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Phytoplankton biodiversity and its relationship with aquatic environmental factors in Lake Uvildy, South Urals, Russia

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Abstract. *Kostryukova AM, Mashkova V, Krupnova TG, Egorov NO. 2018. Phytoplankton biodiversity and its relationship with aquatic environmental factors in Lake Uvildy, South Urals, Russia. Biodiversitas 19: 1422-1428.* Lake Uvildy is one of the largest and the most unique of the South Ural region lakes. This mountain deep lake, which has the status of a natural monument. The purpose of this paper was to study the phytoplankton community structure and the aquatic environmental factors in Lake Uvildy. The phytoplankton samples were collected from 5 sites of Lake Uvildy, then filtered through the plankton net and were preserved in 5% formalin. Species were identified using the handbooks by Sladecek, Yarushina, and Al-Kandari. Water samples were taken for water quality analysis. The several physicochemical parameters were measured in situ by a Portable Meters (Multitest IPL-513 and Multitest KSL-111, Semico Ltd, Russia, Novosibirsk). The others parameters were measured in the laboratory of the Department of Chemistry of the South Ural State University according to the standard methods. The sampling was made during the vegetation period in June-July 2014. The water quality was evaluated using the Shannon biodiversity index. A total of 38 species (11 phyla, 31 genera), including 9 species of Chlorophyta, 13 species of Bacillariophyta, 9 species of Cyanophyta, 4 species of Euglenophyta, 2 species of Chrysophyta, 1 species of Dinophyta, were identified. The phytoplankton species in the lake were mainly represented by Cyanophyta and Bacillariophyta. There were 5 dominant species: *Fragilaria crotonensis, Asterionella formosa, Dolichospermum lemmermannii, Microcystis aeruginosa,* and *Coenococcus planktonicus*. The Shannon index value comprised 1.27-2.21. According to the saprobity index values (1.63-2.35), the water in the late is evaluated as satisfactorily clean. Physico-chemical parameters were factors driving the change in phytoplankton community composition in Lake Uvildy.

Keywords: biodiversity, phytoplankton, environmental factors, lake, Shannon index.

INTRODUCTION

Phytoplankton is a very diverse group of aquatic organisms, incorporating such the major types are diatoms, golden-brown algae, blue-green algae, green algae and dinoflagellates, and as a primary producer it is an important link in aquatic ecosystems (Barinova et al. 2006). The species composition of algae can be an indicator of the algal flora living conditions, and hence the condition of the water body. Thus, studying the phytoplankton community is widely used to evaluate the water quality (Devi et al. 2016).

For efficient monitoring and maintaining the ecological status of water bodies, it is very important to know about various physicochemical and biological water characteristics. Namely, physicochemical water quality indices are the main factors controlling the phytoplankton dynamics and structure. Chemical indices, for example, biogenic elements (Zhu et al. 2010; Kruk et al. 2016), and physical indices-sunlight intensity (Sánchez et al. 2017) or water temperature, etc., can also be also significant. The investigation results (Zhu et al. 2010) obtained from a water body (China) indicated that different concentrations of nitrogen and phosphorus may define the predominant species growth. Kruk et al. (2016) conducted studies on the relationships between nutrients and phytoplankton during one-day hot summer conditions. The investigation results showed that the Cyanoprokaryota biomass depends on for the limited resources of Dissolved Inorganic Nitrogen (DIN) and in the part of the Vistula Lagoon (the southern Baltic Sea), where DIN concentrations were reduced, was above. Sánchez et al. (2017) examined the primary production of phytoplankton and periphyton under such regimes as clear-vegetated, inorganic-turbid or phytoplankton-turbid. For example, Rasconi et al. (2017) studied the influence of the water temperature on the phytoplankton diversity and found that the temperature significantly reduces the biodiversity and leads to the dominance of blue-green and green algae that are more adapted to elevated water temperatures.

Lake Uvildy is located in Chelyabinsk region (South Urals), Russia. Lake Uvildy is the largest and unique lakes in the region. Basic morphometric parameters of Lake Uvildy: the height above the sea level is 272 m, the water surface area is 68.1 km^2, the maximum and average depths are 38 and 13 m (Kostryukova et al. 2015). The lake is a typical tectonic water body and located in a deep range front fault. Most of the winding coastline is covered with pine and mixed forest. The lake water is fresh, by the chemical composition it refers to the hydrocarbonate-calcium type, and by the ion ratio-to the sulfate-sodium (Andreeva 1973).

In 1974-1978, the South Urals experienced the water scarcity as a result of a drought. To solve this problem, a canal was dug between Lake Uvildy and the Argazi Reservoir to discharge water (over one-third of the lake's volume). The water level of the lake decreased by almost 4 m, and significant coastal areas became bare. During the secondary succession, birch forests began to form here. In 1999 there was a water rise, and in 2007 the water level in the lake returned to its average long-term value. Biocoenoses, together with the forming soil cover, were flooded. As a result, many small shallow bays were formed. Both the littoral zone and the coastal geosystems of the water body have changed. As a result, the quality of coastal waters and the degree of the recreational comfort in the coastal zone deteriorated. Earlier, the lake had an oligotrophic status, currently, it has a transitional status between oligo-and mesotrophic. This water body is a natural monument and widely used for recreational purposes.

The species composition of the phytoplankton community of Lake Uvildy was studied earlier. The previous studies of phytoplankton of the Lake Uvildy in 2005-2006 and 2014 revealed diatoms as a dominant algal group, green algae as the second in species diversity in 2005-2006, and blue-green algae became second in species diversity in 2014 (Kostryukova et al. 2015; Mashkova et al. 2017). The most abundant blue-greens were *Anabaena lemmermannii*, *Microcystis aeruginosa* and *Anabaena flos-aquae*, the most numerous diatoms were *Fragilaria crotonensis* and *Asterionella formosa*, greens were *Coenococcus planctonicus* (Kostryukova et al. 2015). The aim of this paper was to investigate the phytoplankton richness and ecological water condition in Lake Uvildy.

MATERIALS AND METHODS

Study area

Lake Uvildy is located in the north of Chelyabinsk region (South Urals)(Figure 1), 80 km north-west of Chelyabinsk City, Russia. The lake is a natural monument, and since the 1970s it has been included in the international list of the most valuable lakes in the world.

The studies were conducted in June-July 2014 (Mashkova et al. 2017). For the study, five sites were selected at Lake Uvildy (Figure 1, Table 1).

Procedures

Identification of phytoplankton species

At each site, the samples were collected and then filtered through the plankton net (mesh size: 100 µm). The retained organisms were transferred into glass containers, and the collected material was preserved in 5% formalin (Abakumov 1983).

Non-diatom algae were analyzed using a magnification of 600× (Altami BIO 2T microscope, Altami Ltd, Russia, St. Petersburg.). Permanent diatom slides were prepared after oxidizing the organic material (by nitric acid and sulfuric acid), and at least 300 valves were counted for each sample using an Altami BIO 2T microscope at 1000× under oil immersion.

Species were identified using the handbooks by Sladecek (1973), Yarushina et al. (2004), and Al-Kandari et al. (2009).

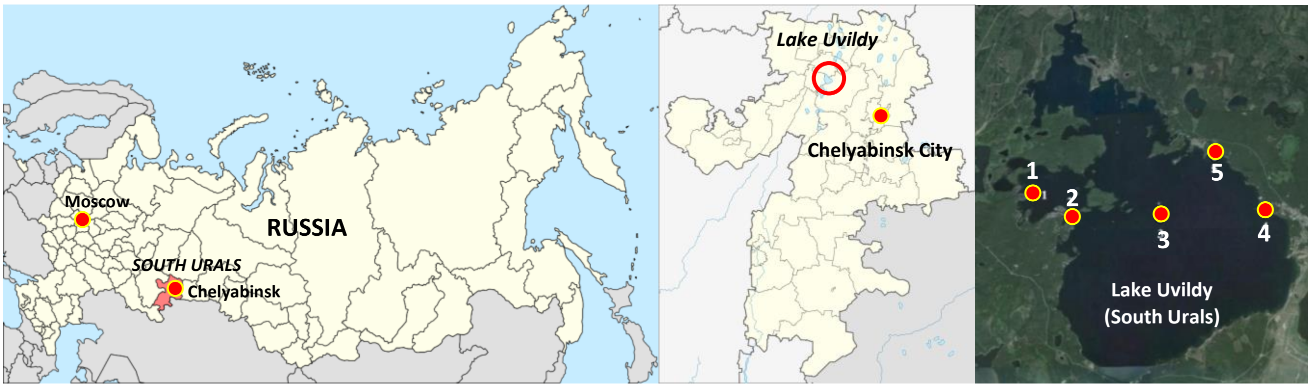


Figure 1. Map of the South Urals region and location of the sites Lake Uvildy (South Urals), Chelyabinsk, Russia

Table 1. Coordinates of sites on Lake Uvildy (South Urals), Chelyabinsk, Russia

Sites	Coordinates	Characteristics
Site 1	55 ° 32'9.13 "N, 60 ° 25'34.05" E	The sites are located in the zones of the densest recreational load of the coast (various sanatoriums, recreational centers, settlements) and flooded tree and shrub vegetation located at the distance of 50-70 m from the shore. The water in the studied areas is characterized by turbidity and high chromaticity.
Site 2	55 ° 31'47.91 "N, 60 ° 26'50.46" E	
Site 3	55 ° 31'41.29 "N, 60 ° 29'58.96" E	
Site 4	55 ° 31'47.42 "N, 60 ° 33'38.89" E	
Site 5	55 ° 32'55.95 "N, 60 ° 31'54.10" E	The site in the center of the lake was chosen as a background site.

Analysis of the physicochemical parameters

The following instream parameters, including pH, dissolved oxygen (DO), and water temperature (WT) were measured in situ by a Portable Meter (Multitest IPL-513, Semico Ltd, Russia, Novosibirsk). The conductivity (COND) and salinity (SALIN) were measured in situ by a Portable Meter (Multitest KSL-111, Semico Ltd., Russia, Novosibirsk).

At each site, water samples were also collected for further laboratory analysis, including redox potential (Eh), nitrate-nitrogen (NO_3^-), nitrite-nitrogen (NO_2^-), ammonium-nitrogen (NH_4^+), orthophosphate-phosphorus (PO_4^{3-}), chlorides (Cl^-), sodium (Na^+), potassium (K^+), total hardness (H), calcium hardness (Ca^{2+}), bicarbonates (HCO_3^-), permanganate oxidability ([O]), and total iron (Fe). For spectrophotometric analysis, the Spectrophotometer KFK-3 was used. All the parameters were measured in the laboratory of the Department of Chemistry of the South Ural State University according to the standard methods (Mashkova et al. 2017).

Data analysis

The Shannon inhomogeneity index was used to evaluate the phytoplankton community structure (Motwani et al. 2014):

$$H = -\sum_{i=1}^{N} p_i \cdot \ln p_i , \tag{1}$$

Where: $p_i = n_i / N$ is the share of the i-th species in the biotope, n_i is the number of the i-th species, N is the total number of organisms.

To determine the taxonomic similarity, we used the Sorensen-Chekanovski quantitative similarity index calculated using ExcelToR, an application for sharing Microsoft Excel and a statistical processing program "R" (Nowakowski 2016).

The Sorensen-Chekanovski index:

$$K_S = \frac{\sum_{i=1}^{N} \min(A_i, B_i)}{\sum_{i=1}^{N} A_i + \sum_{i=1}^{N} B_i} , \tag{2}$$

Where: A_i is the number of organisms of the i-th species in community A, B_i is the number of organisms of the i-th species in community B, N is the total number of species in the corresponding community.

To evaluate the degree of the water body's contamination, we used an extended method to analyze the saprobity of water bodies based on Pantle-Bucc method (Barinova et al. 2006) in the Sladecek modification (Sladecek 1973), using the indices of the number of cells of the indicator species and the value of the indicator significance of species in the formula.

The index of the organic pollution of water bodies by the algae community (Barinova et al. 2006):

$$S = \frac{\sum_{i=1}^{N} S_i \cdot h_i}{\sum_{i=1}^{N} h_i} ,$$

Where: S is the degree of saprobity in the studied zone of the water body; S_i is the saprobic value of the saprobiotic organism; h_i is the frequency of occurrence of the saprobiont in the sample.

Values of saprobity indices by the zones (Barinova et al. 2006): (i) Xenosaprobic (maximally clear water) S = 0-0.50; (ii) Oligosaprobic (clear water) S = 0.51-1.5; (iii) β-mesosaprobic (satisfactorily clear water) S = 1.51-2.50; (iv) α-mesosaprobic (contaminated water) S = 2.51-3.50; (v) Polysaprobic (dirty water) S = 3.51-4.00.

The relationship between the phytoplankton community and the environmental factors was analyzed using the Canonical Correspondence Analysis (CCA). Microsoft Excel 2013 and software module "Graphs" (Nowakowski 2004) were used to organize and analyze the data.

RESULTS AND DISCUSSION

Study of the species composition of phytoplankton of Lake Uvildy

The sampling was made during the vegetation period in June-July 2014 at 5 sites in the north-west and northeast of Lake Uvildy (see Figure 1). The species composition and the abundance of the phytoplankton community are presented in Table 2.

There are 38 species and intraspecific taxons were registered in the phytoplankton composition of Lake Uvildy as a result of the observations (Table 3). They belong to 31 genera, 24 families, 13 orders, 11 classes, 6 divisions. The diatom, green and blue-green algae prevailed by the number of the registered species.

The dominant divisions by the phytoplankton abundance were diatom (Bacillariophyta), they represented 42% of the total number of species, and blue-green algae (Cyanophyta), which corresponded to 39% of the total number of species. (Kostryukova et al. 2015). Studies of phytoplankton in Lake Uvildy in 2005-2006 (Snitko and Snitko 2011) showed a predominance of diatoms (40% of the total number of species) and green algae (34% of the total number of species). The superiority of the algae of the Cyanophyta division is typical of oligotrophic lakes of the temperate zone, which includes Lake Uvildy. The richest in the species diversity were the families of Microcystaceae, Nostocaceae from the Cyanophyta division, and Naviculaceae, Fragilariaceae from the Bacillariophyta division. Algae of the families Microcystaceae and Nostocaceae are known for their blooms. Naviculaceae and Fragilariaceae are often the most dominant groups among other microscopic algae throughout the year in aquatic ecosystems. Some dominant phytoplankton species of Lake Uvildy are shown in Figure 2: *Fragilaria crotonensis* (14.39% of the total number of algae), *Asterionella formosa* (14.72% of the total number of algae) и *Microcystis aeruginosa* (4.58% of the total number of algae).

Table 2. Phytoplankton richness and abundance (unit/L) in Lake Uvildy (South Urals), Chelyabinsk, Russia

Species	Site 1	Site 2	Site 3	Site 4	Site 5
Bacillariophyta					
Asterionella formosa Hassall		+		++++	+
Aulacoseira granulata (Ehrenberg) Simonsen	++++				
Cymbella cistula (Ehrenberg) O.Kirchner					+
Diatoma vulgare Bory	+				
Epithemia argus (Ehrenberg) Kützing				+	
Epithemia turgida var. turgida (Ehrenberg) Kützing				+	+
Fragilaria crotonensis Kitton	++++	++++	++++	++++	++
Gyrosigma acuminatum (Kützing) Rabenhorst				+++	
Navicula radiosa Kützing	+			+	
Pinnularia viridis (Nitzsch) Ehrenberg					+
Rhopalodia gibba (Ehrenberg) Otto Müller			+		+
Surirella linearis W.Smith				+	
Synedra ulna (Nitzsch) Ehrenberg	+				
Cyanophyta					
Anathece clathrata (W.West & G.S.West) Komárek, Kastovsky & Jezberová				+	
*Dolichospermum circinale (*Rabenhorst ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J. Komárek	+++				
Dolichospermum flosaquae (Brébisson ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J. Komárek	++++	+++			
Dolichospermum lemmermannii (Richter) P.Wacklin, L.Hoffmann & J.Komárek	++++	++++	+++	++++	+++
Merismopedia elegans A.Braun ex Kützing				+	
Microcystis aeruginosa (Kützing) Kützing	++++			++	+
Microcystis pulverea (H.C.Wood) Forti	+++				
Oscillatoria limosa C.Agardh ex Gomont				+	
Woronichinia naegeliana (Unger) Elenkin	++				
Chlorophyta					
Closterium parvulum Nägeli	+				
Coenococcus planctonicus Korshikov	++	++	++	+++	+
Cosmarium caelatum Ralfs				+	
Eudorina elegans Ehrenberg				+	
Mucidosphaerium pulchellum (H.C.Wood) C.Bock, Proschold & Krienitz	+			+	+
Oocystis borgei J.W.Snow	+				
Scenedesmus quadricauda (Turpin) Brébisson	+			+	
*Sphaerellocystis ampla (*Kützing) Nováková		+			
Staurastrum paradoxum Meyen ex Ralfs	+			++	+
Euglenophyta					
Euglena gracilis G.A.Klebs					+
Euglenaformis proxima (Dangeard) M.S.Bennett & Triemer	+				
Lepocinclis acus (O.F.Müller) Marin & Melkonian					+++
Trachelomonas euchlora (Ehrenberg) Lemmermann				+	
Chrysophyta					
Dinobryon divergens O.E.Imhof				+++	
Dinobryon sociale var. americanum (Brunnthaler) Bachmann				+	
Dinophyta					
Ceratium hirundinella (O.F.Müller) Dujardin			++++	++	

Note: +-0-50 rare, ++-50-100 frequent, +++-100-200 common, ++++-200 abundant (Sladecek 1973)

The Shannon index values calculated by the results of the algal abundance for each sampling site ranged from 1.27 to 2.21 (Figure 3). The species diversity of algae in Lake Uvildy was the lowest close to the center of the lake (site 3). In the remaining sites of the lake's surface layer, a higher species diversity was registered in the coastal zones. Near these points resorts, zone of private cottages and decaying submerged trees and shrubs are located, that is they are characterized by a higher organic pollution compared to point 3. Snitko (2004) showed that in another water body of the South Ural, Lake Turgoyak, there was the same tendency. The zones of localization of phytoplankton abundance and biomass were confined to the coastal places of the largest complex organic pollution (holiday house, residential settlement, city beach) and shallow gulfs.

According to (Snitko and Snitko 2011) in May-July 2006, the indices of saprobity ranged from 1.97-2.30, and in August-September, they decreased to 1.33-1.77. The authors associate higher values of the index of saprobity in the first half of summer with an increased nutrient load from flooded coastal areas during the summer recreation. The saprobity indices evaluating the degree of water contamination in the studied sites in June-July 2014 varied within the following values of 1.63-2.35 (Figure 4). The water in Lake Uvildy refers to the β-mesosaprobic zone as well as in 2006, i.e., it is characterized by a satisfactory purity degree. The most polluted is site 2, where several recreation centers and a dense zone of private cottages are located, and the lowest species diversity is observed for it among the studied sites in the coastal zone. A high value of the saprobity index is also observed in background site 3. Perhaps the low species diversity in this site, according to the Shannon index, is not only preconditioned by its location in the center of the lake, but also by a more polluted water condition.

Further analysis of the phytoplankton community by the species similarity was conducted using the cluster analysis based on the calculation of the Sorensen-Chekanovski index showed that the sites are divided into two zones: I-sites 2 and 3, and II-sites 1, 4 and 5 (Figure 5). The highest similarity degree was found between the algal floras of sites 2 and 3. The above data on the species diversity and the degree of water contamination confirm the allocation of sites 1 and 2 into a separate zone.

The species registered in each of the studied sites include *Coenococcus planctonicus*, *Dolichospermum lemmermannii* and *Fragilaria crotonensis* (Table 1). Over a half of the number of the observed species were found only in one of the sites: *Oocystis borgei*, *Closterium parvulum*, *Dolichospermum circinale*, *Woronichinia naegeliana*, *Euglenaformis proxima*, *Diatoma vulgare*, *Synedra ulna* (Site 1), *Sphaerellocystis amplau*, *Cymbella cistula* (Site 2), *Rhopalodia gibba* (Site 3), *Cosmarium caelatum*, *Anathece clathrata*, *Merismopedia elegans*, *Oscillatoria limosa*, *Trachelomonas euchlora*, *Dinobryon sociale* var. *americanum*, *Dinobrion divergens*, *Epithemia argus*, *Surirella linearis* (Site 4), *Eudorina elegans*, *Lepocinclis acus*, *Euglena gracilis*, and *Pinnularia viridis* (Site 5).

Table 3. Taxonomic composition of plankton algae in Lake Uvildy (South Urals), Chelyabinsk, Russia

Divisions	Taxons				
	Class	Order	Family	Genus	Species
Chlorophyta	4	4	8	9	9
Bacillariophyta	2	3	8	12	13
Cyanophyta	2	3	5	6	9
Euglenophyta	1	1	1	2	4
Chrysophyta	1	1	1	1	2
Dinophyta	1	1	1	1	1
Total	11	13	24	31	38

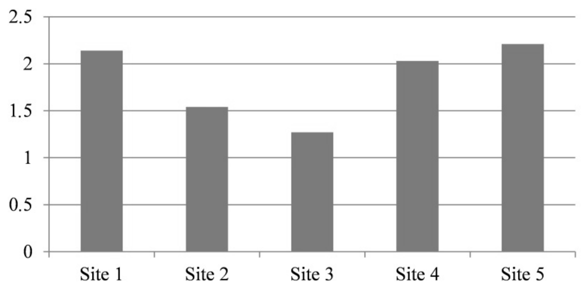


Figure 3. Shannon index values for different sites

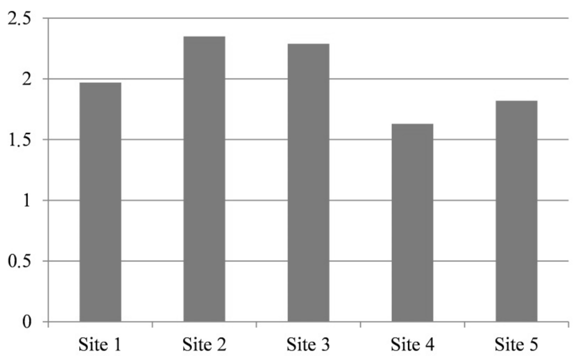
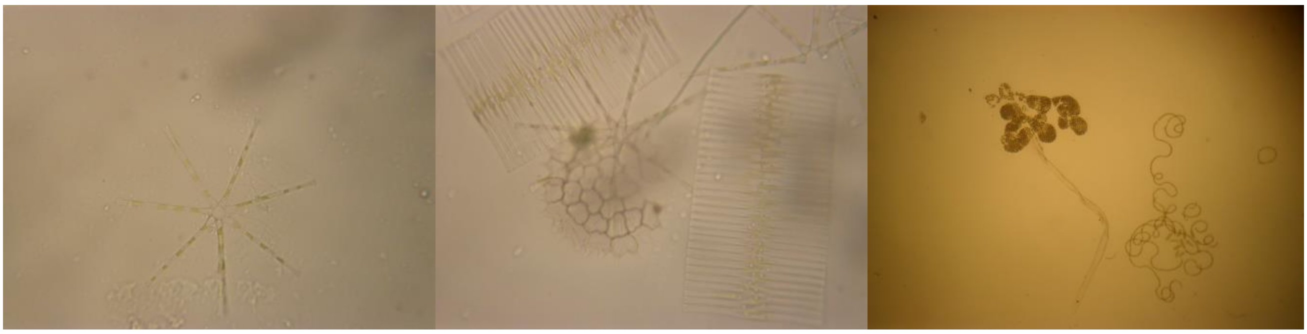


Figure 4. Saprobity index values for different stations



A B C

Figure 2. Dominant phytoplankton species of Lake Uvildy (South Urals), Chelyabinsk, Russia. A. *Asterionella formosa*, B. *Fragilaria crotonensis*, C. *Microcystis aeruginosa*

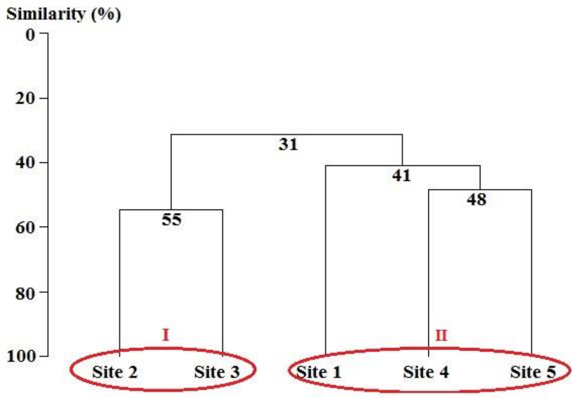


Figure 5. Similarity of the sites by the species composition of phytoplankton (Sorensen-Chekanovski index)

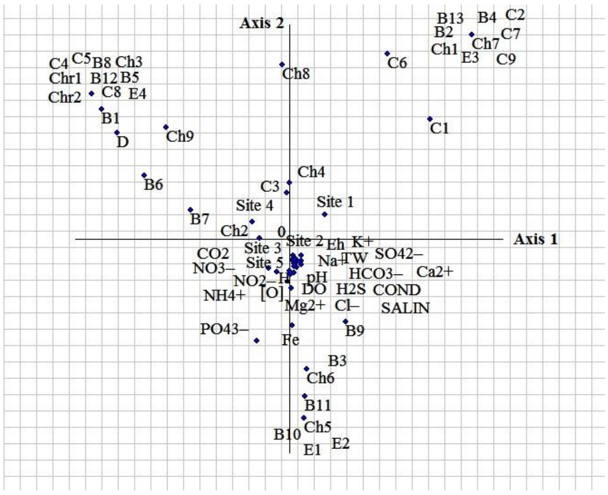


Figure 6. Ordination diagram from the correspondence analysis

Influence of environmental factors

Physicochemical parameters of the water quality in Lake Uvildy obtained as a result of the studies in June-July 2014 are presented in the work of Mashkova et al. (2017).To evaluate the relationship between the water quality indices and the number of observed phytoplankton species, we conducted the canonical correlation analysis in each of the five sites under study (Table 4). There is approximately the same positive correlation with axis 1 for most parameters, such as TW, DO, pH, Eh, COND, SALIN, SO_4^{2-}, Cl^-, HCO_3^-, Na^+, K^+, Ca^{2+}, and a very weak correlation for NO_2^-, H_2S, H, Mg^{2+}, and Fe. A strong negative correlation with axis 2 is registered for PO_4^{3-}, a weaker one-for [O], NH_4^+, NO_3^-, CO_2 (Figure 6).

The studied sites are divided into three different groups by the eighteen physicochemical characteristics and the species composition of phytoplankton. Wherein, one of them includes sites 2, 3 (zone I) and site 5, which is apparently still closer to zone I by its characteristics (Figure 6). The left upper quadrant includes the species that require enough clear water for their growth and vital activity (site 4). They include three algae species that are universal in occurrence: *Coenococcus planctonicus*, *Dolichospermum lemmermannii*, and *Fragilaria crotonensis*. The lower right quadrant includes phytoplankton species that can live in the conditions of a lower water quality (sites 2 and 3). The upper right quadrant includes the species that occupy an intermediate position (site 1). Any previous studies related to this research in similar or different locations in Russia? If any, please present and compare it.

Table 4. Codes of algae species in Lake Uvildy, Chelyabinsk, Russia for the canonical conformity analysis

Species	Code
Bacillariophyta	
Asterionella formosa	B1
Aulacoseira granulata	B2
Cymbella cistula	B3
Diatoma vulgare	B4
Epithemia argus	B5
Epithemia turgida var. turgida	B6
Fragilaria crotonensis	B7
Gyrosigma acuminatum	B8
Navicula radiosa	B9
Pinnularia viridis	B10
Rhopalodia gibba	B11
Surirella linearis	B12
Synedra ulna	B13
Euglenophyta	
Lepocinclis acus	E1
Euglena gracilis	E2
Euglenaformis proxima	E3
Trachelomonas euchlora	E4
Chrysophyta	
Dinobryon divergens	Chr1
Dinobryon sociale var. americanum	Chr2
Dinophyta	
Ceratium hirundinella	D
Cyanophyta	
Dolichospermum flosaquae	C1
Dolichospermum circinale	C2
Dolichospermum lemmermannii	C3
Anathece clathrata	C4
Merismopedia elegans	C5
Microcystis aeruginosa	C6
Microcystis pulverea	C7
Oscillatoria limosa	C8
Woronichinia naegeliana	C9
Chlorophyta	
Closterium parvulum	Ch1
Coenococcus planctonicus	Ch2
Cosmarium caelatum	Ch3
Mucidosphaerium pulchellum	Ch4
Eudorina elegans	Ch5
Sphaerellocystis ampla	Ch6
Oocystis borgei	Ch7
Scenedesmus quadricauda	Ch8
Staurastrum paradoxum	Ch9

In conclusion, Lake Uvildy is the largest lake located in the South Urals and has the status of a specially protected natural monument. The phytoplankton composition of Lake Uvildy is represented by 38 species belonging to 6 divisions. Out of them, the algae of the Bacillariophyta division prevail. This points at the oligotrophic condition of the lake, despite the fact that in the 70s of the 20 century, it was subject to a severe anthropogenic impact, which led to a deterioration in the coastal water quality and the degree of recreational comfort in the coastal zone. The following species are dominant: *Fragilaria crotonensis, Asterionella formosa, Dolichospermum lemmermannii, Microcystis aeruginosa,* and *Coenococcus planctonicus.* In general, the ecological water condition of Lake Uvildy is regarded as satisfactorily clear.

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