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Abstract. The current paper considers changes of phytoplankton community structure in three South Ural (Russia) water bodies different in trophicity: Lake Uvildy, Lake Ilmenskoe, and Shershnevskoe Reservoir. There is no clear relation between the changes of species structure of phytoplankton communities and water-bodies trophicity. The least significant changes in the phytoplankton community structure are registered for the mesoeutrophic Lake Ilmenskoe, which is located on the territory of the State Reserve. Diatomic, green and blue-green algae groups are the most diverse in composition in the studied periods of 1936-1937, 1964-1984 and 1998-2016. But for the last 20 years, Cyanophyta has increased its contribution into the phytoplankton number and biomass of Lake Ilmenskoe. The representatives of the *Bacillariophyta* group dominate in oligotrophic Lake Uvildy. In 1965-1985, the *Chlorophyta* group was the most abundant in Shershnevskoe reservoir (34 % of the total number of species), *Bacillariophyt*a - 32 % and *Cyanophyta* - 18 %. In 2003-2005 and 2017 the number of green algae increased (*Chlorophyta* – 40 %) and that of diatoms decreased (*Bacillariophyt*a - 21%) with the number of blue-green algae being unchanged (*Cyanophyta* – 19 %). The ecological status of the Shershenevskoe Reservoir has transformed from a long-term sustainable mesotrophic to eutrophic. So, for oligotrophic lake Uvildy and mesoeutrophic lake Ilmenskoe, *Bacillariophyta* group is characterized by the greatest taxonomic diversity. While for eutrophic Shershnevskoe Reservoir the absolute abundance of *Chlorophyt*a algae group is marked, which is growing in time. The growing importance of blue-green algae is one more feature of the change of a trophic status.

1. Introduction

Numerous factors affect the species composition of any communities, including phytoplankton, which results in their structural changes. Natural community structure formation is a slow and gradual process, which is disturbed by human activity [1, 2]. Eutrophication is defined as water enrichment with nutrients, nitrogen and phosphorus, first, which stimulates the original production [3-5]. Though no clear relations between species structure of water organisms and trophic status is revealed, phytoplankton could be used as a rather sensitive indicator [4]. As eutrophication grows, some species disappear, species diversity declines, and new dominant phytoplankton species appear [3-5].

South Ural is rich in lakes, many of which are of much economic importance. There are various hydrobiological studies, including early ones, that allow making a rough assessment of a floral list of algae in Chelyabinsk region. But algae flora of many water-bodies in South Ural has not been studied enough. Natural processes and intense anthropogenic and recreational impact on the lakes leading to the change of a trophic status result in altering a species composition of phytoplankton communities. The current paper aims to analyse relations between the changes of species structure of phytoplankton communities and the water-body trophicity

2. Materials and methods

2.1. Study area

Three water-bodies different in trophicity that are located on the territory of South Ural: Lake Uvildy, Lake Ilmenskoe and Shershnevskoe Reservoir are taken as the research objects (figure 1). Table 1 shows the water-bodies morphological parameters.

Figure1. A quick map of reservoirs: 1 - Lake Ilmenskoe, 2 - Lake Uvildy, 3 - Shershnevskoe Reservoir.

Table 1. Morphological parameters of water-bodies under study.

Water-body	Altitude elevation, m	Water surface area, km^2	Water volume, m^3	Depth, m	
				maximal	average
Lake Uvildy	272.0	68.10	1014	38.0	13.0
Lake Ilmenskoe	331.4	4.560	14.6	6.1	3.0
Shershnevskoe Reservoir	222.0	39.00	160	14.0	4.0

The studied water-bodies are not large, which is characterized of South Ural. Their hydrological level could fluctuate up to 2 m. As such fluctuations are not significant the biodiversity of these lakes could be compared for a long time.

Lake Uvildy is situated at the piedmont of the Urals and could be referred to the category of deep lakes (up to 40 m) with the water surface area of 50 km^2 [6, 7] (table 1). According to the chemical composition, it belongs to the hydrocarbonate class of calcium group [7]. Despite the intensive recreational load, the lake is marked as oligotrophic in most of the references [6, 7].

Lake Ilmenskoe is at the southern end of the Ilmenskiy range and belongs to the basin of the Uy river, which flows into the Tobol River. The lake is a medium size, shallow, with anthropogenically disturbed catchments, and is partially located on the territory of the Ilmen State Reserve [7, 8]. Its

chemical composition allows classifying the lake as a freshwater lake of the hydrocarbonate class of calcium group [7]. According to its trophic status, lake Ilmenskoe is mesotrophic [8, 9].

Shershnevskoe Reservoir is in the lowland forest-steppe zone of South Ural in the middle reaches of the Miass river [10-12]. It was created in 1965-1969. Locating within the city of Chelyabinsk, Shershnevskoe Reservoir is freshwater, belongs to the bicarbonate types, the calcium group. According to the trophic status, this Reservoir belongs to eutrophic [10, 11].

2.2. Sample collection

The authors present data of their own that was collected in 2011-2017 [6, 8, 11], analyse the data of other researchers [7, 14, 18]. Sampling was carried out during the vegetation period in June-July of 2011-2013 and 2015-2016, in 5-10 stations distributed along the entire perimeter of Lake Ilmenskoe [8], in June-July of 2014-2016 in 5 stations distributed along the entire perimeter of Lake Uvildy, in June-July 2017 in 8 stations distributed along the entire perimeter of Shershnevskoe Reservoir.

Phytoplankton samples in the amount of 1 liter were scooped from the surface water (0 - 0.2 m) and then filtered through a membrane. At each site, the samples were collected and then filtered through the plankton net (mesh size: 100 μm). They were studied on the day of catching with the help of optical microscope Altami BIO 2T. The retained organisms were transferred into glass containers, and the collected material was preserved in 5 % formalin. The density was counted according to the quantity of cells in 2-3 recurrence in Goryaev chamber.

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 [13-15]. Taxonomic characteristics are specified following algae determinants [16, 17].

3. Results and discussion

3.1. Lake Ilmenskoe

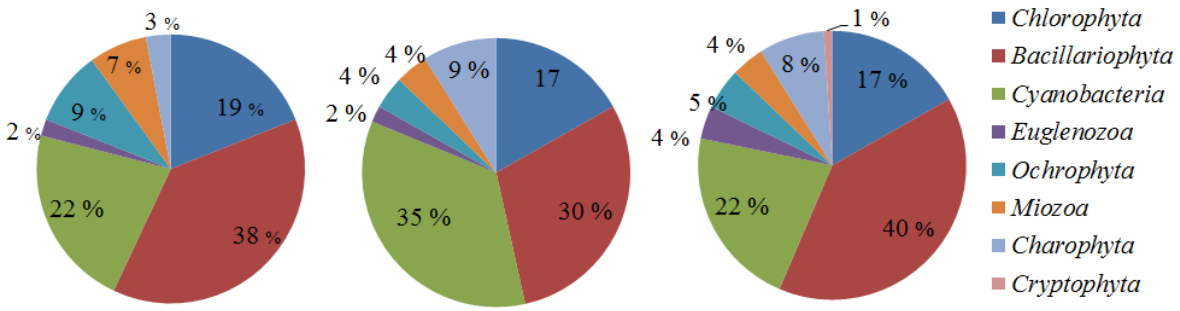
Species composition of phytoplankton community in Lake Ilmenskoe was first studied in 1936 by N.V. Bondarenko and in 1937 by A.O. Tauson. The obtained results are given in unpublished reports that are preserved in the archive of the Ilmen State Reserve. The report's data were analysed and presented in the monographs by Svitko and Sergeeva [18], Yarushina and others [14]. Thus, 58 phytoplankton species belonging to 7 groups were registered in 193-1937 (table 2). According to the data about the occurrence, this period is marked by a massive development of blue-green algae. The dominant species that occurred in the number of more than 30 organisms in the solution were *Microcystis aeruginosa* (Kützing) Kützing 1846, *Microcystis flosaquae* (Wittrock) Kirchner, 1898 and *Dolichospermum flosaquae* (Brébisson ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek, 2009.

The next period belongs to 1964-1984 when phytoplankton was studied in almost 40 water-bodies [14, 18]. Unfortunately, archive data do not have the names of many lakes where species were revealed. 54 phytoplankton species belonging to 7 groups were registered (table 2). Blue-green algae - *M. aeruginosa*, *M. flosaquae*, *Microcystis wesenbergii (*Komárek) Komárek ex Komárek in Joosen 2006, *D. flosaquae, Gloeotrichia echinulata* P.G.Richter, 1894, *Fragilaria crotonensis* Kitton, 1869, *Ulnaria ulna* (Nitzsch) Compère 2001, *Ceratium hirundinella* (O.F.Müller) Dujardin, 1841 and *Dinobryon divergens* O.E.Imhof 1887 prevailed in the studied period (July-August).

According to the data given in the literature [7, 14, 18] in 1998-2003 and the results of the given research [8] in 2011-2016, 161 algae species belonging to 8 groups were registered. Three groups of algae: diatomic, green and blue-green constitute the basis of the species list (table 2). The species abundance of the other groups is significantly lower than for the leading groups.

Table 2. Taxonomic compositions of the phytoplankton.

Algae taxa		Species					
Divisions	Class	Lake Ilmenskoe			Lake Uvildy	Shershevskoe Reservoir	
		1936-1937	1964-1984	1998-2016		1965-1985	2003-2005 and 2017
Bacillariophyta	*Mediophyceae*	3	2	4	2	10	6
	Coscinodiscophyceae	2	-	4	2	4	4
	Bacillariophyceae	17	14	55	33	108	24
	Bacillariophyta classis incertae sedis	-	-	1	-	1	-
	Total	22	16	64	37	123	34
Chlorophyta	*Chlorophyceae*	9	8	22	23	85	50
	Trebouxiophyceae	2	1	3	6	42	13
	Ulvophyceae	-	-	2	1	3	1
	Total	11	9	27	30	130	64
Cyanobacteria	*Cyanophyceae*	13	19	35	29	68	31
Euglenozoa	*Euglenophyceae*	1	1	7	9	25	9
Ochrophyta	*Chrysophyceae*	5	2	7	4	6	5
	Xanthophyceae	-	-	1	1	5	2
	Synurophyceae	-	-	-	-	-	2
	Eustigmatophyceae	-	-	-	-	1	-
	Total	5	2	8	5	12	9
Miozoa	*Dinophyceae*	4	2	6	3	1	3
Charophyta	*Zygnematophyceae*	2	5	13	9	14	10
	Klebsormidiophyceae	-	-	-	-	6	2
	Total	2	5	13	9	20	12
Cryptophyta	*Cryptophyceae*	-	-	1	1	1	-
Total		58	54	161	123	380	162



a) b) c)

Figure 2. The proportion of shares (%) of phytoplankton groups in species composition in Lake Ilmenskoe in different periods: a) 1936-1937, b) 1964-1984, c) 1998-2016.

In general, in all the studied periods there were no significant changes in the distribution of shares of the main phytoplankton groups. Diatomic algae (figure 2a and 2c) comprising more than one third of the species diversity (38 % and 40 % respectively) are of greater importance in the formation of plankton communities in the first (1936-1937) and the last (19998-2016) periods of study. In 1936-1937, for *Bacillariophyta* no genera comprising more than 1-2 species were identified. In 1998-2016, such genera as *Diatoma*, *Cymbella*, *Gomphonema*, *Pinnularia* and *Navicula* were the richest in species diversity (4-5 species). The share of blue-green algae in these two periods was stable - 22 %, with green algae decreased from 19% to 17%. In 1936-1937, according to the number of species of blue-

green algae *Microcystis* genera was a leader (4 species); in 1998-2016, besides *Microcystis* 5 species of *Dolichospermum* genera were registered. For green algae, genera with 1-2 species were identified. Unlike in 1936-1937 and 1998-2016, in the period of 1964-1984 the shares of the main groups were distributed differently (figure 2b). This could be due to the errors in archiving data.

But, among high occurrence species the share of blue-green algae increased in 1998-2003. The dominant species that occurred in the number of more than 30 organisms in the solution were *M. aeruginosa*, *M. flosaquae*, *M. wesenbergii*, *D. flosaquae, Dolichospermum circinale (*Rabenhorst ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek 2009, *G. echinulata*, *F. crotonensis*, *U. ulna*, *C. hirundinella* and *D. divergens*. *Cyanobacteria* group contributed at most to the phytoplankton biomass [19], which is usually characteristic of mesotrophic and eutrophic water-bodies with Lake Ilmenskoe belonging to the latter type.

3.2. Lake Uvildy

Lake Uvildy is a mountain deep oligotrophic lake of the forest zone. This is one of the lakes that gave the start for studying species composition of phytoplankton communities of South Ural. The first reports that identified microalgae species in this water-body trace back to the beginning of the XX century. Bachman [14] was the first who registered such species as *C. hirundinella*, *Peridinium cinctum* (O.F.Müller) Ehrenberg 1832, *D. divergens*, *Dinobryon sociale* (Ehrenberg) Ehrenberg 1834, *Asterionella Formosa* Hassall 1850, *F. crotonensis*, *Ulnaria delicatissima* (W.Smith) Aboal & P.C.Silva 2004, *Botryococcus braunii* Kützing 1849, *Staurastrum gracile* Ralfs ex Ralfs 1848 in 1907. Novikov [14] described *Euglena viridis* (O.F.Müller) Ehrenberg, 1830 in 1908, *Stephanodiscus rotula* (Kützing) Hendey 1964 was described by Zhuze [14] in 1933. According to the Bachman, species *C. hirundinella* (*Dinophyta*) and *A. formosa* (*Bacillariophyt*a) were registered as massive.

Lake Uvildy was under an adverse human-made impact in the 70-s of the XX century. This period was marked as drought in South Ural, so a quarter of the Lake water was thrown into the reservoir with fresh water. This led to the water level decrease, and a significant part of the coastal area became dried up. A birch forest grew on the territory, and it was submerged later during the following water level recovery in Lake Uvildy [6]. Eutrophication of the coastal areas was the result of this process.

Lake Uvildy, being a natural monument since 1969, is the subject to intensive recreational use. Despite this, there are very few studies of the phytoplankton community and they relate to the last 20 years. The taxonomic composition of phytoplankton in Lake Uvildy was compiled based on the results of [14, 18] (2005-2006) and the current research [6] (2014-2016).

123 phytoplankton species were registered (table 2). They belong to 8 groups (figure 3a). The taxa of diatomic (30%), green (24%) and blue-green algae (24%) are the basis of the main part of the floral list. According to the species abundance, *Bacillariophyta* is dominant, which is a characteristic feature of the mountain deep lakes in South Ural [18]. *Fragilaria*, *Cymbella*, *Stauroneis*, *Epithemia* were the genera with the richest species abundance (3-4 species). Diatomic algae *F. crotonensis* and *A. formosa* are dominant constant species [6, 18]. This marks the lake as oligotrophic despite its poor coastal water quality. Among blue-green algae *Oscillatoria* and *Dolichospermum* genera had 3-4 species. The number of species among green algae did not exceed 1-2.

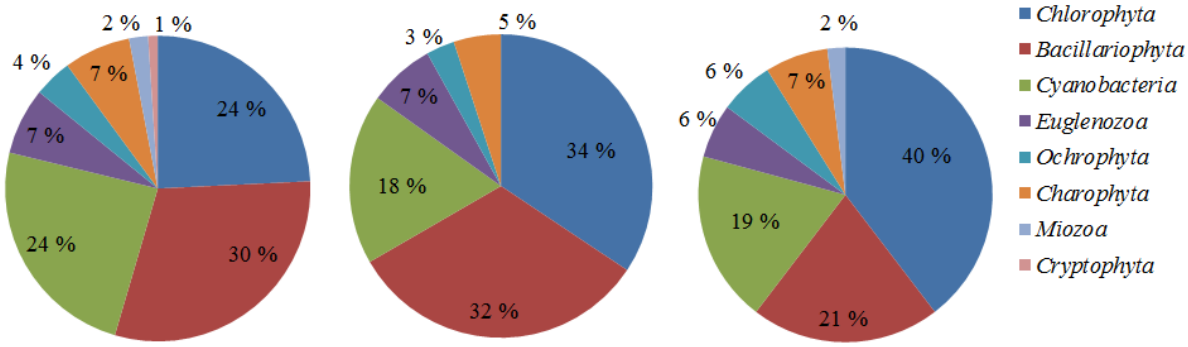
Phytoplankton biomass was determined by two algae group: *Bacillariophyta* and *Chlorophyta*. Growing species abundance is typical for blue-green algae. This process could lead to Lake Uvildy losing its oligotrophic status and coming to mesotrophic, which is noted by some researchers [18].

3.3. Shershnevskoe Reservoir

Shershnevskoe Reservoir is a city source of drinking water and is situated within the limits of the city. The Reservoir is a comparatively new water-body that was constructed in 1963-1969.

The ecosystem of Shershnevskoe Reservoir, as well as its phytoplankton community, have been thoroughly studied since its beginning. The data 1965-1985 were obtained based on the analysis of the literature [14]. The taxonomic composition of phytoplankton in the later period was compiled based on the results of [7] (2003-2005) and the current authors ' research [11] in 2017 (table 2). 380 species

of phytoplankton belonging to 9 groups in 1965-1985 and 162 species from 7 groups in 2000 were registered (table 2).



a) b) c)

Figure 3. The proportion of shares (%) of phytoplankton groups in species composition a) in Lake Uvildy, b) in Shershnevskoe Reservoir in 1965-1985, b) in Shershnevskoe Reservoir in 2003-2005 and 2017. Note: in 1965-1985 the share of *Miozoa* and *Cryptophyta* was less than 1 % in total.

Figures 3b and 3c show the shares of species of the main phytoplankton groups in Shershnevskoe Reservoir. Three groups *Chlorophyta* (34 % in 1965-1985, 40 % in 2003-2005 and 2017), *Bacillariophyta* (32 % and 21 %) and *Cyanophyta* (18 % and 19 %) mainly contribute to the structure of the community on its species abundance. In 1965-1985, for *Chlorophyta* group, a high species abundance was marked for *Desmodesmus*, *Lagerheimia* and *Oocystis* (14, 8 and 6 species respectively), in the second period of study - for *Tetradesmus* and *Monoraphidium* (4 species). In 1965-1985, among diatomic algae the highest number of species was registered for *Nitzschia*, *Navicula*, *Gomphonema*, *Diatoma* and *Fragilaria* (14, 10, 8, 7 and 6 species respectively). In 2003-2005 and 2017, the number of species in genera did not exceed 1- 2. Among blue-green algae in 1965-1985, the number of species was distinguishing for *Microcystis* (8 species), *Merismopedia*, *Phormidium*, *Anabaena* (5 species each), in 2003-2005 and 2017, 7 species were marked for *Dolichospermum* and 6 for *Microcystis.* In all the periods of study, *M. aeruginosa*, *Aphanizomenon flosaquae* Ralfs ex Bornet & Flahault 1886 were dominant for *Cyanophyta*, and *A. formosa*, *F. crotonensis* - for *Bacillariophyta.*

Blue-green and diatomic algae are characterised by the most abundance and biomass despite green algae being the most diverse in the number of species. The study period was registered as the time of massive “bloom” of blue-green algae with their number reaching the hypertrophic level [7, 11]. This phenomenon is the evidence of high eutrophication of the water-body. The trophic status of Shershnevskoe Reservoir has changed from a long-term sustainable mesotrophic to eutrophic.

4. Conclusions

Although there is no clear relation between the changes of species structure of phytoplankton communities and water-bodies trophicity, features that speak about transformations in the trophic status could be defined. The obtained results show that the proportion of shares of the main algae groups constituting algaeflora does not clearly reflect the changes in trophic status. But, for oligotrophic lake Uvildy and mesoeutrophic lake Ilmenskoe, *Bacillariophyta* group is characterized by the greatest taxonomic diversity. While for eutrophic Shershnevskoe Reservoir the absolute abundance of *Chlorophyta* algae group is marked, which is growing in time. This could be explained by anthropogenic eutrophication of the reservoir. There is a marked tendency that in the lakes with a low and medium trophicity level such as Uvildy and Ilmenskoe, genera with one or two species were identified for *Chlorophyta* group; but in the eutrophic reservoir species abundance of this group has increased up to 4 species and more.

The growing importance of blue-green algae is one more feature of the change of a trophic status. According to the author [7], *Cyanophyta* group has contributed a lot to a total biomass and number of phytoplankton for each of the studied water-body. Unfortunately, this parameter was not considered in other works [14, 18], so the given paper could not use biomass as a criterion of trophicity. This research is important as it organizes and structures the obtained results and evaluated a possibility of revealing a relation between the changes in species composition of algaeflora and trophicity of a water-body. The current study will lay the foundation for further research of relations between algaeflora in lakes and reservoirs in South Ural and the process of eutrophication.

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