Acta Biologica Sibirica
Vol 10 (2024): Acta Biologica Sibirica, 489–505
Articles

Trophic state and water quality of the Maloe More Strait, Lake Baikal

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The results of a two-year study on the plankton structure and abundance in the Maloe More strait, Lake Baikal, are presented. This place is an area of increased anthropogenic pressure because it is too popular for tourists. The data obtained, in comparison with other previous data, enabled us to identify recent changes in the plankton structure and assess the trophic state of the strait. It was found that in the pelagic zone, the trophic state increases in years of abundant development of cryophilic Baikalian diatoms and decreases in low-productive years, while in the littoral zone, the situation is opposite. The water quality of the strait was assessed using the bioindication method. Water quality in the pelagic zone corresponded to class 1 called "purity" but in the littoral zone to classes 1 and 2 from "purity" to "satisfactory purity".

Acta Biologica Sibirica 10: 489–505 (2024) doi: 10.5281/zenodo.11220593

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Academic editor: R. Yakovlev | Received 22 February 2024 | Accepted 14 May 2024 | Published 22 May 2024

http://zoobank.org/840593D7-90B7-4246-83D1-CEB85EAE124A

Citation: 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

Keywords

Anthropogenic load, change in climatic parameters, Lake Baikal, phyto- and zooplankton, saprobity, trophic state

Introduction

Lake Baikal, the world's oldest and deepest lake, is situated in Central Siberia, contains 20% of global liquid surface freshwater, and is home to thousands of endemic species including freshwater seals (Kozhov 1963). Lake Baikal is considered to be a secondary or morphometric oligotrophic water body. Its trophogenic zone is usually up to 30 metres deep, sometimes deeper, due to high water transparency and abundant solar radiation. As a result, the phytoplankton primary production exhibits low values in m^3 typical for oligotrophic and utraoligotrophic water-bodies but high values under m^2 (Votintsev et. al. 1975).

The main feature of the Baikalian, including the Maloe More strait, plankton development in the 20th century was the alternation of high and low productive years. The high productive years were years when large-cell diatom algae of the Baikalian complex, i.e. *Aulacoseira baicalensis* (K. Meyer) Sim., *A. islandica* (O. Müll.) Sim., and *Stephanodiscus meyeri* Genk. et Popovsk. earlier classified in the *Melosira* genus, intensively bloomed under the ice (Antipova 1974; Popovskaya 1987). These high productive years so called "melosira years" occurred periodically once in 3 or 4 years. Baikalian zooplankton followed such a dynamics of phytoplankton. The zooplanktonic dominant species *Cyclops kolensis* Lilljeborg directly followed the phytoplankton abundance while another dominant species *Epischura baikalensis* Sars was depressed in "melosira years" exhibiting number peaks between "melosira years" (Kozhova, Beim 1993; Evstafyev et al. 2010).

The first results on the species composition of the summer plankton in the strait date back to the beginning of the last century (Meyer 1922, 1930; Yasnitsky 1925). More recently, the phytoplankton of the Maloe More strait was studied in detail in the 1950s and 1960s (Kozhova 1959). It was found that the level of development of the pelagic phytoplankton in the strait, as well as in the lake itself, varies greatly from year to year: years of abundant development alternate with years of low productivity. The phytoplankton composition of the open zones of the strait is not identical to that of the Mukhor bay and other shallow bays, where intensive development of cyanoprokaryotes (blue-green algae) was observed during the summer period.

In the 1980s of the last century, changes in phytoplankton of the Maloe More strait were revealed (Popovskaya 1989, 1991). It was found that there was a massive development of cyanoprokaryotes not only in the coastal zone of the strait but also in its open zone in summer. Compared to the 1950s, the phytoplankton biomass increased several times, which the author considered to be a consequence of the increasing anthropogenic load in this zone of Lake Baikal (Popovskaya 1991).

Special studies of the zooplankton of the Maloe More were made sporadically during the last century, and there are few data on this area of the lake. The only main work is the paper by I.K. Vilisova (1959). The author examines the species composition and distribution of zooplankton in different seasons of 1951–1953, both in the open pelagic zone of the strait and in the Mukhor bay. It is noted that the zooplankton abundance in the open zone of the Maloe More strait in spring and autumn is determined by the mass development of epishura. In summer, rotifers and cyclops are especially abundant. The zooplankton of the Mukhor bay was dominated by rotifers and cladocera in all seasons.

Later, L.A. Levkovskaya (1977) studied the zooplankton of the Mukhor bay using the data from 1973–1974. The author notes a decrease in the abundance of zooplankton in the bay during the summer maximum compared to 1951–1953.

Regular studies of zooplankton in the Mukhor bay and the southern part of the Maloe More, started in 1997, showed an increase in zooplankton abundance due to a sharp increase in the number of rotifers (Sheveleva, Pen`kova 2005, 2016, 2020; Sheveleva, Pen`kova and Kirushina 2009).

Recently, many freshwater ecosystems vulnerable to climatic changes and growing anthropogenic loads have undergone alterations in composition of their aquatic communities and biota abundances (Rühland et al. 2008; Lake Onega 1999; Hampton et al. 2018; Reavie et al. 2017; Kurashov et al. 2018; Sterner et al. 2020) and the same was in the ecosystem of Lake Baikal (Timoshkin et al. 2016). It was revealed that the cyclicity of phytoplankton of the “melosira years” in the Maloe More srait as well as round Lake Baikal was violated. Also, the structure of the dominant species was changed (Bondarenko et al. 2023a), so that increasing nitrogen and phosphorus organic forms caused changes in algal size structure towards small cells and nanoplanktonic phytoflagellates. Complex analysis of the state of phyto- and zooplankton of the Maloe More strait showed that changes in the structure of zooplankton are closely associated with the reconstructions in its food base (Bondarenko et al. 2023a).

The paper purposes to assess the current state of the plankton in the Maloe More strait using our data collected for the years 2022 and 2023, in particular to evaluate its trophic state and water quality.

Materials and methods

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).

Usually, samples were collected at 2–3 stations in the coastal zone and at 2-3 stations in the pelagic zone (Fig. 1). Sampling was carried out monthly from May to September. Surveys were conducted in March, 2023. The thickness of the ice was from 100 to 120 cm, the snow cover was uneven with patches of pure ice.

We compared our original data collected from 2022 to 2023 with the published data (Kozhova 1959; Popovskaya 1991; Bondarenko et al. 2023a) and the archive data of Drs. Bondarenko N.A. and Sheveleva N.G.

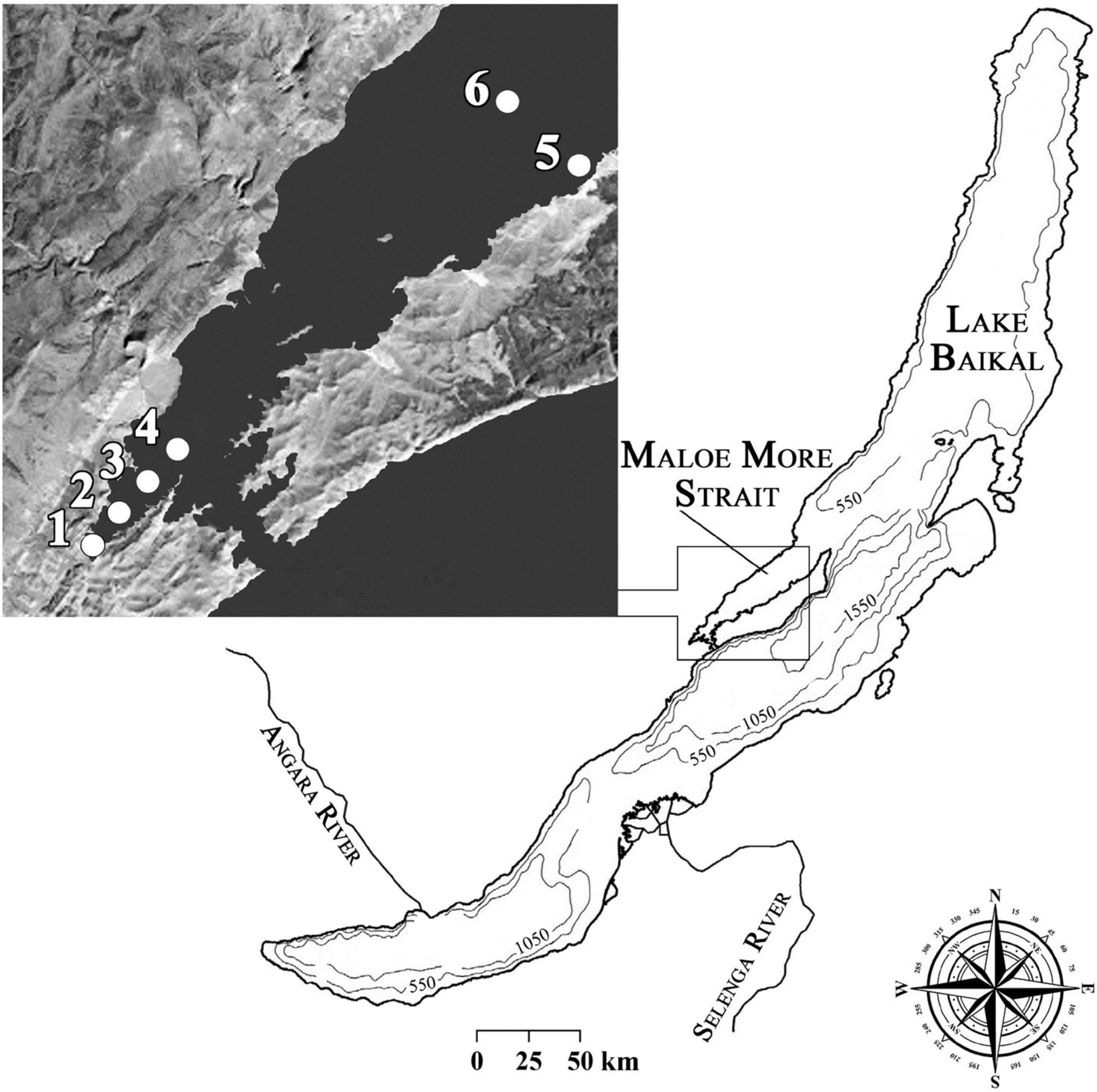


Figure 1. *Map of the research area:* ***1*** *is the littoral zone of the Mukhor bay;* ***2*** *is 4 km from the station 1;* ***3*** *is the pelagic zone of the Mukhor Bay;* ***4*** *is the pelagic zone;* ***5*** *the littoral zone near the Khuzhyr village;* ***6*** *the pelagic zone.*

Collection and processing of phytoplankton samples

1 L of samples were fixed by Utermóhl's solution and concentrated by sedimentation. The concentrates were examined by triple counting in a 0.1 ml Nageotte chamber using a light microscope Peraval. The biomass of algae was assessed taking into account individual volumes of their cells (Makarova, Pichkily 1970). Algae were identified according to (Zabelina et al. 1951; Komarek and Anagnostidis 1998; and others). For statistical processing of the experimental data, we used standard computer programs to counter mean values of the samples with a standard error.

Sampling and processing of zooplankton

Juday plankton net (diameter 37.5 cm, mesh size 110 µm) hauls were made in the upper 25m layer in the pelagic zone and in the 3–5m in the Mukhor bay. Desk studies were performed following routine procedure (Kozhova, Melnik 1978). We used individual weights of the Baikal organisms for biomass estimation (Kozhova, Melnik 1978). Average abundance, N total (thousand individuals/m^3), abundance of three main taxonomic groups (rotifers, cladocera, and copepods), and total biomass (B total, mg/m^3) were calculated for. The ratio of crustacean and rotifer abundance (Ncr/Nrot) and mean individual weight of an organism (w, mg) were based on average values (Andronikova et al. 2000; Lazareva 2001; 2010). For species identification, we used guides and keys (Kutikova 1970; Einsle 1996; Korovchinsky et al. 2021). Species with a relative abundance over 5% were considered dominant (Lazareva 2001).

The trophic state and water quality

The trophic state of the strait was estimated by parameters such as number of species in communities, sizes of the dominant species, total biomass of phyto- and zooplankton, ratio of phyto- and zooplankton biomasses, biomass ratios of crustaceans and rotifers, ratio of large-cell cladocerae and their total number (k/k), and individual mass of zooplankton organisms (Andronikova 1996; Semenchenko, Razlutsky 2011).

The water quality along the research area has been estimated by the bioindication method, i.e., the saprobity index (S) using species values recognized as pollution indexes. This method is widely used in hydrobiology to assess natural waters based on phyto- and zooplankton data.

Saprobic indexes of the wide-spread species were taken from the sources (Sladecek et al. 1981, 1983; Barinova et al. 2006). Saprobic indexes of the Baikalian algae, crustaceans, and rotifers were assumed to be 0.4 as for xenosaprobic species.

The saprobity of the research area has been carried out by the Pantle-Bukk method in its modification (Sladecek 1973)

$S = \sum (h \times s)/ \sum h,$

where h means number of cells per litre for algae and thousand specimens/m^3 for zooplankton,

s was the saprobity value for each species.

The estimation of the water quality has been carried out according to the Instruction RD 52.24.309-2016.

Result

The phytoplankton composition of the pelagic zone of the strait in spring 2022 was similar to that of 2019–2021. *Stephanodiscus meyeri* was the dominant species, although its abundance was lower than in the highly productive year 2021 but higher than in 2019–2020, at 479,000 cells/L. The second representative of the Baikal complex, *Aulacoseira islandica*, reached a significant abundance in the pelagic zone – 33.4–43.6 thousand cells/L. The abundance of the green alga *Koliella longiseta* (Vischer) Hind. and the diatom *Synedra acus* subs. *radians* (Skabitchev), which dominated the spring plankton in recent years, decreased to 23.1–34.3 thousand/L and 30.7–81.4 thousand/L, respectively. Biomass is higher than in 2019–2020 and 2023 but lower than in 2021, 400–660 mg/ m^3 (Table 1). In the Mukhor bay, diatoms also played a dominant role, but the species composition was different: *Nitzschia graciliformis* (Genk. et Popovsk.), 47.3–304.4 thousand cells/L, and *Synedra acus*, 49.1–164.6 thousand cells/L. In the littoral zone, two other dominants were added: the euglenophytes *Phacus* Dujardin (271.5 thousand cells/L) and the diatom *Asterionella formosa* Hass. (98.7 thousand cells/L). The biomass was high (Table 2).

Season	Species number		Sizes of dominant species		Biomass		Biomass ratio	
	ph	z	v,µm	w, mg	ph, mg/m ^{3}	z, mg/m ^{3}	z/ph	c/r
Spring	19	6	400–4300	0.005	366 ± 208	17.3	0.047	5.9
Summer	12	4	200–300	0.040	305 ± 119	268	0.88	100
Autumn	11	11	200–300	0.016	157 ± 1	67	0.43	157

Table 1. *The plankton parameters in the pelagic zone, the Maloe More strait, 2022: ph means phytoplankton, z – zooplankton, c/r – ratio of crustaceans to rotifers, v – algal cell volume, w – individual cell weight*

Season	Species number		Sizes of dominant species		Biomass		Biomass ratio	
	ph	z	v,µm	w, mg	ph, mg/m ^{3}	z, mg/m ^{3}	z/ph	c/r
Spring	26	14	400–1800	0.003	599 ± 683	129 ± 49	0.21	16
Summer	26	11	140–200	0.030	438 ± 503	267 ± 189	0.61	268
Autumn	34	8	150–200	0.040	719 ± 1180	945 ± 174	1.30	954

Table 2. *The plankton parameters in the bay Mukhor, the Maloe More strait, 2022: marked the same as in Table 1*

During the under-ice period of 2023, the diatom *Stephanodiscus meyeri* (46–133 thousand cells/L) and *Synedra acus* subs. *radians* (97–146 thousand cells/L) dominated the pelagic plankton of the strait, as in 2022. The green alga *Koliella longiseta* (45–54 thousand cells/L) was present in a significant quantity. By May, the number of diatoms decreased, and the small-cell *K. longiseta* became the dominant species (344–715,000 cells/L). The biomass was lower (Table 3).

In the Mukhor bay, the under-ice phytoplankton was dominated by dinoflagellates, up to 97.4% of the total biomass, with diatoms accounting for 2.2%. The phytoflagellates *Biecheleria* sp. and *Woloszynskia* sp. have a maximum abundance of 27–32 thousand cells per litre. The biomass was not high (Table 4). In May, the phytoplankton biomass increased sharply. The diatom *Nitzschia graciliformis* (87–233 thousand cells/L) and the chrysophyte *Dinobryon sociale* Ehr. (233–316 thousand cells/L) were dominant.

Season	Species number		Sizes of dominant species		Biomass		Biomass ratio	
	ph	z	v,µm	w, mg	ph, mg/m ^{3}	z, mg/m ^{3}	z/ph	c/r
Under-ice	18	8	300–40000	0.002	508 ± 172	11.0	0.02	2.10
Spring	21	7	200–2000	0.020	337 ± 196	35±12.5	0.10	1.17
Summer	9	10	200–45000	0.010	317 ± 73	25.6 ± 3.9	0.08	13.20
Autumn	18	9	200–45000	0.020	155 ± 96	742 ± 123	4.78	38.00

Table 3. *The plankton parameters in the pelagic zone, the Maloe More strait, 2023: marked the same as in Table 1*

Season	Species number		Sizes of dominant species		Biomass		Biomass ratio	
	ph	z	v,µm	w, mg	ph, mg/m ^{3}	z, mg/m ^{3}	z/ph	c/r
Under-ice	6	8	300–40000	0.005	272 ± 81	20.5	0.07	0.13
Spring	20	10	200–9000	0.020	629 ± 470	88.7	0.14	88.67
Summer	12	12	200–45000	0.009	1091 ± 662	218.7	0.20	8.40
Autumn	10	9	200–2000	0.018	151 ± 66	991.7	6.56	35.30

Table 4. *The plankton parameters in the bay Mukhor, the Maloe More strait, 2023: marked the same as in Table 1*

The summer plankton of the strait were represented by small-cell forms. The dominant species in the coastal zone was *Rhodomonas pusilla* (Bachm.) Javorn., whose number varied between 224 and 277 thousand cells/L and in the pelagic zone 84 and 312 thousand cells/L. The phytoplankton consisted mainly of picoplanktonic forms (up to 200±2.1 million cells/L). Significant amounts of nanoplanktonic dinoflagellates were registered at some stations (9–31 thousand cells/L). Previously, the abundance of this group did not exceed 1885±691 cells/L.

The composition of phytoplankton in the Mukhor bay had marked distinctions: dominance of colonial cyanoprokaryote forms of the genus *Dolichospermum* (Ralfs ex Bornet & Flahault) P. Wacklin, L. Hoffmann & J. Komárek (*D. lemmermannii* (P.G.Richt.) Wacklin, L. Hoffm. & Komárek, *D. spiroides* (Kleb.) Wacklin, L.Hoffm. & Komárek) (689–802 thousand cells/L) and presence of large-celled dinoflagellate *Ceratium hirundinella* (O.F. Müller) Schrank (16 thousand cells/L) and diatom *Asterionella formosa* (70 thousand cells/L).

Observations of the autumn community revealed the development of solely small-sized forms dominated by *Rh. pusilla* (24–373 thousand cells/L). The number of nanoplanktonic dinoflagellates rose to 13–52 thousand cells/L. Biomass varied from 39 to 194 mg/m^3 across the strait, making 441 mg/m^3 only in the Kharagoyskaya bay.

By December, the phytoplankton of the strait became poor: single cells of the diatoms *Nitzschia graciliformis* and *Synedra acus* were observed in the pelagic zone. Phytoplankton biomass in the littoral zone is slightly higher, 37–40 mg/m^3.

It is a well-known fact that the primary production of the pelagic zone of Lake Baikal is provided by the under-ice development of phytoplankton (Votintsev et al. 1975). Phytoplankton biomass during the year in the open part of the strait is also observed in the spring period, and in the Mukhor bay – in the summer-autumn period, i.e. in the pelagic zone of the Maloe More the spring vegetation contributes the main share to the biomass of the year, and in the littoral zone the maximum values of biomass of primary producers are shifted to the summer-autumn period (Table 1–4).

Structural analyses performed during the last century and at the beginning of modern times showed a shift of spring phytoplankton to small-sized species. Large algae with the cell volume attaining ~ 10000 µm^3, such as *A. baicalensis* fell out of the dominant species (Bondarenko et al. 2019; Bondarenko et al. 2023a). Both spring and autumn plankton were dominated by small species with the cell volume ranging from ~ 100 to 2000 µm^3, first of all green *K. longiseta*, diatom *Synedra acus* subs. *radians*, haptophyte *Chrysochromulina parva* Lackey, and cryptophyte *Rh. pusilla*. In autumn, nanoplanktonic forms of the genera *Biecheleria* sp. and *Woloszynskia* sp. joined dominant species.

Zooplankton. The filtrator *Epischura baikalensis* (96-98%) formed the basis of pelagic zooplankton biomass in 2022 as well as in “melosira year” 2021 in spring and summer. The exception was autumn when only 40% of the copepod biomass was present with *Cyclops kolensis* accounting for most of the biomass. The role of cladocera in the zooplankton biomass in spring and summer is negligible – not more than 2%. In autumn, the importance of cladocera in the total biomass increased; they accounted for up to 40%. The absolute dominant in the plankton was *Bosmina longirostris* (O.F. Müller), which is a coarse filtrator and capable of crushing diatoms. The rotifers, due to their low individual mass and insignificant abundance, did not play a significant role after the "melosira year" accounting for 0.3– 0.5% of the total biomass. The Baikal endemics *Notholca intermedia* Voronkov and *Syncheta pachypoida* Kutikova et Vassiljeva (0.6 thousand ind./m^3) dominated in spring, while *Keratella qudrata* (O.F. Müller) (0.21 thousand ind./m^3) and *Conochilus unicornis* Rousselet (0.1 thousand ind./m^3) dominated in summer and autumn.

In the Mukhor bay of 2022, the zooplankton biomass increased from spring to autumn, mainly due to the abundant development of cladocera in autumn. In spring, copepods were leading in biomass (86%) due to the development of *Mesocyclops leuckarti* (Claus), while rotifers were dominant in abundance. The biomass of rotifers was comparable to that of cladocera: 8% in each taxonomic group. The number of cladocera increased during the summer and autumn, while the density of rotifers decreased. In summer, the biomass of cladocera was almost equal to that of copepods, and in autumn, their biomass was 2.5 times higher than that of copepods. In summer and autumn, *Daphnia galeata* Sars was the dominant species (80% of the total zooplankton biomass).

During the 2023 under-ice period in the strait, the composition of zooplankton, both in terms of abundance and biomass, is slightly more than 50% represented by the population of *E. baikalensis* and rotifers, up to 48%. Among rotifers, the endemic *S. pachypoida* (0.4 thousand ind./m^3) and the year-round *Kellicottia longispina* (Kellicott) were leading in abundance (0.2

thousand ind./m^3). In 2023, the zooplankton biomass was determined by copepods: epishura in spring and cyclopoid copepods in summer. Copepods formed the basis of the autumn biomass: the abundance of cladocera increased, with *D. galeata* (44%) and *B. longirostris* (11%) dominating. *E. baikalensis* represented 28% of the total zooplankton biomass.

In the Mukhor bay, the under-ice and spring zooplankton is quantitatively and qualitatively poor. Zooplankton abundance and diversity increased by autumn. No changes in zooplankton structure were observed as of 2022. The role of the rotifers in the bay is very important. They are the most abundant, up to 50%. Crustaceans were dominant in total biomass, with cladocera accounting for 58% in summer and 37% in autumn, and copepods for 31% and 39%, respectively.

Trophic state of the strait. Changes in the structure of plankton during the studied period continued. The dominance of small algae during the open water period, mainly phytoflagellates (cryptophytes, dinophytes, and haptophytes), which were not previously recorded in the plankton of Maloe More (Kozhova 1959; Popovskaya 1989), became a trigger for further rearrangements not only in the microplankton structure but also in the trophic systems. Fine filtrators were leaders in abundance: rotifiers *Keratella cochlearis* (Gosse), *Polyarthra euryptera* Wierzejski, *Keratella quadrata*, *Notholca intermedia*, and carnivores *Synchaeta pachypoida* and *S. grandis* Zacharias. The first three species are indicators of eutrophic waters (Andronikova 1996). In the littoral zone of the strait, and especially in Mukhor bay, intensive vegetation of colonial cyanoprokaryotes of the genus *Dolichospermum* was observed in summer in both years, which is also an indicator of increased trophic state.

Quantitative data (Tables 1–4) for the same period show a mixed picture. Due to the dominance of small forms, the biomass of pelagic phytoplankton at this stage does not exceed the limits typical for oligotrophic waters but in the Mukhor bay in summer, during the periods of intensive cyanoprokaryote vegetation, it can be much higher than 1 g/m^3. In oligotrophic lakes, the biomass of phytoplankton is lower than the biomass of zooplankton, while in meso- and eutrophic lakes it is equal to or much higher (Andronikova 1996). According to this criterion, the pelagic zone of the strait is characterized as mesotrophic in 2022 and spring-summer 2023 and as oligotrophic only in autumn 2023. The data on the seasonal dynamics of the indicators show a special case in the spring of 2022, when the phytoplankton biomass significantly prevailed the zooplankton biomass, as occurs in the lake during productive years.

In the Mukhor bay, only in the autumn period in both years zooplankton biomass significantly prevailed over phytoplankton biomass in both years.

Total zooplankton biomass (11–742 mg/m^3), k/k ratio (0.3–0.46), individual organism mass (0.002–0.04), and the ratio of summer to winter biomass (2.3.) can be considered as more objective indicators. According to these values, the open zone of the strait is characterized as oligotrophic.

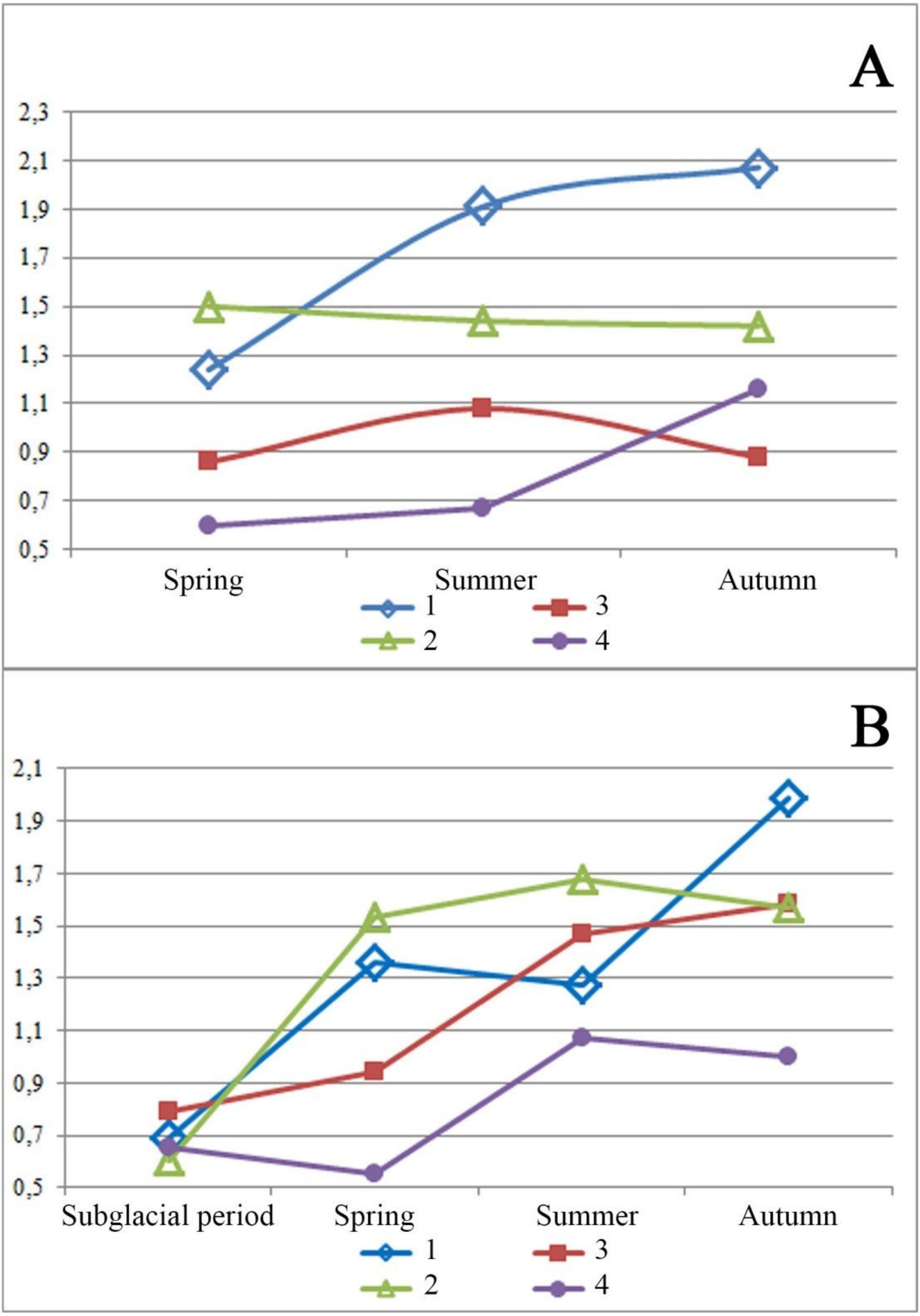
In the Mukhor bay, these zooplankton indicators (Table 2, 4) for 2022 and 2023 in the spring and summer periods confirm the oligotrophic state of this part of the water body. During the autumn, the zooplankton biomass reaches almost 1 g/m^3, which is characteristic of a higher trophic level. This assessment is also supported by the ratio of summer biomass to winter biomass, 10.7.

The mean zooplankter biomass (w) in the pelagic zone in 2022–2023 was 0.027mg. In the Mukhor bay, the values for this period are unstable, ranging from 0.003 to 0.040.

Water quality. An assessment of the water quality in the strait using the bioindicator method showed that at the time of the study, the plankton in the strait contained 23 species of algae and 27 species of zooplankton – indicators of organic pollution in the water. The saprobic index of algae varies in the range of xeno-alphamesosaprobionts to betamesosaprobionts. The main part (89%) of the species composition, both in the pelagic zone of the Maloe More and Mukhor bay, among zooplanktonic organisms were oligomesosaprobes, oligobetamesosaprobes, and xenosaprobic species.

The saprobic index for phytoplankton in the pelagic zone ranged from 0.79 to 1.58 (Fig. 2), characterizing the open part of the strait at the time of the study from a clean (oligosaprobic) zone to a slightly polluted zone with 2 class water. In the weakly polluted zone, the diversity of species reaches a maximum but the number of individual species is low. The level of water pollution in the pelagic zone of the strait and Mukhor bay increased from spring to summer-autumn. The minimum values of phytoplankton in the pelagic zone were obtained for the under-ice period and the maximum values for the Mukhor bay in autumn.

An assessment of the level of zooplankton pollution indicates that the pelagic waters of the strait had low levels of saprobicity (0.6 – 1.16) during the open water period, which is characteristic of the oligosaprobic zone. During the under-ice period, the water of the strait corresponded to the xenosaprobic zone. This is caused by the fact that the main contribution to the zooplankton abundance belonged to the Baikal endemic *E. baikalensis*, which has a low saprobic index, 0.4, as for xenosaprobic species.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Spring
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Subglacial period
Spring
Summer
Autumn
1
2
3
4

Figure 2. *Saprobity index of phytoplankton and zooplankton in the Maloe More strait, 2022 (A) to 2023 (B). 1 – saprobity index of phytoplankton in the Mukhor bay; 2 – saprobity index of zooplankton in the Mukhor bay; 3 – saprobity index of phytoplankton in the pelagic zone; 4 – saprobity index of zooplankton in the pelagic zone.*

In the Mukhor bay of 2022, the average saprobic index during the open water period is 1.47±0.1, with index values decreasing from spring to autumn (Fig. 2), characterizing the bay water as conditionally clean (oligosaprobic). In 2023, the saprobic index values varied from 1.53 (spring) to 1.68 (summer), with a mean of 1.58±0.3. In spring, the leading population in terms of abundance was the β-mesosaprobe population *C. kolensis*. In summer and autumn, *Eudiaptomus graciloides* (Lilljeborg) (betaoligomesosaprob) and *M. leuckarti* (xenosaprob) formed the basis of abundance. Indices of water saprobity in 2023 indicate the prevalence of the “weakly polluted zone” in the whole water area of the bay, which corresponds to quality class 2.

Discussion

In the early 2000s, a sharp increase in the abundance of nanoplanktonic mixotrophic flagellates – indicators of organic pollution of water – was found in the plankton of the strait from spring to autumn as well as in the whole water area of the lake, with the maximum numbers of these organisms noted in places of increased anthropogenic load (Bondarenko et al. 2023a).

Analysis of initial and published data showed that under conditions of intensive anthropogenic load, with redistribution of nitrogen and phosphorus forms towards organic ones (Bondarenko et al. 2023a, b), rearrangements in the taxonomic and size structure of phytoplankton occurred. They caused changes in the zooplankton structure and in the trophic state. While changes in the taxonomic and size structure of the plankton community clearly indicated an increase in the trophic state of the strait, quantitative indicators of phytoplankton and zooplankton did not show such a clear trend (Tables 1–4). For such a unique lake as Lake Baikal, it is difficult to find the right criterion for assessing trophic state. After attempts to find such a criterion, we chose the total biomass of phyto- and zooplankton and the ratio of phyto- and zooplankton biomasses.

In phytoplankton, the tendency to increase trophic state in spring is more pronounced in years with higher concentrations of diatoms of the Baikal complex and less pronounced in years with low productivity; in zooplankton, the reverse is true. During periods when phytoplankton was dominated by small forms, including cryptophytes, haptophytes, and dinophytes, rotifers were abundant, such as in the pelagic zone in 2019 (Bondarenko et al. 2023a). Rotifers become more important as the trophic level of the water body increases but after the highly productive “melosira year” 2021, the importance of rotifers in the plankton of the strait decreases and crustaceans, represented mainly by the endemic *Epischura baikalesis*, dominate from 2022 onwards. The tendency of the last century, when epishura showed peaks of abundance in “intermelosira years” (Kozhova and Beim 1993; Evstafiev et al. 2010), was evident.

According to the classification (Kitaev 2007), the Mukhor bay is characterized as an alpha-beta oligotrophic or eutrophic water body in different years, while the pelagic zone of the strait either retains its natural oligotrophic state or is characterized as a mesotrophic zone in low productive years. In years with abundant spring vegetation in the psychrophilic Baikal complex, the trophic state of the strait increases (Bondarenko et al. 2023b).

Comprehensive plankton studies conducted in the modern period (Bondarenko et al. 2022) confirm the difference in trophic state between the pelagic zone and Mukhor bay: in summer, the Mukhor bay showed significant values of chlorophyll *α* (0.56 µg/L) and primary production (56.5 µg C/L.day). At the same time, these values are lower in the pelagic zone of the lake: primary production is 45.2 µg C/L. day and chlorophyll *α*concentration is 0.46 µg/L.

Changes in the composition of the biota of many aquatic ecosystems in recent decades have motivated researchers to assess the current state of their trophic state and water quality (Kurashov et al. 2018; Bazhenova, Barsukova 2023; Tekanova et al. 2023; Domysheva et al. 2023). The trophic state and water quality of the coastal zone of South Baikal were assessed in June–December 2020 in the area of the Bolshiye Koty bay using classifications based on the determination of concentrations of total nitrogen, phosphorus, nitrate nitrogen and dissolved phosphorus, Chl α content, and algal biomass (Domysheva et al. 2023). The results showed that the water purity ranges from oligosaprobic to mesosaprobic, corresponding to quality classes 2 and 3, and that the coastal zone of the lake in the study area belongs to the oligotrophic type but with minor elements of mesotrophy.

Another large lake, Lake Onega, also underwent a modern trophic and water quality assessment (Tekanova et al. 2023). It was found that the water body remains oligotrophic in terms of chlorophyll α concentration during summer stratification, and a small amount of easily mineralisable organic matter in the water determines a low level of saprophytic bacterial development, corresponding to xenosaprobic and β-oligosaprobic waters. Only the Kondopoga bay of Lake Onega is characterized by a higher level of trophic (mesotrophic) and saprobic (β-mesosaprobic) water due to pollution by wastewater from the paper mill and trout farm waste.

We apply the bioindication method, which shows that the level of water pollution in the Maloe More strait of Lake Baikal increases from spring to autumn, both in the pelagic zone and in the Mukhor bay. The minimum phytoplankton parameters, in contrast to the trophic parameters, were obtained for the pelagic zone in the under-ice period and the maximum for the Mukhor bay in the autumn period of 2022. The Mukhor bay is classified as either clean, with class 1 water quality (spring and summer 2023), or moderately polluted, with class 2 water quality (summer 2022 and autumn both years). The zooplankton indicators are slightly different: the pelagic zone is oligosaprobic in both years studied (xenosaprobic in the under-ice period), while the Mukhor bay is conditionally clean (oligosaprobic) in 2022 but “weakly polluted” in 2023, corresponding to water quality class 2.

Conclusion

We continued our study in the shallow and pelagic zones of the Maloe More strait during 2022 to 2023, which allowed us to estimate a current state of its plankton, i.e. its trophic state and water quality. These 2-year long studies showed that largecell diatoms *Aulacoseira islandica* and *Stephanodiscus meyeri* early belonged to the genus *Melosira* were abundant in 2021 (a “melosira year”) and then new structural changes occurred in the spring plankton. Spring pelagic small-cell algae decreased their number that caused decreasing rotifer number and simultaneous increasing copepoda number mainly endemic *Epischura baikalensis*. Earlier *Epischura* was abundant as a rule in a period between the two “melosira years”. In the summer and autumn plankton, small-cell algae continued to dominate that increased a role of cladocera.

While the changes in taxonomic and size structures of the strait plankton clearly testified to increasing its trophic state, the quantitative data on phyto- and zooplankton did not show the same clear relation. In the pelagic zone, the trophic state has been found to increase in years of intensive under-ice bloom of large-cell diatoms and to decrease in low-productive years while in the littoral zone, it rose in summer and autumn season.

An estimation of the water quality by the bioindication method has showed that the pelagic water was pure of first class during all the seasons excluding the 2023 autumn. The minimal saprobic indexes were observed in the under-ice plankton when cryophilic Baikalian diatoms were dominating. It has been found to increase when wide-spread algae intensively developed in the summer and autumn periods. The water quality of the Mukhor bay has been found to change from pure, 1st class, to slightly polluted, 2nd class.

Acknowledgements

The research was carried out within the state project 0279-2021-0007 of Institute. The authors are thankful to E.M. Timoshkina and Dr. Vladimir Evstafyev for their help in preparing the English version of the manuscript.

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