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ECOLOGY

Zooplankton of Reservoirs in the Upper Reaches of the Kenti River System (Northern Karelia) under Long-Term Industrial Pollution Conditions

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Abstract—An assessment is given for the contemporary state of zooplankton community in the waters of the upper reaches of the Kenti River system under the conditions of long-term potash–sulfate industrial pollution. This article presents a number of structural indicators of the zooplankton community that show simplification in the structure of species diversity and its reduction, as well as the disappearance of a number of systematic groups. It is noted that the number of zooplankton taxa increases with distance from the source of pollution (Kostomukshskoe and Kento lakes), and the average quantitative indicators also increase in this case. A comparison with the results that were previously obtained for the reservoirs of the studied environment has been carried out.

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INTRODUCTION

It is known that the degradation of biotopes and ecosystems at present is directly associated with different forms of anthropogenic influence (Reshetnikov et al., 1982; Sterligova et al., 2002; Dgebuadze, 2003; Alimov et al., 2005). Significant changes in freshwater systems take place due to diverse industrial pollution, water resources engineering, and irrational trade, as well as due to acclimatization and self-colonization of new hydrobiont species.

The Republic of Karelia has a well-developed hydrographic network relating to the basins of the White and Baltic seas. The specificity of hydrography of the region is determined by the peculiarities of the system of natural conditions (geological structure, topography, and climate), as well as by the peculiarities of the geographic location of the region. There are ~23600 rivers and >61100 lakes in Karelia, which makes up 14.7% of the entire territory (Filatov et al. 2001; Litvinenko and Lozovik, 2003; Filatov and Litvinenko, 2010). The chemical composition of Karelian surface waters is formed under the conditions of low-soluble bedrocks of the Baltic crystalline shield, well-washed quaternary deposits, and high bogginess. The waters are normally low-mineralized, high-colored, and with a high iron content. The average mineralization of the surface waters of the republic is 22 mg/L (Litvinenko and Lozovik, 2003).

One of the factors of anthropogenic impact on the reservoirs of the Republic is the waste water discharge by industrial centers. Despite a significant decline in production in the mid-1990s and early 2000s, industrial enterprises still have a significant influence on the state of biological resources of freshwater ecosystems. The Kostomukshskii mining and processing plant constructed in 1982 is one of the largest enterprises in the northwest of Russia, which is designed for ore mining in a volume of 24 million tons per year and for production of up to 9750000 tons of iron concentrate and 8520000 tons of pellets. Waste products enter the artificial reservoir (former Kostomukshskoe Lake), which is an upper reservoir in the lake-river system of the Kenti River and is separated from the downstream lakes by a dam. The polluted waters are further spread over the other reservoirs of the Kenti River system through the bypass channels. The functioning of industrial systems of this scope requires particular attention to monitoring the state of the environment and making adequate decisions on its protection and rational nature management. Changes in the composition and functioning of the plankton community affect the general state of the ecosystem, and one can assess the health of the water ecosystem based on the state of planktonic fauna (Naumenko, 2009).

The objective of this work is to study the dynamics of the quantitative indicators and species diversity of zooplankton in the reservoirs of the upper and middle reaches of the Kenti River under the conditions of long-term technogenic pollution.

Table 1. Hydrological indicators of lakes of the Kenti River system

Indicator	Lakes			
	Kostomukshskoe	Okunevoe	Koivas	Kento
Water-surface area, km^2	34.2	0.3	21.4	30.8
Water-catchment area, km^2	68.4	51	356	676.6
Mean depth, m	–	2.6	4.1	3.8
Maximum depth, m	25	5.6	21	23.5
Volume of water mass, million m^3	430	0.86	89.6	103.1
Period of conventional water exchange, days	–	15	285	198

"–" means no data.

Table 2. Hydrochemical indicators of the reservoirs under study

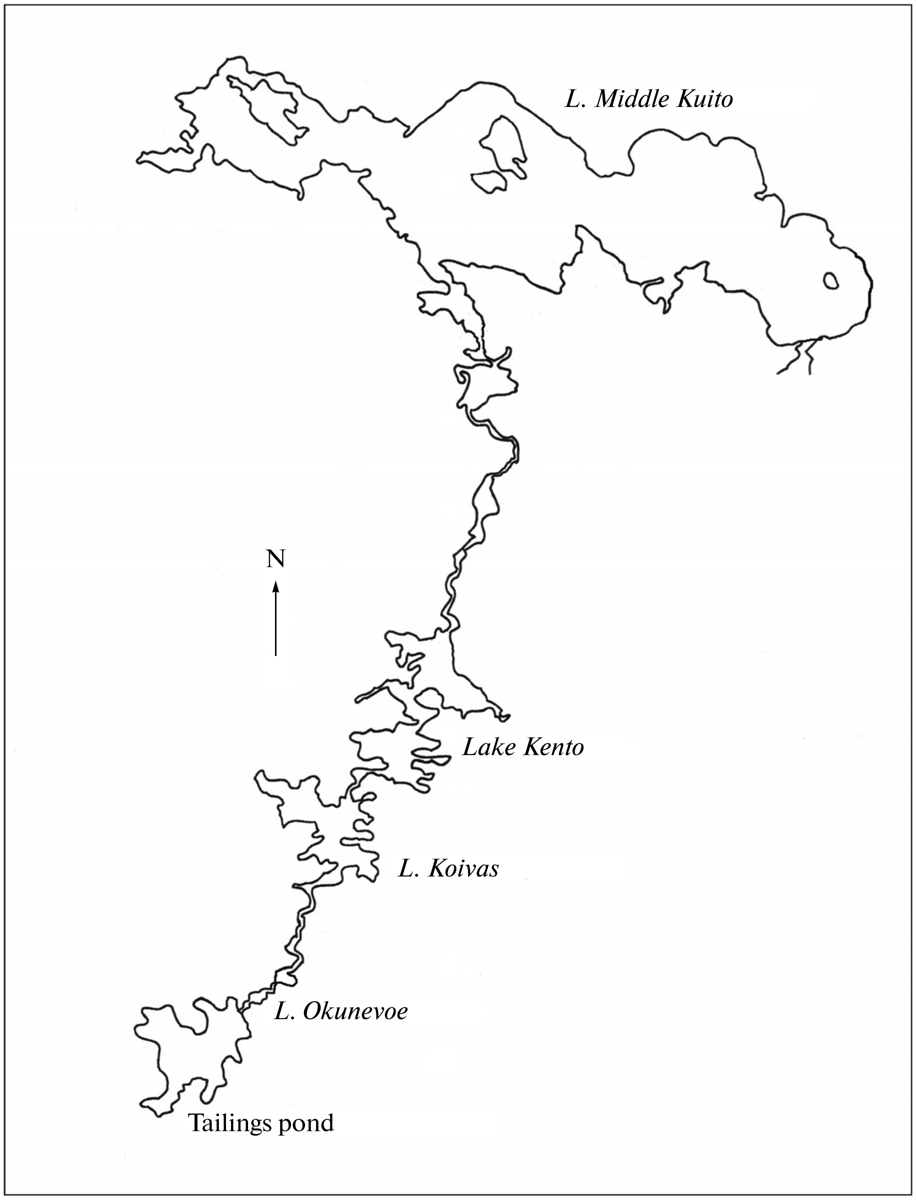
Indicator, mg/L	Lakes:			
	Kostomukshskoe	Okunevoe	Koivas	Kento
Ca^{2+}	40.1	36.7	21.9	11.4
Mg^{2+}	17.8	14.7	9.3	1.8
K^+	154.5	155.9	91.4	36.4
Na^+	17.9	20.8	11.7	5.7
HCO_3^-	124.8	103.4	61.8	28.6
SO_4^{2-}	270.4	305.6	198.6	37
Cl^-	6.9	5.6	3.2	1.8
Σ of ions	632.4	642.7	397.9	122.7
pH	7.6–7.7	7.42	7.05	6.1

MATERIALS AND METHODS

The studies were carried out in the four reservoirs of the Kenti River system (the basin of the White Sea), which are situated in its upper and middle parts, i.e., the Kostomukshskoe reservoir (tailings point) and Okunevoe, Koivas, and Kento lakes. The total length of the lake–river system is 75 km; this represents a cascade from 10 lakes alternating with areas full of rapids (figure). The main hydrological indicators of the reservoirs under study are given in Table 1.

The Kostomukshskoe reservoir is the upper reservoir of the Kenti River system; its indicators changed significantly after the construction of a dam and the river flow control. Thus, its area increased from 5.18 (1978) to 34.2 km^2 (1991) and the water volume increased from 0.017 to 0.43 km^3 (Pal'shin et al., 1994). The reservoir body is used for disposal of the finely-divided suspension and circulating water supply, as a result of which the littoral zone is largely devoid of higher aquatic vegetation. Before the construction of the plant, the waters of the lake were considered as low-mineralized (17–30 mg/L) and related to the hydrocarbonate class of calcium group, with a pH content of 6.3–6.9. Currently, the water is highly mineralized (>600 mg/L), with a weakly alkaline reaction of the medium, and relates to the sulfate class of the potassium group with a low content of organic matter and iron (Lozovik and Kalmykov, 2007). The chemical composition of the suspension entering the reservoir due to leaching of different components has a direct influence on the chemical indicators of the water of the Kostomukshskii reservoir and the downstream lakes. Starting from 1994, release of water from the reservoir has been regularly carried out in them; the average annual volume of discharged technogenic waters was 15.7 million m^3 in 1998–2004. The main influencing factor is pollution with mineral substances, specifically with sulfates and potassium. As a result, substantial changes in the ion water composition and a number of other hydrochemical indicators took place (Table 2). The discharge of organic and biogenic substances was insignificant.

The study of zooplankton was conducted within the integrated program of biological monitoring of the water bodies of the Republic of Karelia from 2009 to 2013. Sampling was made in late June–early July at 5



Scheme of lakes of the Kenti River system.

to 7 stations in each reservoir. A plankton/water sampler with a volume of 2 L was used for sampling, during which all the water layers were extracted with an interval of 1 m and a twofold replication. The integrated samples (surface-bottom) were filtered through a plankton net (with a mesh diameter of 100 microns), concentrated up to 100 mm^3, and fixed with 4-% formalin. The data on the abundance and biomass of zooplankton were averaged for each reservoir. The sample treatment was made according to the generally accepted methods of hydrobiological monitoring (*Rukovodstvo*..., 1992). The biomass of zooplankton was determined by calculation (Ruttner-Kolisko, 1977; Balushkina and Winberg, 1979). The representatives with a relative abundance of >5% were referred to structure-forming species. The biodiversity index was calculated by the Shannon–Weaver formula (Shannon and Weaver, 1963). The trophic status of reservoirs was assessed using the trophic scale for zooplankton according to the Kitaev techniques (2007). The systematics of entomostracans and rotifers is presented according to the modern concepts on the taxonomy of planktonic invertebrates (*Opredelitel'*..., 2010).

RESULTS AND DISCUSSION

Based on the results of observations conducted from 2009 to 2013, 40 crustacean and rotifer taxa were marked as part of the zooplankton in the studied res-

Table 3. Species composition of the zooplankton of reservoirs under study

Taxon	Lakes			
	1	2	3	4
Rotifera type, Eurotatoria class (De Ridder, 1957), Eurotatoria subclass (Bartoš, 1957)				
Saeptiramida order (Markevich, 1990)				
Trichocercidae family (Remane, 1933)				
Trichocerca longiseta (Schrank, 1802)	–	–	–	+
Synchaetidae family (Remane, 1933):				
Synchaeta stylata (Wierzejski, 1893)	–	–	–	+
Polyarthra dolichoptera (Idelson, 1925)	–	–	–	+
Polyarthra sp.	+	–	–	–
Bipalpus hudsoni (Imhof, 1891)	–	–	–	+
Saltiramida order (Markevich, 1989)				
Asplanchnidae family (Harring et Myers, 1925)				
Asplanchna priodonta (Gosse, 1850)	–	–	+	+
Transversiramida order (Markevich, 1990)				
Euchlanidae family (Bartoš, 1959)				
Euchlanis dilatata (Ehrenberg, 1832)	–	+	+	+
Brachionidae family (Wesenberg-Lund, 1899)				
Brachionus calyciflorus (Pallas, 1766)	–	–	–	+
Keratella cochlearis (Gosse, 1851)	–	–	–	+
K. quadrata (Muller, 1786)	+	+	+	+
Kellicottia longispina (Kellicott, 1879)	+	+	+	+
Protoramida order (Markevich, 1989)				
Conochilidae family (Remane, 1933)				
Conochilus unicornis (Rousselet, 1892)	–	–	+	+
Arthropoda type, Branchiopoda class (Latreille, 1816), Cladocera superorder				
Ctenopoda order (Sars, 1865)				
Sididae family (Baird, 1850)				
Sida crystallina (O.F. Muller, 1776)	+	+	+	+
Holopedidae family (Sars, 1865)				
*Holopedium gibberum (*Zaddach, 1855)	–	–	–	+
Anomopoda order (Sars, 1865)				
Daphniidae family (Straus, 1820)				
Ceriodaphnia quadrangula (O.F. Muller,1785)	+	+	+	+
Daphnia cristata (Sars, 1862)	+	–	+	+
D. longispina (O.F. Muller, 1785)	+	–	–	–
Scapholeberis mucronata (O.F. Muller, 1785)	+	+	–	+
Simocephalus vetulus (O.F. Muller, 1776)	–	+	+	+
Ophryoxidae family (Smirnov, 1976)				
Ophryoxus gracilis (Sars, 1862)	–	–	–	+

Table 3. (Contd.)

Taxon	Lakes			
	1	2	3	4
Chydoridae family (Dybowski et Grochowski, 1894)				
Pleuroxus truncatus (O.F. Muller, 1785)	–	–	+	+
Acroperus harpae (Baird, 1834)	–	+	+	+
Alonopsis elongatus (Sars, 1862)	–	+	+	+
Alona quadrangularis (O.F. Muller, 1785)	+	+	+	–
Alona affinis (Leydig, 1860)	–	–	–	+
Chydorus sphaericus (O.F. Muller, 1785)	+	+	+	+
Bosminidae family (Sars, 1865)				
Bosmina (*B.*) *longirostris* (O.F. Muller, 1785)	+	+	+	+
B. (*Eubosmina*) *coregoni* (Baird, 1857)	–	+	+	+
Eurycercidae family (Kurz, 1875)				
Eurycercus lamellatus (O.F. Muller, 1776)	–	–	–	+
Haplopoda order (Sars, 1865)				
Leptodoridae family (Lilljeborg, 1861)				
Leptodora kindtii (Focke, 1844)	–	–	+	–
Onychopoda order (Sars, 1865)				
Polyphemidae family (Baird, 1845)				
Polyphemus pediculus (Linnaeus,1761)	–	+	+	+
Maxillopoda class (Edwards, 1840), Copepoda subclass (Edwards, 1840)				
Calaniformes order (Dussart and Defaye, 2002)				
Temoridae family (G.O. Sars, 1863)				
Heterocope appendiculata (Sars, 1863)	–	–	+	+
Diaptomidae family (G.O. Sars, 1903)				
Eudiaptomus gracilis (Sars, 1863)	–	–	–	+
Cyclopiformes order (Burmeister, 1834)				
Eucyclopinae subfamily (Kiefer, 1927)				
Macrocyclops albidus (Jurine, 1820)	–	–	+	+
Eucyclops macrurus (Sars, 1863)	+	+	–	+
E. serrulatus (Fischer, 1851)	–	–	+	–
Cyclopinae subfamily (Burmeister, 1834)				
Cyclops strenuus (Fischer, 1851)	+	+	+	+
Mesocyclops leuckarti (Claus, 1857)	–	–	+	+
Thermocyclops oithonoides (Sars, 1863)	+	–	–	+
Megacyclops viridis (Jurine, 1820)	–	+	–	–

1–4—Lakes Kostomushskoe, Okunevoe, Koivas, and Kento, respectively. "–" means species is not present, "+" indicates species is present.

Table 4. General characteristic of the zooplankton of reservoirs over the research period

Indicator	Lakes			
	Kostomukshskoe	Okunevoe	Koivas	Kento
Number of taxa	17	19	23	34
Abundance, thousand samples/m^3	1.05	1.53	10.24	17.06
$N_{rot} : N_{clad} : N_{cycl} : N_{cal}$, %	2 : 28 : 70 : 0	5 : 12 : 83 : 0	1 : 92 : 7 : <1	12 : 66 : 21 : 1
Biomass, g/m^3	0.048	0.064	0.363	0.454
The ratio of $B_{rot} : B_{clad} : B_{cycl} : B_{cal}$, %	1 : 67 : 32 : 0	3 : 42 : 55 : 0	<1 : 93 : 6 : <1	2 : 83 : 14 : 1
Dominant species	*D. longispina, B. longirostris, C. strenuus*	*C. strenuus, B. longirostris, C. quadrangula*	*Bosmina* spp., *C. quadrangula, D. cristata*	*Bosmina* spp., *D. cristata, C. strenuus*
Shannon index with respect to abundance, bits/sample	0.55	0.62	1.4	1.72
Typification according to the trophic scale	Ultraoligotrophic	Ultraoligotrophic	Oligotroophic	Oligotroophic

ervoirs, including *Cladocera* (19 taxa), *Copepoda* (9 taxa), and *Rotifera* (12 taxa) (Table 3). The plankton complex was presented by common inhabitants of the northern reservoirs (Kulikova, 2010).

The number of species in the tailings point (Kostomukshskoe Lake) varied from 6 to 15 by years. Eight species of the total number of species (17 species) were marked only in the large-volume qualitative samples, which indicates their rare occurrence. The zooplankton of the tailings point is characterized by low quantitative indicators (Table 4). The biomass is formed due to a limited number of eurytopic structure-forming species: *Daphnia longispina* (Muller), *Bosmina longirostris* (Muller), *Cyclops strenuous* (Fischer), and *Meso-cyclops leuckarti* (Claus). The interannual variations of the biomass of zooplankton are insignificant (0.012–0.082 g/m^3) and are due to the dynamics of the abundance of the species. On the whole, one can note a quantitative predominance of cyclopides represented by nauplial and minor copepodid stages; more than half of the biomass (~70%, on average) is formed by cladocerans. The rotifers are represented by three species; their contribution in the formation of the total biomass does not exceed 1%. Based on the quantitative indicators, the zooplankton of Kostomukshskoe Lake can be referred to the ultraoligotrophic type of reservoirs according to the Kitaev trophic scale (2007).

The zooplankton of Okunevoe Lake was represented by 17 species, of which 11 species related to *Cladocera*, three species related to *Copepoda*, and the other three species related to *Rotifera*. The quantitative predominance at an early developmental stage belonged to cyclopes (83%) which were largely represented by *C. strenuus*, i.e., a eurybiontic species occurring under the conditions of strong water mineralization. *B. longirostris* dominated among cladocerans. There were an insignificant number of rotifers (4.6% of the abundance), and *Euchlanis dilatata* Ehrenberg was marked among them, which is an indicator of polluted waters. The biomass was formed by *C. strenuus*, *B. longirostris*, and *Ceriodaphnia quadrangular* (Muller). By the degree of quantitative development of zooplankton, the reservoir also relates to the ultraoligotrophic type with an average annual biomass of 0.064 g/m^3.

Twenty-three species of rotifers and crustaceans were marked as part of the planktonic fauna in Lake Koivas, 13 species of them related to *Cladocera*, five species related to *Copepoda*, and the other five species belonged to *Rotifera*. Compared with upstream lakes, the plankton complex is enriched with a number of pelagic and thicket species. Rotifers remain the smallest group in plankton, and their average abundance is 183 samples/m^3 (1% of the total abundance). The dominants of this group include *Kellicottia longispina* (Kellicott) and *Conochilus unicornis* Rousselet, which are typical components of the northern rotatory system. Cladocerans are completely prevalent both in abundance and in biomass (91 and 93%, respectively). At pelagic stations, the main background of plankton is based on the species of *Bosmina* and *Daphnia* genera (up to 80% of the total biomass). In the nearshore area, the percentage of phytophilous and near-bottom benthic species (*Sida crystalline* (Muller), *Polyphemus pediculus* (L.), and the species of Chydoridae families) is up to 45%. The copepod crustaceans are largely presented by eurybiontic species including *C. strenuus* and *Mesocyclops leuckarti* (Claus), as well as by thicket species including *Eucyclops serrulatus* (Fischer) and *M. albidus* (Jurine). The level of their quantitative development is low; on average, they comprise 6.1% of the total abundance and 6.2% of the total biomass of zooplankton. One should also note isolated cases when the copepod *Heterocope appendiculata* (Sars), which is absent in Kostomukshskoe and Okunevoe lakes, was found in samples. By the level of quantitative development, the zooplankton of Koivas Lake can be referred to oligotrophic reservoirs.

The species composition of the zooplankton of Kento Lake is represented by 34 rotifer and crustacean species, of which 17 species relate to *Cladocera*, seven species relate to *Copepoda*, and 10 species relate to *Rotifera*. By a number of traits, the plankton complex of Kento Lake obtains the features of oligotrophic reservoirs that experience a moderate anthropogenic load. The abundance of rotifers is, on average, 1200 samples/m^3 (12% of the total abundance). The dominants of this group include *K. longispina*, *Bipalpus hudsoni* (Imhof), and *C. unicornis*, which are typical components of the northern plankton complex. Cladocerans prevail both in abundance and in biomass (66 and 83%, respectively). At pelagic stations, the main background of plankton is formed by the species *Bosmina, Daphnia*, and *Ceriodaphnia*; in the nearshore area, the percentage of *S. crystalline*, *P. pediculus*, and a number of chidorids is up to 42% of the total biomass. The copepod crustaceans are largely presented by eurybiontic species (*C. strenuus* and *M. leuckarti*), as well as by thicket species (*Eucyclops macrurus* (Sars) and *M. albidus*). They take a subdominant position by the level of quantitative development (on average, 20% of the total abundance and 14.6% of the total biomass of zooplankton). Calanus representatives also appear in plankton (0.5 and 0.8% of the total abundance and biomass, respectively). They are presented by *H. appendiculata* and *Eudiaptomus graciclis* (Sars) species, which are absent in the reservoirs of the upper reaches of the Kenti River (except for isolated findings of *H. appendiculata* in Koivas Lake). These species of copepods relate to the group of plankton crustaceans with a low resistance to mineral pollution, particularly to elevated potassium and sulfate concentrations in water (Kalinkina et al., 2003; Kalinkina and Kulikova, 2009); therefore, their presence in the samples may indicate the normalization of the hydrochemical regime of Kento Lake, as compared with the upstream reservoirs. By the level of quantitative development, the zooplankton of Kento Lake can be referred to oligotrophic reservoirs with a biomass of up to 0.5 g/m^3.

The obtained results are in good agreement with the data of studies conducted in the reservoirs of the Kenti River system in 1999–2001 (Kulikova and Kalinkina, 2007). Comparison of the available materials allows one to make a conclusion on the continuation of general trends in the development of zooplankton communities over the last 15 years under continuous technogenic impact. The zooplankton of the reservoirs of the upper reaches of the Kenti River (Kostomukshskoe and Okunevoe lakes) is characterized by low quantitative indicators and a significant depletion of the species composition. The structure-forming species of zooplankton in these reservoirs can be referred to paleolimnic species (Alekseev and Starobogatov, 1996), which, in the course of their evolution, have adapted to living in reservoirs with high vibrations of abiotic factors and in temporary locations. It is noteworthy that the plankton does not have many cladoceran species that are typical for the reservoirs of Karelia, such as *Holopedium gibberum*, as well as species of Cercopagidae and Leptodoridae families and a number of other species relating to mesolimnic families. The calanus group is completely absent, representatives of which are common species in the reservoirs of Karelia. A growth in the number of species and the quantitative indicators of zooplankton is marked in the reservoirs of the middle reaches of the Kenti River (Koivas and Kento lakes), with distance from the source of mineral pollution; this indicates a gradual normalization of habitat conditions for hydrobionts (Tables 2, 4). The rates of correlation between the sum of ions and the abundance, as well as the biomass, of zooplankton in the reservoirs under study, indicate the presence of an inverse relationship (−0.66 and −0.79, which are true at $p < 0.01$), which is primarily due to the elevated concentrations of K^+, SO_4^{2-}, and HCO_3^-.

CONCLUSIONS

The plankton complexes of the reservoirs of the upper reaches of the Kenti River are represented by a limited number of eurybiontic species that can withstand elevated concentrations of inorganic substances (*B. longirostris*, *D. longispina*, *C. strenuus*, and *Keratella quadrata*). The depletion of the species composition and low quantitative indicators of the zooplankton community indicate a state of depression of the planktonic fauna of Kostomukshskoe and Okunevoe lakes. Studies of the aquatic biota of these reservoirs are important in terms of adaptive capabilities of different hydrobiont groups living under the conditions of acute mineral pollution and in cases when it is necessary to refine the list of the most resistant species.

The species diversity and quantitative indicators of the zooplankton community increase in the direction of the flow from Kostomukshskoe Lake to Kento Lake. The total number of species increases from 17 to 34; the typical inhabitants of northern brackish reservoirs appear in the plankton. The biodiversity index estimated with respect to biomass also increases from 0.55 to 1.72 bits/sample. The ratio of the dominant groups changes: the percentage of small cyclops, which represent predators with respect to the type of nutrition, gradually decreases, and the specific weight of Cladoceran filter-feeders increases.

By the level of quantitative zooplankton development, the reservoirs of the upper reaches of the Kenti River (Kostomukshskoe and Okunevoe lakes) are characterized as ultraoligotrophic lakes; the reservoirs of the middle reaches (Koivas and Kento lakes) are characterized as oligotrophic lakes. On the whole, the studies conducted show that the mineral potash–sulfate pollution of reservoirs leads to simplification of the structure and reduction of the quantitative indicators of the zooplanktonic community, as well as to the disappearance of stenobiontic species.

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