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## Planktonic communities (cyanobacteria, algae and invertebrates) in Lake Arey (Zabaykalsky Krai, Russia)

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**Abstract.** The paper presents first data on the species composition and structure of plankton communities based on phytoplankton and zooplankton research conducted in Lake Arey in 2019–2020. The lake is a functioning natural monument of regional significance in the Trans-Baikal territory. The research revealed 102 algae taxa and 50 zooplankton species. The species composition of planktonic flora and fauna consisted of cosmopolitan, eurybiontic and freshwater species. The total abundance and biomass of the planktonic community changed widely during the entire research period. The density of phytoplankton was the highest in September and July (due to Cyanobacteria and Bacillariophyta), the lowest in March, whereas the zooplankton peak was in September (due to rotifers) with a decline in July. The dominant complexes were represented by ten phytoplankton taxa (*Aphanizomenon flos-aquae*, *Coelomon pusillum*, *Limnothrix planctonica*, *Aphanothece* sp., *Microcystis pulverea*, *Cyclotella meneghiniana*, *Asterionella formosa*, *Ulnaria ulna*, *Aulacoseira granulata*, *Fragilaria radians*) and eleven invertebrate species (*Keratella cochlearis*, *Keratella quadrata*, *Kellicottia longispina*, *Synchaeta kitina*, *S. pectinata*, *Polyarthra dolichoptera*, *Filinia longiseta*, *Asplanchna priodonta*, *Neutrodiaptomus incongruens*, *Cyclops vicinus*, *Mesocyclops leuckarti*). The lake is oligo-mesotrophic, according to the diversity index values.

**Key words:** phytoplankton, zooplankton, abundance, biomass, dominants, Lake Arey.

## Планктонные сообщества (цианобактерии, водоросли и беспозвоночные) озера Арей (Забайкальский край, Россия)

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**Аннотация.** В работе впервые приведены материалы о видовом составе и структуре планктонных сообществ озера Арей – действующего памятника природы регионального значения, по данным исследований 2019–2020 гг. За период изучения в составе фитопланктона отмечено 102 таксона, рангом ниже рода и 50 видов в зоопланктоне. Основу видового состава составляли пресноводные, эврибионтные и широко распространенные виды. Количественные показатели фито- и зоопланктона варьировали в широких пределах. Высокие значения численности и биомассы водорослей отмечались в июле и сентябре (за счет массового развития цианобактерий и диатомовых водорослей), низкие – в марте, тогда, как максимум развития зоопланктона регистрировался весной (за счет коловраток), и спад – летом. Доминирующий комплекс планктона формировали среди водорослей: *Aphanizomenon flos-aquae*, *Coelomon pusillum*, *Limnothrix planctonica*, *Aphanothece* sp., *Microcystis pulverea*, *Cyclotella meneghiniana*, *Asterionella formosa*, *Ulnaria ulna*, *Aulacoseira granulata*, *Fragilaria radians*, в зоопланктоне: *Keratella cochlearis*, *K. quadrata*, *Kellicottia longispina*, *Synchaeta kitina*, *S. pectinata*, *Polyarthra dolichoptera*, *Filinia longiseta*, *Asplanchna priodonta*, *Neutrodiaptomus incongruens*, *Cyclops vicinus*, *Mesocyclops leuckarti*. По показателям индексов разнообразия, озеро отнесено к олиго-мезотрофному типу трофности, с высоким видовым разнообразием и большей выравненностью сообщества в летне-осенний период.

**Ключевые слова:** фитопланктон, зоопланктон, численность, биомасса, доминанты, озеро Арей.

## Introduction

The study of specially protected natural areas (protected areas) is of great theoretical and practical value as it focuses on ecosystems existing in conditions as close to natural

as possible. Many protected areas include water bodies, water courses or water complexes (Malysheva et al. 2018). As it is commonly known, the species composition of hydrobiota responds to all processes in a water ecosystem (Rysin 1995; Barinova, Medvedeva 1996). Plankton species are an integral part of hydrobiocenoses in protected areas, being an environmental indicator of any adverse effects in the whole water ecosystem, even only under short-term observation.

Lake Arey (Areyskoye), located in the Trans-Baikal territory, is a unique natural monument that became a protected area in 1980. Areysky Nature Park was established on May, 24, 2013 (Pomazkova 2020).

Lake Arey and the nature park are located in the saddle between the Yablonovy Range and the Malkhansky Range, 240 km southwest from Chita, the capital of the Zabaykalsky Krai. The area is located in the Ingoda River basin with elevations between 996 m and 1400 m above sea level. The lake lies close to the Great World Watershed dividing river basins of the Pacific Ocean and the Arctic Ocean. The lake belongs to the Amur basin and has a groundwater run-off to the Dabaty Creek that flows into the Tanga River. The lake is oval-shaped, with a slightly indented shoreline stretching from north to south. Western and northern shores are flat with mud and coastal herbaceous vegetation. Northeastern and eastern shores are sandy with nice clean beaches transforming into coastal ramparts with mixed thickets of birches, pines, and larches. In southeastern and southern parts, the narrow sandbank and beach turns into a steep bank with birches in the southeast and pines in the south. The lake has no streams flowing into it and is replenished by precipitation and underground waters.

The catchment area of Lake Arey is 17.1 km<sup>2</sup>. The lake is 3.1 km long, 2 km wide with a coastline length of 8.5 km, its water surface area is 4.6 km<sup>2</sup>, maximal depth is 13.5 m, and average depth is 4–8 m being deepest in the northeastern part and shallowest in the southern part. The area's climate is very sharp due to the general atmospheric circulation and orographic features. The average annual air temperature is between -2.0 °C and -3.2 °C. January is the coldest month. The duration of consistent freezing weather reaches 140 days. July is the warmest month. The duration of the frost-free period reaches 79–84 days. The lake freezes in late October and the ice breaks up from late May to early June. The ice thickness reaches 130–140 cm. The lake is covered in snow during all winter (Pomazkova, Lazarevskaya 2012).

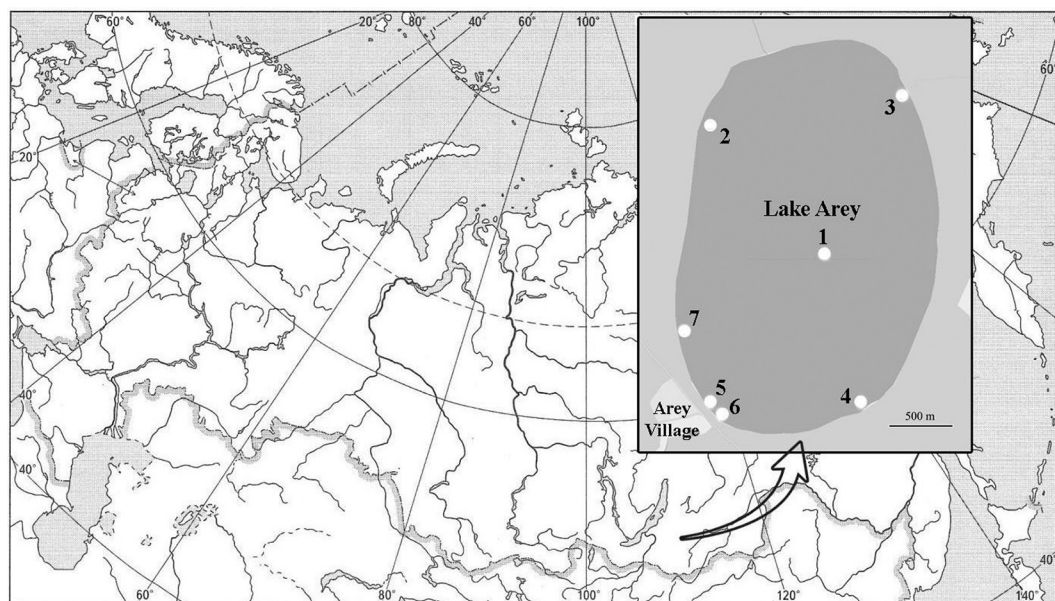
Lake Arey is a freshwater lake (TDS = 139–175 ppm), slightly alkaline and alkaline (pH = 7.9–8.7), with water turbidity is 43.9–134 NTU, and ORP is 63–188 mV (Tsybekmitova, Morozova 2021).

The lake features organized recreational facilities including recreation centers with beach facilities, and non-organized recreation zones along the remaining area (Pomazkova 2020).

There is no data on aquatic organism communities in Lake Arey. Only one-time zooplankton collections results are available (Krivenkova 2011). Our aim is to determine the species composition, quantitative and structural characteristics of the plankton community in Lake Arey.

## **Materials and methods**

We conducted hydrobiological studies in 2019–2020 and covered all biological seasons: autumn (September), winter (December), spring (March), and summer (July). Samples were collected at 7 sites (fig.).



**Fig.** Schematic map of the sampling site locations in Lake Arey: 1 – center station (N 50°59.8657', E 111°14.1410'); 2 – northwestern coast (N 50°59.8836', E 111°15.4172'); 3 – the Kristall tourist base (N 50°58.7316', E 111°15.0106'); 4 – southeastern coast (N 50°58.7474', E 111°14.1384'); 5 – the Arey tourist base (N 50°59.0378', E 111°13.9848'); 6 – Bezymyanny Stream (N 50°59.3193', E 111°14.0639'); 7 – the Arey camp (N 50°59.0032', E 111°13.9462').

**Рис.** Карта-схема расположения станций отбора проб на оз. Арей: 1 – центральная станция (N 50°59.8657', E 111°14.1410'); 2 – северо-западное побережье (N50°59.8836', E111°15.4172'); 3 – турбаза «Кристалл» (N 50°58.7316', E 111°15.0106'); 4 – юго-восточное побережье (N 50°58.7474', E 111°14.1384'); 5 – турбаза «Арей» (N 50°59.0378', E 111°13.9848'); 6 – ручей Безымянный (N 50°59.3193', E 111°14.0639'); 7 – лагерь «Арей» (N 50°59.0032', E 111°13.9462').

Phytoplankton samples were taken layer-by-layer (in the surface and near-bottom water layers in the littoral zone; in the surface water layer, at the Secchi disk depth, and near the bottom in the central site) using a Patalas bathometer. Zooplankton samples were collected using standard methods (Kiselev 1969). We used a Juday net (mesh size of 64  $\mu\text{m}$ ) to sample totally (from bed to surface). In shallow sites, water was scooped up with a bucket and filtered (100 L) through a hydrobiological net (mesh size of 94  $\mu\text{m}$ ).

All samples were fixed with 4% formaldehyde solution and examined under a Nikon Eclipse E200 microscope with a DS Camera Control Unit DS-L2 (1000 $\times$ ) (for phytoplankton), MBS-9 (98 $\times$ ) and Altami BIO 8 (1000 $\times$ ) microscopes (for zooplankton). The phytoplankton samples were prepared by the sedimentary method. Each sample was processed separately. Algae were counted according to the Hansen method using a counting plate. The biomass was determined based on the volume of individual algae cells or colonies and their geometric figures. The specific weight was taken equal to one unit (Sadchikov 2003). To determine the species of diatoms we prepared permanent preparations. The material was calcined until complete combustion of the organic matter and then embedded in a synthetic resin (refractive index above 1.6) (Sadchikov 2003). The average length of the zooplankters was converted to weight by methods of Ruttner-Kolisko (1977), Balushkina, Vinberg (1979), and Egsmont-Karabin (1998). Taxon classification and synonymy of each group of algae were given according to the algological website

AlgaeBase (Guiry and Guiry © 1996–2021). The following guide and keys were used for identifying zooplankters (Kutikova 1970; Borutsky et al. 1991; Tsalolikhin (ed.) 1995; Korovchinsky et al. 2021). The names of zooplankton species are given in accordance with modern nomenclature (WoRMS2022). Analysis of phytoplankton species composition was conducted according to S. S. Barinova et al. (2006), zooplankton species were identified according to the above keys.

The selected biodiversity indices included Shannon-Weaver, Pielou's evenness, and species dominance indices (Magurran 1992; Andronikova 1996). We used the arithmetic mean value (M) and the error of the mean value (m), also minimum (min) and maximum (max) values.

## Results and discussion

The sampling depth in the coast changed from 0.3 to 6 m. The depth in the central part was 9.3–10 m. Water transparency varied from 1.9 (in September) to 4.5 m (in March) in the deepest part. The surface water temperature changed from 0.1–2.9 (in December) to 19.8–23.2 (in July). The ice thickness was 0.8–1.1 m (tab. 1).

**Tab. 1.** Sampling depth, water transparency and temperature in Lake Arey in 2019–2020.

**Табл. 1.** Глубина отбора, прозрачность и температура воды оз. Арейское в 2019–2020 гг.

Month	Number site	Sampling depth, m	Transparency, m	Temperature, °C
September	2–7	0.3–1.1	0.3–1.1	12.8–14.4
	1	10	1.9	13.6
December	2–7	1.3–6	1.3–2.5	0.1–1.1
	1	9.3	2.7	2.9
March	2–7	1.6–5.3	1.6–4.5	3.7–4
	1	9.7	4.5	4.0
July	2–7	0.5–4.8	0.5–2.1	20.8–23.2
	1	9.9	2.2	19.8

In the plankton community there were 102 algae taxa below the genus level (Cyanobacteria – 14, Bacillariophyta – 10, Chrysophyta – 10, Cryptophyta – 3, Dinophyta – 3, Charophyta – 4, Chlorophyta – 55, Euglenophyta – 3) and 50 species of invertebrates (Rotifera – 26, Cladocera – 18, Copepoda – 6). Seasonally, the number of phytoplankton species varied from 43 to 69. The highest species richness was observed in July and September, while the lowest in December. In zooplankton, the species number varied from 18 to 33. The rotifers were the most diverse in the autumn, whereas the crustaceans in the summer.

According to ecological and geographical characteristics, the phytoplankton consisted of cosmopolitan species (82% of total species composition) and freshwater species (90%). Most species were indifferent to water pH (74%). Plankton habitants played a significant part in algal flora (50%). In zooplankton, species were mainly Holarctic and cosmopolitan (38% each), while Palearctic species were 25%. In terms of tolerance to the habitat characteristics, the eurytopic species prevailed among the zooplankton (46%). There were 22% planktonic and littoral species. The share of meiyobenthic and phytophilous forms was 10%.

The phytoplankton abundance averaged from  $54.74 \pm 12.67 \times 10^3$  cells L<sup>-1</sup> (in March) to  $1152.90 \times 10^3$  cells L<sup>-1</sup> (in July) and mean biomass varied within  $54.74 \pm 12.67$  (March) –  $688.23 \pm 170.82$  mg m<sup>-3</sup> (September) (tab. 2).

During the growing season, Cyanobacteria (25–77% of the total abundance and 11–78% of the total biomass; mainly *Aphanizomenon flos-aquae* Ralfs ex Bornet &

**Tab. 2.** Changes in the phytoplankton abundance (N,  $\times 10^3$  cells L<sup>-1</sup>), biomass (B, mg m<sup>-3</sup>), and diversity indices (Shannon-Weaver (H), Pielou's evenness (e), species dominance (I<sub>d</sub>)), and dominant species in Lake Arey in 2019–2020.

**Табл. 2.** Изменения численности (N, тыс. кл./л), биомассы (B, мг/м<sup>3</sup>), индексов разнообразия (Шеннона-Уивера (H), Пиелоу (e), доминирования (I<sub>d</sub>)) и доминирующих видов фитопланктона оз. Арей в 2019–2020 гг.

Indicator		Month			
		Sep	Dec	Mar	Jul
N	Min–Max	56.16–1756.56	87.78–406.50	15.75–209.52	821.28–1655.12
	M±m	925.04±215.79	231±46.79	52.27±28.77	1152.90±117.29
B	Min–Max	25.18–1346.80	130.12–956.55	18.61–114.64	316.02–649.42
	M±m	688.23±170.82	444.88±115.63	54.74±12.67	502.32±55.25
H	Min–Max	2.74–3.58	1.86–2.01	1.97–2.05	2.09–3.66
	M±m	3.11±0.11	1.93±0.02	2.01±0.01	3.31±0.23
e	Min–Max	0.81–0.99	0.52–0.64	0.13–0.35	0.04–0.98
	M±m	0.90±0.03	0.59±0.02	0.19±0.03	0.65±0.16
I <sub>d</sub>	Min–Max	0.12–0.25	0.09–0.17	0.10–0.16	0.11–0.90
	M±m	0.17±0.02	0.25±0.10	0.13±0.01	0.354±0.13
Dominant species		Lp, Mp, Asp, Cm, Fr, Cp, Af	Uu, Fr, Cm, Ag	Cm, Uu, Ds	Lp, Mp, Af-a, Asp

**Примечание.** Lp – *Limnithrix planctonica*; Mp – *Microcystis pulverea*; Af-a – *Aphanizomenon flos-aquae*; Asp – *Aphanothece* sp.; Cp – *Coelomoron pusillum*; Cm – *Cyclotella meneghiniana*; Fr – *Fragilaria radians*; Uu – *Ulnaria ulna*; Ag – *Aulacoseira granulata*; Af – *Asterionella formosa*; Ds – *Dinobryon sertularia*.

Flahault, *Coelomoron pusillum* (Van Goor) Komárek, *Limnithrix planctonica* (Wołoszyńska) Meffert, *Aphanothece* sp., and *Microcystis pulverea* (H. C. Wood) Forti and Bacillariophyta (5–60% and 9–98% respectively; *Cyclotella meneghiniana* Kützing, *Asterionella formosa* Hassall, *Ulnaria ulna* (Nitzsch) Compère, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Fragilaria radians* (Kützing) D. M. Williams & Round) were the most abundant, while Chrysophyta prevailed in winter and spring (6–60% and 7–58% respectively; *Chrysococcus rufescens* Klebs, *Dinobryon divergens* O. E. Imhof, *D. sertularia* Ehrenberg). Chlorophyta (species of genera *Oocystis*, *Monoraphidium*, *Chlamydomonas*, *Scenedesmus*) dominated in summer (17–81% of the total abundance).

The zooplankton in Lake Arey showed wide abundance and biomass ranges, from  $64.62 \pm 21.44 \times 10^3$  ind. m<sup>-3</sup> and  $710.57 \pm 440.56$  mg m<sup>-3</sup> (in July) to  $1249.01 \pm 365.46 \times 10^3$  ind. m<sup>-3</sup> and  $2053.48 \pm 935.19$  mg m<sup>-3</sup> (in March). The peak density (up to 90% of total abundance) was formed by the spring rotifer complex (tab. 3).

The dominant complex of zooplankton consisted of rotifers (*Synchaeta pectinata* Ehrenberg, *S. kitina* Rousselet, *Polyarthra dolichoptera* Idelson, *Asplanchna priodonta* Gosse, *Keratella cochlearis* (Gosse), *K. quadrata* (Müller), *Kellicottia longispina* (Kellcott), *Filinia longiseta* Ehrenberg) and copepods (*Neutrodiaptomus incongruens* (Poppe), *Cyclops vicinus* Uljanin, *Mesocyclops leuckarti* (Claus)). At the same time, rotifers were predominant on almost all sampling dates, and copepods were somewhat less so. The density of zooplankton did not coincide with that of the phytoplankton.

Probably, the lower abundance of zooplankters in the summer was due to the summer depression (Gorlachev 1972), when one complex of hydrobionts (summer thermophilic (stenothermic) ones) changes to another (autumn psychrophilic (eurythermic)). However, low abundance and biomass values were registered in August 2011 ( $27.13–59.20 \times 10^3$  ind. m<sup>-3</sup> and  $367.32–834.82$  mg m<sup>-3</sup> respectively) (Krivenkova 2011).

**Tab. 3.** Changes in the zooplankton abundance (N,  $\times 10^3$  ind.  $m^{-3}$ ), biomass (B,  $mg\ m^{-3}$ ), and diversity indices (Shannon-Weaver (H), Pielou's evenness (e), species dominance ( $I_d$ )), and dominant species in Lake Arey in 2019–2020.

**Табл. 3.** Изменения численности (N, тыс. экз./ $m^3$ ), биомассы (B,  $mg/m^3$ ), индексов разнообразия (Шеннона-Уивера (H), Пиелу (e), доминирования ( $I_d$ )) и доминирующих видов зоопланктона оз. Арей в 2019–2020 гг.

Indicator		Month			
		Sep	Dec	Mar	Jul
N	Min–Max	27.43–371.04	86.05–355.72	192.35–2487.65	7.15–142.93
	M $\pm$ m	188.90 $\pm$ 48.92	191.08 $\pm$ 50.28	1249.01 $\pm$ 365.46	64.62 $\pm$ 21.44
B	Min–Max	50.04–4334.17	485.03–2761.38	523.40–7130.38	20.16–3067.16
	M $\pm$ m	1303.98 $\pm$ 696.53	1207.91 $\pm$ 935.19	2053.48 $\pm$ 935.19	710.57 $\pm$ 440.56
H	Min–Max	1.95–2.85	1.56–3.15	1.49–2.82	1.99–3.50
	M $\pm$ m	2.51 $\pm$ 0.28	2.07 $\pm$ 0.20	2.07 $\pm$ 0.24	2.73 $\pm$ 0.24
e	Min–Max	0.42–0.77	0.34–0.68	0.32–0.55	0.43–0.70
	M $\pm$ m	0.55 $\pm$ 0.06	0.45 $\pm$ 0.04	0.45 $\pm$ 0.04	0.59 $\pm$ 0.05
Id	Min–Max	0.12–0.45	0.19–0.46	0.26–0.49	0.13–0.46
	M $\pm$ m	0.26 $\pm$ 0.06	0.36 $\pm$ 0.03	0.36 $\pm$ 0.03	0.21 $\pm$ 0.05
Dominant species		Kc, Kq, Sp, Ni, Cv	Kq, Fl, Sk, Pd, Ap, Cv	Sk, Pd, Fl, Cv	Kc, Kl, Ml

**Примечание.** Kc – *K. cochlearis*, Kq – *Keratella quadrata*, Kl – *Kellicottia longispina*, Sk – *Synchaeta kitina*, Sp – *S. pectinata*, Pd – *Polyarthra dolichoptera*, Fl – *Filinia longiseta*, Ap – *Asplanchna priodonta*, Ni – *Neurodiaptomus incongruens*, Cv – *Cyclops vicinus*, Ml – *Mesocyclops leuckarti*.

The average values of the Shannon-Weaver, Pielou's, and dominance indexes respectively varied within  $1.93 \pm 0.02$ – $3.11 \pm 0.114$ ,  $0.19 \pm 0.03$ – $0.90 \pm 0.03$ , and  $0.13 \pm 0.01$ – $0.35 \pm 0.13$  (for phytoplankton) and  $2.07 \pm 0.20$ – $2.73 \pm 0.24$ ,  $0.45 \pm 0.04$ – $0.59 \pm 0.05$ , and  $0.21 \pm 0.05$ – $0.36 \pm 0.03$  (for zooplankton). These values correspond to the oligo-mesotrophic type of the trophicity of the lake (Magurran 1992; Andronikova 1996) with high species diversity and more even plankton assemblages in the summer-autumn period.

### Conclusion

The phytoplankton in Lake Arey consisted of 102 algae taxa over the entire research period. Chlorophytes were the most diverse (55 taxa below the genus level). According to the ecological and geographical characteristics the phytoplankton consisted of cosmopolitan species (82% of total species composition), freshwater species (90%), species indifferent to pH (74%), and plankton habitants (50%). Total abundance and biomass varied from  $54.74 \pm 12.67 \times 10^3$  cells  $L^{-1}$  to  $1152.90 \times 10^3$  cells  $L^{-1}$  and from  $54.74 \pm 12.67$  to  $688.23 \pm 170.82$   $mg\ m^{-3}$  respectively. The highest density was in July and September, the lowest in March. Cyanobacteria and Bacillariophyta were the most abundant in all seasons, Chrysophyta prevailed in winter and spring and Chlorophyta in summer. Phytoplankton species *Aphanizomenon flos-aquae*, *Coelomoron pusillum*, *Limnithrix planctonica*, *Aphanothece* sp., *Microcystis pulverea*, *Cyclotella meneghiniana*, *Asterionella formosa*, *Ulnaria ulna*, *Aulacoseira granulata*, and *Fragilaria radians* were dominant. The zooplankton consisted of 50 species and subspecies. Rotifers showed the greatest species diversity (26 taxa). Holarctic and widespread species (76% in total), eurytopic species (46%) prevailed in the species composition. The quantitative indicators averaged from  $64.62 \pm 21.44 \times 10^3$  ind.  $m^{-3}$  and  $710.57 \pm 440.56$   $mg\ m^{-3}$  to  $1249.01 \pm 365.46 \times 10^3$  ind.  $m^{-3}$  and  $2053.48 \pm 935.19$   $mg\ m^{-3}$ . The maximum value was in July, the minimum in March.

Rotifers mostly prevailed in all seasons. The dominant complex consisted of *Keratella cochlearis*, *K. quadrata*, *Kellicottia longispina*, *Synchaeta kitina*, *S. pectinata*, *Polyarthra dolichoptera*, *Filinia longiseta*, *Asplanchna priodonta*, *Neutrodiaptomus incongruens*, *Cyclops vicinus*, *Mesocyclops leuckarti*. According to the conditional division of the diversity index values, the lake is oligo-mesotrophic with high species diversity and more even plankton assemblages in the summer-autumn period.

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