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### Article

## Features of under-ice zooplankton in Lake Pleshcheyevo (Yaroslavl Region, Russia)

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**Abstract.** In March 2019, we studied the taxonomic composition, vertical and horizontal distribution of under-ice zooplankton in Lake Pleshcheyevo and revealed that its quantity (abundance 11.5–13.8 thous. ind./m<sup>3</sup>, biomass <0.1 g/m<sup>3</sup>) was much lower than in the same season of 1980–1990. The cryophilic species *Cyclops kolensis* dominated among crustaceans. An increase in the share of representatives of the genus *Synchaeta* (12–27% of the total abundance of rotifers) was also noted. At the same time, previously dominant during the under-ice period *Eudiaptomus graciloides* demonstrated the reduced abundance.

**Keywords:** deep lake, climate change, winter zooplankton, taxonomic composition, spatial distribution, abundance, biomass, water temperature, dissolved oxygen

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**Научная статья****Особенности подледного зоопланктона озера Плещеево (Ярославская обл., Россия)**С.М. Жданова\*, М.И. Малин*Институт биологии внутренних вод им. И.Д. Папанина РАН, 152742, Россия, Ярославская обл., Некоузский р-н, пос. Борок, д. 109*

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**Аннотация.** В марте 2019 г. изучены таксономический состав, вертикальное и горизонтальное распределение зоопланктона в оз. Плещеево. Установлено, что его обилие невелико (численность 11.5–13.8 тыс. экз./м<sup>3</sup>, биомасса < 0.1 г/м<sup>3</sup>), значительно ниже, чем регистрировали в этот сезон в 1980–90-х гг. Среди ракообразных, как и прежде, преобладал холодолюбивый *Cyclops kolensis*. Отмечено возрастание доли представителей р. *Synchaeta*, которые составляли до 12–27% общей численности коловраток. В то же время наблюдалось снижение обилия *Eudiaptomus graciloides*, ранее многочисленного в подледный период.

**Ключевые слова:** глубоководное озеро, изменение климата, зимний зоопланктон, таксономический состав, пространственное распределение, температура воды, растворенный кислород

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## Introduction

Nowadays, the climate-induced reduction of a freeze-up period is observed in many water bodies of the temperate zone (Benson et al., 2012; Klyuev and Lebedev, 2019; Sharma et al., 2021; Su et al., 2021). This process strongly affects the habitat of cold-loving species of planktonic animals (Jansen et al., 2021; Lazareva and Sokolova, 2017; Rivier, 2012; Syarki and Fomina, 2017). Winter zooplankton from the Rybinsk Reservoir (Lazareva and Sokolova, 2017), water bodies of the Upper and Middle Volga basins (Rivier, 1986, 2012; Salakhutdinov, 2003), Lake Onega (Syarki and Fomina, 2017), and the Novosibirsk Reservoir (Ermolaeva, 2000) has been currently studied. Among under-ice complexes of cold-loving and year-round planktonic species, rotifers and copepods are the most abundant. In winter zooplankton, the species composition is depleted. Some water bodies are characterized by low abundance of planktonic animals (Lazareva and Sokolova, 2017; Syarki and Fomina, 2017) or, on the contrary, by a peak in the annual cycle (Ermolaeva, 2000; Salakhutdinov, 2003).

Winter and winter-spring zooplankton of deep-water Lake Pleshcheyevo was thoroughly studied in January–March 1980–1985 and 1990–1991 (Rivier, 1986, 2012; Rivier et al., 1992; Stolbunova, 1992, 2006). It was found that the planktonic community, i.e. specific winter (cryophile, cold-loving) and eurythermal (year-round with cold-loving generation) species reached their maximal development in the under-ice period in March.

The purpose of the work was to study the composition and vertical distribution of zooplankton in the under-ice period of 2019.

## Materials and methods

The studies of under-ice (ice thickness: ~50 cm) zooplankton were carried out on March 30, 2019 at three stations located in the northwestern part of Lake Pleshcheyevo (Table 1). Samples were collected using a Van Dorn plankton sampler (volume: 4.2 l) at 1–2 m layers from the surface to the bottom followed by filtration through a plankton sieve (mesh size: 64  $\mu\text{m}$ ). At each horizon, double volumes of sampler were taken and then poured layer-by-layer into separate flasks.

To implement the laboratory processing of samples, we applied the generally accepted method (Metodologiya..., 1975; Metodicheskie rekomendatsii..., 1982). Zooplankton biomass was calculated based on the equations for the body length dependence of individual mass (Balushkina and Vinberg, 1979; Ruttner-Kolisko, 1977). Species with the relative abundance > 5% and biomass > 5% were considered dominant. For identification of planktonic animals, the key book of L.A. Kutikova (1970) and “Opredelitel’ zooplanktona i zoobentosa presnykh vod Evropeiskoi Rossiii” (2010) were used. The nomenclature of Cladocera is presented according to N.M. Korovchinsky et al. (2021), Rotifera – to H. Segers (2007), T. Horton et al. (2022), and Copepoda – “Opredelitel’...” (2010) and Horton et al. (2022).

Water temperature and dissolved oxygen concentrations were measured at the stations by the thermooxymeter YSI ProODO from the surface to the bottom discretely with an interval of 1 m.

We performed the data processing and analysis using Microsoft Office Excel 2010 (Microsoft Corp.) and statistical calculations – STATISTICA 6.0 software (Statsoft Inc., USA). The mean value was calculated as the arithmetic mean of the collected samples.

## Results and discussion

### *Climatic features of winter 2018–2019*

According to the Roshydromet data<sup>1</sup>, the winter of 2018–2019 was moderately warm with the mean anomaly for the Central Federal District (CFD) of +2.90 °C. The spring was very warm with the mean anomaly for CFD of +2.59 °C. In Russia, the snow cover duration (winter of 2018–2019) was on average much shorter than the climatic norm. In CFD, this indicator made up 8.68 days.

Ice phenomena (first shore ice) on Lake Pleshcheyevo were recorded in November 21, 2018. Incomplete freezing occurred on December 9; by December 18, the lake was completely covered with ice. Flange ice appeared on the lake on April 8, 2019; shifts and clearing of ice began on April 11. Rare floating ice was observed starting from April 13. By May 1, the lake was overall free from ice (Avtomatizirovannaya..., 2014). In 2017–2019, shore ice occurrence and complete freeze-up took place 20–28 days later than in 1931–1975. Note that the breakup period on the lake remained the same (Table 2).

<sup>1</sup> Report on climate features in the territory of the Russian Federation for 2019, 2020.

**Table 1.** Physical-chemical characteristics and indicators of zooplankton in the study sites of Lake Pleshcheyevo (March 2019).  $N_{tot}$  – total abundance of zooplankton,  $N_{rot}$  – abundance of rotifers,  $N_{clad}$  – abundance of cladocerans,  $N_{cop}$  – abundance of copepods,  $B_{tot}$  – total biomass of zooplankton,  $B_{rot}$  – total biomass of rotifers,  $B_{clad}$  – biomass of cladocerans,  $B_{cop}$  – biomass of copepods,  $S_{tot}$  – total number of species,  $n$  – number of observations (zooplankton samples) at the station. Above the line, abundance, thousand ind./m<sup>3</sup> (mean  $\pm$  mean error); below the line, relative abundance (% of total zooplankton abundance).

Indicator	Station			
	1 (n=11)	2 (n=6)	3 (n=7)	
Coordinates	N 56° 47.677' E 38° 46.453'	N 56° 47.805' E 38° 46.664'	N 56° 47.888' E 38° 46.786'	
Distance from the coast, km	1.1	0.8	0.6	
Depth, m	20	9	7	
Water temperature at the surface, °C	0.5	0.8	1.0	
Water temperature at the bottom, °C	2.7	1.5	1.1	
$N_{tot}$ , thsd. ind./m <sup>3</sup>	12.7 $\pm$ 3.1	11.5 $\pm$ 1.6	13.8 $\pm$ 2.3	
$N_{rot}$ , thsd. ind./m <sup>3</sup>	9.3 $\pm$ 1.6	7.8 $\pm$ 1.8	8.4 $\pm$ 2.0	
$N_{clad}$ , thsd. ind./m <sup>3</sup>	< 0.1	< 0.1	< 0.1	
$N_{cop}$ , thsd. ind./m <sup>3</sup>	4.3 $\pm$ 1.3	3.6 $\pm$ 1.1	4.4 $\pm$ 1.3	
$B_{tot}$ , mg/m <sup>3</sup>	29.4 $\pm$ 2.3	12.4 $\pm$ 7.3	9.9 $\pm$ 2.3	
$B_{rot}$ , mg/m <sup>3</sup>	2.2 $\pm$ 0.6	2.0 $\pm$ 0.5	2.2 $\pm$ 0.5	
$B_{clad}$ , mg/m <sup>3</sup>	1.3 $\pm$ 1.0	0.2 $\pm$ 0.2	1.6 $\pm$ 1.4	
$B_{cop}$ , mg/m <sup>3</sup>	26.0 $\pm$ 13.4	10.2 $\pm$ 7.4	6.2 $\pm$ 1.9	
$S_{tot}$	14	15	16	
Dominant species	<i>Keratella hiemalis</i>	$\frac{5.7 \pm 1.9}{45}$	$\frac{3.1 \pm 0.6}{27}$	$\frac{4.4 \pm 0.9}{32}$
	<i>Synchaeta lakowitziana</i>	$\frac{1.5 \pm 0.8}{12}$	$\frac{3.1 \pm 1.6}{27}$	$\frac{3.3 \pm 1.3}{24}$
	<i>Filinia terminalis</i>	$\frac{0.5 \pm 0.1}{4}$	$\frac{0.8 \pm 0.3}{7}$	$\frac{1.0 \pm 0.3}{7}$
	Cyclopoida nauplii	$\frac{3.2 \pm 1.0}{25}$	$\frac{2.9 \pm 0.8}{25}$	$\frac{4.3 \pm 1.3}{31}$
	<i>Cyclops copepodites</i>	$\frac{0.9 \pm 0.5}{7}$	$\frac{0.5 \pm 0.5}{4}$	$\frac{0.1 \pm 0.1}{7}$

**Table 2.** Freeze-up duration at Lake Pleshcheyevo (according to the data from \* – Ekosistema..., 1989; \*\* – Avtomatizirovannye..., 2014).

Year	Freeze-up period	Flange ice appearance	Complete ice clearing	Shore ice formation
1931–1975*	2.XII	10.IV	1.V	4.XI
2017**	absent by 31.XII	29.III	30.IV	24.XI
2018**	18.XII	18.IV	2.V	21.XI
2019**	absent by 31.XII	8.IV	1.V	21.XI

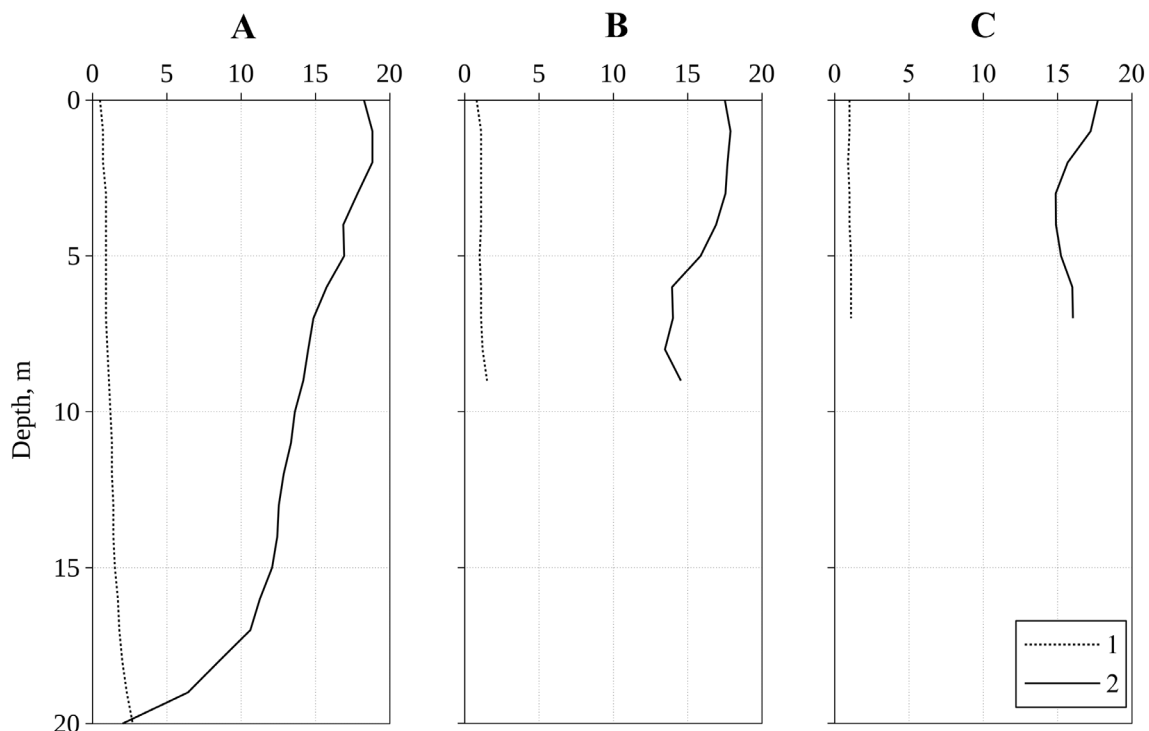
In March 2019, in the deep-water zone of the lake, a reverse weakly pronounced thermal stratification (Table 1, Fig. 1), typical for this period, was recorded (Ekosistema..., 1989). The lake had a favorable oxygen regime at all depths (more than 10 mg/l), except for the bottom layer with its low content of dissolved oxygen (2 mg/l).

### Zooplankton

In March 2019, we identified 21 species of planktonic animals in Lake Pleshcheyevo, among which were rotifers (11 species) and crustaceans (10 species; Cladocera – 5, Copepoda – 5). Planktonic forms dwelling in the reservoir all the year round (9 species) predominated (43%). Winter cold-loving species accounted for 24% (5 species), summer ones – 19% (4 species) (Table 3).

Zooplankton abundance was similar in all study sites of the lake. Due to mass development of copepods *Cyclops kolensis* in the bottom layer (Fig. 3), biomass of planktonic animals in the deep-water area (st. 1) was 3 times higher than in other sites (Table 1, Fig. 2). The majority of the winter community was formed by rotifers (68–73%) and copepods provided the basis of biomass (63–88%). Cladocera were few in number during the ice period (Table 1). This was earlier reported by other investigators as well (Rivier, 1986; Stolbunova, 2006). Zooplankton dominants were represented by winter and cold-loving species (Table 2).

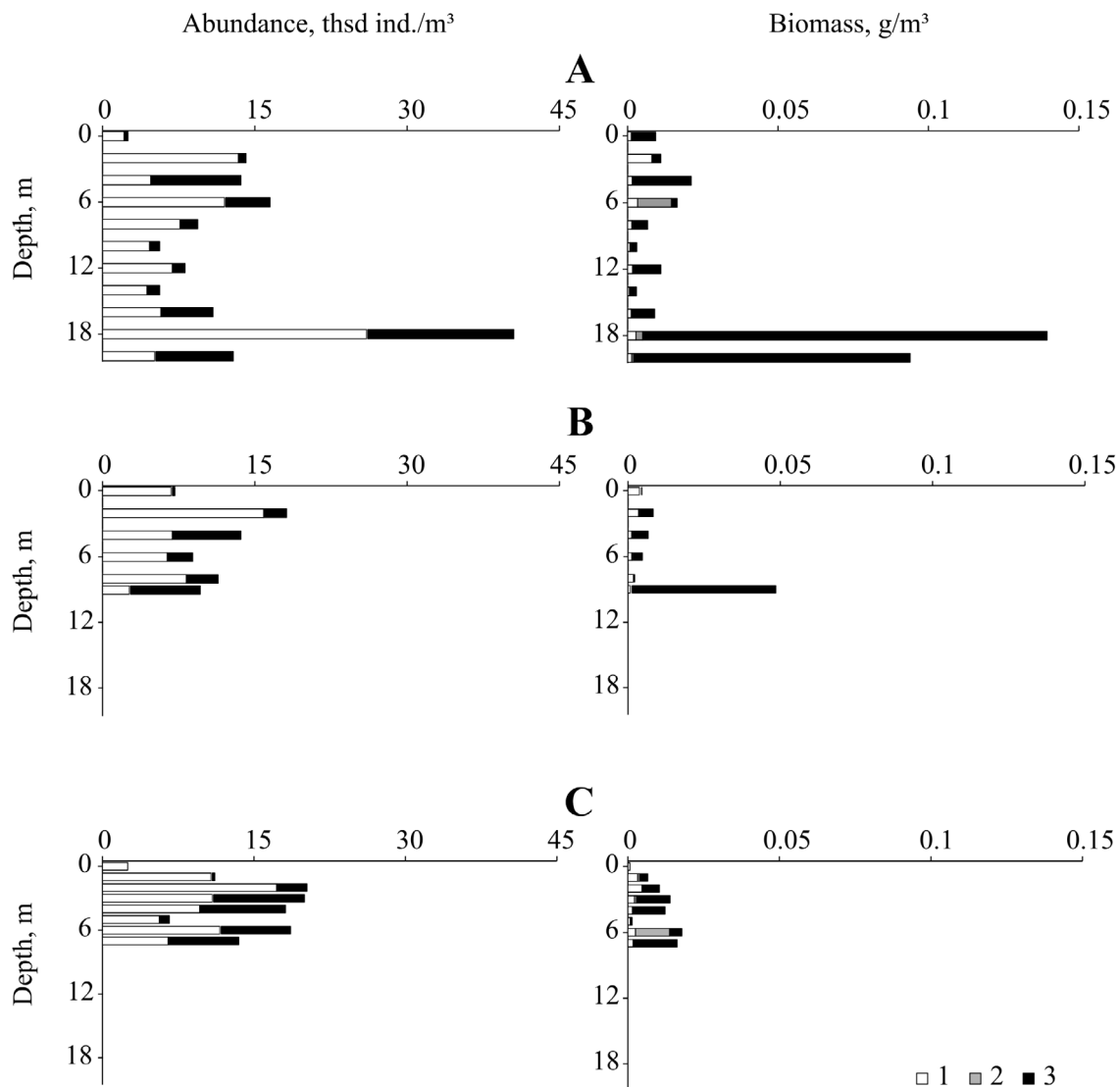
High abundance and biomass of the community were noted in the bottom layers at depths of 20 and 9 m (Fig. 2). In vertical zooplankton structure rotifers dominated, except for the bottom layer with its numerous copepods (Fig. 2). Cold-loving rotifers prevailed in the surface (0–2 m) (*Synchaeta lakowitziana*, 60–64% of the total zooplankton abundance) and deeper layers (>6 m) (*Keratella hiemalis*, 43–69%) (Fig. 4). Cyclopoid copepods formed a noticeable abundance in the 4-m layer due to nauplii (60% of the total zooplankton abundance) and in the near-bottom layer because of nauplii and copepods of the genus *Cyclops* (57%). A similar structure of vertical distribution of planktonic animals in late winter is typical of the Rybinsk Reservoir (Lazareva and Sokolova, 2017), lakes Vidogoshch, Ferapontovo and Siverskoye (Dzyuban et al., 1998). The bacterioplankton development and dissolved oxygen concentrations are crucial for vertical distribution of zooplankton in winter (Dzyuban et al., 1998; Rivier, 1986, 2012). For instance, in flooded Lake Vidogoshch, nauplii were concentrated in the layers with high abundance



**Fig. 1.** Vertical distribution of temperature (1), °C and dissolved oxygen concentrations (2), mg/l in Lake Pleshcheyevo (March 2019): **A** – station 1; **B** – station 2; **C** – station 3.

**Table 3.** Species composition of winter zooplankton in Lake Pleshcheyevo. \* –according to the data from Rivier (1986, 2012), Rivier et al. (1992), Stolbunova (1992, 2006)). Ecotype (according to Lazareva and Sokolova, 2017; Riviere, 1986): P – planktonic, M – meiobenthic, W – winter, S – summer, Y – year-round, D – in a diapause state.

	Taxon	January–March 1980–1992*	March 2019	Ecotype
Rotifera	<i>Asplanchna priodonta</i> Gosse, 1850	+	–	P, S
	<i>Brachionus quadridentatus</i> Hermann, 1783	+	–	P, S
	<i>B. calyciflorus</i> Pallas, 1766	+	–	P, S
	<i>Brachionus diversicornis</i> (Daday, 1883), <i>B. d. homoceros</i> (Wierzejski, 1891)	+	–	P, S
	<i>B. angularis bidens</i> Plate, 1886	+	–	P, S
	<i>Conochiloides natans</i> (Seligo, 1900)	+	–	P, W
	<i>Conochilus unicornis</i> Rousselet, 1892	+	–	P, S
	<i>Filinia terminalis</i> (Plate, 1886) syn <i>Filinia maior</i> (Colditz, 1924)	+	+	P, W
	<i>Filinia longiseta</i> Ehrenberg, 1834	–	+	P, S
	<i>Kellicottia longispina</i> (Kellicott, 1879)	+	+	P, Y
	<i>Keratella cochlearis</i> (Gosse, 1851) syn <i>K. c. macrocantha</i> (Lauterborn, 1898)	+	+	P, Y
	<i>K. hiemalis</i> Carlin, 1943	+	+	P, W
	<i>K. quadrata</i> (O.F. Müller, 1786)	+	+	P, Y
	<i>Notholca squamula</i> (O.F. Müller, 1786)	+	–	P, W
	<i>N. foliacea</i> (Ehrenberg, 1838)	+	–	P, W
	<i>Polyarthra dolichoptera</i> Idelson, 1925	+	+	P, W
	<i>P. longiremis</i> Carlin, 1943	–	+	P, S
	<i>P. major</i> Bruckhardt, 1900	–	+	P, S
	<i>Synchaeta pectinata</i> Ehrenberg, 1832	+	+	P, Y
	<i>S. oblonga</i> Ehrenberg, 1832	+	–	P, W
<i>S. lakowitziana</i> Lucks, 1930	–	+	P, W	
Cladocera	<i>Bosmina longirostris</i> (O.F. Müller, 1785)	+	+	P, Y
	<i>B. (Eubosmina) cf. longispina</i> Leydig	+	+	P, Y
	<i>Chydorus sphaericus</i> (O.F. Müller, 1776)	+	–	P, Y
	<i>Coronatella rectangula</i> (Sars, 1862)	+	–	P, S
	<i>Daphnia cristata</i> Sars, 1862	+	–	P, Y
	<i>D. cucullata</i> Sars, 1862	–	+	P, S
	<i>D. galeata</i> Sars, 1864	–	+	P, Y
<i>D. longispina</i> (O.F. Müller, 1776)	+	+	P, Y	
Copepoda	<i>Cyclops kolensis</i> Lillijborg, 1901	+	+	P, W
	<i>C. vicinus</i> Uljanin, 1875	+	–	P, Y
	<i>Thermocyclops oithonoides</i> (Sars, 1863)	–	+	P, D
	<i>Mesocyclops</i> sp. (copepodit)	+	+	P, D
	<i>Paracyclops fimbriatus</i> (Fisher, 1853)	–	+	M, Y
<i>Eudiaptomus graciloides</i> (Lillijborg, 1888)	+	+	P, Y	

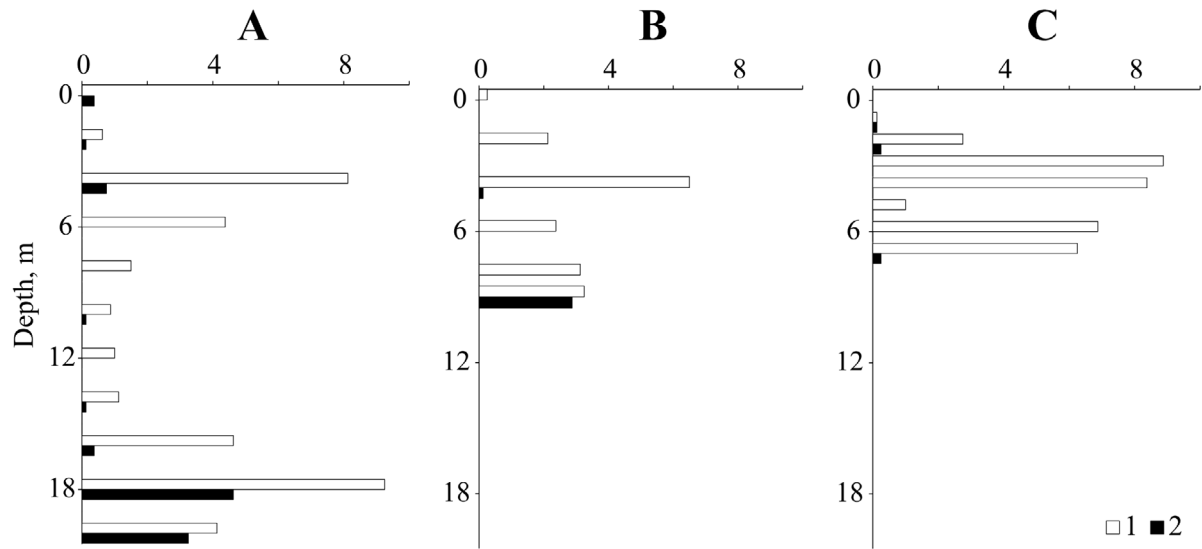


**Fig. 2.** Vertical distribution of under-ice zooplankton in Lake Pleshcheyevo (March 2019): **A** – station 1; **B** – station 2; **C** – station 3. 1, Rotifera, 2, Cladocera, 3, Copepoda.

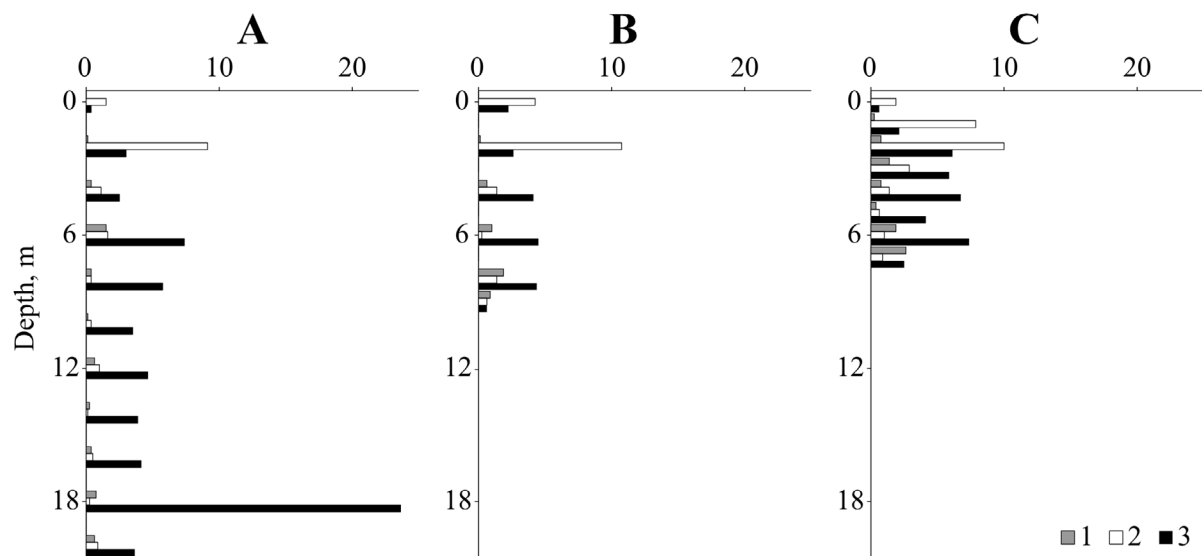
of bacteria (Dzyuban et al., 1998). At oxygen deficit (less than 2 mg/l), zooplankton aggregations were formed above the oxycline (Rivier, 2012).

Among copepods, one species – *Cyclops kolensis*, dominated. Copepods of the genera *Thermocyclops*, *Mesocyclops*, and *Paracyclops* were sporadic. In the end of March 2019, not numerous population *Cyclops kolensis* (up to 4600 ind./m<sup>3</sup>) was noted near the bottom at depths of about 20 m (Fig. 3). Formerly, this crustacean was also found in the bottom layers of deep parts of the lake; its abundance significantly varied over the years (3000–36000 ind./m<sup>3</sup>) (Rivier, 1986; Stolbunova, 2006).

In March 2019, single adults of eurythermal calanoid copepods *Eudiaptomus graciloides* were found in the lake (0.25 thsd. ind./m<sup>3</sup>). Previously, this species was distinguished by much greater abundance (up to 24 thsd. ind./m<sup>3</sup>) (Rivier et al., 1992; Stolbunova, 2006). *E. graciloides* inhabited upper layers (up to 5–11 m); at a temperature of 0.7–1.1 °C in March, its share in the total zooplankton biomass reached 53–84%. Being represented by sexually mature individuals, the crustaceans did not breed in winter. The number of its winter generation depended on the number of individuals, which entered under ice. High abundance of Diaptomidae in winter is a favorable condition for fish existence in the water body. In late April of 1996, before the lake breakup, crustaceans were few. Previous studies suggest that it is associated with their predation by vendace (Stolbunova, 2006).



**Fig. 3.** Vertical abundance distribution (thous. ind./m<sup>3</sup>) of dominant crustaceans in under-ice zooplankton of Lake Pleshcheyevo (March 2019): **A** – station 1; **B** – station 2; **C** – station 3. 1, Cyclopoida nauplii; 2, copepods of the genus *Cyclops*.



**Fig. 4.** Vertical abundance distribution (thous. ind./m<sup>3</sup>) of dominant rotifer species in under-ice zooplankton of Lake Pleshcheyevo (March 2019): **A** – station 1; **B** – station 2; **C** – station 3. 1, *Filinia terminalis*, 2, *Synchaeta lakowitziana*, 3, *Keratella hiemalis*.

As compared to the 1980s – early 1990s, zooplankton development during our study was insignificant: 2–5 times lower in abundance and 5.5–30 – in biomass (Table 4). This is due to low density of *E. graciloides*. In the early 2000s, a reduced number of the closely related species *E. gracilis* in under-ice zooplankton was recorded in the Rybinsk Reservoir (Lazareva, 2010), though in the 1970s, this crustacean was one of the most numerous species (Rivier, 1986).

In Lake Pleshcheyevo, the composition of dominant rotifer species has changed as well. In particular, the share of the genus *Synchaeta* in zooplankton community increased. Previously, the representatives of the genera *Keratella* (*K. cochlearis macrocantha*, *K. hiemalis*), *Filinia* and *Conochiloides* (Rivier et al., 1992; Stolbunova, 2006) prevailed in the under-ice period most often. As in earlier studies by (Rivier, 1986, 2012), we noted similar changes in the composition of dominants (i.e. an increase in the share of representatives of the genus *Synchaeta*) in the Rybinsk Reservoir (Lazareva and Sokolova, 2017).

Probably, the reduction in the freeze-up period (especially at the initial stages of its formation) leads to changes in abundance and structure of winter zooplankton (Jansen et al., 2021). It was reported in (Grosbois et al., 2017) that availability of phytoplankton fatty acids remained high in the period preceding the freeze-up and at the beginning of winter that allowed the copepods *Leptodiptomus minutus* (Lilljeborg in Guerne & Richard, 1889) to accumulate and metabolize n-3 polyunsaturated fatty acids (PUFAs) throughout the winter thereby providing their growth and reproduction under the ice. However, it is expected that the predicted shortening of the ice cover duration induced by climate change will increase phytoplankton (i.e. cyanobacteria) with poor PUFAs (Grosbois et al., 2017).

## Conclusion

Maximum abundance of planktonic animals was recorded in deep parts of Lake Pleshcheyevo due to the near-bottom peak of copepod development, whereas zooplankton biomass in its sublittoral was 2.5–3 times lower. In contrast to studies of the 1980s–1990s, zooplankton development in March of 2019 turned out to be low (i.e. 2–5 times less in abundance and 5.5–30 – in biomass). The composition of crustaceans did not change significantly, but *Eudiaptomus graciloides*, which previously formed up to 84% of the zooplankton biomass, fell out of the list of dominant species. Some winter and year-round species were absent among the Rotifera. The composition of dominant rotifer species also changed compared to the period of 1980–1990. *Synchaeta lakowitziana* and *Keratella hiemalis* dominated in the water column. Representatives of the genus *Synchaeta*, not identified before in the reservoir, became numerous. The reasons for such changes are not clear and require further study. Probably, the shortening of the freeze-up period (especially at the initial stages of its formation) brings to changes in winter zooplankton abundance and its structure.

**Table 4.** Long-term changes in abundance ( $N_{tot}$ ) and biomass ( $B_{tot}$ ) of zooplankton during the under-ice period (March) in deep-water areas of Lake Pleshcheyevo (according to the data from Riviere (1986, 2012), Riviere et al. (1993), Stolbunova (2006) for 1980–1996).

Year	$N_{tot}$ , thsd. ind./m <sup>3</sup>	$B_{tot}$ , g/m <sup>3</sup>
1980	42	0.86
1982	12	0.49
1984	23	0.59
1985	49	0.75
1988	48	1.02
1989	33	0.64
1990	23	0.33
1991	63	1.05
1992	28	0.16
1996	10	0.03
2019	13 ± 3	0.029 ± 0.02

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