Phytoplankton of unique karst lakes (by the example of the Lake Klyuchik, the basin of the Cheboksary Reservoir)

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Abstract. The features of the composition, development and spatial distribution of phytoplankton of a small highly mineralized karst low-temperature lake (Lake Klyuchik or Svyatoe Doskinskoe, Nizhny Novgorod Region) with atypically high for the forest zone (subzone of mixed coniferous and broad-leaved forests) values of water salinity are considered. The lake is characterized by an expressed ecotone in terms of hydrological and hydrochemical indicators.

1. Introduction
Middle Volga basin, including the Cheboksary reservoir, is the zone of the classical manifestation of Karst, presented in this area by various forms. The reservoirs formed in the sites of these sinkholes are often characterized by a unique combination of environmental parameters, a specific composition and a structural and functional organization of hydrobionts developing here [11]. On the territory of the Nizhny Novgorod Volga region, the lake Klyuchic with its unique characteristics is regarded to be one of natural-historical monuments of nature. The purpose of this work was the determination of the composition and the basic parameters of the coenotic structure of phytoplankton in a unique combination of environmental factors in the presence of an ecotone effect.

2. Materials and methods
Lake Klyuchik is located in the Pavlovsky district of the Nizhny Novgorod region (55.975452, 43.327220) in the downstream basin of the Surin spring of the right tributary of the river Kishma, which, in turn, is the right tributary of the river Oka. In the right bank part of the Pavlovsky district, where erosion incisions are numerous in the area of the river Kishma and her tributaries karst processes are widespread. The process of dissolving rocks in the lake is actively continuing now [2]. According to the morphometric characteristics the lake Klyuchic refers to the class of small water bodies, has an oval shape, stretched from west to east, with a weakly sinuous coastline and moderately steep coastal slopes. The lake is distinguished by a complex bottom relief – it is uneven, with pits, sandy-silty [1].
In terms of mineralization and electrical conductivity, the lake Klyuchik refers to saltwater reservoirs [3]. Water in the western part of the lake is painted in a bluish colour, in the central and eastern parts – in green. Water chromaticity is gradually increasing from 40 degrees in the western part of the lake to 62 and 80 degrees in central and eastern parts. Source of underground nutrition of the lake – the Surin River, located in the western part of it and is unloaded in the voklina at a depth of 15 m [8]. Because of this, in the winter period, the lake is not completely covered with ice. The western part of the lake does not freeze even in the coldest winter, is characterized by a uniform vertical temperature distribution, oxygen content and pH magnitude throughout the year [3]. In the transition zone (from the western part to the central), maximum changes in hydrological and hydrochemical indicators are recorded.

The phytoplankton integral samples were taken in June-September 2020 by the Ruttner bathometer at five stations, selected taking into account the hydrochemical features of the lake – station 1 and 2 were located in the western part of the reservoir; 4 and 5 – in central and eastern, respectively; 3 – in the transitional ecotone zone. In parallel with the collection of algological material, the main hydrophysical indicators were measured and samples were selected for hydrochemical analysis (st. 1, 3, 5). The determination of hydrochemical indicators was carried out on the basis of the Center for the Collective Use "New Materials and Resource-Saving Technologies" of the Scientific Research Institute of Chemistry of Lobachevsky State University.

Method of collecting material, preparation of it to microscopy, list of guides used when specifying species were discussed in the previous publications. From the parameters of the algocenoses structure the number (N, Mln CL/L), biomass (B, g/m³), specific species wealth (α-diversity, SP – the number of species in the sample), Shannon diversity index for numbers (HN, bit/Ex) and biomass (HB, bit/g), Simpson dominance index (DN) and biomass (DB), Piel alternation (EN and EB) are investigated. The dimensional structure of algocenoses was estimated by the average coenotic volume of the cell in the sample (Vc, μm³ × 10-3, B/N). The dominant species are those, the number or biomass of which was at least 10 % of the total value [10]. The similarity of the parameters of algocenoseses was evaluated using the Mann–Uitney criterion (U-criterion). Statistical processing is made in the Statistica 8.0 software package.

3. Results and discussion

During the study period, the transparency of water in the lake Klyuchik varied from 3.4 to 6.5 m. In the ecotone zone (st. 3) the values of transparency were less and were determined by a slight depth (up to 1 m). The temperature of the surface layer of water in the western part of the lake (st. 1, 2) during the studies was 7.0-8.4°C in the central shallow water (st. 3, the isthmus) and the eastern parts of the lake (st. 4, 5) – 18.3-21.6°C. Vertical stratification of water strata in the lake was absent. Oxygen concentration in the eastern part of the lake Klyuchik was from 9.1 to 13.7 mg O₂/l (saturation % is more than 115 %). The highest values of this indicator (9.8-14.6 mg O₂/l) were recorded in the ecotone zone. The western part was characterized by a low oxygen content (3.7-12.5 mg O₂/l; 30-57 % saturation) in the surface horizon and the presence of hydrogen sulphide in water, probably due to the influence of an underground flow from swallow hole in this part of the lake. The pH indicator ranged from neutral alkaline to the medium oligo alkaline reaction, and as a rule was higher in an eastern well-warmed part of the lake, where significant thickets of higher aquatic plants are located.

From hydrochemical perspective the water of the lake was characterized by high mineralization (range 1100-1274 mg/dm³), the electrical conductivity varied from 1682 to 1985 μS/cm (these indicators were higher in the western part of the lake than in the ecotone zone and in the eastern part). Concentration of sulphates in the lake Klyuchik was high (from 890 to 1100 mg/dm³) when the content of hydrocarbonate ions varied from 73 to 160 mg/dm³. The reservoir demonstrated high concentrations of phosphates, nitrate and nitrite forms of nitrogen. According to these indicators, the quality class of water was evaluated as a "dirty – very / extremely dirty waters" [9]. The concentration of iron in the surface horizon of the reservoir (0.05-0.10 mg/dm³) corresponded to the very low content in natural waters. The concentration of silicon was within the limits of average values for
continental reservoirs (from 2.9 to 6.2 mg/dm$^3$) [7]. The content of this element was significantly higher at st. 1, where lake water is mixed with the waters of the underground river flowing from the voklina. Calcium content was 240-400 mg/dm$^3$, which several times exceeds the concentration of this element in the surface waters of moderate mineralization (up to 50 mg/dm$^3$) and is more characteristic of groundwater with a high content of bicarbonates and for water saturated with plaster.

The obtained data on the hydrochemical composition of the water of the lake Klyuchik is mainly consistent with the data of the studies of karst lakes with the corrosion-sinkhole origin of the hollows of other regions [6]. Such funnel-lakes are hydrogeological windows, in which the lower part of the lake hollow is developed below the level of groundwater, mainly has an underground nutrition carried out through the swallow hole at the bottom of the hollow. The hydrochemical water composition of this type of lakes is characterized by relatively high mineralization, often more than 500 mg/dm$^3$ (range 350-1100 mg/dm$^3$), the values of the hydrogen indicator in them vary in the range of 6.8-7.5. In the case when the nutrition from indigenous karst sulphate sediments is dominated in the lake waters, an increased content of sulphate ions is recorded in the range of 300-700 mg/dm$^3$ (as noted in the lake Klyuchik) when the content of hydrocarbonate ions varies from 50 to 150 mg/dm$^3$ [6].

In algal flora of the Lake Klyuchik 133 species and infraspecific taxons of algae were revealed, as well as taxa defined to genus, which belonged to 9 divisions [5]. In creation of general species wealth, the leading role belonged to diatomic algae (Bacillariophyta), which formed 46 % of the diversity of the general list of species. Other systematic groups were represented in a poorer way: Chlorophyta (24 %), Chrysophyta (11 %), Cyanoprokaryota (8 %), Xanthophyta, Raphidophyta, Euglenophyta, Cryptophyta and Dinophyta (every less than 3 %). In the summer season, the basis of algocenosis in the western cold-water portion of the reservoir was diatomic algae.

Representatives of centric diatoms – Cyclotella distinguenda Hustedt and Handmannia comta (Ehrenberg) Kocio.Lek & Khursevich were the most numerous ones. The representatives of Melosira, Ulnaria, Navicula, Pinnularia and Nitzschia were also met. Representatives of this division formed up to 97-99 % of the total biomass values here. C. distinguenda – rare, atypical for ponds in coniferous-broadleaved forests of the basin of the Volga river type of centric diatoms – was noted in a group of structure-forming species with 100 % of the dominance frequency, or as the main component of the cenosis, or in a complex with pennate diatoms from the genus of Navicula and Pinnularia. This species created from 24.4 % to 74 % of the total number and from 17.5 to 80.2 % of the total biomass of phytoplankton. In the autumn, the contribution of C. distinguenda to general numbers and biomass amounted to 96.7 and 92.5 %. The quantitative indicators of phytoplankton in this season increased to the values characteristic of eutrophic hypertrophic water (up to 19.68 million kl./L and 27.82 g/m$^3$, respectively).

In the ecotone zone in summer, there was a decrease in the coenotic role of diatoms (up to 55-56 %) and the increase in the role of phytoflagellate (up to 38 % of dinoflagytic and 15 % cryptomonads). In terms of numbers, small-cell green algae (genus Oocystis – up to 35 %) and cyanobacteria (genus Aphanocapsa – up to 54 %) are leading. At the beginning of the autumn, the leading position of diatoms was restored, which may be due to a seasonal decrease in the water temperature and the intensification of the flow of water with the underground river. In this part of the reservoir, the formation of algocenosis was noted with the predominance of large-cell diatoms, including C. distinguenda. They created up to 63 % of the total biomass of phytoplankton. However, abnormally high presence of the abundance (biomass up to 130 g/m$^3$) against the background of the formation of oligodominant cenosis with the dominance of C. distinguenda, as it was in 2017 [5], was not observed. The phytoplankton of the central and eastern parts of the lake was characterized by a more variegated composition of the dominant species and the enhancement of the role in its structure of phytoflagellate (up to 50-70 % of the total biomass values). As the main dominants in number, fine-cell cyanobacteria from the genus Aphanocapsa (up to 44 %) and green algae from the genus Oocystis (up to 72 %) were most often registered here. According to the biomass, representatives of the phytoflagellates of the type Carteria (up to 42 %), Cryptomonas (up to 27 %), Peridinium (up to 52 %), Ceratium hirundinella (O.F.Müller) Dujardin (up to 22 %) dominated almost exclusively. The phytoplankton community in
the warm-water eastern zone was distinguished by greater productivity. The average calculation of the number and biomass of algae here was higher than 13.5 and 4.1 times, respectively.

The difference between the structure of algocenosis of the warm-water and cold-water parts of the lake was also manifested in other coenotic indicators. So, in the western cold-water part of the lake, lower species diversity values were noted (HB: from 1.29 to 2.68), higher degree of dominance (DB: from 0.21 to 0.65) and the average value of cell volume (Vc: from 977.74 to 2422.27). The differences were statistically significant. The basis of this phytoecenosis was constituted by large cell diatoms with a pronounced domination of C. distinguenda. On the contrary, in the eastern warm-water part in algocenosis, various fine-cell cyanobacteria, chlorococcal green and cryptophyted algae were present.

4. Conclusion

Thus, in summer season in the western and the eastern parts of the lake, two excellent algocenosis structures were formed, the existence of which was determined by hydrological, hydrophysical and hydrochemical features of the reservoir. The abiotic conditions of the lake identified the relative poverty of the total composition of phytoplankton, in comparison with the meso-eutrophic reservoirs of the middle Volga basin. High mineralization of waters, favourable light conditions, low temperature background, thermal stability of aqueous thickness in the presence of a pronounced ecotone effect in some years contributed to the formation of diatom algocenosis with a uniquely high for Volga basin reservoirs biomass [5]. In an interannual aspect, the structural organization of the phytoplankton of the lake (the formation of unique diatom complexes, monodominization, a decrease in the conditions of a low-temperature background of the role of phytoflagellate) was sufficiently similar.

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