THE ROLE OF PLANKTONIC ALGAE IN THE ECOLOGICAL ASSESSMENT OF STORAGE-RESERVOIRS OF THE ILI-BALKHASH BASIN

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ABSTRACT

The largest wastewater treatment systems include Sorbulak and Kurty reservoirs, and the small storage ponds were studied in the summer of 2017 and characterized mainly by organic pollution. Phytoplankton communities were represented by species tolerant of organic and toxic pollution. Cyanobacteria dominated in the reservoirs, and dinophyte algae were only in the Kurty Reservoir. According to the results of CCA analysis, only Cr and certain nutrients had a significant effect on the abundance of algae. A statistically positive significant association between the Shannon index and the average algal cell mass was established. The results obtained are a particular example reflecting the non-linearity of changes in plankton communities in the gradient of nutrient loading and eutrophication of aquatic ecosystems.

ZUSAMMENFASSUNG: Die Rolle der Planktonalgen in der ökologischen Beurteilung von Staubecken im Einzugsgebiet des Ili-Balkhash.

Die größten Abwasserbehandlungssysteme, das Sorbulak und Kurty Reservoir sowie kleinere Wasserspeicher, vor allem solche, die sich durch organische Verschmutzung kennzeichnen, wurden im Sommer 2017 untersucht. Die Phytoplankton-Gemeinschaften waren durch Arten vertreten, die gegenüber organischer und toxischer Verschmutzung tolerant sind. Cyanobacterien dominierten in den Stauseen, während Dinophyten nur im Kurty-Reservoir vorkamen. Nach den Ergebnissen der CCA-Analyse hatten nur Cr und einige Nährstoffe einen signifikanten Einfluss auf die Abundanz der Algen. Es wurde ein statistisch positiv signifikanter Zusammenhang zwischen dem Shannon-Index und der durchschnittlichen Algenzellmasse festgestellt. Die erzielten Ergebnisse stellen ein besonderes Beispiel dar, das die Nichtlinearität von Veränderungen in Planktongemeinschaften in Bezug auf den Grad der Nährstoffbelastung und der Eutrophierung aquatischer Ökosysteme widerspiegelt.

REZUMAT: Rolul algelor planctonice în evaluarea ecologică a lacurilor de acumulare din bazinul Ili-Balkhash.

Cele mai mari sisteme de epurare a apelor uzate, inclusiv Sorbulak, rezervoarele Kurty și mici iazuri de depozitare, au fost studiate în vara anului 2017 fiind caracterizate în principal de poluarea organică. Comunitățile fitoplanctonice au fost reprezentate de specii care tolerează poluarea organică și toxică. Cianobacteriile au dominat rezervoarele, algele dinofile numai rezervorul Kurty. Conform rezultatelor analizei CCA, doar Cr și substanțele nutritive au avut un efect semnificativ asupra abundenței algelor. A fost stabilită o asociere pozitivă semnificativă statistic între indicele Shannon și masa medie a celulelor algelor. Rezultatele reprezintă un exemplu care reflectă nelinearitatea schimbărilor în comunitățile de plancton în gradientul încărcării cu nutrienți și al eutrofizării ecosistemelor acvatice.

INTRODUCTION

Planktonic algae are widely used in ecological assessments of water quality (Poikane et al., 2011, 2015; Momeu et al., 2012; Stevenson, 2014).

It is very important to know about algal diversity in inland waters because most of algal species can be used as environmental indicators.

The algal diversity in the lakes of Kazakhstan is partly studied (Barinova et al., 2009; Krupa et al., 2016; Barinova and Krupa, 2017), the contaminated water reservoirs phytoplankton research is now in an initial stage but still as important for wastewater storages ecosystem self-purification capacity assessment.

Almaty, the largest city in the Ili-Balkhash Basin, is the core of the Almaty agglomeration with a total population of 2.5 million. The water supply of the city and its environs are carried out at the expense of underground artesian basins, as well as the mountain river Ulken Almaty. The sewage of Almaty and its environs is mixed in the composition. The main part – up to 35-40%, are domestic sewage. The share of industrial effluents in the total volume of sewage in recent decades has decreased from 35% to 11%. Despite the population growth, in the period from 1998 to 2004, specific water consumption was decreased from 288.0 to 126.0 one day^{-1} per person. Accordingly, the volume of discharged effluents decreased from 135.7 to 101.5 million m^3 (Dostay and Tyumenev, 2009), which is mainly due to an increase in the number of equipments for consumed water.

The sewage waters of Almaty and the surrounding areas are stored in the Sorbulak storage reservoir (Figs. 1 and 2) after preliminary treatments at sewage treatment plants. Its filling began in 1973. The Sorbulak storage reservoir is located in a natural depression of the relief of the foothill plain at an altitude of about 590-620 m a.s.l. in 40 km north of Almaty. Its maximum depth is 20 m, the water surface is about 58 km^2. The potential volume of the reservoir, taking into account the height of the dam is about 1,000 million m^3 at the altitude of its surface of about 622 m. Sorbulak is one of the largest wastewater storage facilities.

In the event of a threat of overflow, part of the waste water, bypassing Sorbulak, along the Right Bank Sorbulak Canal (RBSC) (Figs. 1 and 5a) is discharged into storage ponds and further into the Ili River. RBSC ponds are shallow, with maximum depths of no more than six-seven m. Their area varies considerably and depends on the volume of wastewater discharged. The largest are pond no. seven and pond no. eight, the most terminal in the system (Figs. 1, 3 and 4). The sewage is chlorinated before discharging to the river Ili that poses an additional serious threat to the biota and the river ecosystem as a whole. The mass mortality of aquatic invertebrates and fish was noted by us in 1996, on the Ili River section about 70 km below the confluence of the RBS Canal (Matmuratov et al., 1999). The Ili River flows into lake Balkhash, one of the largest fishery reservoirs in Kazakhstan, so the quality of the water in the river also affects the ecological situation in the Balkhash Lake.

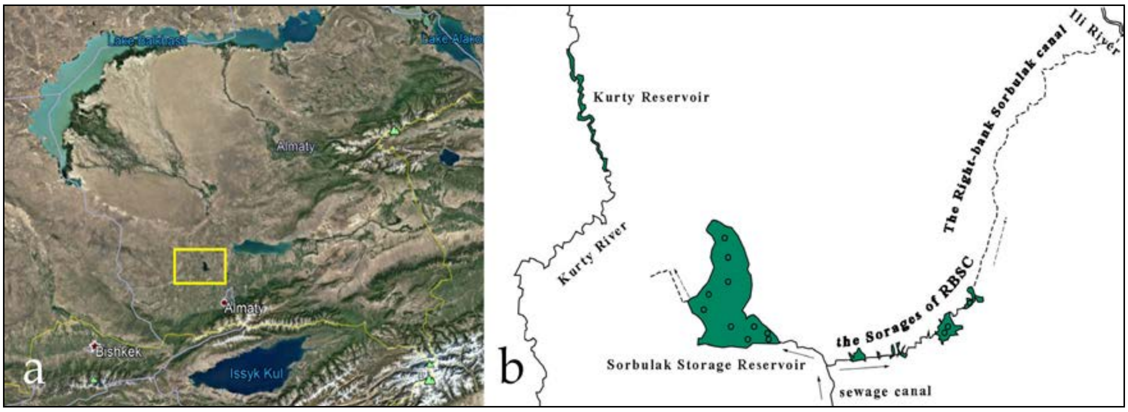

Figure 1: Schematic diagram of the location of wastewater reservoirs (a)
and the Kurty Reservoir (b).

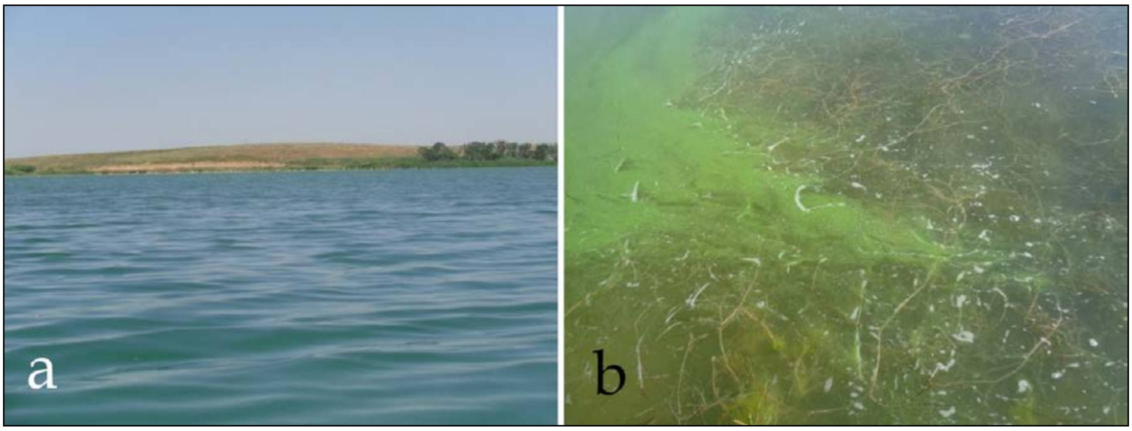

Figure 2: The Sorbulak Reservoir (a)
and the coastal zone of the reservoir with blue-green bloom (b).

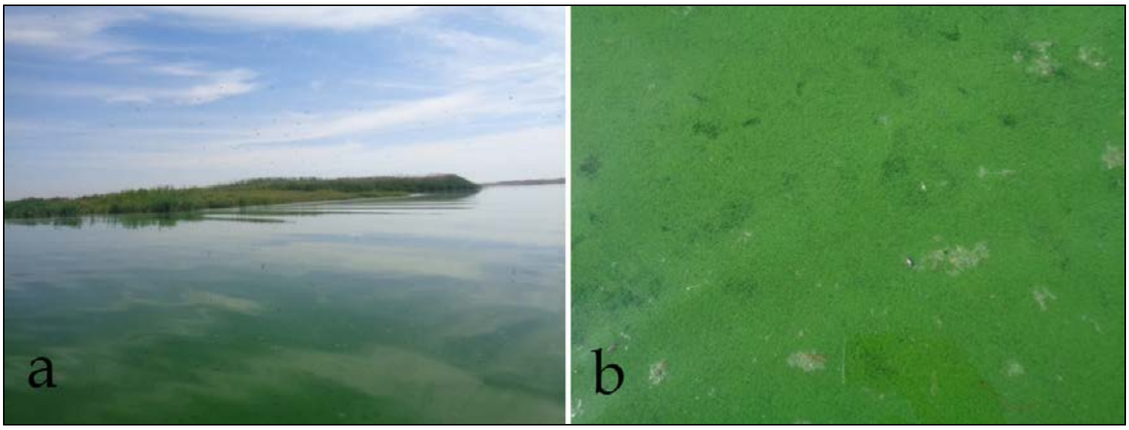

Figure 3: Storage pond RBSC no. seven (a)
the bloom of cyanobacteria throught the water area of the reservoir (b).

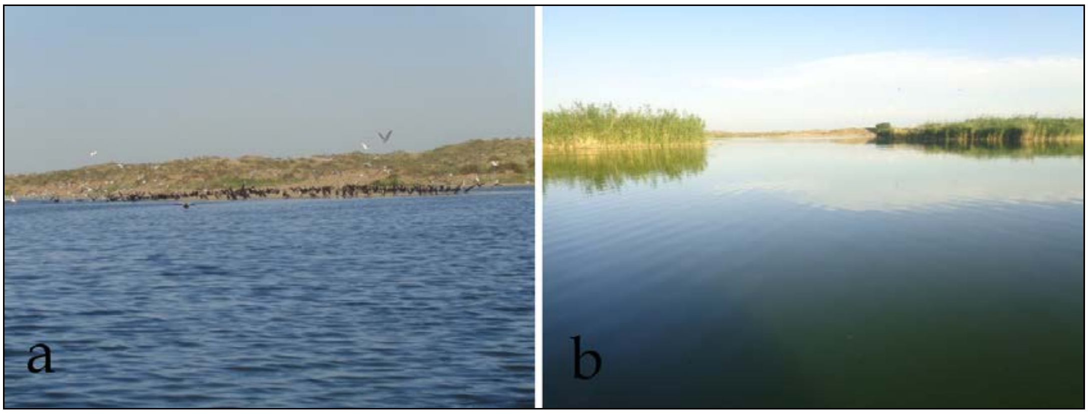

Figure 4: The storage pond RBSC no. eight;
in the background there are groups of cormorants and gulls.

Figure 5: The channel of emergency discharge of sewage
between storage ponds RBSS no. seven and no. eight (a); reservoir Kurty (b).

The storage reservoirs are places of accumulation of water birds. Many birds stop here on migration, some winters (Auezov et al., 1980).

At a distance of 12 km from the Sorbulak Reservoir, the Kurty River flows, on which the canyon type, the Kurty Reservoir is located. It is long and narrow (Fig. 5b). Its depth is about 30 m, the surface area is 4.2 km^2. Sewage in the Kurty River and the reservoir is not discharged. But it is potentially possible to get contaminants into Kurty through an underground runoff, as a result of drive impact of technologically polluted aquifer formation in the zone of the Sorbulak large sewage reservoir (Dostay and Tyumenev, 2009).

The purpose of this work is a comparative assessment of the ecological state of storage reservoirs of the RBSC system and the Kurty Reservoir on the basis of quantitative variables of phytoplankton and water chemistry.

MATERIAL AND METHODS

Phytoplankton studies of the reservoirs of the RBSC system and the Kurty Reservoir were carried out in July of 2017. A total of 20 phytoplankton samples of one liter from the surface layer of the waters were taken. The samples were fixed with 4% formaldehyde. Samples were processed using standard methods for species definition with using conventional handbooks. In parallel, water samples were taken to determine the chemical composition, the content of biogenic elements and heavy metals.

The measures of the temperature and pH values of the surface water layers were taken in the field environment. Water transparency was measured with Secchi disk. Coordinate referencing of the stations was done by Garmin eTrex GPS-navigators. The samples for heavy metals were fixed in the site by adding nitric acid. All collected samples were transported to the lab in an icebox.

Conventional methods of chemical analysis of water were used. Water samples were analyzed in three – four replications. The error of estimate for major ions in the water was 0.5-5.0%, depending on the analyte. Concentrations of heavy metals were determined by AAS-1N atomic absorption spectrophotometer (Carl Zeiss Industrielle Messtechnik GmbH, Germany). The device allows for the detection of the various chemical elements in complex matrices, including those in the sea and grey water and in the biological objects in micro-trace quantities. Test-sensitivity of AAS-1N spectrophotometer is 0.001-0.0025% mass. (Semenova, 1977; Fomin, 1995)

The diversity indices of Shannon and W-statistic Clarke were calculated in the Primer 5.0 program. Canonical Correspondence Analysis plots were statistically generated in the CANOCO 6.0 program. Nonparametric correlation analysis and spatial mapping in wafer plots was done on Statistica 12.0.

RESULTS

The biggest depth of the Sorbulak Reservoir all along the research was 17 m, the Kurty Reservoir – 26 m, the RBSC ponds – not over 6.5 m. In all reservoirs macrophytes are underdeveloped. The water color varies from bright green to grassy-green. The sediments are black silt in Sorbulak smelling of hydrogen sulfide, in the Kurtinsky Reservoir – gray mud. In the RBSC ponds at the bottom was a thick layer of blue-green algae. The maximum transparency of water was recorded in the reservoirs Sorbulak and Kurty. The water temperature was 25.8-28.0°C (Tab. 1).

All reservoirs were slightly mineralized with a maximum value of TDS in the Sorbulak Reservoir (Tab. 1). In Sorbulak and RBSC ponds, water was of chloride class, in the reservoir of Kurty – sulfate class, sodium group. The water of the ponds was soft, in the reservoirs of Kurty and Sorbulak, it was of medium hardness. The amount of easy oxidizable organic matter was at middle level and in the pond RBSC no. seven at an elevated level. The RBSC no. seven pond was also characterized by the highest content of nitrites and phosphates in its water. The content of heavy metals was insignificant. The exception was the pond RBSC no. seven, in the water of which increased concentrations of copper and zinc were recognized.

Table 1: The environmental variables of the studied reservoirs of the Almaty region, July 2017.

Variables	units	Sorbulak Reservoir	RBSC no. 7	RBSC no. 8	Kurty Reservoir
Depth	m	7.2 ± 1.9	5.0 ± 1.2	2.9 ± 0.6	18.3 ± 3.3
Transparency	m	1.5 ± 0.3	0.2 ± 0.1	0.5 ± 0.03	2.0 ± 0.2
Temperature	°C	27.0 ± 0.2	28.5 ± 0.01	27.8 ± 1.1	26.1 ± 0.1
pH		9.0 ± 0.6	8.5 ± 0.01	9.4 ± 0.06	8.3 ± 0.2
TDS	mg dm^{-3}	1,234.3 ± 37.8	517.5 ± 20	584.1 ± 40.1	886.7 ± 67.3
Hardness	mg-eq. dm^{-3}	4.9 ± 0.03	2.3 ± 0.01	2.8 ± 0.3	5.3 ± 0.1
BOD	mg O_2 dm^{-3}	11.2 ± 0.04	21.8 ± 0.1	10.9 ± 0.9	5.6 ± 0.3
Si	mg dm^{-3}	2.1 ± 0.4	8.7 ± 0.1	8.3 ± 0.1	5.3 ± 0.2
NO_2	mg dm^{-3}	0.038 ± 0.004	1.06 ± 0.02	0.020 ± 0.009	0.158 ± 0.004

Table 1 (continued): The environmental variables of the studied reservoirs of the Almaty region, July 2017.

Variables	units	Sorbulak Reservoir	RBSC no. 7	RBSC no. 8	Kurty Reservoir
NO_3	mg dm^{-3}	0.67 ± 0.33	4.63 ± 1.36	0.35 ± 0.23	6.74 ± 0.49
NH_4	mg dm^{-3}	0.58 ± 0.70	0.47 ± 0.07	0.35 ± 0.13	0.26 ± 0.10
PO_4	mg dm^{-3}	0.15 ± 0.07	0.80 ± 0.27	0.28 ± 0.02	0.0008±0.0008
Fe	mg dm^{-3}	0.70 ± 0.14	0.93 ± 0.19	1.20 ± 0.40	0.44 ± 0.04
Mn	mg dm^{-3}	0.005 ± 0.001	0.0 ± 0.0	0.003 ± 0.001	0.005 ± 0.001
Cd	mg dm^{-3}	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Cr	mg dm^{-3}	0.007 ± 0.0003	0.007±0.0001	0.006±0.0006	0.007 ± 0.0003
Cu	mg dm^{-3}	0.001 ± 0.0008	0.043 ± 0.042	0.0 ± 0.0	0.0006±0.0003
Ni	mg dm^{-3}	0.0051 ± 0.0003	0.006 ± 0.003	0.005±0.0001	0.0046±0.0004
Pb	mg dm^{-3}	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Zn	mg dm^{-3}	0.012 ± 0.003	0.037 ± 0.030	0.010 ± 0.006	0.009 ± 0.005

The species richness of the phytoplankton was low (Tab. 2). In total 18 taxa, six species of diatoms, five greens, two charophytic algae, three dinophytes, and two cyanobacteria were identified. The abundant species in Sorbulak and RBSC ponds cyanobacteria *Microcystis flosaquae* and *Pseudanabaena mucicola*, whereas in the Kurty Reservoir dinophyte species *Peridinium cinctum* and *Ceratium hirundinella* were prevalent in total cell numbers.

Table 2: Species composition of phytoplankton of wastewater storage reservoirs and the Kurty Reservoir, July 2017.

Taxa	Sorbulak Reservoir	RBSC no. 7	RBSC no. 8	Kurty Reservoir
Bacillariophyta				
Encyonema ventricosum (Agardh C.) Grunow	+			
Diatoma elongata (Lyngbye) Agardh C.	+			
Fragilaria capucina Desmazières				+
Navicula tripunctata (Müller O. F.) Bory				+
Pleurosigma salinarum (Grunow) Grunow				+
Surirella minuta Brébisson ex Kützing				+
Chlorophyta				
Coelastrum microporum Nägeli	+			
Korshikoviella limnetica (Lemm.) Silva P. C.	+			
Pseudopediastrum boryanum Hegewald E.	+			
Pediastrum duplex Meyen	+			
Desmodesmus communis Hegewald E.				+
Charophyta				
Cosmarium botrytis Meneghini ex Ralfs	+			
Staurastrum gracile Ralfs ex Ralfs				+
Cyanobacteria				
Microcystis flosaquae (Wittrock) Kirchner	+	+	+	
Pseudanabaena mucicola Schwabe	+	+	+	
Dinophyta				
Ceratium hirundinella (Müller O. F.) Dujardin	+	+		+
Peridinium bipes Stein				+
Peridinium cinctum (Müller O. F.) Ehrenberg				+
Total	**10**	**3**	**2**	**9**

The abundance and biomass of phytoplankton in the sewage water reservoirs reached a high level (Tab. 3). Absolute dominant position was occupied by the cyanobacteria *Microcystis flosaquae*, cells of which were up to 95.6-98.4% of the total abundance, and 87.4-100.0% of the biomass in the communities. Its scum was visible on the water surface, especially in the RBSC ponds (Fig. 3b). The abundance of phytoplankton of the Kurty Reservoir was two orders of magnitude, and the biomass was about half that of storage reservoirs. Dinophyte algae were dominated with a leading position of *Ceratium hirundinella* (42.6% of abundance, and 84.1% of biomass), and *Peridinium cinctum* (32.7%, and 15.1% respectively). Green alga *Desmodesmus communis* was formed up to 15.8% of the total abundance in Kurty Reservoir.

The diversity of phytoplankton was very low (Tab. 4), which is associated with both the limited number of species entering the community and the pronounced predominance of one-three species. Phytoplankton communities of studied reservoirs were represented by small-celled organisms. The volume of the the cells increased in the row “pond no. eight – pond no. seven – Sorbulak”. The most large-scale composition was in phytoplankton of the Kurty Reservoir, where the large-celled dinophyte species were dominated.

Table 3: The abundance and biomass of phytoplankton in the wastewater storage reservoirs and reservoir Kurty, July 2017.

Object	Bacillariop.	Chlorop.	Charop.	Cyanob.	Dinophyta	Total
Abundance, mln. cells m^{-3}						
Sorbulak	0.5 ± 0.5	59.2 ± 16.1	0.5 ± 0.4	6,252.0 ± 2,225.7	2.2 ± 0.9	6,287.3 ± 2,220.5
PSC-7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5,888.3 ± 778.3	3.3 ± 3.3	5,891.7 ± 781.7
PSC-8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	6,073.9 ± 799.3	0.0 ± 0.0	6,073.9 ± 799.3
Kurty	1.3 ± 0.6	5.3 ± 5.3	0.3 ± 0.3	0.0 ± 0.0	26.7 ± 7.4	33.7 ± 7.8
Biomass, mg m^{-3}						
Sorbulak	1.0 ± 1.0	326.3 ± 117.0	23.3 ± 16.6	4,918.1 ± 1,782.5	354.3 ± 15.3	5,623.0 ± 1,805.0
PSC-7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4,745.3 ± 708.1	545.1 ± 545.1	5,290.4 ± 1,253.2
PSC-8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4,762.0 ± 606.5	0.0 ± 0.0	4,762.0 ± 6,06.5
Kurty	8.0 ± 42	5.6 ± 5.6	9.4 ± 9.4	0.0 ± 0.0	2,764.2 ± 726.6	2,782.2 ± 717.8

Table 4: Structural variables of phytoplankton of sewage water reservoirs and reservoir Kurty, July 2017.

Object	Average species number	Shannon AB	Shannon BI	AVERAGE bioMASS, MG 10-6
Sorbulak	4.0 ± 0.5	0.44 ± 0.11	0.70 ± 0.21	1.08 ± 0.16
PSC-7	2.0 ± 0.0	0.11 ± 0.10	0.33 ± 0.32	0.89 ± 0.10
PSC-8	2.0 ± 0.0	0.25 ± 0.02	0.006 ± 0.0007	0.79 ± 0.004
Kurty	3.4 ± 0.4	1.43 ± 0.09	0.74 ± 0.08	86.2 ± 11.6

Spatial distribution of phytoplankton in the Sorbulak Reservoir

The green algae were the main contributors to the total species richness of the phytoplankton of the Sorbulak Reservoir. The highest number of species of this taxonomic Division was recorded along the perimeter of the reservoir, including the zone of the confluence of the sewage channel (Fig. 6). The highest species richness of the whole community was observed in the same areas.

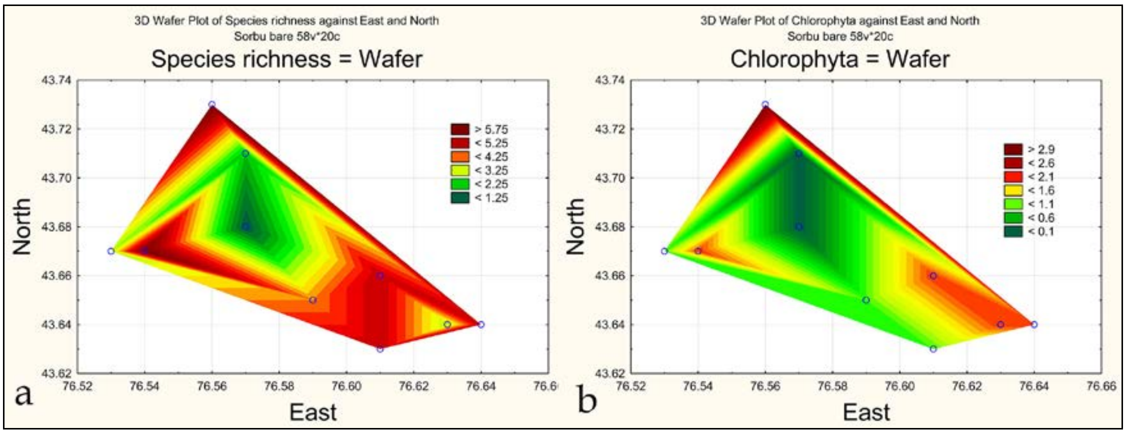

Figure 6: Distribution of species richness of phytoplankton (a) and green algae (b) along the water surface of the Sorbulak storage reservoir, July 2017.

The spatial distribution of phytoplankton abundance and biomass was synchronous, with the maximum values of both variables along the northeastern coast (Fig. 7) due to cyanobacteria (Fig. 8).

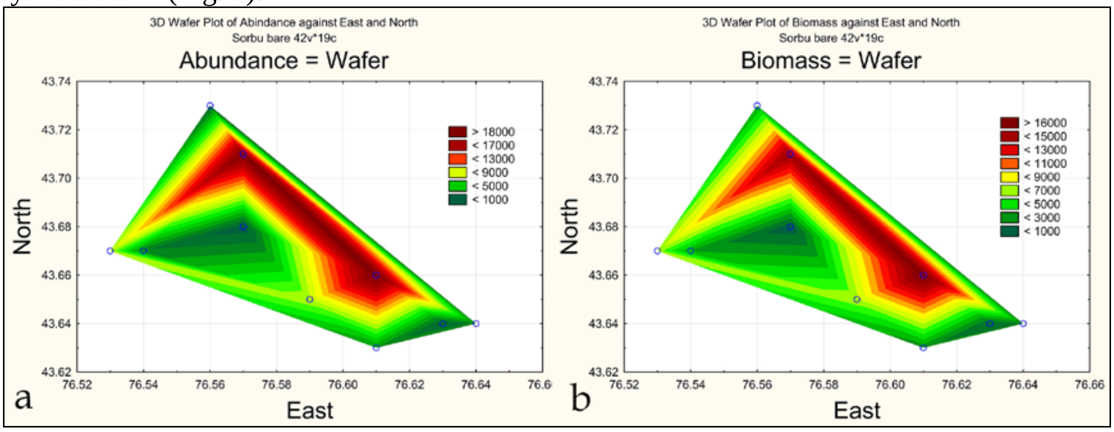

Figure 7: Distribution of abundance (a) and biomass of phytoplankton (b) along the water surface of the Sorbulak Reservoir, July 2017.

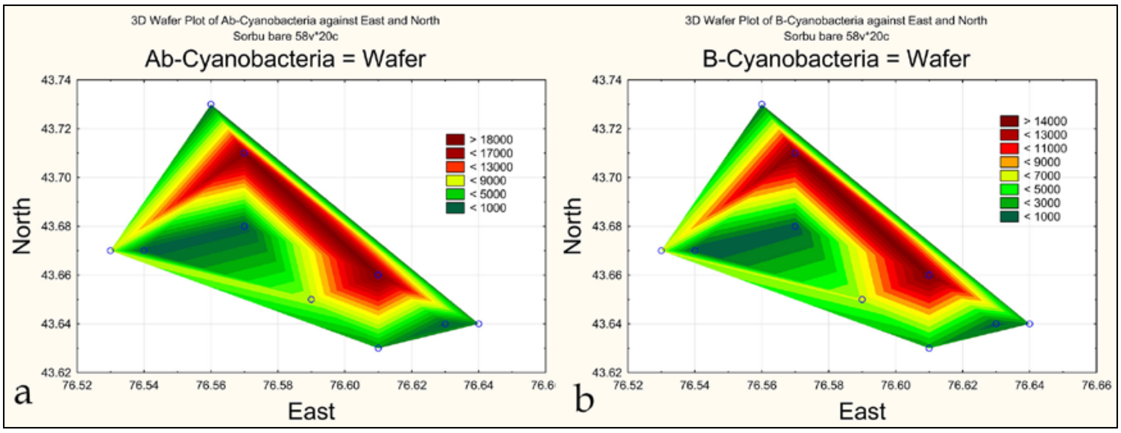

Figure 8: Distribution of the abundance (a) and biomass of cyanobacteria (b) along the water surface of the Sorbulak Reservoir, July 2017.

The accumulations of green algae were recorded in the zone of influence of the sewage channel, in the eastern coastal strip, and also in the northern part of the reservoir (Fig. 9).

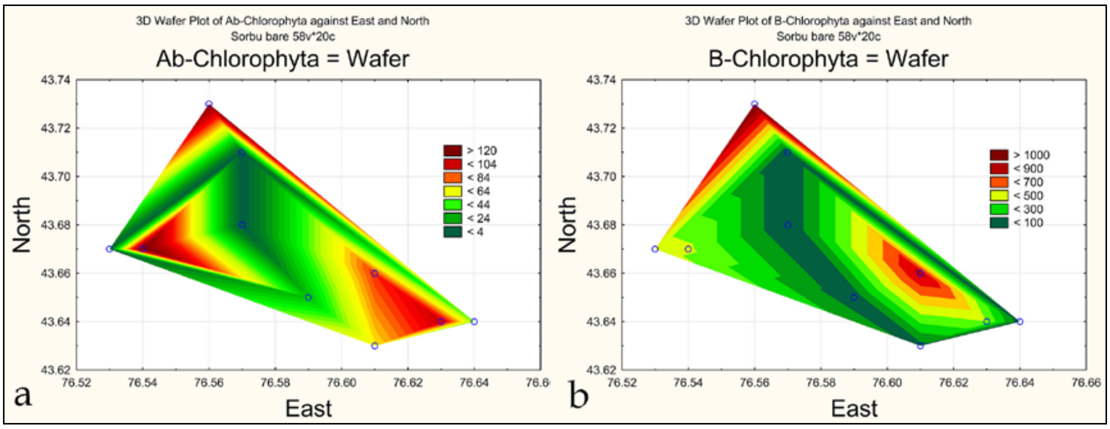

Figure 9: Distribution of abundance (a) and biomass of green algae (b) along the water surface of the Sorbulak Reservoir, July 2017.

Statistical analysis of the data did not revealed influence of external factors on the structural variables of the phytoplankton of the Sorbulak Reservoir. Species richness (number of species) and species diversity (Shannon Ab and Shannon Bi) of phytoplankton communities increased due to green and, to a lesser extent, dinophyte algae (Tab. 5). Enrichment of communities with green and dinophyte algae led to an increase in the average cell size and an increase in the values of Shannon Bi. The values of the Shannon Ab index grew less with the enrichments of algae species in communities. A very strong statistically significant positive relationship was found between the average cell mass and W-Clarke values. Similar in strength and direction, statistically significant relationships within phytoplankton communities were also revealed when data on ponds RBSC no. seven, and RBSC no. eight were included in the analysis.

Table 5: Spearman correlation coefficients (R) between structural variables of phytoplankton of Sorbulak Reservoir, $p < 0.05$.

Pair of variables	R	Pair of variables	R
Chlorophyta Ab – Species Number	0.830	Dinophyta Ab – Average Biomass	0.778
Chlorophyta Ab – Shannon Ab	0.875	Shannon Ab – Average Biomass	0.685
Chlorophyta Ab – Shannon Bi	0.912	Shannon Ab – W-Clarke	0.673
Chlorophyta Ab – Average Biomass	0.790	Shannon Bi – Average Biomass	0.939
Chlorophyta Ab – W-Clarke	0.784	Shannon Bi – W-Clarke	0.891
Dinophyta Ab – Species Number	0.740	W-Clarke – Average Biomass	0.939
Dinophyta Ab – Shannon Bi	0.727		

Canonical Correspondence Analysis for divisional abundance and chemical variables were done on the base of tables 1 and 2 data for Sorbulak and Kurty reservoirs (Fig. 10).

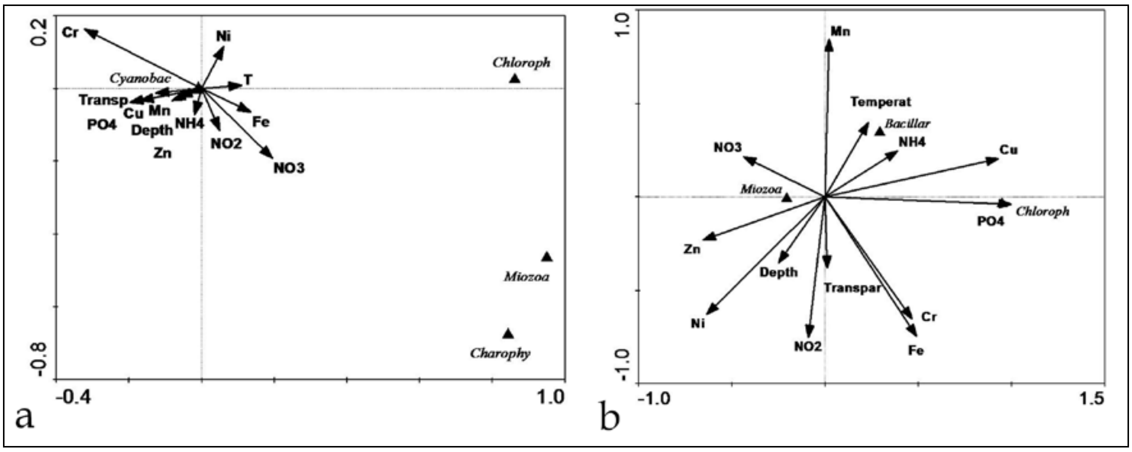

Figure 10: CCA biplots for algal community abundance in the Sorbulak (a) and Kurty (b) reservoirs in July 2017.

The CCA plot for the Sorbulak community show that only two water variables, Cr and organic matter, demonstrate important influence for algal abundance (Fig. 10a). Whereas cyanobacteria was indifferent to chemical variables, other algal groups were favoured with nutrients (as Nitrates) input and slightly suppressed by the presence of chromium.

The relationship of algal abundance and water variables in the Kurty Reservoir is not clear. The CCA biplot (Fig. 10b) show no significant difference for water variables influence to algal community. We can see that Mn, Cu, water temperatures, and phosphates slightly stimulated the development of diatoms and green algae. Opposite of these variables are Zn, Ni, Nitrites, Fe, Cr, and reservoir depth. This distribution can reflect the water mass uniformity and the upper water surface layer favourable for the algal community development.

DISCUSSION

Sewage storage reservoirs are model reservoirs for studying the effects of mixed pollution (organic in combination with toxic) on aquatic communities. In the summer of 2017 the reservoirs of the Right-Bank Sorbulak Canal were characterized mainly by organic pollution. This was evidenced by the high values of BOD, nitrogen compounds and phosphates (Tab. 1).

The content of heavy metals in the water of all the studied water bodies was low. The total concentration of Zn, Cu, Cd, and Pb in the Sorbulak Reservoir decreased from 0.064-0.116 mg dm^{-3} in 2000-2002 to 0.025 mg dm^{-3} in 2017; in the pond of PSC no. eight it fell from 0.068 to 0.022 mg dm^{-3}. This is mainly due to a reduction in the share of industrial effluents in the total volume of wastewater in recent decades (Dostai and Tyumenev, 2009). The Kurty Reservoir does not accept wastewater. However, the total content of heavy metals in the water of the Kurty Reservoir also decreased from 0.068 mg dm^{-3} in 2000 to 0.022 mg dm^{-3} in 2017.

Thus, the change in the ecological situation in the studied sewage reservoirs and the Kurty Reservoir was synchronous. It can indicate the presence of additional sources of toxic pollution common to all studied water bodies in the region. This may be an underground runoff polluted by sewage, although its contribution to the contamination of the Kurty Reservoir is considered negligible (Dostai and Tyumenev, 2009), and also surface runoff from the catchment areas.

One of the reasons for the low concentrations of heavy metals in Sorbulak and PSC ponds can be a high abundance of plankton algae. Under favorable trophic conditions, the biomass of phytoplankton communities in the reservoirs reached an average of 4,762.0-5,623.0 mg dm^{-3}. As is known, algae have the ability to remove and accumulate metals in the following order: Zn > Cd > Ni > Cu > Cr (Shehata et al., 1999). Several species of green algae have effectively removed Zn from water at concentrations up to 5-20 mg dm^{-3} (Bácsi et al., 2015; Novák et al., 2015). Zn concentrations of more than 0.25 mg dm^{-3} are inhibiting the growth of the green alga *Cladophora* (De-ju et al., 2015). Lower concentrations of Zn are stimulating the growth of *Cladophora*. The effect of Cu on phytoplanktonic assemblage is stronger than Zn, although the intracellular accumulation of Zn is higher than Cu (Pandey et al., 2015). The sensitivity of periphytonic algae to Cu is decreased with an increase in phosphate concentrations in water (Serra et al., 2010) that we can recognize in the investigated reservoirs in 2017.

The blue-green algae dominated the Sorboulak phytoplankton and the PSC ponds. Green algae were subdominants in Sorbulak communities. Diatoms were presented only in Sorbulak, but their numbers were low. As is known, blue-green algae are the most tolerant to heavy metals (Shehata et al., 1999). On the second place of sensitivity there are green algae. The most sensitive group to heavy metals is diatoms.

Correlation analysis did not reveal impact of environmental factors, even heavy metals, on the structure of phytoplankton communities in the studied wastewater storage reservoirs. According to the results of CCA analysis, only Cr and nitrates had some effect on the abundance of algae. Whereas cyanobacteria were indifferent to the chemical variables, other algal groups were favoured with nitrates, and slightly suppressed by the presence of chromium. In Sorbulak and RBSC ponds, the chromium content (0.006-0.007 mg dm^{-3}) was at a lower level than zinc (0.010-0.037 mg dm^{-3}). The weak negative effect of chromium on algae is due to its higher toxicity, compared to zinc (Shehata et al., 1999; Kapkov, 2003).

The phytoplankton abundance of the Kurty Reservoir was two orders of magnitude, and the biomass was two times lower than in the sewage reservoirs (Tab. 3). Unlike studied wastewater storages, in the phytoplankton of the Kurty Reservoir all founded algal taxonomic Divisions were represented, except for the blue-green ones. Dinophytes were dominated in abundance and biomass. The total content of nitrogen compounds in the water of the Kurty Reservoir (7.16 mg dm^{-3}) was higher in storage reservoirs (0.72-6.16 mg dm^{-3}). Obviously, the very low concentrations of phosphates were an unfavorable factor for algae of the Kurty Reservoir, an average of 0.0008 mg dm^{-3}. This is four orders of magnitude smaller than in Sorbulak and RBSC ponds.

The pronounced dominance of dinophyte algae may indicate an unfavorable ecological situation in the Kurty Reservoir. It has been shown that the composition of algal communities changes towards the predominance of species capable of heterotrophic nutrition under the conditions of toxic effect (Barinova et al, 2010a, 2010b, 2015). Such species are usually flagellate algae from the dinophyte Division. Under normal conditions, dinophytes are fed by chlorophyll. In toxic effects, the species of this Division switch to direct food with dissolved organic matter. The reasons for the suppression of photosynthesis may be different, from lack of light energy, to increased concentrations of nutrients or heavy metals but in any case the protein photosynthesis can be impacted.

The values of the Shannon Ab and Shannon Bi index were very low and have a positive correlation with the average individual cell mass. We have previously shown that, between Shannon Bi and the average mass of the algal cell, the correlation can be both negative (Barinova and Chekryzheva, 2014; Krupa et al., 2016), and positive (Krupa and Barinova, 2017). Analysis of large data sets showed that a positive relationship between diversity and organism body size is reflected in the relatively early stage of succession of plankton communities (Krupa and Barinova, 2017). Aquatic communities are enriched with small-size species with further eutrophication of reservoirs, and the relationship between diversity and cell-size becomes negative. The obtained results once again confirmed the nonlinearity of changes in the structural indicators of planktonic communities in the gradient of nutrient loading and eutrophication of aquatic ecosystems that we identified here and earlier.

CONCLUSIONS

Sorbulak and associated ponds of RBSC are one of the world's largest systems of biological wastewater treatment water reservoirs, with a total capacity of about 1,000 million m^3. The Kurty Reservoir is located in the immediate vicinity of the Sorbulak Reservoir, but the sewage is not discharged into it. All the water bodies surveyed were characterized mainly by organic pollution in the summer of 2017. The content of heavy metals in the water was low. The synchronous decrease in the content of heavy metals in the water of all reservoirs from 2000 to 2017 can be recognized. It is assumed that a potential source of contamination of the Kurty Reservoir may be poluted underground runoff formed in the Sorbulak reservoir zone.

Species richness and species diversity of phytoplankton communities of all studied water bodies were at a low level. Phytoplankton communities of wastewater reservoir facilities were represented mainly by species tolerant to organic and toxic pollution. Blue-greenalgae dominated reservoirs. The pronounced dominance of dinophyte algae may indicate an unfavorable ecological situation in the Kurty Reservoir. The significant effect of external factors on the structural variables of phytoplankton in reservoirs by means of correlation analysis has not been revealed.

According to the results of CCA analysis, only Cr and nutrients had a significant effect on the abundance of algae. A positive statistically significant relationship between the Shannon index and the average algal cell mass was established. The obtained results once again confirmed the nonlinearity of changes in the structural indicators of plankton communities in the gradient of nutrient loading and eutrophication of aquatic ecosystems that we revealed earlier. These results can be developed in future investigations of this important system of purification water object in the region.

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