ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Environmental Variables Regulating the Phytoplankton Structure in High Mountain Lakes.

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ABSTRACT

The research on the Kolsay mountain lakes was carried out in August 2015. Phytoplankton was represented by 28 species. The richness of algal communities increased with a decrease in altitude of the lake. Nutrients were one of the main factors influencing the diversity, quantitative indicators and size structure of phytoplankton of the Kolsay lakes. The nitric nitrogen as well as manganese and silicon played the main role with the exhaustion of phosphorus. The average algal cell mass is decreased in the gradient of saprobic index values. The cell average mass was also influenced by the ammonium and total toxic pollution, the latter reflected in the WESI index. The results of multifactorial analysis allowed us to assume that organic contamination enters Kolsay lakes together with a number of toxic elements, with chromium in particular, stimulating the growth of algal species abundance in general. The CCA analysis revealed groups of species that are sensitive to the content of silica (diatoms), salinity (mostly green algae), manganese, chromium, nitrite and nitrate nitrogen (most species). The WESI index showed a slight inhibition of phytoplankton in the three out of four Kolsay lakes despite low concentrations of heavy metals. Cadmium, copper and iron made the main contribution to the overall level of toxic pollution of studied lakes.
Keywords: Mountain lakes, phytoplankton, structure, environmental factors, altitude.

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INTRODUCTION

High mountain lakes upper about two thousand meters in altitude are not only quite difficult accessible but also represent the interesting aquatic objects for study of climatic related factors influence on its ecosystem. Earlier we studied aquatic ecosystems in the Caucasus Mountain [1, 2], the Hindu Cush Mountains [3], the Pamir Mountains piedmont [4], and Israel [5, 6], and reveal that altitude-related factors are regulated biodiversity of algal communities [7].

The Kolsay mountain lakes are situated in the Kungei Alatau, Southeastern Kazakhstan. They are located at the altitudes of 1829 to 3170 m above sea level in the protected area of the National Park that established in 2007. The lakes Lower, Middle and Upper Kolsay are in the spruce belt, flow through, canyon type, with a steep increase in the depth starting from the shore. Their area is 0.07–0.67 km^2, with maximum depths of 25.0–54.0 m and water transparency of 8.0–9.0 m. The maximum water temperature is 10.1–13.7°C, and it increases in the direction from Upper to Lower Kolsay. The Sary-Bulak Lake is located in the alpine zone. It feeds from groundwater and precipitation. Its depth is 2.5 m, water transparency is to the bottom. The bottom of the lake is overgrown with filamentous charophyte algae. The water temperature in the Sary-Bulak Lake is slightly higher (12.7°C) than in lower situated lakes Upper and Middle Kolsay. The water in all the lakes is alkaline, with pH values ranging from 8.27 to 9.60.

The lakes are remote from the agricultural and industrial areas. Anthropogenic impact on their ecosystems is associated with the recreational load and acclimatization activities. In 1965, the rainbow trout *Oncorchynchus mykiss* (Walbaum, 1792) was introduced to the lakes and it has successfully assimilated into the two lower lakes [8]. The Upper Kolsay and Sary-Bulak lakes are fishless.

Due to the inaccessibility, the Kolsay Lakes are poorly explored. Fragmentary data is available only on zooplankton of the Lower and Middle Kolsay lakes [9, 10]. The information on the structure of phytoplankton of the Kolsay lakes and its relation to environmental factors is first introduced in the present paper.

The aim of study was to determine major environmental factors that influenced phytoplankton structure in the high mountain protected lakes of the Kungei Alatau with different statistical methods.

MATERIALS AND METHODS

The studies of the Lower, Middle, and Upper Kolsay lakes and Sary-Bulak Lake (Fig. 1) were carried out in August 2015. The temperature, pH and electrical conductivity of the surface water layers were measured by means of HANNA HI 98129 devices in the field environment. Water transparency was measured by Secchi disk. On each lake, a sample of 1 liter of phytoplankton was taken. Each sample consisted of subprobe selected in three to five different parts of the lake. Subprobes were mixed, and then one integrated sample of required volume was selected. The water samples to determine the mineralization and chemical composition, the content of easily oxidized organic matter, nutrients and heavy metals were collected using the same principle.

Figure 1: Site location and total view of the Kolsay lakes

The conventional methods of chemical analysis of water were used [11, 12]. All water samples were analyzed in three-four replications. Determination of heavy metals in water was performed by mass-spectrographic method with inductively coupled plasma using the Agilent 7500A manufactured by the Agilent Technologies, USA (ST RK ISO 17294-2-2006).

For the processing of phytoplankton samples, the settling method was used [13]. Species identification of planktonic algae was performed by using determinants [14-19]. The modern taxonomy of phytoplankton is given in accordance with algaebase.org.

The Shannon-Weaver Index was calculated in the Premiere 5 program through the logarithm to the base 2 [20] according to the formula (1). Index values were calculated in two versions: by the total abundance (bit per individual), and by the total biomass (bit/mg).

$$H = -\sum_{i=1}^{k} Pi \cdot \log_2 P\,i \qquad (1)$$

where H is the Shannon-Weaver index (bit per individual, or bit per mg), P_i – the share of the i^{th} species in the abundance or in the biomass of community.

The average mass of the algal cell (10^{-6} mg) was calculated as the ratio of the total biomass to the total number of phytoplankton cells.

The statistical methods used were those recommended by Heywood [21] for the development of taxonomic studies, namely the CANOCO program [22] for redundancy analysis (RDA) and canonical correspondence analysis (CCA) [23, 24], for principal component analysis (PCA) and comparative floristic analysis the GRAPHS program [25]. Surface plots for biological and environmental variables relationship analysis were built in the Statistica 12.0 program.

The impact of environmental variables to the phytoplankton photosynthesis was conducted through calculating the index of the aquatic ecosystem state WESI (Water Ecosystem State Index) as the quotient from dividing the classification rank of saprobity index S to the classification rank to the nitric nitrogen concentration [6, 26]. The WESI index ranges from 0 to 9. If it is less than one, then the ecosystem is exposed to the toxic effects; if equal to or greater than 1 – the self-purification is not suppressed.

RESULTS

The Kolsay lakes are ultrafresh (Table 1). Water is of the carbonate class of calcium group, the second type, very soft. Mineralization and hardness of water is decreased with altitude. Values of permanganate oxidation (BOD) marked a low concentration of easily oxidized organic substances in the water of the lakes. The amount of nitrite in water increased in the direction from upper to lower lake. Nitrates varied within a relatively small range. In the Sary-Bulak Lake, nitrates were not found. Ammonia was absent in the water of the Lower Kolsay, and in other lakes its concentration varied insignificantly. Phosphorus was not found in the water. The content of heavy metals in water, with the exception of copper, was at a very low level. The concentrations of lead, copper, zinc, nickel and chromium in water increased from the Upper to the Lower Kolsay. The content of heavy metals was higher in the most high-altitude lake Sary-Bulak.

Table 1: Chemical and physical variables in the Kolsay lakes, August 2015

Variable	Unit	Kolsay Sary-Bulak	Upper Kolsay	Middle Kolsay	Lower Kolsay
Altitude	m above sea level (a.s.l.)	3170	2642	2242	1829
TDS	mg L^{-1}	26.6	102.2	116.0	123.9
Hardness	mgEq. L^{-1}	0.25	1.1	1.2	1.4
Depth	m	2.5	25.0	54.0	36.6
Secchi	m	2.5	9.0	9.0	9.0
BOD	mgO L^{-1}	2.14	1.20	1.20	1.36
NO_2	mg L^{-1}	0.011	0.02	0.03	0.028
N-NO_2	mg L^{-1}	0.003	0.006	0.009	0.008

NO_3	mg L^{-1}	0.0	0.516	0.344	0.688
$N\text{-}NO_3$	mg L^{-1}	0.0	0.117	0.078	0.155
NH_4	mg L^{-1}	0.22	0.15	0.2	0.0
$N\text{-}NH_4$	mg L^{-1}	0.171	0.117	0.156	0.0
PO_4	mg L^{-1}	0.0	0.0	0.0	0.0
Fe	mg L^{-1}	0.440	0.044	0.164	0.140
Si	mg L^{-1}	1.0	4.4	6.3	4.2
Mn	mg L^{-1}	0.010	0.008	0.008	0.0165
Pb	mg L^{-1}	0.0005	0.0001	0.00009	0.00014
Cu	mg L^{-1}	0.0055	0.0026	0.0031	0.0038
Zn	mg L^{-1}	0.0016	0.0002	0.0010	0.0009
Cd	mg L^{-1}	0.0004	0.0006	0.0004	0.00045
Ni	mg L^{-1}	0.0027	0.0014	0.0017	0.0018
Cr	mg L^{-1}	0.0005	0.00065	0.0007	0.0008

Phytoplankton was represented by 28 species. The highest diversity (Table 2) and abundance of planktonic algae (Table 3) were recorded in the Lower Kolsay Lake. The blue-green algae are prevailed (90%) in abundance. Dominant complex included *Planktolyngbya contorta*, *P. limnetica*, *Geitlerinema amphibium*. In the Sary-Bulak Lake, the diversity and abundance of phytoplankton had been minimal compared with communities of other lakes. Green algae formed up to 85.5% of the total abundance, and diatoms up to 14.5%. The most numerous were green algae *Lindavia comta*, *Closteriopsis longissima*, *Monoraphidium contortum*, *M. obtusum*, charophytes *Spirogyra* sp. Phytoplankton was represented only by diatoms in the Middle Kolsay, In contrary, the Upper Kolsay community was dominated by diatoms numerically (69.7%), and green algae were running second (30.3%). In these two lakes, the largest contribution to the formation of phytoplankton abundance was made by *Lindavia comta, Cyclotella meneghiniana, C. planctonica*, and *Sphaerocystis planctonica* (in Upper Kolsay only).

Table 2: Taxonomy of algal communities and species biomass (mg m^{-3}) in the Kolsay lakes, August 2015

Taxa	Code	Kolsay Sary-Bulak	Upper Kolsay	Middle Kolsay	Lower Kolsay
Cyanobacteria					
Geitlerinema amphibium (C.Agardh ex Gomont) Anagnostidis	GeiAmp	0	0	0	7.7
Planktolyngbya contorta (Lemmermann) Anagnostidis & Komárek	PlaCon	0	0	0	1.5
Planktolyngbya limnetica (Lemmermann) Komárková-Legnerová & Cronberg	PlaLim	0	0	0	1.7
Bacillariophyta					
Achnanthidium minutissimum (Kützing) Czarnecki	AchMin	0	0.7	1.4	2.1
Cocconeis placentula Ehrenberg	CocPla	0	16.7	16.7	0
Cyclotella meneghiniana Kützing	CycMen	0	139.8	90.0	79.8
Cyclotella planctonica Brunnthaler	CycPla	0	184.0	173.6	61.3
Cymbella parva (W.Smith) Kirchner	CymPar	0	0	0	4.3
Diatoma vulgaris Bory	DiaVul	0	0	3.3	0
Encyonema minutum (Hilse) D.G.Mann	EncMin	0	0	0	
Fragilaria acus (Kützing) Lange-Bertalot	FraAcu	0	0	0	4.0
Gomphonema longiceps Ehrenberg	GomLon	0	13.4	0	0
Gomphonema olivaceum (Hornemann) Brébisson	GomOli	0	9.2	0	3.1
Gomphonema truncatum Ehrenberg	GomTru	0	0	6.5	0
Lindavia comta (Kützing) Nakov, Gullory, Julius, Theriot & Alverson	LinCom	14.4	84.8	155.1	0
Navicula cincta (Ehrenberg) Ralfs	NavCin	0	0	1.5	0
Tetracyclus lacustris Ralfs	TetLacu	0	13.5	0	0
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	PlaLan	0	0	2.6	0
Euglenophyta					
Trachelomonas hispida (Perty) F.Stein	TraHis	0	0	0	16.7
Trachelomonas intermedia P.A.Dangeard	TraInt	0	0	0	35.0
Chlorophyta					
Chlorolobion braunii (Nägeli) Komárek	ChlBra	0	0	0	2.2

Closteriopsis longissima (Lemmermann) Lemmermann	ChlLon	2.9	0	0	2.9
Crucigenia quadrata Morren	CruQua	0	1.2	0	0
Monoraphidium contortum (Thuret) Komárková-Legnerová	MonCon	0.7	0	0	0
Monoraphidium griffithii (Berkeley) Komárková-Legnerová	MonGri	0	0	0	0.7
Monoraphidium obtusum (Korshikov) Komárková-Legnerová	MonObt	2.0	0	0	0
Sphaerocystis planctonica (Korshikov) Bourrelly	SphPla	0	14.0	0	0
Charophyta					
Spirogyra sp.	Spirog	58.3	0	0	0

Table 3: Biological variables in the Kolsay lakes, August 2015

Variable	Unit	Kolsay Sary-Bulak	Upper Kolsay	Middle Kolsay	Lower Kolsay
Abundance	cells 10^6 m^{-3}	11.7	110.1	75.0	510.2
Biovolume	mg m^{-3}	78.3	477.3	450.7	225.7
Shannon (Abundance)	bit	2.24	2.67	2.38	2.16
Shannon (Biomass)	bit	1.14	2.25	1.94	2.61
Average cell mass	mg 10^{-6}	6.692	4.335	6.009	0.442
Index Saprobity S	-	0.76	0.99	1.12	1.51
Index WESI	-	0.50	1.00	0.67	0.50
Species richness	no.	6	10	8	15

The phytoplankton biomass was highest in the Middle and Upper Kolsay lakes (Table 3). The diatoms were formed from 69.7 to 100.0% of the total cell numbers in the three lower lakes. The euglenoids were sub-dominants in the Lower Kolsay Lake making up to 22.9% of the phytoplankton biomass. The Sary-Bulak Lake phytoplankton biomass was represented by green algae, which made the main contribution (81.6%), with diatoms (18.4%) as sub-dominants. The diatoms *Cyclotella meneghiniana* (20.0–35.4%) and *C. planctonica* (27.2–38.6 %) occupied the dominant position on biomass in the three lower lakes. The dominant complex in the Lower Kolsay was included *Trachelomonas intermedia* (15.5%). *Lindavia comta* played a significant role in the formation of phytoplankton biomass of the Middle, Upper Kolsay and Sary-Bulak lakes (18.4–34.4%). The charophyte algae *Spirogyra* sp. made the largest contribution (74.5%) to the formation of the Sary-Bulak Lake phytoplankton biomass.

The average algal cell mass in phytoplankton of the lakes was fluctuated from 6.7 to 0.44 mg 10^{-6} (Table 3). The most small-size composition was belonged to the community in the Lower Kolsay Lake where the blue-green algae were dominated. The values of Shannon-Weaver index reflected the low level of species diversity of phytoplankton in all the lakes. The level of organic pollution of the lakes according to the values of the saprobic index was grown with decrease in altitude.

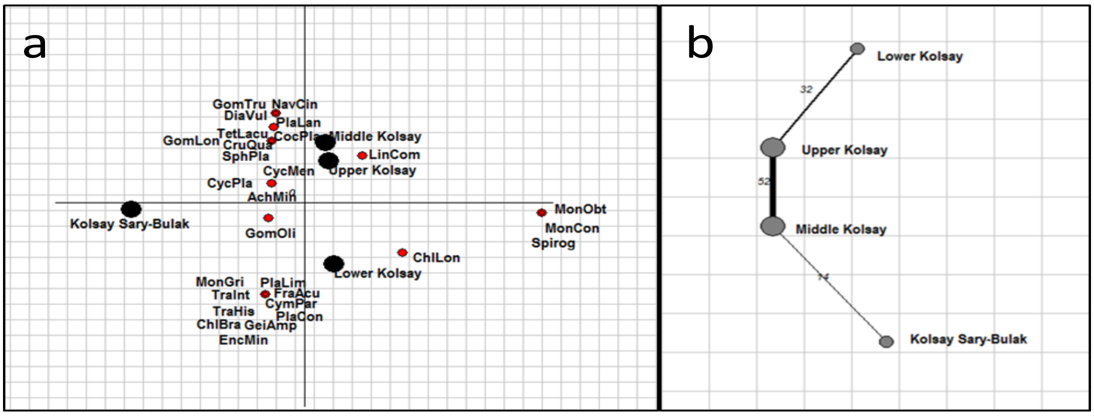

Figure 2: PCA plot (a), and dendrite of similarities in species composition (b) of phytoplankton in the Kolsay lakes, August 2015

Principal component analysis (PCA) (Fig. 2a) and comparative floristic dendrite (Fig. 2b) showed that the phytoplankton communities in the Middle and Upper Kolsay were distinct from it's in the Lower Kolsay and Sary-Bulak lakes (Fig. 2).

Correlation analysis, multifactorial analysis and correlation plot were performed on the base of Tables 1, 2, 3 and allowed us to identify the main factors that determine the differences in the phytoplankton structure of the Kolsay lakes.

Pearson correlation coefficient (Table 4) show that species richness of phytoplankton was increased with growth of the interrelated parameters such as the maximum depth and water hardness, concentrations of chromium, nitrates and the level of organic pollution expressed in saprobic index S, and decreased under the influence of ammonia. The phytoplankton biomass decreased under the influence of BOD, copper and nickel. The abundance of planktonic algae was increased with growing concentrations of manganese, saprobic index S values, and decreased under the influence of ammonia. The growth of the communities abundance was accompanied by the averaged algal cell size reduction against the backdrop of increased levels of organic pollution.

Table 4: Pearson correlation coefficient between biological and environmental variables of the Kolsay lakes ecosystem, August 2015

Variables	Pearson correlation coefficient
Deep – Hardness	0.99***
Secchi – Hardness	0.96**
Hardness – No of Species	0.84**
Depth – No of Species	0.89**
Cr – No of Species	0.94**
Index Saprobity S – No of Species	0.96**
$N\text{-}NO_3$ – No of Species	0.96**
$N\text{-}NH_4$ – No of Species	-0.94**
BOD – Biovolume	-0.89**
Cu – Biovolume	-0.96**
Ni – Biovolume	-0.90**
$N\text{-}NH_4$ – Abundance	-0.99***
Mn – Abundance	0.92**
Saprobity Index S – Abundance	0.93**
$N\text{-}NH_4$ – Average cell volume	0.98***
Saprobity Index S – Average cell volume	-0.89**

Where ** $p<0.01$, *** $p<0.001$

Three-dimensional graphs show the changes of biological parameters in relation to environmental factors (Figs. 3, 4). The species richness and the Shannon-Weaver index were decreased with altitude, and increasing with the concentrations of total iron in the water as well as reduction of the amount of nitrates. The Shannon-Weaver index was decreased under the influence of nitrates and increasing of the total biomass of phytoplankton. Size reduction of cells in algal communities took place against the background of biomass reduction and in conditions of growing nitrate concentration in the water. The total abundance of phytoplankton was stimulated by nitrates and the salinity of lakes water.

ISSN: 0975-8585

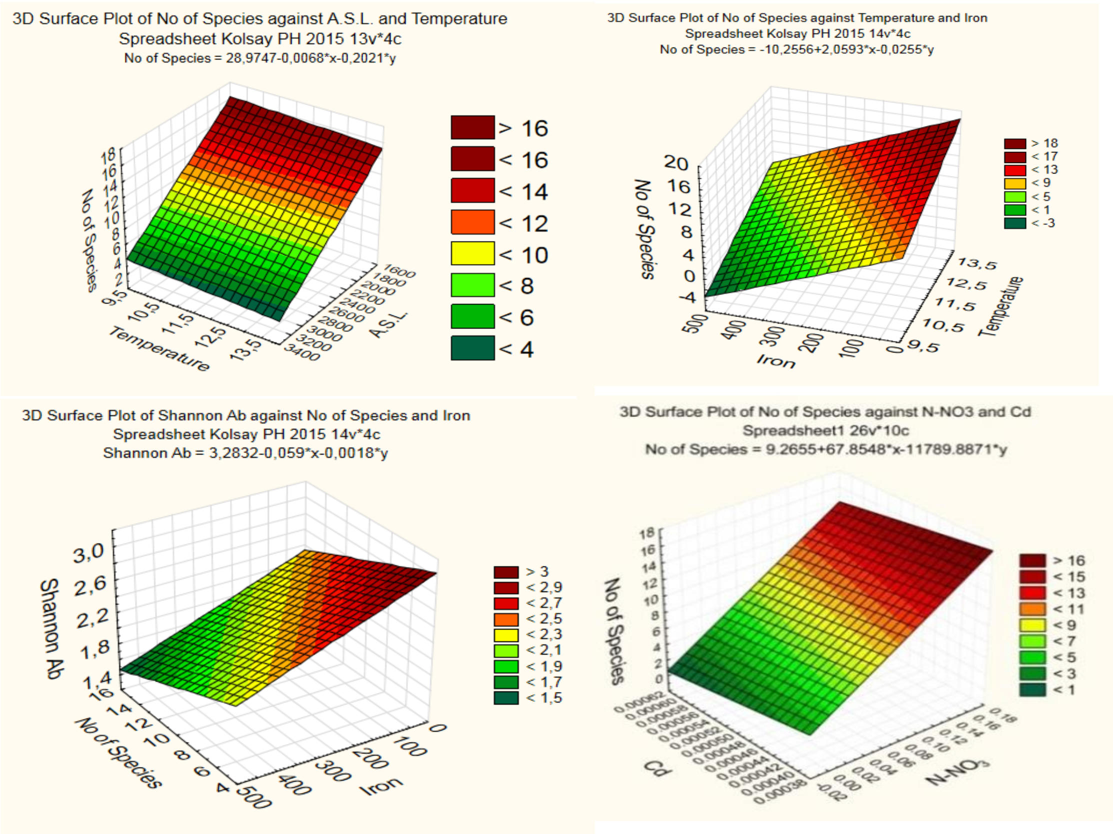

Figure 3: Surface plots of environmental (Altitude, Temperature, Iron, Cadmium, Nitrates) and biological (No of Species, Index Shannon) variables in the Kolsay lakes, August 2015

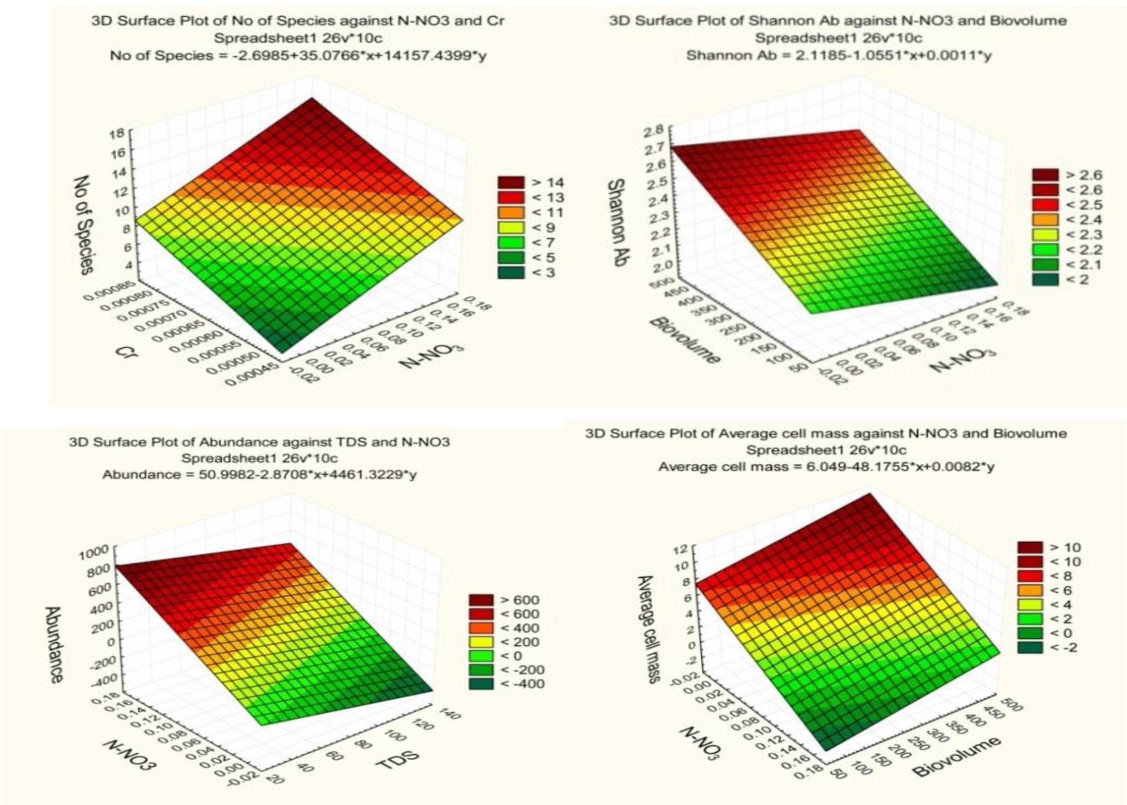

Figure 4: Surface plots of environmental (TDS, Chromium, Nitrates) and biological (Species richness, Abundance, Biovolume, Average cell mass) variables in the Kolsay lakes, August 2015

The CCA plot (Fig. 5a) represents two groups of factors acting on the algal taxonomic divisions in the opposite directions. The first group of factors included cadmium, chromium, silica, manganese, nitrates and nitrites, together influenced the blue-green algae and euglenoids. The second group of factors was represented by copper, nickel, zinc, lead, iron, ammonia, salinity and dissolved organic matter, determined the total abundance of phytoplankton.

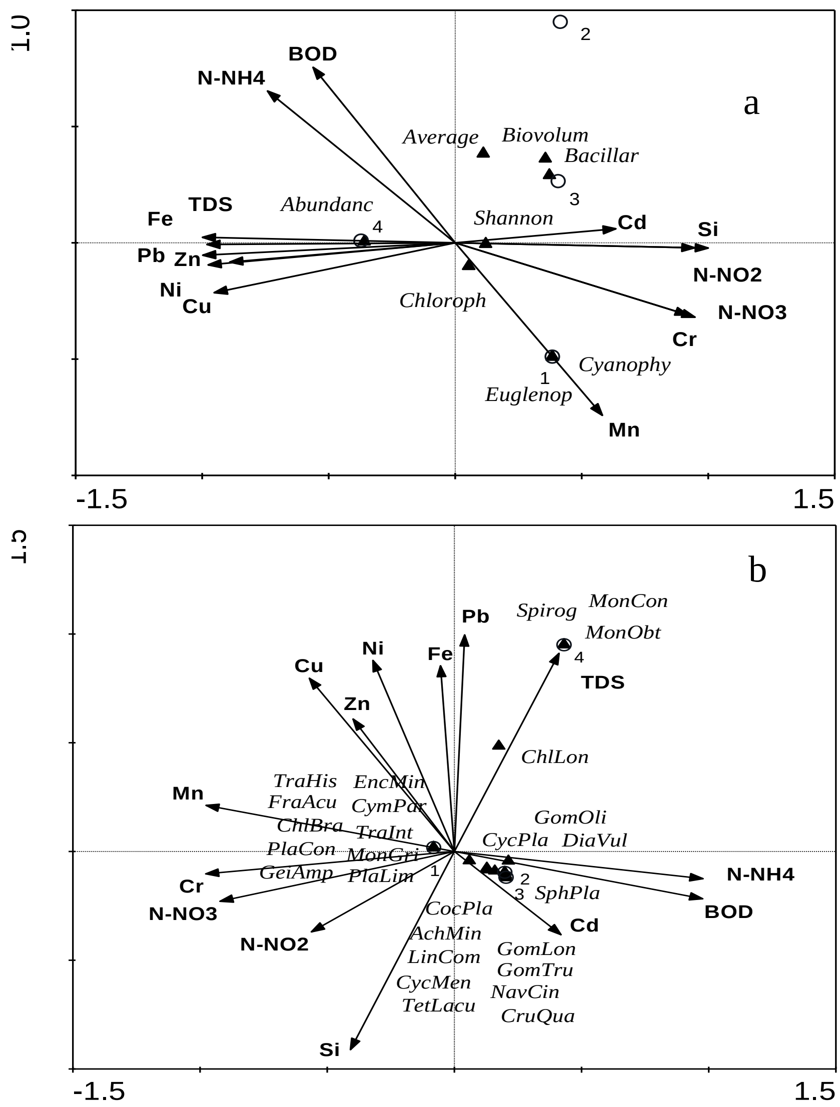

Figure 5: CCA triplots of environmental variables and phytoplankton taxonomic Divisions (a) and species (b) relationships in the Kolsay lakes. Full names of species are presented in Table 2

The CCA analysis at the level of species showed that diatoms Achnanthidium minutissimum, Cyclotella meneghiniana, Tetracyclus lacustris, *Lindavia comta, Cocconeis placentula* are sensitive to silica concentration (Fig. 5b). The main factor influencing the green algae *Monoraphidium obtusum, Monoraphidium contortum, Closteriopsis longissima* and charophyte *Spirogyra* sp. was the water salinity. The group of species (*Sphaerocystis planctonica, Gomphonema truncatum, Navicula cincta, Crucigenia quadrata, Gomphonema longiceps*) was marked as sensitive to cadmium. The abundance of the largest part of planktonic algae was dependent on the contents of manganese, chromium, nitrite and nitrate nitrogen.

Multivariate regression analysis (Table 5) showed that the species richness in the community was stimulated by the organic pollution input, and the algal cell abundance was increased with the silica concentration. The average cell volume was influenced by ammonia and total toxic substances that reflected by the WESI index. Diatoms and green algal species richness was impacted by the lead and nitrites concentration, whereas euglenoids and cyanobacteria were stimulated by manganese. In is interesting that organic pollution which is represented in the Index Saprobity S was positively correlated with chromium concentration, as well as total toxic substances as the WESI index value was positively correlated with concentration of cadmium. That led us to assume that organic pollution comes to the Kolsay lakes ecosystem together with some toxic instances and stimulates algal species richness as a whole, but heavy metal ions from the input influence the major diversity representors such as diatoms and greens.

Table 5: Multivariate regression stepwise statistical analysis combined results of environmental (independent) and biological (dependent) variables in the Kolsay lakes, August 2015

Depended variables	Step 3 (last)	Step 2 (second)	Step 1 (first)
No. of Species	Sap 0.96**	Sap, Cd 0.96**	-
Abundance	Si 0.77**	Si, Pb -0.92***	-
Biovolume	Cu -0.96***	Cu, Ni -0.99***	-
Avg. cell volume	N-NH_4, WESI 0.99***	-	-
Bacillariophyta	Pb -0.99**	Pb, N-NO_3 -0.99**	-
Chlorophyta	N-NO_2 -0.72***	N-NO_2, Mn -0.99***	-
Euglenophyta	Mn 0.99***	-	-
Cyanobacteria	Mn 0.99***	-	-
Saprobity	Cr 0.96**	Cr, Pb 0.99**	-
Index WESI	Cd 0.91*	Cd, BOD 0.82*	-

Where * $p<0.05$, ** $p<0.01$, *** $p<0.001$

DISCUSSION

Phytoplankton of the Kolsay lakes during the research period was characterized by low species richness, which was also noted for the algal communities of mountain lakes in other regions [27, 28]. As well as in Pakistan [3], the species richness in algal communities of the Kolsay lakes was increase with altitude. The same situation was revealed in Turkey [29], [30, 31], Georgia [1], and Israel [6] algal communities. The altitude are determines first and foremost the temperature conditions being one of the main factors influencing the formation of algal communities [3, 32]. The positive effect of temperature on phytoplankton is enhanced under conditions of high nutrient load [33 , 34, 35]. The combined effect of these factors leads to the growth of total biomass and mass development of blue-green algae, i.e. to acceleration of the eutrophication of water bodies [36]. Short-term changes in phytoplankton of the Piburger See were linked to the ratio of nitrogen and silica, while the interannual variability of composition was due to an increase in water temperature [37].

Similar results were obtained by our study of the Kolsay lakes. Nutrition elements were one of the main factors influencing the diversity, quantitative parameters and size structure of phytoplankton communities of the Kolsay lakes. With the exhaustion of the phosphorus in aquatic ecosystems, the main role was played by nitrogen, manganese and silica. The average mass of the algal cell was decreased with the Index saprobity values, which confirms once again the sensitivity of the size structure of communities [38] to intensification of the organic load and eutrophication of water bodies.

The results of multifactorial analysis allowed us to assume that organic contamination enters the Kolsay lakes together with some toxic elements, such as chromium in particular, which was stimulating the growth of algae species richness in general. The CCA analysis revealed groups of species that are sensitive to the content of silica (diatoms *Achnanthidium minutissimum, Cyclotella meneghiniana, Tetracyclus lacustris, Lindavia comta, Cocconeis placentul*a); of cadmium *Sphaerocystis planctonica*, *Gomphonema truncatum, Navicula cincta, Crucigenia quadrata, Gomphonema longicep*s); to salinity (green algae *Monoraphidium obtusum, Monoraphidium contortum, Closteriopsis longissima* and charophyte *Spirogyra* sp.); to the content of manganese, chromium, nitrite and nitrate nitrogen (most species). The link between diatoms and silica is conditioned by significant physiological role of the latter to the species shells grows in this division [39].

Heavy metals depending on the concentration and physical conditions can have an inhibitory or stimulatory effect on aquatic biota. The toxicity of heavy metals to algae decreases in the row $Hg^{2+}>Cu^{2+}>Cd^{2+}>Cr^{2+}>Zn^{2+}>Ni^{2+}$ [40]. The growth of green algae in artificial sea water was inhibited even in conditions of trace amounts of copper [41]. At the same time, the form of the metal is often more significant than the absolute concentration in the environment. The form of metal and the degree of toxicity to aquatic organisms is regulated to a large extent by the presence the organic or inorganic substances in environment

[42, 43], and the pH values of water; therefore the contamination of oligotrophic mountain lakes is extremely dangerous.

At the very low concentrations of heavy metals, the WESI index evidenced a slight inhibition of phytoplankton in three out of four Kolsay lakes. Apparently, cadmium and copper primarily contributed to the overall level of toxic pollution of the studied lakes, being the most toxic elements for algae after mercury [40]. Lead exerted the negative influence on the diversity of diatoms. Unlike most of the analyzed components, Kolsay lakes were characterized by the high total content of iron. Its concentration in the three out of four lakes (Table 1) was at the level 1.4 – 4.4 times higher than the maximum permissible concentration [44] and caused a reduction in the diversity of planktonic algae. Iron is an essential element for the growth of phytoplankton [45], but in large quantities has a negative impact on the aquatic biota [46].

Ecosystems of high mountain cold-water lakes were appeared sensitive to any external factors and are indicators not only of the global climate change but also of the air pollution. In the Central Asian region the eutrophication of mountain lakes remote from the economic activity can be stimulated by the phosphorus and nitrogen [47] coming from the atmospheric dust [48].

CONCLUSION

Our studies of the high mountain lakes show that climate related factors such as temperature was regulated of species distribution in the lakes communities with altitude. Our analysis confirm the sensitivity of its ecosystem to the external factors such as climatic related and pollution, and the need to monitor of their ecological state. The statistical analysis was evidenced that the Kolsay lakes, most of all the lowest, are currently undergoing eutrophication. The symptoms of eutrophication are the dominance of the blue-green algae and small-size structure of phytoplankton, as well as the development of charophyte filamentous algae in the coastal zone of the Lower Kolsay. Toxic pollution of mountain lakes is especially dangerous under the conditions of low organic load. In the context of background concentrations of heavy metals, their impact on the phytoplankton communities may be linked to the oligotrophic status of the Kolsay lakes. The ongoing changes in the ecosystems of the studied lakes can be caused by the double-plus growth of the recreational load over the last decade, climate change and air pollution.

ACKNOWLEDGEMENTS

This work was partially carried out within the project G.2015 commissioned by Committee of Science, Ministry of Education and Science of the Republic of Kazakhstan "Development of methods of control of ecological state of water bodies of Kazakhstan." The work was partly funded by the Israel Ministry of Absorption.

REFERENCES

[1] Barinova SS, Kukhaleishvili L, Nevo E, Janelidze Z. Turk J Bot 2011; 35:729-774.
[2] Barinova S, Kukhaleishvili L. J Biodivers Photon 2014; 113: 305-338.
[3] Barinova S, Ali N, Barkatullah FM. Sarim. Expert Opin Environ Biol 2013; 2(2):1-15.
[4] Barinova S, Boboev M, Hisoriev H. Turk J Bot 2015; 39:535-546 and Supplement 1-22.
[5] Barinova S. Curr Top Plant Biol 2011; 12: 89-95.
[6] Barinova S. Algal diversity dynamics, ecological assessment, and monitoring in the river ecosystems of the eastern Mediterranean. Nova Science Publishers, New York, USA, 2011, 363 p.
[7] Barinova S, Gabyshev V, Boboev M, Kukhaleishvili L, Bilous O. Applied Ecology: Problems, Innovations 2015; 4(3-1): 72-77.
[8] Mitrofanov VP, Dukravets GM. History of fish acclimatization in Kazakhstan. Pisces of Kazakhstan, Vol 5, Alma-Ata, Science, 1992, pp. 6-44. (In Russian)
[9] Kurmangaliyeva SG. Biol Sci 1974; 7:87-91. (In Russian)
[10] Smirnova DA. Kazakh National University Bulletin, Biology series 2000; 4:54–60. (In Russian)
[11] Semenova AD (ed). Guidelines for chemical analysis of surface water. Gidrometeoizdat, Leningrad, 1977, 541 p. (In Russian)
[12] Fomin GS. Water. Control of chemical, bacterial and radiation safety according to international standards, NGO "Alternative", Moscow, 1995, 618 p. (In Russian).

[13] Kiselev A. Methods to study plankton. The life of fresh waters in the USSR, Vol. 4. Science Academy of the USSR, Moscow, Leningrad, 1956, pp. 183-265. (In Russian)
[14] Hollerbach MM, Kosinskaya EK, Polyansky VI. Determinant for freshwater algae of the USSR, Vol 2. The blue-green algae, Soviet Science, Moscow, 1953, 654 p. (In Russian)
[15] Matvienko AM. Determinant for freshwater algae of the USSR, Vol 3. Golden algae, Soviet Science, Moscow, 1954, 189 p. (In Russian)
[16] Moshkova NA, Hollerbah MM. Determinant for freshwater algae of the USSR, Vol 10(1). Green algae, Class Ulotricha, Order ulotrichous, Soviet Science, Moscow, 1986, 361 p. (In Russian)
[17] Palamar-Mordvintseva GM. Determinant to freshwater algae of the USSR, Vol 11 (2). Green algae, Class conjugates, Order desmids (2), Soviet science, Moscow, 1982, 621 p. (In Russian)
[18] Popova TG. Determinant to freshwater algae of the USSR, Vol 7. Euglene algae, Soviet Science, Moscow, 1955; 213 p. (In Russian)
[19] Zabelina MM, Kiselev IA, Proshkina-Lavrenko AI, Sheshukova VS. Determinant for freshwater algae USSR, Vol 4. Diatoms, Soviet Science, Moscow, 1951, 622 p. (In Russian)
[20] Magurran AE. Ecological diversity and its Measurement, World, Moscow, 1998, 184 p. (In Russian)
[21] Heywood V. Turk J Bot 2004; 28:7-16.
[22] Ter Braak CJF, Šmilauer P. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power Press, Ithaca, 2002.
[23] Ter Braak CJF. Vegetatio 1987; 69: 69-77.
[24] Ter Braak CJF. Psychometrica 1990; 55: 519-531.
[25] Novakovsky AB. Scientific Reports of Komi Scientific Center, Ural Division of the Russian Academy of Sciences, 2004; 27:1-28.
[26] Barinova SS, Medvedeva LA, Anissimova OV. Diversity of algal indicators in environmental assessment. Pilies Studio, Tel Aviv, 2006, 246 p.
[27] Vundtsetel MF. The fauna of the lake Son-Kul. In: Ichthyologic and hydrobiological studies in Kyrgyzstan. Frunze, Ilim, 1977, pp. 3-26 (In Russian)
[28] Bondarenko NA, Sheveleva NG, Domysheva VM. Limnology 2002; 3:127-133.
[29] Kolayli S, Şahin B. Turk J Bot 2009; 33:27-32.
[30] Şahin B. Turk J Bot 2009; 33: 457-460.
[31] Şahin B, Akar B, Bahceci İ. Turk J Bot 2010; 34: 441-448.
[32] Gallina N, Salmaso N, Morabito G, Beniston M. Aquat Ecol 2013; 47:177-193.
[33] Elliott JA, Jones ID, Thackeray SJ. Hydrobiologia 2006; 559:401-411.
[34] Salmaso N, Buzzi F, Garibaldi L, Morabito G, Simona, M. Aquat Sci 2012; 74:555-570.
[35] Hong L, Jun Y, Lemian L, Xiaoqing Y, Zheng Y, Penchi C. Environ Sci Pollut Res 2014; 21:5917-5928.
[36] Goncharov AV. Water Res 2007; 34(1):70-74.
[37] Tolotti M, Manca M, Angeli N, Morabito G, Thaler B, Rott E, Stuchlik E. Hydrobiologia 2012; 698:61-75.
[38] Dokulil MT, Donabaum K, Teubner K. Hydrobiologia 2007; 578:59-63.
[39] Shrestha RP, Tesson B, Norden-Krichmar T, Federowicz S, Hildebrand M, Allen AE. Genomics 2012;13:499.
[40] Kapkov VI. Algae as a biomarker of heavy metal pollution in marine coastal ecosystems. Author... Doctor of biol sciences, Moscow, 2003, 43 p.
[41] Aleem AA. Helgoländer Wiss Meeresunters 1970; 20: 229-248.
[42] Gillespie PA, Vaccaro RF. Limnol Oceanogr 1978; 23: 543-548.
[43] Serra A, Guasch H, Admiraal W, Van der Geest HG, Van Beusekom SAM. Ecotoxicol 2010; 19:770-780.
[44] Bespamyatnov GP, Krotov YA. Maximum permissible concentrations of chemicals in the environment. Leningrad, Chemistry, 1985, 528 p. (In Russian).
[45] Vrede T, Tranvik LJ. Ecosystems 2006; 9:1094-1105.
[46] Bakker ES, Donk EVI, Anne K. Aquat Ecol 2016; 50:121-135.
[47] Mamane Y, Gottlieb J. Atmospheric Env 1992; 26(9): 1763-1769.
[48] Tsugeki NK, Agusa T, Ueda Sh, Kuwae M, Oda H, Tanabe Sh, Tani Y, Toyoda K, Wang W, Urabe J. Ecol Res 2012; 27: 1041-1052.