva EL (1977) Biology of the Baikalian *Epischura*. Nauka Publisher, Novosibirsk, 144 pp. [In Russian]

Belykh OI, Sorokovikova EG, Tikhonova IV, Saphonova TA (2006) Autotrophic picoplankon of Lake Baikal: species composition and structure. Hydrobiology 568(supl. 1): 9–17. https://doi.org/10.1007/s10750-006-0340-8

Bondarenko NA, Guselnikova NE (1989) The importance of pico- and nanoplankton algae in the production processes in Lake Baikal. Biological sciences 12: 34–36. [In Russian]

Bondarenko NA, Rusanov II, Chernitsyna CM Shubenkova OV, Zaharenko AS, Pogodaeva TV, Pimenov NV, Zemskaya TI (2022) Structure and production potential of summer phytoplankton of Lake Baikal in the present period. Water Resources 49(1): 98–108. http://dx.doi.org/10.1134/S0097807822010055

Bondarenko NA, Tomberg IV, Pen'kova OG, Sheveleva NG (2023) Structural changes of phyto- and zooplankton under the influence of climate change and anthropogenic load (Lake Baikal, Russia). Inland Waters Biology 16(6): 955–966. http://dx.doi.org/10.1134/S1995082923060056

Bondarenko NA, Pen'kova OG, Zaitseva YeP, Sheveleva NG (2024) Trophic state and water quality of the Maloe More Strait, Lake Baikal. Acta Biologica Sibirica 10: 489–505. https://doi.org/10.5281/zenodo.11220593

Einsle U (1996) Copepoda: Cyclopoida. Genera *Cyclops*, *Megacyclops*, *Acanthocyclops*. Guides to the identification of the Microinvertebrates of the continental waters of the World. SPB Academic Publishing, New York, Amsterdam, 112 pp.

Dong A, Yu X, Yin Y, Zhao K (2022) Seasonal variation characteristics and the factors affecting plankton community structure in the Yitong River, China. International Journal of Environmental Research and Public Health 19(24): 17030. https://doi.org/10.3390/ijerph192417030

Genkal SI, Kulikovskiy MS, Kuznetsova IV (2020) The recent freshwater centric diatoms of Russia. Filigran Publisher, Yaroslavl, 430 pp. [In Russian]

Gerasimova TN, Sadchikov AP (2024) Ecological Characteristic of a Highly Eutrophic Pond: The Role of Green Algae in Eutrophication. Russian Journal of General Chemistry 94(13): 3462–3466. https://doi.org/10.1134/S1070363224130024

Gilyarov AM (1977) Observations on the composition of the food of rotifers of the genus *Asplanchna*. Zoologicheskiy Journal 56(12): 1874–1876. [In Russian]

Gutel'makher BL, Sadchikov AP, Filippova TG (1988) Nutrition of zooplankton. General ecology. Biocenology. Hydrobiology. Results of Science and Technology. Moscow, 156 pp. [In Russian]

Izmest'eva LR, Moore MV, Hampton SE, Ferwerda CJ, Gray GK, Woo KH, Pislegina HV, Krashchuk LS, Shimaraeva SV, Silow EA (2016) Lake-wide physical and biological trends associated with warming in Lake Baikal. Journal of Great Lakes Research 42: 6–17. https://doi.org/10.1016/j.glr.2015.11.006

Kitaev SP (2007) Basic limnology for hydro-biologists and ichthyologists. Petrozavodsk, 395 pp. [In Russian]

Komárek J, Anagnostidis K (1998) Cyanoprokaryota. Chlroococcales. Süßwasserflora von Mitteleuropa. Bd 19/1. Spektrum, Akad. Verl., Heidelberg, Berlin, 548 pp.

Korovchinsky NM, Kotov AA, Sinev AYu (2021) Cladocera (Crustacea: Cladocera) of Northern Eurasia.Vol. II. Systematic part. KMK Scientific Press, Moscow, 544 pp. [In Russian]

Kozhov MM (1955) Seasonal and annual changes in Lake Baikal plankton. Proceedings of the All-Union Hydrobiol. Society 6: 133–157. [In Russian]

Kozhov MM (1963) Lake Baikal and its Life. Junk Publishers, Netherland, 344 pp.

Kozhova OM (1959) Phytoplankton of Maloe More. Proceedings of the Baikalian limnological station. Nauka Publishers, Moscow, Leningrad, 255–274. [In Russian]

Kozhova OM, Melnik NG (1978) Manual to process plankton samples by counting. Irkutsk, 51 pp. [In Russian]

Kutikova LA (1970) Rotifers in the fauna of the USSR (Rotatoria). Euritatoria subclass (orders Ploimida, Monimotrochida, Paedotrochida). Nauka Publisher, Leningrad, 744 pp. [In Russian]

Lazareva VI (2004) Seasonal development cycle and nutrition of predatory rotifers of the genus *Asplanchna* in the Rybinsk reservoir. Biology of Inland Waters 4: 59–68. [In Russian]

Lazareva VI, Lebedeva IM, Ovchinnikova NK (2001) Changes of the zooplankton community in the Rybinsk water-reservoir along 40 years. Inland Water Biology 4: 46–57. [In Russian]

Maberly SC, Chao A, Finlay BJ (2022) Seasonal patterns of phytoplankton taxon richness in lakes: effects of temperature, turnover and abundance. Protist 173(6). https://doi.org/10.1016/j.protis.2022.125925

Makarova IV, Pichkily LO (1970) To some questions how calculate phytoplankton biomass. Botanical Journal 55(10): 1488–1492. [In Russian]

Mazepova GF (1978) Cyclopes of Lake Baikal. Nauka Publisher, Novosibirsk, 144 pp. [In Russian]

Monakov AV (1998) Nutrition of freshwater invertebrates. Rossel'khozakademiya, Moscow, 319 pp. [In Russian]

Moore JW (1981) Influence of temperature, photoperiod and trophic conditions on the seasonal cycles of phytoplankton and zooplankton in two deep subarctic lakes of Northern Canada. International Review of Hydrobiology 66(5): 745–770.

Pislegina EV (2005) Dependence of pelagic zooplankton on water temperature in Southern Baikal. In: Fundamental problems of studying and using water and water resources. Irkutsk, 426–428. [In Russian]

Popovskaya GI (1989) Changes in the phytoplankton of the Maloye More. News of the Siberian Branch of the USSR Academy of Sciences 1: 41–47. [In Russian]

Popovskaya GI (1991) Phytoplankton of Lake Baikal and their long-term changes (1958 to 1990). Abstract of a dissertation for the degree of Doctor of Biological Sciences. Novosibirsk, 32 pp. [In Russian]

Riv'er IK (1986) Composition and ecology of winter zooplankton communities. Nauka Publisher, Leningrad, 160 pp.

Riv'er IK (2012) Cold-water zooplankton of lakes in the Upper Volga basin. Printing House of I.P. Permyakov, Izhevsk, 381 pp. [In Russian]

Sheveleva NG, Pen'kova OG (2020) Long-term dynamics of the zooplankton community in the southern part of Maloye More Strait, Lake Baikal. Limnology and Freshwater Biology 4: 746–747. https://doi.org/10.31951/2658-3518-2020-A-4-746

Sheveleva NG, Pen'kova OG, Misharina EA (2025) Early summer zooplankton of the Southern Baikal basin. Izvestia Irkutsk University. Biology series. Ecology. [In press] [In Russian]

Starmach KI (1985) Chrysophyceae Und Haptophyceae. Gustav Fischer Verlag, Jena, 515 pp.

Reynolds CS (2006) Ecology of phytoplankton. Cambridge University Press, Cambridge, 535 pp.

Sommer U (1986) The periodicity of phytoplankton in Lake Constance (Bodensee) in comparison to other deep lakes of central Europe. Hydrobiologia 138: 1–7.

Talling JF (1993) Comparative seasonal changes, and inter-annual variability and stability, in a 26-year record of total phytoplankton biomass in four English lake basins. Hydrobiologia 268: 65–98.

The Third Assessment Report of Roshydromet on Climate Changes and Their Consequences on the Territory of the Russian Federation (2022). General Summary. Science-Intensive Technologies, St. Petersburg. [In Russian]

Timoshkin OA, Samsonov DP, Yamamuro M, Moore MV, Belykh OI, Malnik VV, Sakirko MV, Shirokaya AA, Bondarenko NA, Domysheva VM, Fedorova GA, Kochetkov AI, Kuzmin AV, Lukhnev AG (2016) Rapid ecological change in the coastal zone of Lake Baikal (East Siberia): Is the site of the world's greatest freshwater biodiversity in danger? Journal of Great Lakes Research 42: 487–497. https://doi.org/10.1016/j.jglr.2016.02.011

Trifonova IS (1990) Ecology and succession of lacustrine phytoplankton. Nauka Publisher, Leningrad, 180 pp. [In Russian]

Vilisova IK (1959) Zooplankton of Maloe More strait. In: Proceedings of the Baikalian limnological station. Nauka Publishers, Moscow, Leningrad, 275–304. [In Russian]

Votintsev KK, Mescheryakova AI, Popovskaya GI (1975) Turnover of the organic substances in Lake Baikal. Nauka Publisher, Novosibirsk, 190 pp. [In Russian]

Wentzky VC, Tittel J, Jäger CG, Bruggeman J, Rinke K (2020) Seasonal succession of functional traits in phytoplankton communities and their interaction with trophic state. Journal of Ecology 108(4): 1227–1774. https://doi.org/10.1111/1365-2745.13395