Taxonomic structure of phytoplankton in Shershnevskoe Reservoir (Chelyabinsk, Russia), an artificial lake

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Abstract. Shershnevskoe Reservoir is the main source of water supply of the Chelyabinsk city (South Ural, Russia). It is an artificial reservoir, filled in 1963-1969. The water protection zone of the Shershnevskoe Reservoir is subject to significant anthropogenic impact. Variations in phytoplankton community composition in the artificial waters are still poorly understood. The purpose of this work is to study the changes in composition of phytoplankton that have occurred since the creation of the reservoir. Identified taxa (381) of the phytoplanktonic community in 1965-1985 are as follows: 150 Chlorophyta, 123 Bacillariophyta, 69 Cyanophyta, 25 Euglenophyta, 6 Chrysophyta, 6 Xanthophyta, 1 Dinophyta and 1 Cryptophyta. Identified taxa (134) of the phytoplanktonic community in 2004-2017 are as follows: 67 Chlorophyta, 26 Bacillariophyta, 25 Cyanophyta, 9 Euglenophyta, 4 Chrysophyta, 2 Xanthophyta and 1 Dinophyta. The dominants were blue-green algae. The presence of Cyanobacteria as the dominant complex indicates a high degree of eutrophication of the reservoir. The following species were dominant until 2014-2015 Aphanizomenon flos-aquae Ralfs ex Bornet & Flahault, Snowella lacustris (Chodat) Komárek & Hindák and Microcystis aeruginosa (Kützing) Kützing, but after 2014-2015 it is Planktothrix agardhii (Gomont) Anagnostidis & Komárek. Over the fifty years of the existence of the Shershnevskoe Reservoir, its ecological state has passed from a long-term sustainable mesotrophic to a eutrophic one.

1. Introduction
Reservoirs exist in many countries of the world. They are intended for leveling the seasonal fluctuations of river levels and water storage. The reservoirs created in the river valleys combine the features of the lake and the river, and have individual characteristics and properties [1]. The water in them, unlike lakes, maintains a progressive movement, i.e. has more flow, but this movement is much slower than the river. The thermal regime of the reservoir differs from the rivers by temperature heterogeneity, and from the deep-water lakes by unstable stratification and relatively high temperatures of the bottom layers in the summer season. In the temperature regime of the reservoirs has much in common with the temperature regime of shallow lakes. In addition, they are usually characterized by significant catchment and surface area ratios, which leads to higher nutrient loads and bottom sediments compared to natural lakes. Algae productivity is higher, with higher sedimentation rates and less biological diversity. The construction of artificial reservoirs violates the functional relationships of river biocenoses and leads to the dominance of certain phytoplankton species. Thus, a
more accelerated process of ecosystem degradation and eutrophication is characteristic for reservoirs, especially those that subject to intensive anthropogenic impact [2,3].

There are several artificial reservoirs on the Chelyabinsk territory (South Ural, Russia). The Shershnevskoe Reservoir is most important. The Shershnevskoe Reservoir was built in 1960-1969 to supply water for the Chelyabinsk city. Various studies conducted since 2002 indicate anthropogenic eutrophication of the reservoir [4] and characterize its state as a mesotrophic-eutrophic class with a gradual transition to a polytrophic state [5,6]. Water quality class evaluated as “very polluted” in 2016 [7]. There is a sufficient volume of published studies describing the phytoplankton community of Shershnevskoe Reservoir in different years [4,5,8-10]. However, these studies are scattered and do not provide an overall picture of the species composition changes that have occurred.

In this paper, we have systematized the available information and added our own research data. Our aim is to study the changes that have occurred in the structure of the phytoplankton community of the Shershnevskoe Reservoir (Chelyabinsk, the South Ural) since its building.

2. Materials and methods

2.1. Study area
Shershnevskoe Reservoir is an artificial reservoir. The dam was built in 1963-1969 on the river Miass. The reservoir was created to supply water to the Chelyabinsk city and the cities adjacent to it.

The Shershnevskoe Reservoir is located on the territory of the Chelyabinsk city (South Ural, Russia). Its catchment area is 5460 km², the average water surface area is 39 km², the volume is 160 million m³, the average depth is 4 m. The length is 18 km, the width is 2.2-3.5 km [6]. Its underwater area was 2959 hectares of agricultural land and 300 hectares of forest.

The reservoir is elongated. There are villages, gardens, a city forest and a whole district of Chelyabinsk along its banks [6]. The pollutant inflow into the reservoir occurs with surface run off from the catchment area and organized discharge of wash water from the treatment facilities of the Sosnovskye water intake. According to the data of the Ministry of Ecology (Chelyabinsk Region), the water quality class of the reservoir corresponds to a much polluted one [7].

Shershnevskoe Reservoir is freshwater (salinity 88–123 mg/l), it belongs to the bicarbonate types, the calcium group. Water is slightly alkaline with a pH of 8.16–9.26 [6].

The studies were conducted in June-July 2017. For the study, eight sites were selected at Shershnevskoe Reservoir (Figure 1).

2.2. 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.

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 [11-13]. Taxonomic characteristics are specified in accordance with algae determinants [14,15].
2.3 Data analysis
The Shannon inhomogeneity index was used to assess the structure of the phytoplankton community [16]:

\[ H' = - \sum_{i=1}^{N} p_i \cdot \ln p_i, \]  

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.

The Simpson index was used to estimate the species abundance:

\[ C = \sum_{i=1}^{N} \frac{n_i(n_i - 1)}{N(N - 1)}, \]  

where: \( n_i \) is the significance estimate of each species (abundance or biomass), \( N \) is the sum of significance estimates.

Indexes were calculated using a special program module "GRAPHS" [17].

3. Results and discussion
The study is based on the data collected in June-July 2017, as well as on the data of other researchers studying the phytoplankton of the Shershnevskoe Reservoir.

The literature data analysis [12] showed that the phytoplankton community of the Shershnevskoe Reservoir included 381 species in 1965-1985 (Table 1): 150 Chlorophyta, 123 Bacillariophyta, 69 Cyanophyta, 25 Euglenophyta, 6 Chrysophyta, 6 Xanthophyta, 1 Dinophyta and 1 Cryptophyta. There were four dominant species: Aulacoseira granulata (Ehrenberg) Simonsen, Asterionella formosa Hassall, Microcystis aeruginosa (Kützing) Kützing and Aphanizomenon flosaquae Ralfs ex Bornet & Flahault. These species are dominant in the South Ural lakes [18-21]. The reservoir was characterized by a stable mesotrophic state [8].
**Table 1.** Taxonomic compositions of the planktonic of Shershnevskoe Reservoir.

| Divisions   | Class | Order | Family | Genus | Species |
|-------------|-------|-------|--------|-------|---------|
| 1965-1985   |       |       |        |       |         |
| Chlorophyta | 5     | 10    | 28     | 79    | 150     |
| Bacillariophyta | 4   | 16    | 26     | 51    | 123     |
| Cyanophyta  | 2     | 6     | 19     | 33    | 69      |
| Euglenophyta| 1     | 1     | 2      | 6     | 25      |
| Chrysophyta | 1     | 1     | 1      | 4     | 6       |
| Xanthophyta | 2     | 2     | 3      | 6     | 6       |
| Dinophyta   | 1     | 1     | 1      | 1     | 1       |
| Total       | 17    | 38    | 81     | 181   | 381     |
| 2017        |       |       |        |       |         |
| Chlorophyta | 5     | 7     | 17     | 44    | 67      |
| Bacillariophyta | 3   | 13    | 17     | 22    | 26      |
| Cyanophyta  | 1     | 4     | 12     | 16    | 25      |
| Euglenophyta| 1     | 1     | 2      | 3     | 9       |
| Chrysophyta | 1     | 1     | 1      | 3     | 4       |
| Xanthophyta | 1     | 2     | 2      | 2     | 2       |
| Dinophyta   | 1     | 1     | 1      | 1     | 1       |
| Total       | 13    | 29    | 52     | 91    | 134     |

Green algae were a permanent component of this phytoplankton community. They were dominant in the number of species, but weren’t dominant in number (Table 2). By species diversity, the genus *Desmodesmus* (14 species), *Lagerheimia*, *Cosmarium*, *Oocystis* and *Elakatothrix* (8, 7, 6, and 6, respectively) were distinguished. Diatoms occupied the second place in the number of species. The greatest species abundance was distinguished by the genus *Nitzschia* (14 species) and *Navicula* (10 species). Blue-green algae were the third division of species richness, but they characterized by the largest number. By species richness the genus *Microcystis* was distinguished (8 species).

**Table 2.** Species’s diversity of Shershnevskoe Reservoir phytoplankton community.

| Taxa           | Class, Order                  | Species |
|----------------|-------------------------------|---------|
|                |                               | 1965-1985 | 2017 |
| Chlorophyta    | *Chlorophyceae, Chlamydomonadales* | 14       | 6    |
|                | *Chlorophyceae, Sphaeropleales* | 71       | 41   |
|                | *Trebouxiophyceae, Chlorellales* | 37       | 8    |
|                | *Trebouxiophyceae, Trebouxiophyceae ordo incertae sedis* | 4       | 3    |
|                | *Trebouxiophyceae, Prasiolales* | 1        | 0    |
|                | *Klebsormidiophyceae, Klebsormidiales* | 6       | 2    |
|                | *Conjugatophyceae (Zygmatophyceae), Desmidiales* | 12      | 6    |
|                | *Conjugatophyceae (Zygmatophyceae), Zygnematales* | 2       | 0    |
|                | *Ulvophyceae, Ulotrichales* | 1        | 1    |
|                | *Ulvophyceae, Cladophorales* | 2        | 0    |
|                | Total Chlorophyta             | 150      | 67   |
| Bacillariophyta| *Mediophyceae, Thalassiosirales* | 2        | 1    |
|                | *Mediophyceae, Stephanodisccales* | 6       | 1    |
|                | *Mediophyceae, Chaetocerotales* | 2       | 0    |
Coscinodiscophyceae, Melosiraales 1 1
Coscinodiscophyceae, Aulacoseirales 3 2
Bacillariophyceae, Tabellariales 8 3
Bacillariophyceae, Liemophorales 9 1
Bacillariophyceae, Fragilariales 12 2
Bacillariophyceae, Mastogloiales 1 0
Bacillariophyceae, Cymbellales 18 5
Bacillariophyceae, Naviculales 22 3
Bacillariophyceae, Cocconeidales 5 3
Bacillariophyceae, Tabellariales 8 1
Bacillariophyceae classis incertae sedis, Bacillariophyta ordo incertae sedis
Total Bacillariophyta 123 26

Cyanophyta
Chlorophyceae, Sphaeropleales 1 0
Chlorophyceae, Chroococcales 15 6
Chlorophyceae, Synechococcales 25 7
Chlorophyceae, Oscillatoriales 13 2
Chlorophyceae, Spirulinales 1 0
Chlorophyceae, Nostocales 14 10
Total Cyanophyta 69 25

Euglenophyta
Euglenophyceae, Euglenales 25 9

Chrysophyta
Chrysophyceae, Chromulinales 6 4
Xanthophyceae, Mischochoccales 5 1
Xanthophyceae, Tribonematales 0 1

Xanthophyta
Eustigmatophyceae, Eustigmatales 1 0
Total Xanthophyta 6 2

Dinophyta
Dinophyceae, Gonyaulacales 1 1

Cryptophyta
Cryptophyceae, Cryptomonadales 1 0

The results of our research are presented in Tables 1 and 2 in June-July 2017. There were recorded 134 species of microalgae of the Shershnevskoe Reservoir belonging to 91 genus, 52 families, 29 orders, 13 classes and 7 divisions.

As in 1965-1985, Chlorophyta, Bacillariophyta and Cyanophyta made a major contribution. Their distribution by species richness preserved (Table 2). New species, which didn’t found in 1965-1985, discovered in 2017: 6 species from the division Chlorophyta - Pandorina morum (O.F. Müller) Bory, Ankyra judayi (G.M. Smith) Fott, Lambertia gracilipes (F.D. Lambert) Korshikov, Closterium archerianum Cleve ex P.Lundell, Coenococcus planctonicus Korshikov and Ulothrix sp. Küting; and one species in the divisions of Cyanophyta and Bacillariophyta - Cuspidothrix issatschenkoi (Usachev) P.Rajaniemi, Komárek, R.Willame, P. Hrouzek, K.Kastovská, L.Hoffmann & K.Sivonen and Gyrosigma acuminatum (Küting) Rabenhorst respectively.

Gavrilova [9] investigated the algal blooms of reservoir in 2004-2007. It was noted that algal blooms are associated with outbreaks of cyanobacteria and diatoms. During the years of research, as a result of an increase in temperature, blue-greens from the genus Anabaena began to develop intensively in June, followed (in July) by Aphanizomenon flosaquae Ralfs ex Bornet & Flahault and Snowella lacustris (Chodat) Komárek & Hindák. Further different types of Microcystis could join: (M. aeruginosa (Kützing) Kützing, M. flosaquae (Wittrock) Kirchner, M. ichthyoblabe (G.Kunze) Kützing and M. wesenbergii (Komárek) Komárek ex Komárek) and Planktothrix agardhii (Gomont) Anagnostidis & Komárek can join. Vegeation Cyanophyta lasted until late autumn. Outbreaks of diatom algae Aulacoseira granulata (Ehrenberg) Simonsen periodically occurred. Algae from other
departments throughout the season were represented in insignificant quantities in terms of abundance and biomass. During the study period, a massive phytoplankton bloom was recorded, accompanied by the dominance of blue-green algae (Anabaena flos-aquae) Ralfs ex Bornet & Flahault, Snowella lacustris (Chodat) Komárek & Hindák, Planktothrix agaradhii (Gomont) Anagnostidis & Komárek and Microcystis aeruginosa (Kützing) Kützing), which leads to adverse changes in water quality. The presence of cyanobacteria as the dominant complex indicates a high degree of reservoir eutrophication.

It can be seen from the data in Table 2 that there is reduction of diversity species for all divisions (see Table 2). The Shannon index averages decreased just below and were 2.5±0.67 in 1965-1985 and 2.01±0.51 in 2017, characterized diverse phytoplankton community as medium. The average Simpson indexes value were 0.26±0.15 in 1965-1685 и in 0.35±0.23 2017, the degree of dominance of one species increased. Gayazova et al. [10] considered the patterns of change in the dominant phytoplankton community of the Shershevskev Reservoir. It was noted that until 2014, the dominant species were Anabaena flos-aquae Ralfs ex Bornet & Flahault and Microcystis aeruginosa (Kützing) Kützing. The species Planktothrix agaradhii (Gomont) Anagnostidis & Komárek was for the first time recorded in the 1980-1990s and its maximum concentrations were lower one hundred and ten times with respect to A. flos-aquae Ralfs ex Bornet & Flahault and M. aeruginosa (Kützing) Kützing. In July-October 2015, there was a sharp increase in the number of P. agaradhii (Gomont) Anagnostidis & Komárek, as a result, M. aeruginosa (Kützing) Kützing was expelled (its number was 13 times lower compared to P. agaradhii (Gomont) Anagnostidis & Komárek). Similar trends are observed in many European water bodies [22, 23] and are beginning to be noted in water bodies of the temperate zone of Russia [24-26], subject to significant anthropogenic eutrophication.

4. Conclusions

Thus, over fifty years of the Shershevskev Reservoir existence, diversity species of the phytoplankton community decreased, although main division’s structure has not changed. The dominant phytoplankton complex is the Cyanophyta division. The dominant species were Anabaena flos-aquae Ralfs ex Bornet & Flahault, Snowella lacustris (Chodat) Komárek & Hindák and Microcystis aeruginosa (Kützing) Kützing. However, M. aeruginosa (Kützing) Kützing was replaced as the dominant species by another species of blue-green algae - Planktothrix agaradhii (Gomont) Anagnostidis & Komárek in 2015. Artificial reservoirs are not initially stable and sustainable ecosystems; therefore, they have rapidly emerging phenomena that lead to deterioration of water quality. The Shershevskev Reservoir ecological state has passed from a long-term sustainable mesotrophic to a eutrophic one. As a result, there is a significant deterioration in the properties of the water of the reservoir, which is the only source of drinking water for the Chelyabinsk city.

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