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Article

Taxonomic diversity of phytoplankton of the Kalmius River and its reservoirs

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Abstract. The paper presents data on the taxonomic diversity of phytoplankton in the middle section of the Kalmius River and the reservoirs located on it. Floristic analysis showed the presence in the aquatic biocenosis of 291 species of algae and 162 intraspecific taxa belonging to 8 divisions, 18 classes, 42 orders, 66 families and 105 genera. The divisions Cyanophyta, Chlorophyta, and Bacillariophyta dominated in frequency of occurrence. The Shannon-Weaver index varied the most in the Starobeshevsk Reservoir. The Sorensen-Chekanovsky coefficient evidences the isolation of the phytoplankton algal flora of the Starobeshevsk Reservoir. In the Nizhnekalmius Reservoir, a regular annual repetition of the dominant types of algoflora development has been established.

Keywords: algal flora, water biocenosis, reservoirs, Donbass.

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Introduction

An aquatic biogeocenosis (ecosystem) is a natural object that forms the unity of the environment and the inhabiting biota. In order to understand the processes taking place in the aquatic ecosystems, it is necessary to consider both hydrological (abiotic) parameters and the indicators of the biotic part of the ecosystem (Barinova, 2006). The characteristic of the development of the autotrophic elements of the community makes it possible to give an integral assessment for the entire water body. The structural features of phytoplankton (abundance, biomass, biodiversity, temporal and spatial variability of population development) are the most indicative for this purpose (Odum, 1975).

Donbass is one of the CIS regions lacking enough fresh water. This is due to the large mineral reserves in the Donetsk coal basin, which contribute to the rapid development of industry and a significant increase of the population in this region (Buntovsky, 2015). The Kalmius River is located in the northern part of the Sea of Azov, its basin does not exceed the borders of the central Donbass. The river flow is regulated by four dams. These reservoirs have been established simultaneously, they all are used for the needs of the population and industry of Donbass.

The Verkhnekalmius Reservoir is located near the source of the Kalmius River in its upper reaches, it is the closing reservoir of the Seversky Donets – Donbass channel. It provides drinking water to the city of Donetsk and adjacent settlements; the reservoir does not receive urban runoff and is not used by industry (Buntovsky, 2015; Styopkin, 2008). There are two other reservoirs, Nizhnekalmius and Starobeshevsk, locate in the middle reaches of the Kalmius River. The Nizhnekalmius Reservoir is used to supply water to the industrial enterprises of the city; it is fed by precipitation and mine waters. The Starobeshevsk Reservoir locates downstream nearby the village of Novy Svet, it serves as a cooling reservoir for the Starobeshevsk TPP. The water balance of the Starobeshevsk Reservoir is formed due to the inflow from the Kalmius River and the Gruzskaya River. In addition to thermal pollution, this reservoir receives agricultural and household runoff, which affects the state of the biota (Skibenko, 2013; Styopkin, 2008). In the lower reaches of the Kalmius River, 30 km upstream the Sea of Azov, the Pavlopol Reservoir is situated, which is intensively used for irrigation of agricultural land locating nearby. The water is characterized by high mineral content and is polluted with nutrients and pesticides (Skibenko, 2013; Styopkin, 2008). Therefore, according to the hydrological characteristics, the Kalmius River belongs to the category of small rivers with a high degree of anthropogenic impact (Doganovsky and Malinin, 2004), which attracts much scientific interest.

The study of the algoflora of the Kalmius River basin has started in the 1990s. The studies were performed in the particular sections of the river from its source to the mouth, as well as in the reservoirs. Meanwhile, comprehensive studies of the entire river basin have not been carried out. Due to the fact that the existing data are still fragmentary, it is necessary to describe the composition and development of phytoplankton algae in detail. The study aims to describe the biodiversity of phytoplankton in anthropogenically modified areas of the Kalmius River.

Materials and methods

The studies were performed in 2017–2020. The phytoplankton samples were taken monthly in two reservoirs (Starobeshevsk and Nizhnekalmius) and in the middle reaches of the Kalmius River. Sampling was carried out according to the generally accepted method, GOST 51592-2000 (Fomin, 2000). The minimal water volume of one sample was 1.5 L.

Samples were concentrated by vacuum filtration using a funnel with a membrane filter on a Bunsen flask connected to a Komovsky pump (Fomin, 2000). The processing of phytoplankton samples was performed by direct light microscopy under a Primo Star light microscope (Zeiss). The algae were identified according to taxonomic keys (Gollerbakh and Polyansky, 1951–1960, etc.). Statistical and graphical processing of the obtained results was carried out in the program Statistica 10 and Excel MS Office.

Results and discussion

In total, 291 species and 162 intraspecific taxa (IST) belonging to 8 divisions, 17 classes, 42 orders, 66 families, and 105 genera have been found in the phytoplankton of the Kalmius River basin. Divisions Bacillariophyta (33% of the total number of species) and Chlorophyta (28%) dominated by biodiversity.

Division Cyanophyta was represented significantly less (19% of the total number of species and IST), Euglenophyta and Ochrophyta formed in total 14% (Table 1). Divisions Cryptophyta, Dinophyta, and Charophyta were represented by single specimens and made up 6% of the total number of species and IST.

When analyzing the systematic structure of phytoplankton according to Fott (Fott, 1971), the families Scenedesmaceae (9% of the total number of species and IST) with 4 genera (*Coelastrum, Scotiellopis, Scenedesmus,* and *Tetrastrum*) and Naviculaceae (10% of total species and IST) with 3 genera (*Caloneis, Gyrosigma,* and *Navicula*) dominated by the species number (Table 2). The prevailing position of these families was due to the presence of many eurybiont (ubiquitous) species. The filamentous green algae (Oscillatoriacea, 5%

Table 1. Rank structure of phytoplankton of the Kalmius River, Nizhnekalmius and Starobeshevsk reservoirs.

Division	Number of taxa					
	Classes	Orders	Families	Genera	Species	IST
Cyanophyta	1	6	14	24	55	19
Euglenophyta	1	1	3	5	27	16
Ochrophyta	3	4	6	8	14	2
Cryptophyta	1	1	1	1	2	0
Dinophyta	1	3	3	3	7	5
Bacillariophyta	3	12	16	26	95	80
Chlorophyta	5	12	19	33	82	38
Charophyta	2	3	4	5	9	2
TOTAL	**17**	**42**	**66**	**105**	**291**	**162**

of the total number of species), including 3 genera (*Oscillatoria, Lyngbya,* and *Phormidium*) and the diatoms belonging to families Bacillariaceae and Fragilariaceae, bringing together 12% of the total number of species and IST, were subdominants.

Sixty-six families formed floristic diversity of phytoplankton in the basin of the Kalmius River. According to the species frequency of occurrence, only 16 families, bringing together 71% of the total diversity of phytoplankton, migh be considered as statistically significant, i.e. the standard deviation of which exceeded 1.73 (Fig. 1).

The most commonly found species in samples were:

Cyanophyta – *Anabaena spiroides* Kleb.*; Aphanizomenon flos-aquae* (L.) Ralfs; *Microcystis aeruginosa* (Kütz.) Kütz.; *Oscillatoria lacustris* (Kleb.) Geitler*; O. sancta* (Kütz.) Gomont;

Chlorophyta – *Crucigenia tetrapedia* (Kirchn.) West et G.S. West; *Oocystis lacustris* Chodat; *Monoraphidium minutum* (Nägeli) Komárk.-Legn.; *Coelastrum micronium,* Nägeli in A. Braun; *Scenedesmus quadricauda* Meyen; *Ulothrix variabilis* (Kütz.) Kütz.; *Pediastrum boryanum* (Turpin) E. Hegew. in Buchheim et al.*;*

Bacillariophyta – *Fragilaria intermedia* Lyngb.; *Synedra acus* Kütz.; *S. ulna* (Nitzsch) Ehrenb.; *Diatoma vulgare* Bory.; *Nitzschia longissima* W. Sm.; *N. sigmoidea* (Nitzsch) W. Sm.; *Cymbella lata* Grunow in Cleve; *Navicula viridis* Grunow; *N. pupula* Kütz.; *Stephanodiscus hantzschii* var. *hantzschii* Grunow in Cleve et Grunow; *Melosira varians* C. Agardh;

Charophyta – *Spirogyra varians* Link in C.G. Nees; *Elakatothrix genevensis* (Reverdin) Hindák;

Euglenophyta – *Euglena oxyuris* Ehrenberg; *Trachelomonas caudata* Ehrenberg; *Phacus longicauda* Dujardin;

Ochrophyta – *Dinobryon divergens* O.E. Imhof.

Therefore, the core of the algal flora in the ecosystem of the Kalmius River was represented by a diatom-protococcal complex with an insignificant participation of blue-green algae (Fig. 2).

It is important to note that the species composition of phytoplankton differed significantly in particular reservoirs and the river sections. In the Nizhnekalmius Reservoir, 216 species and IST have been identified, where predominant divisions Bacillariophyta and Chlorophyta equally formed 66% of the algoflora (Table 3). Cyanophyta accounted for 21%, the other divisions brought less than 10% to the total number of species and IST.

In the Nizhnekalmius Reservoir, a heterogeneous species distribution within the phytoplankton divisions, especially pronounced in summer, was observed. The number of taxa descreased from the upper section to the dam. In the upper part of the

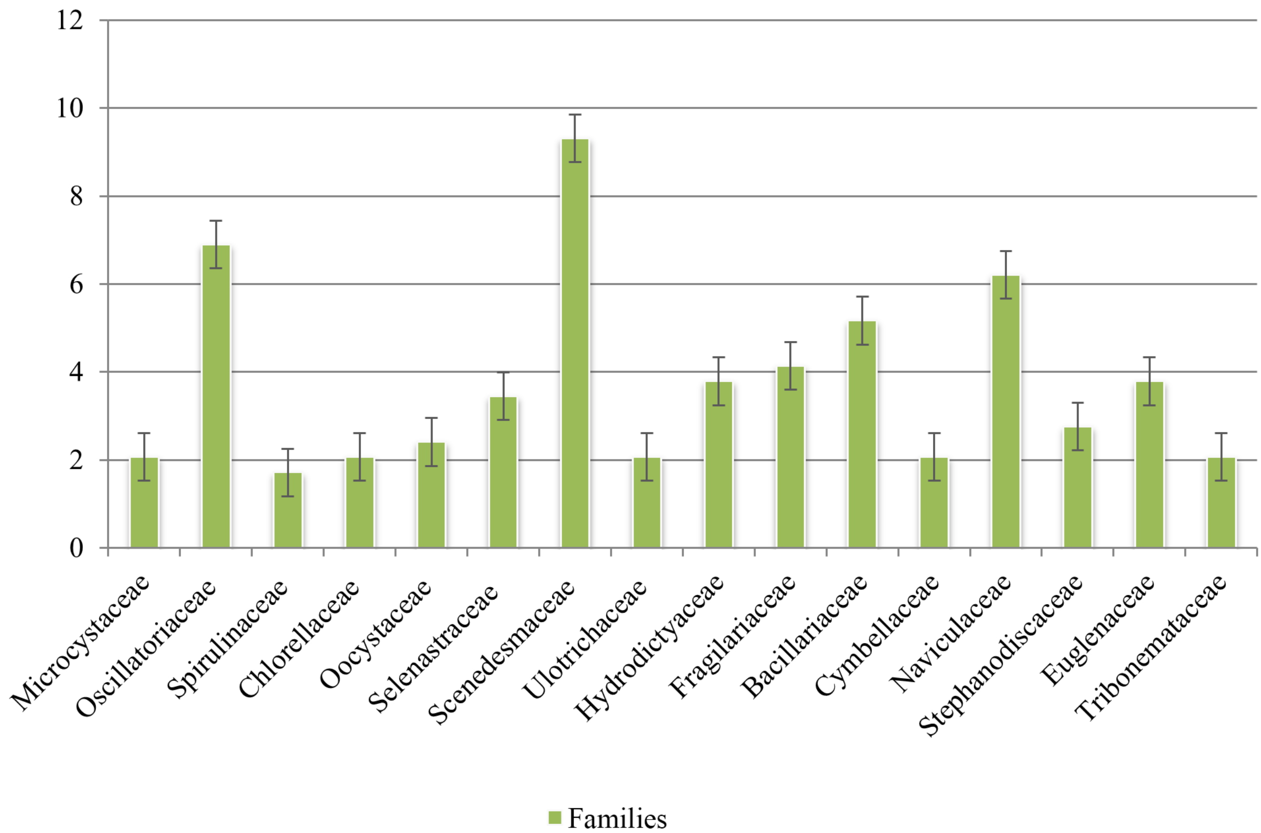

Fig. 1. The number of species of statistically significant families of phytoplankton in the Kalmius River, Nizhnekalmius and Starobeshevsk reservoirs.

Table 2. Systematic structure of phytoplankton according to Fott (Kalmius River, Nizhnekalmius and Starobeshevsk reservoirs).

No	Family	Genera	Share, %	Species	Share, %	IST	Share, %
	DIVISION CYANOPHYTA (CYANOBACTERIA. CYANOPROKARIOTA)						
1	Nostocaceae	2	1.9	3	1.03	2	1.23
2	Aphanizomenonaceae	2	1.9	2	0.69	1	0.62
3	Aphanothecaceae	1	0.95	2	0.69	2	1.23
4	Chroococcaceae	3	2.86	4	1.37	0	0
5	Microcystaceae	2	1.9	6	2.06	3	1.85
6	Gomphosphaeriaceae	1	0.95	1	0.34	1	0.62
7	Cyanothecaceae	1	0.95	1	0.34	0	0
8	Oscillatoriaceae	3	2.86	21	7.22	8	4.94
9	Spirulinaceae	1	0.95	5	1.72	1	0.62
10	Hyellaceae	1	0.95	1	0.34	0	0
11	Hydrococcaceae	1	0.95	1	0.34	0	0
12	Merismopediaceae	3	2.86	4	1.37	1	0.62
13	Coelosphaeriaceae	2	1.9	3	1.03	0	0
14	Leptolyngbyaceae	1	0.95	1	0.34	0	0
	TOTAL	**24**	**22.86**	**55**	**18.90**	**19**	11.73
	DIVISION CHLOROPHYTA						
15	Chlorellaceae	3	2.86	6	2.06	3	1.85
16	Trebouxiophyceae	1	0.95	4	1.37	0	0
17	Chlorellaceae	3	2.86	4	1.37	0	0
18	Oocystaceae	3	2.86	8	2.75	0	0
19	Koliellaceae	1	0.95	2	0.69	0	0
20	Selenastraceae	2	1.90	10	3.44	2	1.23
21	Scenedesmaceae	4	3.81	19	6.53	17	10.49
22	Characiaceae	1	0.95	1	0.34	0	0
23	Radiococcaceae	1	0.95	1	0.34	0	0
24	Chaetopeltidaceae	2	1.90	2	0.69	0	0
25	Chlamydomonadaceae	1	0.95	3	1.03	0	0
26	Ulotrichaceae	2	1.90	6	2.06	2	1.23
27	Ulvaceae	2	1.90	2	0.69	2	1.23
28	Volvocaceae	1	0.95	1	0.34	0	0
29	Chaetophoraceae	1	0.95	1	0.34	0	0
30	Schroederiaceae	1	0.95	2	0.69	0	0
31	Sphaerocystidaceae	1	0.95	1	0.34	0	0
32	Hydrodictyaceae	2	1.90	7	2.41	10	6.17
33	Neochloridaceae	1	0.95	2	0.69	2	1.23
	TOTAL	**33**	**31.43**	**82**	**28.18**	**38**	**23.46**

No	Family	Genera	Share, %	Species	Share, %	IST	Share, %
			DIVISION CHAROPHYTA				
34	Closteriaceae	1	0.95	2	0.69	1	0.62
35	Desmidiaceae	1	0.95	3	1.03	1	0.62
36	Elakatotrichaceae	1	0.95	1	0.34	0	0
37	Zygnemataceae	2	1.90	3	1.03	0	0
	TOTAL	**5**	**4.76**	**9**	**3.09**	**2**	**1.23**
			DIVISION BACILLARIOPHYTA				
38	Eunotiaceae	1	0.95	1	0.34	1	0.62
39	Achnanthaceae	1	0.95	4	1.37	1	0.62
40	Fragilariaceae	1	1.90	12	4.12	10	6.17
41	Tabellariaceae	2	2.86	4	1.37	8	4.94
42	Bacillariaceae	5	1.90	15	5.15	11	6.79
43	Cocconeidaceae	1	0.95	1	0.34	1	0.62
44	Cymbellaceae	1	0.95	6	2.06	5	3.09
45	Gomphonemataceae	1	0.95	3	1.03	1	0.62
46	Rhoicospheniaceae	1	0.95	1	0.34	1	0.62
47	Naviculaceae	3	2.86	21	7.22	16	9.88
48	Pleurosigmataceae	1	0.95	2	0.69	1	0.62
49	Pinnulariaceae	1	0.95	4	1.37	3	1.85
50	Amphipleuraceae	1	0.95	2	0.69	0	0
51	Catenulaceae	4	3.81	7	2.41	9	5.56
52	Stephanodiscaceae	2	1.90	8	2.75	9	5.56
53	Melosiraceae	1	0.95	4	1.37	3	1.85
	TOTAL	**26**	**24.76**	**95**	**32.65**	**80**	**49.38**
			DIVISION EUGLENOPHYTA				
54	Euglenaceae	1	0.95	10	3.44	5	3.09
55	Phacidaceae	1	0.95	5	1.72	3	1.85
56	Euglenidae	3	2.86	12	4.12	8	4.95
	TOTAL	5	4.76	27	9.28	16	9.88
			DIVISION CRYPTOPHYTA				
57	Cryptomonadaceae	1	0.95	2	0.69	0	0
	TOTAL	**1**	**0.95**	**2**	**0.69**	**0**	**0**
			DIVISION DINOPHYTA				
58	Ceratiaceae	1	0.95	1	0.34	3	1.85
59	Peridinidiaceae	1	0.95	2	0.69	1	0.62
60	Glenodiniaceae	1	0.95	4	1.37	1	0.62
	TOTAL	**3**	**2.86**	**7**	**2.41**	**5**	**3.09**

No	Family	Genera	Share, %	Species	Share, %	IST	Share, %
	DIVISION OCHROPHYTA						
61	Centritractaceae	2	1.90	2	0.69	0	0
62	Ophiocytiaceae	1	0.95	1	0.34	0	0
63	Pleurochloridaceae	1	0.95	1	0.34	0	0
64	Goniochloridaceae	1	0.95	2	0.69	0	0
65	Tribonemataceae	2	1.90	6	2.06	0	0
66	Dinobryaceae	1	0.95	1	0.34	2	1.23
	TOTAL	**8**	**7.62**	**14**	**4.81**	**2**	**1.23**
	TOTAL IN ALGOFLORA	**105**	**100**	**291**	**100**	**162**	**100**
	Standard deviation	**0.75**	**11.26**	**1.73**	**12.97**	**3.87**	**2.39**
	Coefficient of variation	**0.48**	**1.05**	**0.78**	**1.24**	**1.53**	**1.53**

reservoir, Chlorophyta (*Monoraphidium minutum, Scenedesmus quadricauda,* and *Pediastrum boryanum*) and Bacillariophyta (*Tabellaria fenestrata* var. *kuetzingiana* Hilse sensu Hust., *Diatoma vulgare* var. *vulgare, Melosira varians,* and *Tabellaria fenestrata* var. *fenestrata* (Lingb.) Kütz.) dominated. In addition, blooms of representatives of Dinophyta (*Ceratium hirundinella* f. *hirundinella* (O.F. Müll.) Bergh) and Euglenophyta (*Euglena proxima* P.A. Dang. and *Trachelomonas* sp.) have been registered from time to time. Cyanophyta constantly dominated with the most common genera (*Aphanizomenon, Microcystis,* and *Anabaena*) downstream in the backwaters and shallow waters, as well as in the dam area. This phytoplankton pattern was observed almost throughout the entire year, most pronounced in the summer period. The Shanonn-Weaver diversity index varied from 0.92 to 1.24 bit/ind. (in winter and summer, respectively) and from 1.98 to 3.12 bit/ind. (in spring and autumn, respectively). Therefore, phytoplankton biodiversity varied greatly in the Nizhnekalmius Reservoir during the year, from the poor to rich one.

The phytoplankton diversity in the Starobeshevsk Reservoir differed significantly comparing to that observed in the Nizhnekalmius Reservoir (Table 4). In this section of the river basin, Bacillariophyta dominated (41% of the total number of species and IST). Chlorophyta was represented by a smaller number of species (29%), followed by Cyanophyta (18%). Regard must be also paid to the periodic outbreaks of Euglenophyta representatives (10% of the total number of species and IST).

Therefore, both Starobeshevsk and Nizhnekalmius reservoirs are the ecosystems formed under the influence of anthropogenic factors (Beznosov and Suzdaleva, 2005). Here, the species composition of algae is characterized by an uneven spatial distribution, which is due to the influx of heated waters. Filamentous blue-green algae and colonial diatoms, forming up to 60% of the total algal diversity, dominate in a number of coastal areas. In shallow waters, accumulations of *Melosira varians, Fragilaria capucina* var. *capucina* Desm., *Ulothrix zonata* (Weber et Mohr) Kütz., *Enteromorpha prolifera* (O.F. Müll.) J. Agardh, *Lyngbya limnetica* Lemm., and *Phormidium ambiguum* var. *ambiguum* Gomont have been noted. This pattern is explained by the development of filamentous algae, which form large-scale mats, consuming significant amounts of nitrogen and phosphorus from the water and thus preventing the development of other forms of algae (Beznosov et al., 2004). The pelagial of the Starobeshevsk Reservoir was characterized a high species diversity (Shannon-Weaver index varied from 1.64 to 4.06 bit/ind).

The middle reaches of the Kalmius River, located between the reservoirs, was characterized by low biodiversity, which was almost 3 times lower. Bacillariophyta (46% of the total number of species and IST) and Chlorophyta (32%) were characterized by the maximum species diversity. The species diversity of Cyanophyta has decreased by more than 3 times compared to both reservoirs. Peri- and epiphytic forms of phytoplankton prevailed in this section of the river (*Ulothrix variabilis, U. tenuissima* Kütz., *Navicula placentula* (Ehrenb.) Kütz., *Cymbella cymbiformis* var. *cymbiformis* Ehrenb., *C.* var. *tumida* (Ehrenb.) Mills, *Eunotia lunaris* var. *lunaris* (Ehrenb.) Mills, *Pinnularia microstauron* var. *brebissonii* (Kutz.) Rabenh., *Pinnularia capitata* Ehrb., *Nitzchia linearis* var. *linearis* W. Sm., *Surirella spiralis* Kutz., and *Enteromorpha pilifera* (Roth) Ag.). The Shannon-Weaver index here did not exceed 2.12 bit/ind.

Therefore, in the studied aquatic biocenoses of the Kalmius River basin, the Starobeshevsk Reservoir was characterized by the greatest species richness (371 species and IST), the Nizhnekalmius Reservoir, by the lowest one (216 species and IST). The reservoirs were characterized by the constant dominance of Cyanophyta (Makukha and Mirnenko, 2019; Mirnenko, 2018, 2019, 2021a, b: Mirnenko and Komarova, 2021; Mirnenko and Makukha, 2021), which quickly assimilated nutrients, reduced the amount of dissolved oxygen, and inhibited the development of other phytoplankton taxa. In addition, this fact was confirmed indirectly by satellite images obtained by the Google Earth Pro during the study period (Fig. 3).

The water in the Kalmius River basin is characterized by a high mineralization, due to which invasive marine species are introduced mainly in two ways and acclimatized successfully (Dudakova et al., 2015; Mirnenko, 2021a, b). The first (the most probable) way is due to the bird migration from the coasts of the Sea of Azov; the second way is associated with the aeolian transport. Invasive species belonging to Cyanophyta (*Phormidium boryanum, Ph. ambiguum* var. *ambiguum,* and *Anabaena variabilis* f. *variabilis* Kütz.) and Bacillariophyta (*Amphiprora alata* (Ehrenb.) Kütz., *A. paludosa* W. Sm., *Bacillaria paradoxa* J.F. Gmel. in Linne, *Gyrosigma peisonis* (Grunow) Hust. in Pascher, *Navicula digitoradiata* (W. Greg.) Ralfs in A. Pritch., *Navicula peregrina* var. *peregrina* (Ehrenb.) Kütz., *Nitzschia vivax* var. *hyperborea* W. Sm., *Nitzschia longissima* var. *longissima* (Bréb. ex Kütz.) Grun., and *Synedra tabulata* (C. Agardh) Kütz.) are widely distributed here.

During the study period, the floristic similarity of phytoplankton has been assessed according to the Sørensen-Chekanovsky index (Gorodnichev, 2019; Sakharova, 2017). The maximum values were noted in the middle reaches of the Kalmius River and in the Starobeshevsk Reservoir in 2018–2019 (0.71–0.75); the least similarity of algoflora was constantly observed in the summer period of 2017–2020 between the Nizhnekalmius and Starobeshevsk reservoirs (0.26–0.35).

Clustering of the species composition evidenced that the phytoplankton of the Starobeshevsk Reservoir (stations nos. ST1 and ST3) belonged a separate cluster, in which a regular annual dynamics of algoflora development was traced. The rest of the studied areas formed two groups of clusters with a similar distance (Fig. 4).

Conclusion

Therefore, the most diverse phytocenosis was formed in the Starobeshevsk Reservoir due to the operation of the Starobeshevskaya TPP, when the discharge of heated water into the surface layer of the reservoir caused an artificial increase of summer stratification period, suppressing seasonal convection of oxygen and nutrients. This leads to an increase in the growing season (Beznosov, 2004). The middle reaches of the Kalmius River form a transition zone. The Nizhnekalmius Reservoir is characterized by low taxonomic diversity due to the morphometric structure of this water body. Shallow depths and large areas of shallow water are the most affected by anthropogenic impact, which leads to malfunction of the biological potential of the entire ecosystem.

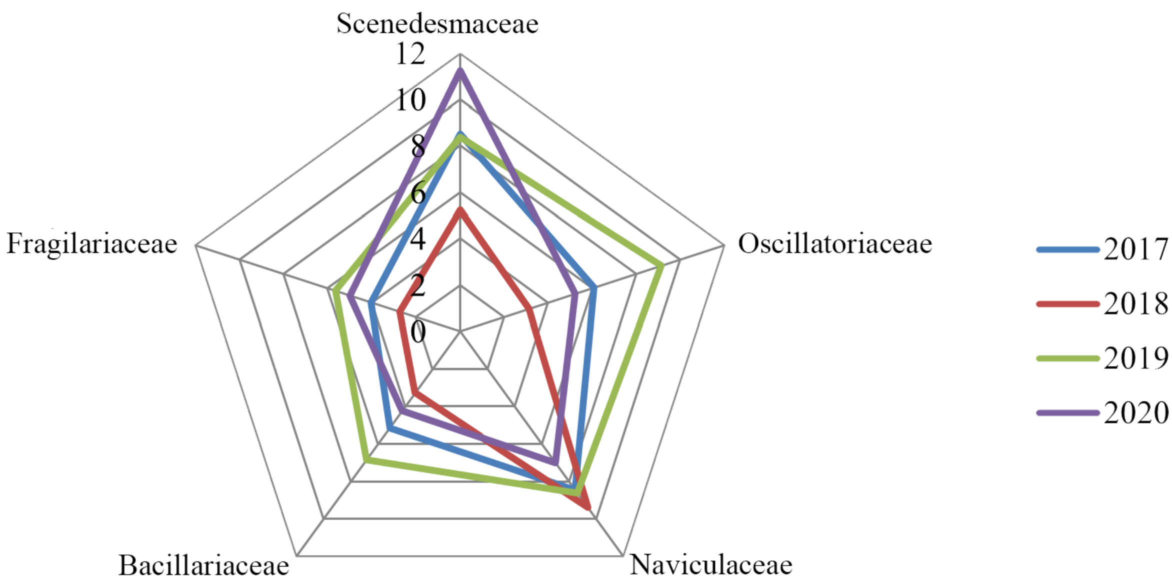

Fig. 2. Long-term dynamics of the species richness of the main families of phytoplankton in the Kalmius River, Nizhnekalmius and Starobeshevsk reservoirs.

Table 3. Taxonomic composition of phytoplankton of the Nizhnekalmius Reservoir.

Division	Number of species	Number of IST	Total	Share, %
Cyanophyta	32	13	45	20.83
Euglenophyta	12	5	17	7.87
Ochrophyta	3	2	5	2.31
Dinophyta	4	2	6	2.78
Bacillariophyta	37	34	71	32.87
Chlorophyta	51	21	72	33.33
TOTAL	**139**	**77**	**216**	**100**

Table 4. Taxonomic composition of phytoplankton of the Starobeshevsk Reservoir.

Division	Number of species	Number of IST	Total	Share, %
Cyanophyta	49	16	65	17.52
Euglenophyta	20	10	30	8.09
Ochrophyta	9	0	9	3.56
Cryptophyta	5	2	7	2.43
Bacillariophyta	89	64	153	41.24
Chlorophyta	81	26	107	28.84
TOTAL	**253**	**118**	**371**	**100**

Table 5. Taxonomic composition of phytoplankton in the middle section of the Kalmius River.

Division	Number of species	Number of IST	Total	Share, %
Cyanophyta	9	4	13	10.48
Euglenophyta	6	2	8	6.45
Ochrophyta	1	0	1	0.81
Cryptophyta	2	1	3	2.42
Bacillariophyta	36	21	57	45.97
Chlorophyta	31	9	40	32.26
Dinophyta	1	0	1	0.81
Chrysophyta	1	0	1	0.81
TOTAL	**87**	**37**	**124**	**100**

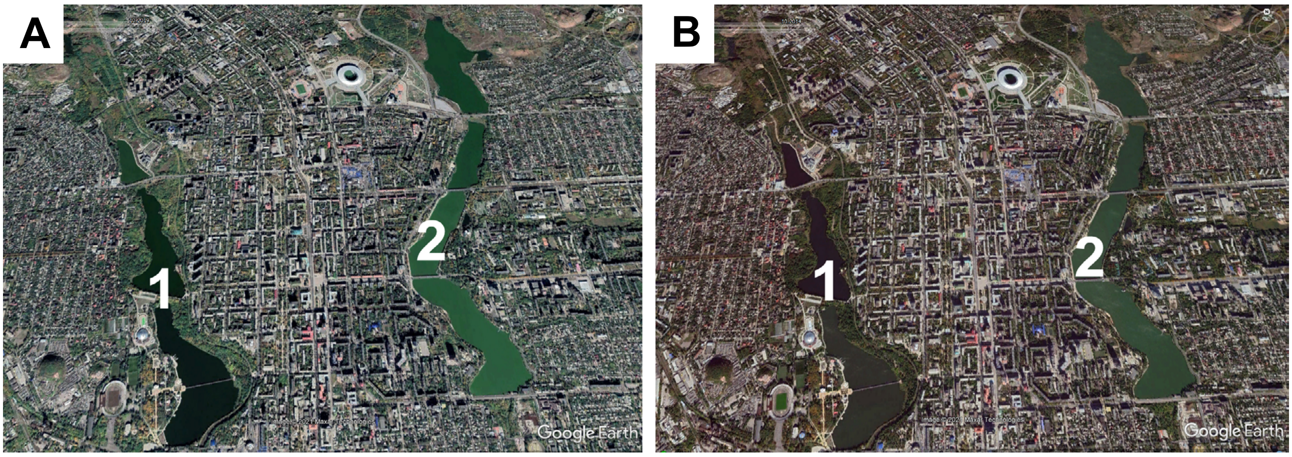

Fig. 3. "Blooming" of blue-green algae in the Nizhnekalmius Reservoir. **A** – June 2019; **B** – August 2019. 1 – City ponds; 2 – Nizhnekalmius Reservoir.

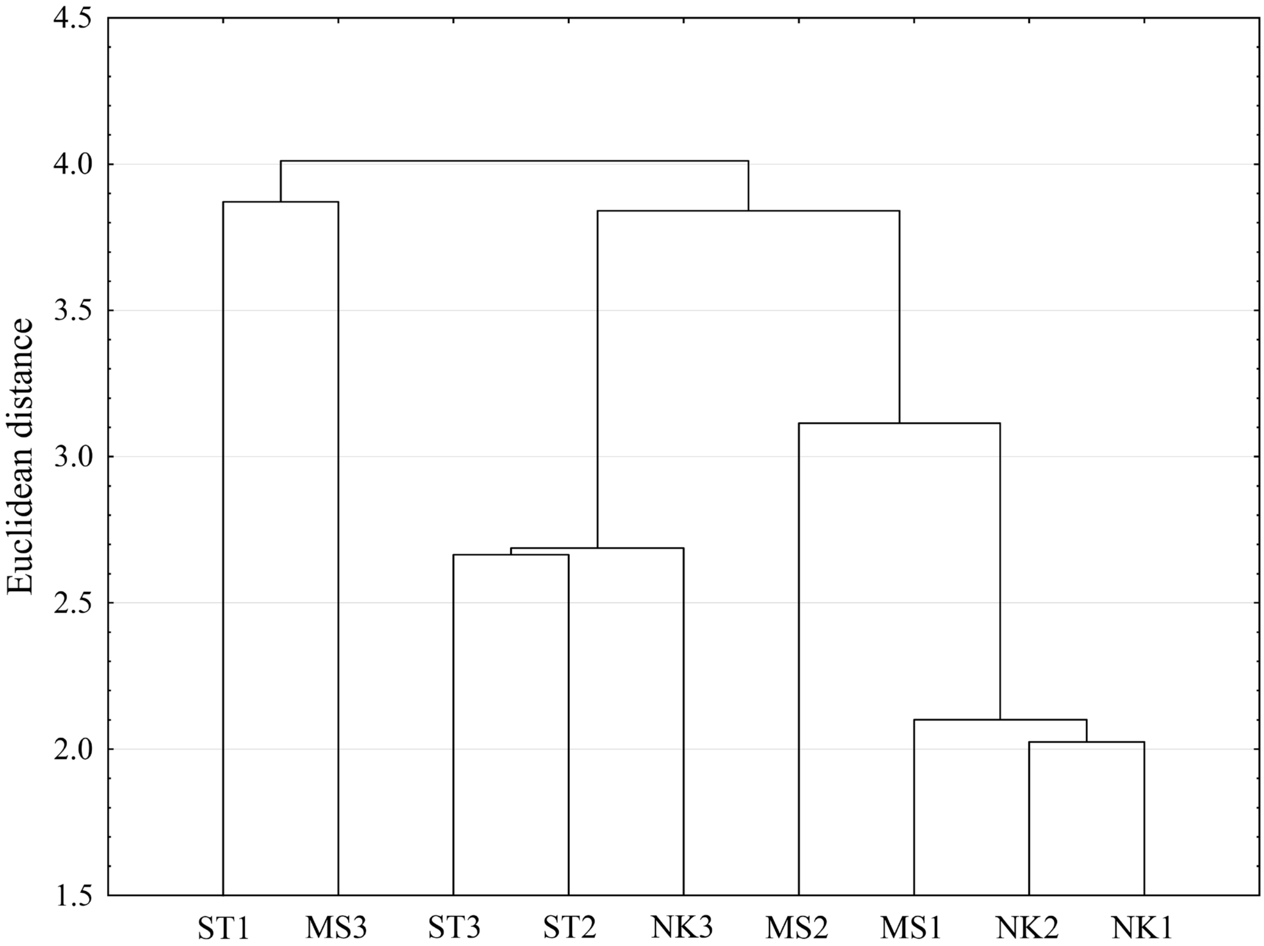

Fig. 4. Dendrogram of the floristic diversity of phytoplankton in the water bodies of the Kalmius River basin in 2019. NK, Nizhnekalmius Reservoir; ST, Starobeshevsk Reservoir; MS, the middle section of the Kalmius River; 1–3 – sampling sites.

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