KnE Life Sciences

BRDEM-2019
International applied research conference
«Biological Resources Development and Environmental Management»
Volume 2020

Conference Paper

The State of the Lake-river System Affected By Mineral Production

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Abstract

The current state of four water bodies in the upper and middle reaches of the River Kenti system, Western Karelia, affected by long-term industrial potassium-sulphate pollution, is assessed. The upper water body of the system, Lake Kostomukshskoye, is supplied by waste water from an iron mining concentration plant. Lakes Okunevoye, Poppalijärvi and Koivas are located downstream. Analysis of some hydrochemical indices and phyto- and zooplankton communities has shown that as the distance from the pollution source increases, the hydrological regime is stabilized, species diversity increases and the quantitative indices of the biotic constituent of the lake-river system grow. For example, the total mineralization value decreases from 632 до 45 mg/l, the concentrations of major polluting agents, such as K^+ and Na^+ ions, decline by an average of two orders of magnitude and the medium reaction passes from alkaline (pH 7.7) to neutral (pH 6.8). The species composition of the phytoplankton varies from 18 to 23 species of six 6 divisions. The number of zooplankton taxa increases from 15 to 24 and average quantitative indices grow from 0.048 g/m^3 (1.1 thousand individuals/m^3) to 0.368 g/m^3 (10.3 thousand individuals/m^3), respectively. The data obtained were compared with earlier results.

Keywords: ecosystems, anthropogenic impact, monitoring, phytoplankton, zooplankton

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Received: 24 December 2019
Accepted: 9 January 2020
Published: 15 January 2020

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the BRDEM-2019 Conference Committee.

1. Introduction

The degradation of biotopes and ecosystems has been shown to be directly related to various human economic activities [1], [2], [3], [4], [5], [6]. Considerable changes in freshwater ecosystems result from various types of industrial pollution, hydraulic engineering, poorly organized commercial fishing and the acclimatization and self-colonization by new aquatic organism species.

In spite of some problems caused by the economic sanctions imposed in 2014, mining companies continue to markedly affect the biological resources of freshwater ecosystems. Kostomuksha Mining Concentration Plant, built in 1982, is one of the

biggest industrial plants in NW Russia. Production waste is supplied into an artificial reservoir storage (former Lake Kostomukshskoye), an upper water body in the water-river system of the River Kenti. The polluted water is then spreading into other water bodies of the system. Environmental monitoring is conducted to assess the impact of such big industrial complexes and to make adequate decisions for nature protection and the use of natural resources.

2. Materials and Methods

Materials for the present project were provided by the results of the integrated studies conducted in the summer and fall of 2017 on four water bodies of the Kenti River system, the White Sea basin, located in its upper and middle sectors: Kostomukshskoye Storage Reservoir and lakes Okunevoye, Poppalijärvi and Koivas.

Samples from each water body were taken at 4 - 7 hydrobiological stations in triple replication with regard for the sizes and morphology of the lakes. Samples were collected with a 2 litre planktobathometer and treated using generally accepted hydrobiological monitoring methods [7]. Several manuals were used for identification of the organisms [8], [9], [10]. The degree of organic water pollution was estimated using the indicator organisms revealed in the phyto- and zooplankton by the method of Pantle-Bukk modified by Sladeček [11]. The trophic status of each water body was estimated from the nutrient content scale after S.P. Kitaev [12].

3. Results and Discussion

Hydrochemical regime. The lake system of the River Kenti, flowing through 10 lakes into Lake Sredneye Kuito, is part of the Kemi River watershed (Figure 1). Lake Kostomukshskoye (a tailings storage) (30°50' N and 64°40' E) is the upper water body of the Kenti River system. As a result of dam construction, the hydrological and hydrochemical indices of the lake have markedly changed. Most lakes of the Kenti River system are small and lotic, except for two lower lakes, Koivas and Kento, the biggest lakes with slow water exchange (Table 1). 10-20 M m^3 of water are discharged from the tailings storage every year since 1994, depending on the annual amount of water. The effect of human activities on the Kenti River system is generally related to the discharge of mineral substances, such as potassium and sulphates, as well as nitrates, lithium and nickel. Before the construction of the mining concentration plant the lake water was poorly mineralized (17-30 mg/l) and was classified as water of the hydrocarbonate class,

calcium group. Its pH value was 6.3-6.9. The water is now highly mineralized (over 600 mg/l), displays a weakly alkaline medium reaction, belongs to a sulphate class and a potassium group and contains low organic matter and iron concentrations [13]. The chemical composition of the suspension supplied into the lake because of the leaching of various components directly affects the chemical indices of the water of Kostomukshskoye Storage Reservoir and the lakes located downstream (Table 2).

Table 1: Hydrological indicators of lakes of the Kenti river system [14], [15].

Indicator	L. Kostomukschskoye	L. Okunevoye	L. Poppalijärvi	L. Koivas
Water surface area, km^2	34,2	0,3	1,6	21,4
Catchment area, km^2	68,4	51,0	128	356
Average depth, m	-	2,6	4,3	4,1
Maximum depth, m	25	5,6	10,7	23
Water volume, million m^3	430	0,86	7,3	89,6
Period of conditional water exchange, day	-	15	65	285

Table 2: Hydrochemical indicators in lakes of the Kenti river system.

Indicator	L. Kostomukschskoye	L. Okunevoye	L. Poppalijärvi	L. Koivas
K^+, mg/l	158,3	155,7	43,2	34,4
HCO_3^-, mg/l	120,1	110,1	75,1	59,8
SO_4^{2-}, mg/l	411,2	345,4	171,8	120,3
Σ ion, mg/l	713	635	294,7	64,3
pH	7,7	7,4	7,2	7,05

Phytoplankton. The results of our monitoring conducted in 2017 showed that the phytoplankton of the water bodies studied consisted of 40 subgenus-ranking algal taxa of 6 divisions such as diatoms (Bacillariophyta) -- 13 (32%), green algae (Chlorophyta) -- 16 (40%), dynophytes **(**Dynophyta) -- 2 (5%), blue-green algae (Cyanophyta) -- 6 (15%), cryptophytes (Cryptophyta) -- 1 (3%) yellow-green algae (Chrysophyta) -- 2 (5%). The highest species diversity in plankton is displayed by green algae and diatoms which collectively make up 72% of the total species composition. The quantitative indices of the phytoplankton community for each water body are shown in Table 3.

Lake Kostomukshskoye (tailings storage). Its phytoplankton, consisting of 7 diatom species, is qualitatively and quantitatively poor. The pelagic zone is dominated by *Aulacoseira islandica, Fragilaria capucina* and *Fragilaria sp.* The plankton of the littoral

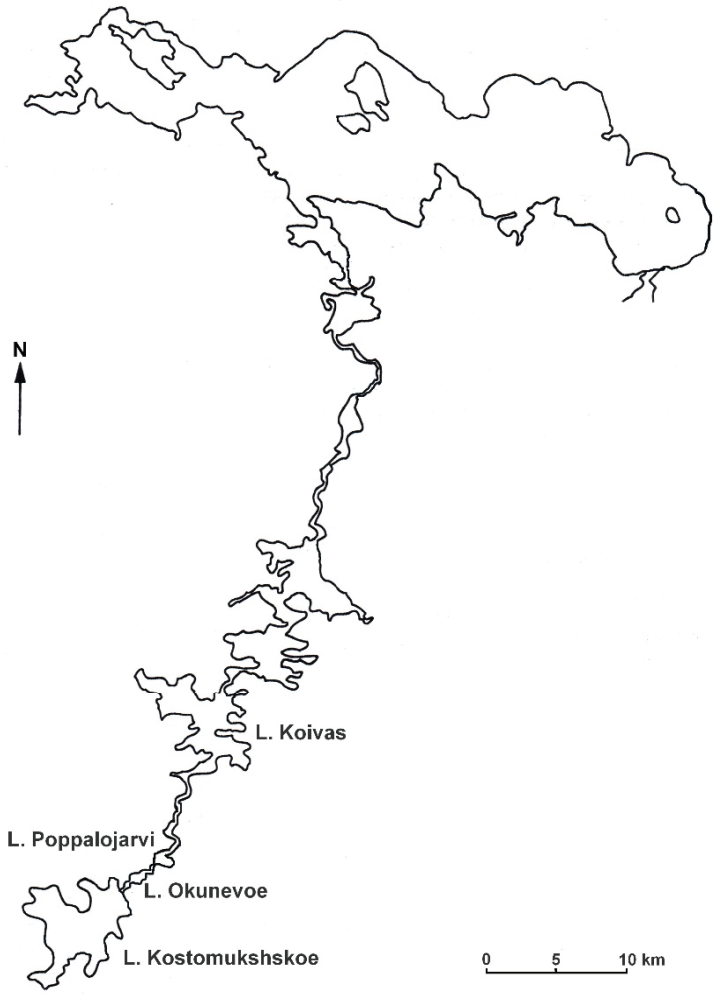

Figure 1: Scheme of location of the investigated water bodies.

zone is enriched in large forms of benthic diatom species (species of the genera *Pinnularia* and *Cymbella*), affecting abundance indices.

Lake Okunevoye. Its phytoplankton consists of 22 algal species of 4 divisions: diatoms -- 8 (36%), green algae -- 10 (46%), dynophytes -- 2 (9%) and blue-green algae - 2 (9%). The numbers of species of all systematic divisions in the pelagic and littoral zones do not differ markedly. Diatoms are the most abundant, making up 49% and 58% in the pelagic and littoral zones, respectively. The bulk of the biomass is formed of dynophytic algae (71%) in the pelagic zone and by diatoms (94%) in the littoral zone. Cenosis-forming taxa are represented by *Peridinium pigmaeum*, *Fragillaria acus* and *F. nana*.

Lake Poppalijärvi. Its phytoplankton consists of 20 algal species of 5 divisions: diatoms -- 5 (25%), yellow-green algae -- 2 (10%), green algae -- 8 (40%), blue-green algae -- 4 (20%) and cryptophytic algae -- 1 (5%). Green and blue-green algae and diatoms are the most diverse, collectively making up 85% of all the species revealed. Diatoms (52% and 61% in the pelagic and littoral zones) are the most abundant. The bulk of the biomass is formed of diatoms: 95% in the pelagic zone and 87% in the littoral zone. The diatom *Puncticulata comta* is a mass species in the pelagic zone, making up 51-59% of the total abundance and 85-93% of the total phytoplankton biomass. The yellow-green alga *Dinobryon divergens* is another mass species, whose contribution to the total abundance of phytoplankton in the pelagic and littoral zones was 15-16%. Most of the plankton species occurring in the lake are indicative of oligo- or β-mesosaprobic conditions.

Lake Koivas. Its phytoplankton consists of 26 algal species of 6 divisions: diatoms -- 10 (38%), green algae -- 10 (38%), blue-green algae -- 3 (12%), cryptophytic algae -- 1 (4%), dynophytic algae -- 1 (4%) and yellow-green algae -- 1 (4%). The numbers of species in the systematic divisions of algae in the pelagic and littoral zones do not differ considerably. Green, blue-green algae and diatoms are equally abundant in the pelagic and littoral zones (30% on the average). The bulk of the biomass is formed of diatoms and blue-green algae: 47% and 40% in the pelagic and littoral zones, respectively. Diatoms (*Puncticulata comta, Aulacoseira islandica, Tabellaria flocculosa*) and blue-green algae (*Phormidium tenue*, *Merismopedia tenuissima*) contribute mostly to abundance indices. Mass algal species, characteristic of β-mesosaprobic environments, contribute markedly to quantitative indices. Two blue-green algal species, *Ph. tenue* and *M. tenuissima*, are indicative of β-α-mesosaprobic conditions.

Table 3: Quantitative indicators of phytoplankton (P -- pelagial, L -- littoral).

Lake	Abundance, thousand cells/l		Biomass, g/m^3		Saprobity	
	P	L	P	L	P	L
Kostomukshskoye	52	95	0,048	0,076	1,50	1,50
Okunevoye	313	96	0,305	0,094	1,55	1,75
Poppalijärvi	154	247	0,434	0,292	1,50	1,55
Koivas	121	66	0,125	0,077	1,76	1,76

Zooplankton. Our 2017 monitoring showed that the zooplankton of the above water bodies consists of subgenus-ranking crustaceans and rotifers: Cladocera -- 19, Copepoda -- 9 and Rotifera -- 9. The main indices for the zooplankton community are shown in Table 4.

Lake Kostomukshskoye (tailings storage). Its zooplankton is qualitatively and quantitatively poor. Four out of nine species were revealed only in large qualitative samples, suggesting their scarcity. The community is dominated by a limited number of eurytopic structure-forming species such as *Bosmina longirostris, Cyclops strenuus, Mesocyclops leuckarti* and *Daphnia longispina*. The cyclops Cyclopiformes are the most abundant, while Cladocera make up over ½ of the biomass (about 7-% on the average). Rotifera are represented by 3 species, making up no more than 1% of the total biomass.

Lake Okunevoye is another water body in the Kenti River system located downstream from the tailings storage. Its hydrochemical regime is totally controlled by the composition of the waste water supplied. Okunevoye Lake zooplankton is similar to Kostomukshskoye Lake zooplankton in poor species composition, low quantitative indices and the same predominant species. The community consists of 17 species: Cladocera -- 9, Copepoda -- 3 and Rotifera -- 5. The highest abundance indices in the study period were displayed by Cladocera (55%) and Rotifera (34%) dominated by eurybiotic species capable of withstanding highly mineralized aquatic environments: *B. longirostris*, *Chydorus sphaericus* and *Keratella quadrata*. The lake biomass is dominated (74%) by *B. longirostris, D. longispina* and *Ch. sphaericus*.

Poppalijärvi Lake zooplankton displays higher species diversity and abundance indices than the tailings storage and Lake Okunevoye. The list of species consists of 19 taxa, of which three are stenobiotic species poorly resistant to mineral pollution. These are *Heterocope appendiculata, Leptodora kindtii* and *Bythotrephes longimanus,* which actually disappeared in the 1990s -- 2000s. [16]. The presence of these species have led us to tentatively conclude that the plankton organisms adapt gradually to elevated water mineralization levels and normalizing ecological conditions in the lake. Eurytopic Cladocera species predominate and form the bulk of the biomass.

Koivas Lake zooplankton consists of 26 rotifer and crustacean species: Cladocera -- 15, Copepoda --5 and Rotifera -- 6. The planktonic complex is enriched in some pelagic and thicket species that do not occur in the lakes located upstream. Cladocera prevail in both abundance and biomass (92% and 93%, respectively). At the pelagic stations the plankton is dominated by pp. *Bosmina и Daphnia* (up to 80% of the total biomass), while in the littoral zone phytophylic and near-bottom-benthic species (*Sida, Polyphemus* and species of the family *Chydoridae*) make up 45% of the total biomass. Copepoda are represented by the eurybiotic species *C. strenuus* and *Mesocyclops leuckarti* and the thicket species *Eucyclops serrulatus* and *Macrocyclops albidus*. The samples also contain the stenobiotic species *Heterocope appendiculata* and *Leptodora kindtii* that do not occur in lakes Kostomukshskoye and Okunevoye.

Table 4: General characteristics of zooplankton.

Indicator	L. Kostomukshskoye	L.Okunevoye	L.Poppalijärvi	L.Koivas
Total number of taxa	9	17	19	26
Number of taxa in the sample	5,3±1,25	9,8±1,92	13,0±2,45	15,6 ± 4,32
Shannon Index Of (H_N)	0,82±0,13	1,13±0,31	1,57±0,32	1,62 ±0,22
The average number (min-max), thous. ind./m^3	1,25 (0,42-2,85)	6,12 (2,15-18,05)	39,65 (29,3-56,4)	10,29 (3,21--26,75)
Average biomass (min-max), g/m^3	0,048	0,096 (0,016-0,188)	0.454 (0.152-0.808)	0,368 (0,122--0,504)
Dominant species	*C. strenuus B. longirostris*	*C. strenuus B.longirostris*	*Bosmina spp. D. longispina C.strenuus*	*Bosmina spp. C. quadrangula D. cristata*
Trophicity type	ultraoligotrophic	ultraoligotrophic	oligotrophic	oligotrophic

4. Conclusion

The results obtained show that the species diversity of the phytoplankton community in the Kostomukshskoye-Koivas lake system gradually increases from 7 (1 division) to 26 species (6 divisions). Quantitative indices also increase gradually in the direction of runoff. The phytoplankton is dominated by diatoms and green algae. Most of the above species are indicative of oligosaprobic or β-mesosaprobic conditions. The saprobity index values obtained (S=1.50-1.76) show that the water in all the water bodies studied is of quality class 3 (satisfactorily pure), grade 3a (satisfactorily pure), which is consistent with a β-mesosaprobic zone on the saprobity scale. The quantitative growth of phytoplankton shows that all the water bodies studied represent an ultraoligotrophic type on the nutrient supply scale [12].

Comparison of our data on zooplankton with 1999–2001 data [17] has led us to conclude that the general evolution trend of the zooplankton communities in the past 20 years has remained unchanged. The zooplankton of the water bodies in the upper reaches of the River Kenti (lakes Kostomukshskoye and Okunevoye) display low quantitative indices and markedly impoverished species composition. Structure-forming zooplankton species in these water bodies may be identified as paleolimnic [18]. While evolving, they gradually adapted to living in water bodies with highly variable abiotic factors. The absence of many Cladocera species typical of Karelia's water bodies, such as *Holopedium gibberum*, species of the families *Cercopagidae*, *Leptodoridae* and some other (mesolimnic) species, is noteworthy. As the distance from the mineral pollution source increases, the number and abundance indices of zooplankton species are observed to grow, suggesting that the ambient conditions of the aquatic organisms

gradually become normal (Table 3). The quantitative evolution of lakes Kostomulshskoye and Okunevoye shows that they are ultraoligotrophic, while lakes Poppalijärvi and Koivas are oligotrophic. The correlation coefficients between total ions and abundance and the biomass of zooplankton in the above water bodies are indicative of a negative feedback (-0.68 and -0.82 valid at $p<0.01$), which is primarily due to elevated K^+, SO_4^{2-} and HCO_3^- ion concentrations. The results obtained show that as a result of the mineral potassium-sulphate pollution of water bodies, the structure of the zooplankton community becomes simpler, its quantitative indices decrease and stenobiotic species disappear.

Funding

This work was supported from the federal budget for implementation of state task No. [0218-2019-0081], and by the Russian Fund for Basic Research, Grant No. [18-04-00163].

Acknowledgement

The authors would like to thank their colleague for their contribution and support to the research. They are also thankful to all the reviewers who gave their valuable inputs to the manuscript and helped in completing the paper.

Conflict of Interest

The authors have no conflict of interest to declare.

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