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The taxonomic and ecological-floristic characteristics of the phytoplankton of a technogenic reservoir after the cessation of industrial exploitation by the example of Lake Shlamonakopitelnoe Samara Region, Russia)

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The plankton algae species composition in the technogenic reservoir and the changes observed after the cessation of industrial exploitation have been studied using Lake Shlamonakopitelnoe as an example (Vasilievskie Ozera lake system, Samara Region, Russia). Comparison of the species composition and taxonomic structure of phytoplankton during the period of active industrial exploitation (1991–1992) and the post-exploitation period (2001) revealed an increase in the algae species richness and an increased complexity of the taxonomic structure. Therefore, this was the positive transformation of the phytoplankton community. The high species specificity of algaeflora and the low level of species continuity in each study period indicated a significant degree of ecosystem transformation against the background of cessation of exploitation.

Keywords: phytoplankton, technogenic water body, floristic analysis, ecological-geographical analysis, indicator species, graphical analysis, saprobity.

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Introduction

Small urbanized water bodies have great environmental and aesthetic value. However, they are subject to a strong anthropogenic load; as a result, the cycles of their natural functioning are disrupted. In this regard, assessment of their condition, as well as monitoring and forecasting the changes is one of the urgent problems of modern ecology (Kleeberg, 2003).

The “technogenic” reservoirs are among the most vulnerable groups of such reservoirs, they are regularly or periodically exploited for industrial use (Ostvald, 1987; Spiridonov, 2006). Currently, some of them have already ceased to be necessary for industrial enterprises, so the action is underway to preserve and restore particular reservoirs (Anneville et al., 2002; Birch and McCaskie, 1999; Mingazova et al., 2014).

Nevertheless, there is an insufficient amount of data on the processes that occur during their self-cleaning, in particular when predicting the development of a “zero” recultivation scenario, during which self-restoring of disturbed ecosystems takes place without any anthropogenic impact (Spiridonov, 2006).

In the urban district of Togliatti, there is a chain of small urbanized reservoirs – the Vasilievskie Ozera lakes, – which appeared in late 1950s after the launching of the dam of the Zhigulevskaya hydroelectric station as a result of groundwater raising that filled up the natural depressions. In addition to the active use of these reservoirs for daily recreational purposes, summer cottages were built around some of them, some were used for fish aquaculture, and some of them were operated by the city industrial enterprises and used as receivers of TPP waste. As a result, some of the lakes have dried up or turned into ponds of the ephemeroïd type. Practically, by the end of the 1990s, which coincided with the beginning of the studies of the Vasilievskie Ozera lake system by the Institute of Ecology of the Volga River Basin, only one of these lakes was preserved, namely, Lake Shlamonakopitelnoe, which had turned into an ephemeroïd reservoir by 2004 (Krivina and Tarasova, 2017b; Protisty i bakterii..., 2009).

The research aims to study the features of the taxonomic structure of the phytoplankton of a technogenic reservoir after the cessation of industrial exploitation by the example of Lake Shlamonakopitelnoe.

Materials and methods

Lake Shlamonakopitelnoe is a small reservoir of natural origin from the Vasilievskie Ozera lake system, located on the north-eastern margin of the Togliatti urban district.

For a long time, this reservoir was actively exploited for technogenic purposes. Even until the 1990s, Lake Shlamonakopitelnoe was used as a receiver of ash and slag from the Togliatti TPP. Wastewater discharged into the reservoir contained phosphates, chlorides, iron, copper, sulfates, ammonia nitrogen, and petroleum products. Since 1992, the discharge of waste into the water bodies has been significantly reduced due to a decrease in the intensity of industrial production. Since 1994, as a result of the introduction of low-waste and resource-saving technologies, the waste volume dumping into the reservoir has

decreased; and in 1996, the dumping has been stopped completely. Subsequently, due to a decrease in water level, the lake split into a number of shallow reservoirs with a depth of not more than a meter; it is now completely dry (Materialy otsenki vozdeystviya..., 2012; Ogurechnikova and Pimenov, 2012, 2015).

The environmental situation in the area of the Vasilievskie Ozera lake system has been influenced for a long time by the northern industrial hub of Togliatti, as well as horticultural and country cooperatives, which supplied and continue to supply biogenic elements to the local water bodies (Protisty i bakterii..., 2009; Ogurechnikova and Pimenov, 2012, 2015).

According to the outline of the water area, Lake Shlamonakopitelnoe belongs to type IV, oval (Litinsky, 1960). According to the main morphological indicators (Table 1), the reservoir may be classified as a small / very small lake (Kitaev, 1989).

The algological samples have been taken every 10 days from June through September 1991 and from May through October 1992; monthly, from May through October 2001.

The study of the lake phytoplankton was performed according to standard hydrobiological methods. Samples were taken with a Ruttner bathometer, fixed with a 40% formalin solution, and concentrated by direct filtration. Cell counting was carried out in Uchinskaya counting chamber (0.01 mL volume), the biomass was calculated by the method of reduced geometric figures (Metodika izucheniya..., 1975).

The algae classification is given in accordance with the recommendations of algologists of Papanin Institute of Biology of Inland Waters, Russian Academy of Sciences (Borok), summarized in the work of L.G. Korneva (2015), and the system presented in (Wasser et al., 1989), which is a transformed system of M.M. Hollerbach (1977), where Cryptophyta, Dinophyta, and Raphidophyta are considered as independent phyla. The names of supraspecific taxa of diatoms are given according to the classification accepted in the book “Diatomovye vodorosli SSSR” (1988); Dinophyta, by J. Popovsky and L. Pfister (Popovsky and Pfister, 1990), Chlorococcales order, according to P.M. Tsarenko (1990); green phytoflagellates, according to N.A. Moshkova and M.M. Gollerbakh (1986). The work took into account systematic revisions in floristic reports on cyanobacteria (Komárek and Anagnostidis, 1999, 2005). The names of species and intraspecific taxa of diatoms are presented according

Table 1. Some morphometric indicators of Lake Shlamonakopitelnoe.

Study period	Geographic position	Area, m ²	Length, m	Volume, m ³	Average depth, m
1991–1992	N 53°52'12", E 49°50'94"	205 024	596	307 536	1.5
2001		101 232	244	50 616	0.5

to the works of K. Krammer and H. Lange-Bertalot (Krammer and Lange-Bertalot, 1986, 1988, 1991a, b).

Ecological and geographical analysis of algoflora was carried out according to the data presented in the taxonomic keys, based on the most well-known and developed systems (Sládeček, 1973, 1986; Wegl, 1983), generalized for reservoirs of the Middle and Lower Volga River in the number of publications by the Institute of Ecology of the Volga River Basin (Fitoplankton Nizhney Volgi..., 2003; Protisty i bakterii..., 2009). If this information was absent in the sources cited above, the reference was made to literature data (Barinova and Medvedeva, 1996; Barinova et al., 2006; Davydova, 1985; Ekologicheskiye problemy..., 2001; Fitoplankton Nizhney Volgi..., 2003; Gerasimova, 1996; Korneva, 2015; Okhapkin, 1994; Okhapkin et al., 2003; Proshkina-Lavrenko, 1953).

The nature of the ecosystem transformation of the water bodies subjected to long-term technogenic exploitation was assessed according to the accepted methodology for graphic analysis modified for anthropogenically transformed aquatic ecosystems (Kolmar, 2006; Ostvald, 1987; Razumovsky and Moiseenko, 2009).

Results and discussion

Over the entire period of the study, 76 algal taxa of a rank lower than the genus have been found in the algal flora of the plankton of Lake Shlamonakopitelnoe, belonging to 7 phyla, 11 classes, 15 orders, 29 families, and 42 genera (Table 2).

The ratio of the species richness of the main algae phyla in the studied reservoir had a number of features that were not characteristic of many small reservoirs belonging to the basin of the Middle and Lower Volga River. Usually, in small reservoirs of this territory, most of the species, varieties and forms of algae belong to Chlorophyta and Bacillariophyceae,

followed, as a rule, by Euglenophyta, less often, by Cyanobacteria (Gerasimova, 1996; Okhapkin et al., 2003; Fitoplankton Nizhney Volgi..., 2003; Protisty i bakterii..., 2009). In Lake Shlamonakopitelnoe, as in most water bodies, green algae dominated and accounted for 30% of the total number of species, varieties and forms. However, the diversity of Cyanobacteria was atypically high, having the second place in terms of species richness. The share of Cyanobacteria slightly exceeded that of diatoms and amounted up to 21% of the total species richness of planktonic algoflora in the studied reservoir. The diatoms accounted for 20%. The share of other algae phyla was significantly lower and, as a rule, did not exceed 10%: Cryptophyta, 10%; Streptophyta, 8%, Euglenophyta, 7%; Dinophyta, 4%. The unusually high share of cyanobacteria was probably associated with specific conditions in the reservoir formed under the influence of industrial exploitation.

A complete list of species, varieties and forms of algae found in Lake Shlamonakopitelnoe at different periods of the study, and their ecological and geographical characteristics are presented in Table 3.

During the exploitation of the reservoir as a waste pond for thermal power plants (hereinafter, 1991–1992), the species richness of planktonic algoflora was minimal (31 algae taxa of a rank lower than the genus). After the cessation of the technogenic and especially toxicogenic impact on the water body (hereinafter, 2001), the total number of species and intraspecific taxa of algae increased by 2.3 times and amounted to 71 species and intraspecific taxa of algae.

Changes were also noted in the taxonomic structure of algoflora (Table 4). In 1991–1992, planktonic algoflora of Lake Shlamonakopitelnoe could be characterized as cyanobacteria-diatom with a noticeable participation of Cryptophytes and Chlorophyta; in 2001, it was dominated by

Table 2. Taxonomic structure of phytoplankton of Lake Shlamonakopitelnoe in the terminal phase of succession.

Phylum	Class	Order	Family	Number of taxa			
				Genus	Taxa below the genus level		
					Species	Intraspecific taxa	Total
Cyanoprokaryota	2	3	7	11	16	0	16
Bacillariophyta	2	4	6	7	14	1	15
Cryptophyta	1	1	1	3	8	0	8
Dinophyta	1	2	2	3	3	0	3
Euglenophyta	1	1	1	2	4	1	5
Chlorophyta	3	3	10	13	23	0	23
Streptophyta	1	1	2	3	5	1	6
Total	11	15	29	42	73	3	76

Table 3. The species composition of phytoplankton in Lake Shlamonakopitelnoe in different periods of the study. List of designations characteristics by habitat: B – benthic, L – littoral, P – planktonic, P-B – planktonic-benthic; by geographical distribution: b – boreal, c – cosmopolitan, n-a – north-alpine, st – subtropical; by halobility: Hph – halophilic, Ind – indifferent, Ohb – oligohalobiont; in regard to the pH of the medium: Al – alkaliphilic + alkalibiont, Ind – indifferent, Ac – acidophilic + acidobiont; by saprobity: o – oligosaprobic, o-β – oligo-β-mesosaprobic, β-o – β-oligo-mesosaprobic, o-α – oligo-α-mesosaprobic, β – β-mesosaprobic, β-α – β-α-mesosaprobic, α-β – α-β-mesosaprobic, β-p – β-meso-polysaprobic, α – α-mesosaprobic. “?” – no data.

	Habitat	Geographic distribution	Halobility	pH	Saprobity	Occurrence		
						1991–1992	2001	
Class CHROOCOCCEAE								
Order CHROOCOCCEALES								
Family SYNECHOCOCCACEAE								
	<i>Cyanothece aeruginosa</i> (Näg.) Komarék	L	c	Ind	?	o	-	+
Family MERISMOPEDIACEAE								
	<i>Aphanocapsa incerta</i> (Lemm.) Croberg et Krámer	P	c	Ind	?	β	+	+
	<i>Merismopedia tenuissima</i> Lemm.	P	c	Ind	?	α	-	+
Family MICROCYSTACEAE								
	<i>Microcystis aeruginosa</i> (Kütz.) Kütz.	P	c	Ind	Al	β	+	+
	<i>M. pulverea</i> (Wood) Forti emend. Elenk.	P	c	Ind	Al	o-α	+	+
Family CHROOCOCCACEAE								
	<i>Chroococcus turgidus</i> (Kütz.) Näg.	L	c	Hph	?	o-β	-	+
	<i>C. vacuolatus</i> Skuja	B	b	Ind	?	?	+	-
Class HORMOGONIOPHYCEAE								
Order OSCILLATORIALES								
Family PSEUDANABAENACEAE								
	<i>Geitlerinema amphibium</i> (Ag. ex Gom.) Anag.	P-B	c	Hph	?	o-α	-	+
	<i>Limnotrix planctonica</i> (Wolosz.) Meff.	P	c	Ind	?	β	+	+
	<i>Pseudoanabaena mucicola</i> (Hub.) Anag. et Komárek	P	c	Ind	?	o-β	+	+
	<i>P. limnetica</i> (Lemm.) Kom.	P-B	c	?	?	β-o	+	+
Order NOSTOCALES								
Family ANABAENACEAE								
	<i>Anabaena flos-aquae</i> (Lyngb.) Breb.	P	c	Ind	?	β	+	+
	<i>A. planctonica</i> Brunnth.	P	?	Hph	?	β-o	-	+
	<i>A. variabilis</i> Kütz.	B	c	Ind	?	β	-	+
	<i>Anabaenopsis Raciborskia</i> Wolosz.	P	st	?	?	?	-	+
Family APHANIZOMENONACEAE								
	<i>Aphanizomenon flos-aquae</i> (L.) Ralfs.	P	c	Ind	?	β	+	+

	Habitat	Geographic distribution	Halobility	pH	Saprobity	Occurrence		
						1991–1992	2001	
	Class CENTROPHYCEAE							
	Order THALASSIOSIRALES							
	Family THALASSIOSIRACEAE							
	<i>Skeletonema subsalsum</i> (Cl.-Euler) Bethge	P	c	Hph	?	β - α	-	+
	Family STEPHANODISCACEAE							
	<i>Cyclotella radiosa</i> (Grun.) Lemm.	P	c	Ind	Al	o- β	-	+
	<i>C. stelligera</i> Cl. et. Grun.	P	c	Ind	Al	β -o	+	+
	<i>Stephanodiscus hantzschii</i> Grun.	P	c	Ind	Al	α - β	+	+
	Order MELOSIRALES							
	Family AULACOSIRACEAE							
	<i>Aulacoseira granulata</i> (Ehr.) Sim.	P	c	Ind	Al	β - α	+	+
	Class PENNATOPHYCEAE							
	Order ARAPHALES							
	Family FRAGILARIACEAE							
	<i>Fragilaria atomus</i> Hust.	B	?	Ind	?	o	-	+
	<i>F. ulna</i> var. <i>acus</i> Sippen	P	c	Ind	Al	o- β	-	+
	Order RAPHALES							
	Family NAVICULACEAE							
	<i>Navicula capitata</i> var. <i>hungarica</i> (Grun.) Ross.	L	c	Ind	Al	β - α	+	+
	<i>N. cincta</i> (Ehr.) Ralfs	B	c	Hph	Al	α - β	-	+
	<i>N. clementis</i> Grun.	B	c	Ind	Al	o- β	-	+
	Family NITZSCHIACEAE							
	<i>Nitzschia closterium</i> (Ehr.) W. Sm.	P	c	Hph	?	?	-	+
	<i>N. palea</i> (Kütz.) W. Sm.	L	c	Ind	?	α	+	+
	<i>N. paleacea</i> Grun.	P	c	Ind	?	α	-	+
	<i>N. pusilla</i> Grun.	L	c	Ohb	Ind	β	+	+
	<i>N. sublinearis</i> Hust.	?	?	?	?	?	+	-
	Class CRYPTOMONADOPHYCEAE							
	Order CRYPTOMONADALES							
	Family CRYPTOMONADACEAE							
	<i>Chroomonas acuta</i> Uterm.	P	c	Ind	?	β	+	+
	<i>C. minima</i> Czosn.	L	?	?	Ac	?	+	+
	<i>Cryptomonas borealis</i> Skuja	P	c	Ind	Ac	?	-	+
	<i>C. caudata</i> Schiller	P	c	Ind	?	?	+	+
	<i>C. erosa</i> Ehr.	P	c	?	?	β	-	+
	<i>C. marssonii</i> Skuja	P	c	Ind	Ind	β -o	+	+
	<i>C. reflexa</i> Skuja	P	c	Hph	?	β -o	+	+
	<i>Rhodomonas lens</i> Pasch. et Ruttn.	P	n-a	Ind	Ind	o- β	+	+

PHYLUM BACILLARIOPHYTA

PHYLUM CRYPTOPHYTA

		Habitat	Geographic distribution	Halobility	pH	Saprobity	Occurrence		
							1991–1992	2001	
		Class DINOPHYCEAE							
		Order GYMNODINILES							
PHYLUM DINOPHYTA	Family GYMNODINIACEAE								
	<i>Gymnodinium mitratum</i> Schiller	P	?	?	?	?	-	+	
	Order PERIDINIALES								
PHYLUM DINOPHYTA	Family PERIDINIACEAE								
	<i>Peridiniopsis elpatiewsky</i> (Ostenfeld) Bourrelly	P	?	?	?	?	-	+	
	<i>Peridinium aciculiferum</i> Lemm.	P	?	?	?	?	-	+	
		Class EUGLENOPHYCEAE							
		Order EUGLENALES							
PHYLUM EUGLENOPHYTA	Family EUGLENACEAE								
	<i>Euglena minima</i> France	L	?	?	?	o	-	+	
	<i>E. limnophyla</i> var. <i>swirenkoi</i> (Arnold.) Popova	L	c	Ind	?	?	-	+	
	<i>Trachelomonas hispida</i> (Perty) emend. Defl.	P	c	Ind	Ind	β	-	+	
	<i>T. vas</i> Defl.	P	?	?	Ac	?	+	+	
	<i>T. volvocina</i> Ehr.	P	c	Hph	Ind	β	+	-	
		Class CHLOROPHYCEAE							
		Order CHLOROCOCCALES							
PHYLUM CHLOROPHYTA	Семейство CHARACIACEAE								
	<i>Schroederia setigera</i> (Schrod.) Lemm.	P	c	Ind	?	o-α	+	+	
	Family GOLENKINIACEAE								
	<i>Golenkinia radiata</i> Chod.	P	c	Ind	?	o-α	-	+	
	Family BOTRYOCOCCACEAE								
	<i>Dictyosphaerium subsolitarium</i> von Goor	P	c	Ind	?	?	-	+	
	Family OOCYSTACEAE								
	<i>Lagerheimia genevensis</i> (Chod.) Chod.	P	c	Ind	?	β	-	+	
	<i>Oocystis submarina</i> Lagerh.	P	c	Hph	?	?	+	+	
	Family CHLORELLACEAE								
<i>Monoraphidium arcuatum</i> (Korsch.) Hind.	P-B	c	?	?	β	+	+		
	<i>M. circinale</i> (Nyg.) Nyg.	P	?	Ind	Al	?	+	-	
	<i>M. contortum</i> (Thurn.) Kom.-Legn.	P	c	Ind	?	β	-	+	
	<i>M. griffithii</i> (Berk.) Kom.-Legn.	P	c	Ind	?	β	-	+	

	Habitat	Geographic distribution	Halobility	pH	Saprobity	Occurrence		
						1991–1992	2001	
	Class CHLOROPHYCEAE							
	Order CHLOROCOCCALES							
	Family COELASTRACEAE							
	<i>Coelastrum microporum</i> Näg. in A. Br.	P	c	Ind	Ind	β	-	+
	Family SCENEDESMACEAE							
	<i>Crucigenia tetrapedia</i> (Kirchn.) W. et G. S. West	P	c	Ind	Ind	β	-	+
	<i>Didymocystis planctonica</i> Korsch.	P	c	Ind	?	β	-	+
	<i>Scenedesmus falcatus</i> Chod.	P	c	Ohb	Al	β	-	+
	<i>S. intermedius</i> (R. Chod.) Hegew	P-B	c	?	?	β	-	+
	<i>S. obliquus</i> (Turp.) Kütz.	P-B	c	?	?	β-p	+	-
	<i>S. protuberans</i> Fritsch	P	c	Ind	Ind	?	-	+
	<i>S. quadricauda</i> (Turp.) Bréb.	P	c	Ohb	Ind	β	-	+
	Class CHLAMYDOPHYCEAE							
	Order CHLAMYDOMONADALES							
	Family CHLAMYDOMONADACEAE							
	<i>Carteria globosa</i> Korsch.	P	c	Ind	?	?	-	+
	<i>C. multifilis</i> (Fres.) Dill.	P	c	Ind	?	β-α	-	+
	<i>Chlamydomonas globosa</i> Snow.	P	c	Ohb	?	β	+	+
	<i>C. simplex</i> Pasch.	P	c	Ind	?	α	-	+
	Family PHACOTACEAE							
	<i>Pteromonas aculeata</i> Lemm.	P	c	Ind	?	β	-	+
	Class ULOTRICHOPHYCEAE							
	Order ULOTRICHALES							
	Family ULOTROCHACEAE							
	<i>Koliella longiseta</i> (Vischer) Hind.	P	c	Ind	?	β	-	+
	Class CONJUGATOPHYCEAE							
	Order DESMIDIALES							
	Family CLOSTERIACEAE							
	<i>Closterium acutum</i> (Lyngb.) Bréb. var. <i>acutum</i>	P	c	Ind	?	β-o	+	+
	<i>C. acutum</i> var. <i>variabile</i> (Lemm.) Krieg.	B	?	?	?	β	-	+
	Family DESMIDIACEAE							
	<i>Cosmarium abbreviatum</i> W. et G.S. West	P	c	?	?	?	-	+
	<i>C. margariferum</i> Menegh.	B	c	Ind	?	?	-	+
	<i>C. rectangulare</i> Grun.	L	c	?	?	?	-	+
	<i>Staurastrum tetracerum</i> Ralfs	P	c	Ind	?	o	-	+

PHYLUM CHLOROPHYTA

PHYLUM STREPTOPHYTA

Chlorophyta and Cyanobacteria with a noticeable share of diatoms, which was closer to the natural taxonomic composition of planktonic algal flora of small water bodies (Korneva, 2015; Krivina and Tarasova, 2017a, b; Protisty i bakterii..., 2009).

During the period from 1991–1992 to 2001, there was an increase in the number of algae species capable for a mixotrophic type of nutrition (Cryptophyta, Dinophyta, Euglenophyta, a number of diatoms and Chlorophyta) in the studied reservoir along with an increase in the total species richness of algal flora, although Dynophyta was totally absent in the reservoir in 1991–1992. Probably, the cessation of the severe technogenic impact on the lake resulted also for the start of the destructive processes, when organic matter available for the feeding of mixotrophic algae began to appear; the number of bacteria, also served as the food items, increased as well (Balashova et al., 1989; Kopylov and Kosolapov, 2011).

The saturation level of large taxonomic ranks of planktonic algal flora (orders and families) of the studied reservoir calculated by applying the floristic coefficients (Shmidt, 1980, 1984) has increased from 1991 to 2001 (Fig. 1). This reflects the increase in the complexity of the taxonomic structure of the plankton community in the reservoir, and thus it is a positive sign of the transformation of the ecosystem of the reservoir after the cessation of industrial exploitation. However, the level of genus and species richness was low at each period of the study, when most of the species and genera of the planktonic algal flora were presented by one or two representatives only. This allows us to suggest that, despite the general positive dynamics, “harsh” living conditions with clearly pronounced processes of anthropogenic eutrophication remained up to 2001, which was also noted for other reservoirs in the Vasilievskie Ozera lake system (Okhapkin et al., 2003; Protisty i bakterii..., 2009; Trifonova, 1990).

Planktonic algal flora of Lake Shlamonakopitelnoe was characterized by a high level of species specificity in each study period. The Sørensen's similarity coefficient (K_s) between the algal communities during the period of intensive industrial exploitation (1991–1992) and after its cessation (2001) was low and amounted to 44%. The level of succession of algae species was also low (28%). The complex of successive species and intraspecific taxa comprised 22 algae species. The succession rate the most taxonomically significant divisions was 58% for cyanobacteria, diatoms, 38%, Chlorophyta, 22%.

A graphical analysis of the dominance curves of the number of particular phytoplankton species was applied in accordance with the accepted methodology (Kolmar, 2006; Ostvald, 1987; Razumovsky and Moiseenko, 2009) in order to assess the degree of transformation of the taxonomic structure of Lake Shlamonakopitelnoe phytoplankton from 1991 to 2001. In the study period, the spatiotemporal transformation of taxonomic proportions occurred according to the type of generation of the resulting lines with a single localization center (Fig. 2), i.e. the transformation was in the active phase.

The equations of the resulting lines according to the power dependence $Y = kX^a$ between the values of X (taxon order) and Y (its relative abundance) obtained in the logarithmic coordinate system are presented in Table 5. The change in the values of the a , parameter from 1991 to 2001 demonstrates the weakening of the negative impact on the ecosystem. A decrease in the k , coefficient indicates an increase in the number of taxa supporting the ecological stability of an aquatic ecosystem and a decrease in the allowable lower threshold for their relative abundance, i.e., the ecosystem stability over time and its ability to withstand external adverse environmental factors are gradually increasing (Kolmar, 2006; Razumovsky and

Table 4. The role of the major phyla in forming the taxonomic structure of the phytoplankton of the Lake Shlamonakopitelnoe at various stages of the study. Numbers left to slash indicate the number of taxa below the genus level, right to slash, % of the total number of species, varieties, and forms of algae.

Phylum	1991–1992	2001
Cyanoprokaryota	9/29	15/21
Bacillariophyta	7/23	14/20
Cryptophyta	6/19	8/11
Dinophyta	0/0	3/4
Euglenophyta	2/7	4/6
Chlorophyta	6/20	21/30
Streptophyta	1/3	6/9
Total	31	71

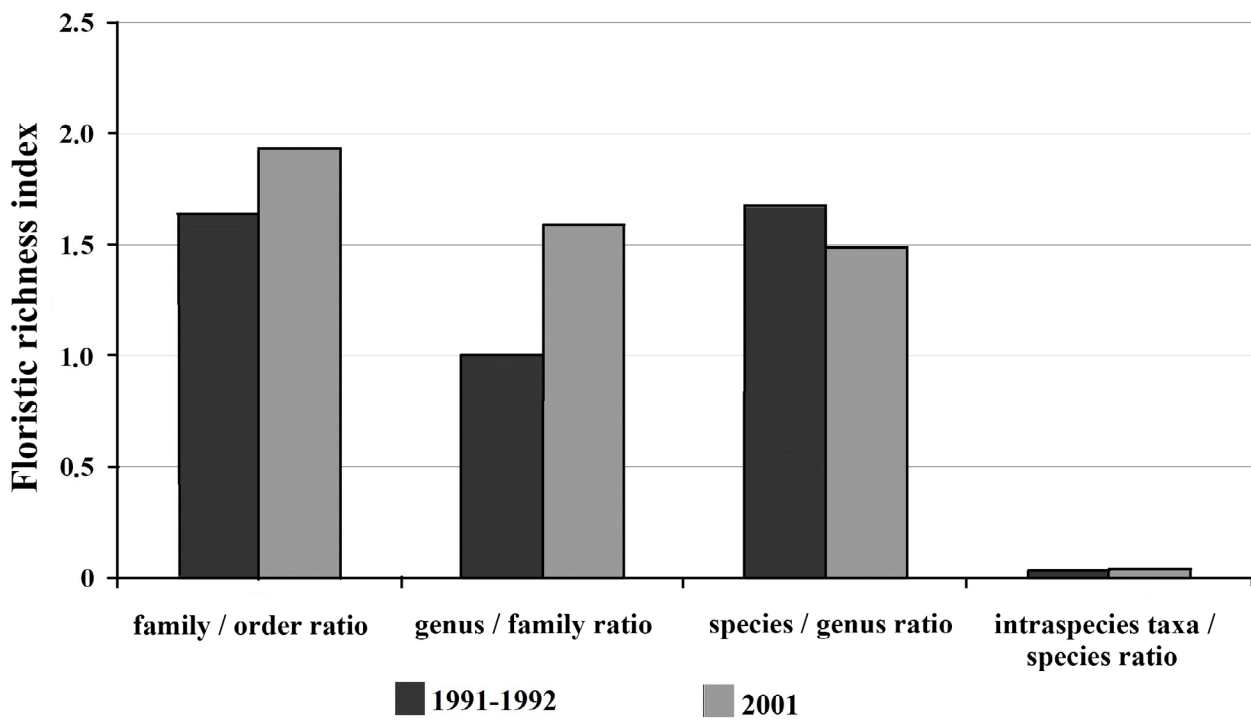


Fig. 1. The floristic richness index of the different taxonomic ranks of plankton algal flora of Lake Shlamonakopitelnoe.

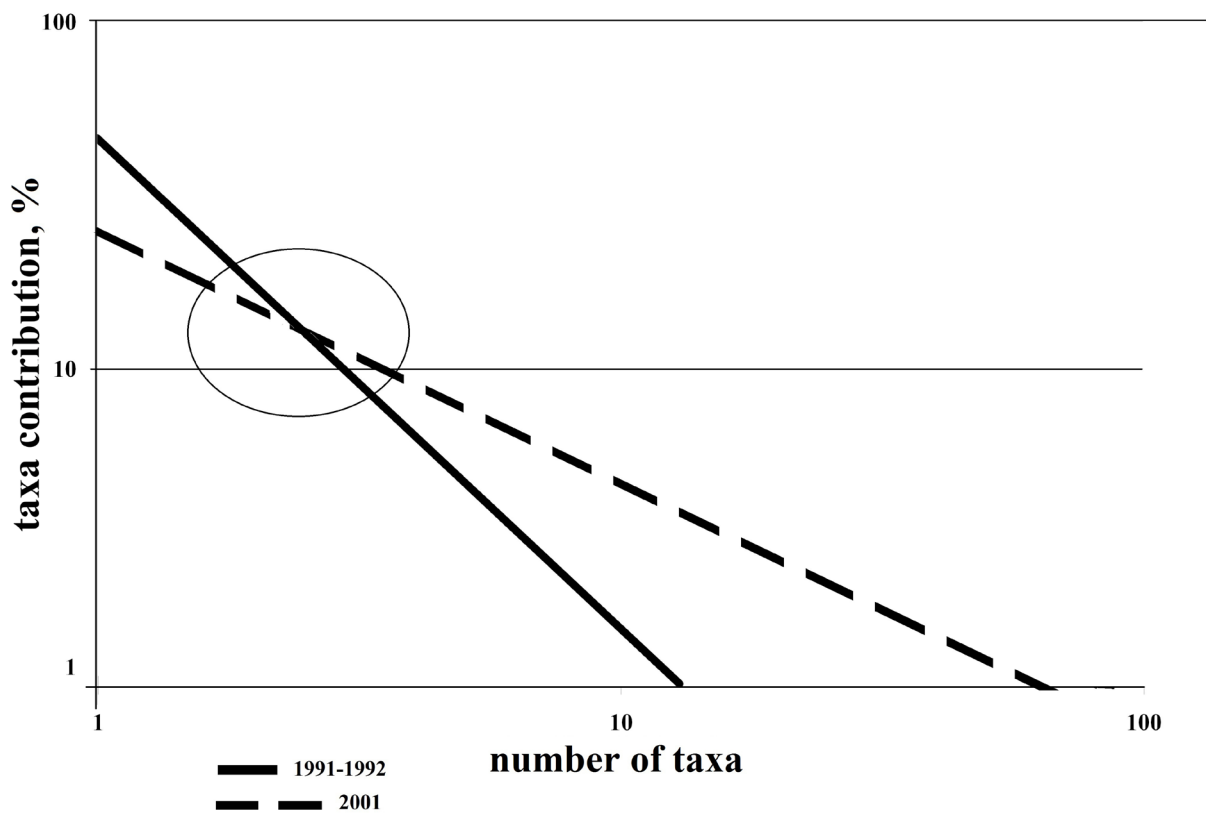


Fig. 2. Graphical analysis of transformation of the taxonomic structure of phytoplankton in Lake Shlamonakopitelnoe in 1991–1992 and in 2001 in the logarithmic coordinate system.

Table 5. Equations of the resulting lines of transformation of the taxonomic structure of phytoplankton in Lake Shlamonakopitelnoe in 1991–1992 and in 2001.

Years	Equation	Determination coefficient R^2
1991–1992	$y = 46.21x^{-1.41}$	0.859
2001	$y = 26.47x^{-0.53}$	0.895

Table 6. Ecological and geographical characteristics of phytoplankton of Lake Shlamonakopitelnoe in different periods of the study. Designations are given in Table 3.

	1991–1992	2001
Habitat		
B	1	6
L	4	9
P	22	52
P-B	3	4
Total	30	71
Halobility		
Hph	3	8
Ind	20	45
Ohb	2	4
Total	25	57
Geographic distribution		
b	1	0
c	25	60
n-a	1	1
st	0	1
Total	27	62
pH		
Al	7	11
Ind	4	8
Ac	2	3
Total	13	22

Moiseenko, 2009). This is undoubtedly a positive sign of spontaneous transformation of the ecosystem after the termination of technogenic press.

Therefore, it can be assumed that the ecosystem transformation was positive and could ultimately lead to a stable ecological equilibrium of the lake ecosystem if the intensive siltation of groundwater sources and, as a consequence, subsequent shallowing and transformation of the reservoir into an ephemeroid type did not take place.

Despite a significant increase in species richness, ecological and geographical analysis did

not reveal significant differences between the main characteristics of the planktonic algaeflora of Lake Shlamonakopitelnoe in 1991–1992 and in 2001. Most of the registered species, varieties and forms of algae belonged to planktonic organisms in regard to the traditional habitat (73% of the number of associated intra-genus taxa in 1991–1992 and in 2001, Table 6); the share of littoral forms was also noticeable (13% and 12% in 1991–1992 and in 2001, respectively).

Most species, varieties and forms of algae were characterized by a wide geographical distribution (93% and 97% of the number of algae taxa of a rank lower

than the genus, for which their geographical distribution is known, in 1991–1992 and 2001, respectively).

In regard to water salinity, most algae were indifferent species (80% in 1991–1992 and 79% in 2001). The share of halophilic (12% and 14%) and oligohalobic organisms (8% and 7%) was noticeable.

In regard to the pH of the medium, alkaliphilic species, varieties, and forms dominated, which amounted to 54% in 1991–1992 and 50% in 2001 of the total species number, for which the preferable pH range is known. The share of the indifferent forms was also noticeable: 31% in 1991–1992 and 36% in 2001.

The species indicating different degrees of organic pollution of the water bodies belonged to 24 taxa of a rank lower than the genus in 1991–1992 and to 54 taxa in 2001. Most saprobic algae belonged to β -mesosaprobies, i.e. the indicator species of medium degree of organic pollution (42% in 1991–1992 and a similar share in 2001). The indicator species of a low degree of organic pollution accounted for 38% in 1991–1992 and 37% in 2001; high degree, 20% in 1991–1992 and 21% in 2001.

Conclusions

The cessation of the commercial exploitation of the reservoir contributed to a significant increase in the species richness of the plankton algae of Lake Shlamonakopitelnoe at the level of all taxonomic ranks and to an increase of the number of polytypic genera. This allows us to suggest that the nature of the transformation of the phytoplankton community was positive, and the ecosystem of the reservoir, even after long-term technogenic and especially toxicogenic effects, had great potential for self-healing and self-purification.

The high species specificity of algoflora and the low level of species continuity during the period of intensive industrial exploitation (1991–1992) and after its termination (2001) indicate a significant transformation of the ecosystem against the background of the termination of industrial exploitation, while the taxonomic composition of the planktonic algoflora of this reservoir started to approach the floristic type usual for this region.

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