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Influence of chemical water composition on spatial distribution of phytoplankton in the Balkhash Lake (Kazakhstan).

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ABSTRACT

The effect of the Total Dissolved Solids (TDS), the absolute content of anions and cations, as well as the ratios of K^+/Na^+, K^+/Ca^{2+}, Mg^{2+}/Ca^{2+} on the spatial variability of quantitative variables of phytoplankton in the Balkhash Lake was researched in summer 2004. The growing salinity of water from West to East followed by increase in the relative content of potassium, sodium and magnesium was favorable for Cyanobacteria, but it oppressed the abundance of other species, with exception of Bacillariophyta. The influence of K^+/Na^+, K^+/Ca^{2+}, Mg^{2+}/Ca^{2+} ratios on the abundance and biomass of the divisions of planktonic algae was noted predominantly at the TDS of about 2000-2200 mg dm^{-3}. Based on the obtained results and literature data, it is assumed that Total Dissolved Solids at the level of 1800-2000 mg dm^{-3} is a barrier separating the freshwater and brackish-water fauna and flora for the Balkhash Lake and for other inland water bodies in Kazakhstan. Our results correspond with the main points of the theory of critical salinity by Remane–Khlebovich and with the concept of the relativity and multiplicity of zones of barrier salinities by Aladin.
Keywords: phytoplankton, TDS, main ions ratios, critical salinity, the Balkhash Lake, Kazakhstan

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INTRODUCTION

Salinity is the most important factor determining the composition and diversity of aquatic fauna and flora [1-4]. The model of variation of biological diversity in the salinity gradient was proposed by A. Remane [5] and was substantially refined in a number of subsequent studies [6-13].

The ratios of the main ions – chlorides, sulfates, carbonates, magnesium, potassium, sodium and calcium – often exert a stronger influence on the biota of water bodies than their total content in water. One of the most important chemical elements for living organisms are ions of calcium, potassium, sodium and magnesium [14-16] along with chlorides and sulfates [17]. Unicellular algae are highly sensitive to the content of cations in water. Threshold concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} which determine the distribution boundaries of *Spirogyra* sp. in fresh water were 0.003-0.007, 0.002-0.003, 0.0017-0.0022 and 0.0012-0.0018 mmol/l, respectively [14], or 0.069-0.161, 0.078-0.117, 0.0681-0.0882, 0.0292-0.044 mg/dm^3. Ammonium intake, chlorophyll and phycocyanin content in the cells of the blue-green algae *Microcystis* are decreased with an increase in K^+ concentrations but the content of carotenoids increased [15]. These studies showed that K^+ can regulate the bloom of *Microcystis*, preventing the absorption of nutrients. It was found that the K^+/Na^+ ratio remained at 0.034±0.001 in the extracellular fluid of freshwater, marine and terrestrial animals [16].

The effects of chemical composition of water on aquatic organisms are usually studied experimentally [17-21]. The Balkhash Lake with a pronounced gradient of water chemical variables [22] provides a unique opportunity to assess the influence of the ionic composition of water on the biota in natural environment.

There is no information regarding the ways, how chemical variables affect aquatic community in sporadically study of phytoplankton in the Balkhash Lake [23-24]. The aim of this work is to analyze the distribution of quantitative parameters of algal communities within the water TDS gradient, the absolute content of anions and cations, and the ratios of K^+/Na^+, K^+/Ca^{2+}, Mg^{2+}/Ca^{2+} cations in the water of the Balkhash Lake, the results of which can fills this gap.

MATERIALS AND METHODS

The research of phytoplankton, the Total Dissolved Solids (TDS), the absolute content of the major ions, as well as the ratios of K^+/Na^+, K^+/Ca^{2+}, Mg^{2+}/Ca^{2+} cations in the water of the Balkhash Lake and the inflowing rivers Ili, Aksu and Lepsy was carried out by means of a grid of 58 stations (Fig. 1) in June and July of 2004. The measures of the temperature and pH values of the surface water layers were taken during the sampling trip. Water transparency was measured with Secchi disk. Coordinate referencing of the stations was done by Garmin eTrex GPS-navigator.

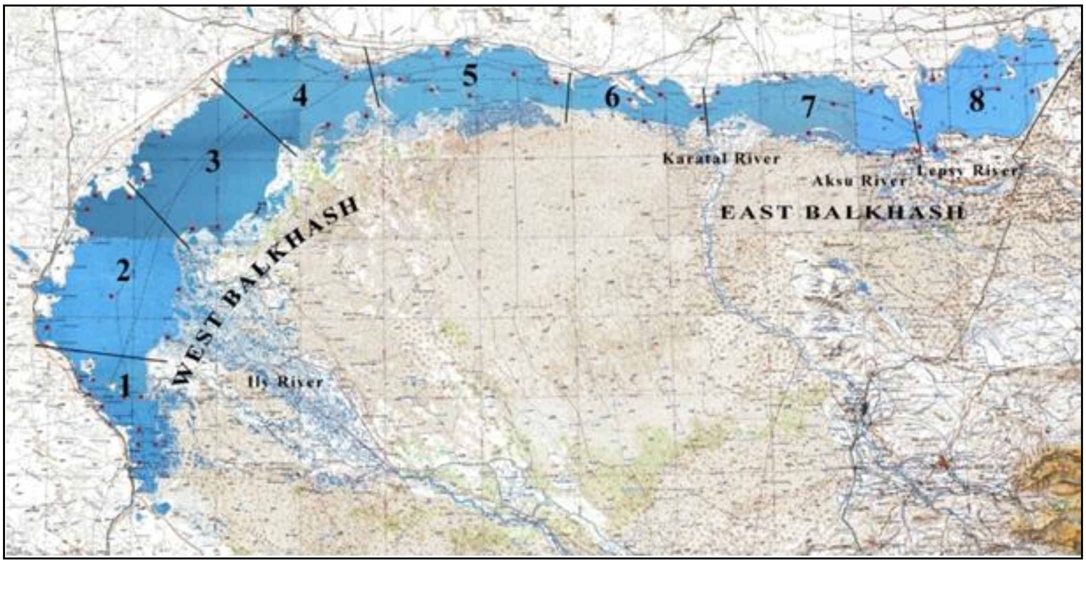

Fig 1: The map of sampling stations (red points) in the Balkhash Lake, summer 2004. 1-8 – Hydrochemical regions

Conventional methods of chemical analysis of water were used [25]. 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. For the processing of phytoplankton samples, the settling method was used [26]. Species identification of planktonic algae was performed by using handbooks for relevant divisions [27-30].

The innovative approach with Surface plots' construction was applied using the Statistica 12.0 program for analysis of biological and environmental variables' relationship. In order to determine the relationship between biotic and abiotic parameters, the same program was used to calculate the Spearman rank correlation coefficients.

DESCRIPTION OF THE STUDY SITE

Balkhash, one of the largest drainless lakes in Kazakhstan, has a length of 614 km and an area of about 16.4 thous. km^2 [22]. The Strait Uzynaral divides it into two parts – the Western and Eastern Balkhash. The Western Balkhash is wide and shallow; the Eastern Balkhash is narrower and deeper. The rivers feeding the lake flow from the south. The greatest volume of flow comes from the Ili River that flows into the western part of the lake. The rivers Karatal, Aksu and Lepsy flow into the Eastern Balkhash. Like in most water bodies in the arid zones, the water of the Balkhash Lake is characterized by an elevated content of dissolved solids. The average value of TDS across different years varies in the water area from 600-1200 to 4040-5600 mg dm^{-3} [22]. The lake is divided into 8 hydrochemical regions according to the TDS gradient (Fig. 1). The total content of dissolved solids increases with linear trend from west to east, that is, from the 1st hydrochemical region to the 8th. The ionic composition of water changes in the same direction.

RESULTS

The eastern deep-water part of the lake was characterized by a higher temperature, transparency and water pH, compared to the western, shallow part of the water area in summer 2004 (Table 1). Statistically, the Total Dissolved Solids content in the Eastern Balkhash water was significantly higher than in the Western Balkhash. Sulfates and sodium prevailed throughout the lake in terms of ionic composition with a relatively high content of potassium, especially in the water of the eastern part. The pH, the content of all anions and cations increased with an increase in TDS in the direction from west to east, except for calcium, whose amount decreased.

Table 1: Physical and chemical variables of water in the Balkhash Lake, summer 2004

Variable	Whole Balkhash	Western Balkhash	Eastern Balkhash
Temperature, °C	24.14±0.14	23.49±0.16	24.77±0.14
Depth, m	5.58±0.49	4.34±0.28	6.86±0.81
Transparency, m	1.13±0.15	0.53±0.02	1.74±0.25
pH	8.63±0.04	8.52±0.02	8.74±0.09
TDS, mg dm^{-3}	2286.0±236.0	1080.3±83.4	3436.8±286.7
Ca^{2+}, mg dm^{-3}	40.4±2.5	48.8±4.4	32.4±1.3
Mg^{2+}, mg dm^{-3}	67.4±6.6	35.0±2.2	98.4±8.4
Na^{+}, mg dm^{-3}	448.9±51.1	193.8±2.2	692.4±63.3
K^{+}, mg dm^{-3}	30.4±4.1	8.8±1.0	51.0±4.9
HCO^{-}, mg dm^{-3}	415.1±31.6	254.3±11.0	568.6±38.6
SO_4^{2-},mg dm^{-3}	834.9±93.1	369.1±344	1279.5±116.2
Cl^{-}, mg dm^{-3}	473.3±58.9	170.5±18.6	762.4±71.3

The calculated values of Mg^{2+}/Ca^{2+}, K^{+}/Ca^{2+}, and Mg^{2+}/Ca^{2+} ratios increased within the TDS gradient and, statistically, they were significantly higher in the eastern part of the lake (Table 2), but the connection of these parameters with the TDS was different in strength. There was almost linear increase in the K^{+}/Ca^{2+} ratio within the TDS gradient, whereas the Mg^{2+}/Ca^{2+} values increased with lower intensity, and the relationship of the K^{+}/Na^{+} to the TDS ratio was moderate.

Table 2: Mean values with standard deviation (in the numerator), the range of fluctuations in the values of the ratios of alkali metal ions (in the denominator), and their correlation to the water TDS of the Balkhash Lake, summer 2004

Variable	Whole Balkhash	Western Balkhash	Eastern Balkhash	Spearman Rank Order Correlations with TDS
K^+/Na^+	0.063±0.004 0.043-0.174	0.046±0.0009 0.043-0.056	0.080±0.005 0.062-0.174	0.735
Mg^{2+}/Ca^{2+}	2.021±0.256 0.424-5.934	0.749±0.039 0.424-1.070	3.235±0.331 1.387-5.934	0.871
K^+/Ca^{2+}	0.978±0.161 0.047-3.491	0.196±0.022 0.047-0.394	1.725±0.215 0.723-3.491	0.953

The value of the K^+/Na^+ ratio decreased linearly from 0.056 to 0.043 within the TDS gradient changing from 490.0 to 1980.0 mg dm^{-3} in the western, desalinated part of the lake (Fig. 2a). In the Eastern Balkhash, the trend was reversed: with the increase of the TDS from 2,310 to 4,490 mg/dm^3, the K^+/Na^+ values increased from 0.062 to 0.093. That is, with a relatively smooth increase in TDS from West to East, the K^+/Na^+ ratio changed non-linearly and peaked in the most desalinated areas of the Western Balkhash. The K^+/Na^+ values increased due to an increase in potassium concentrations that were more intensive compared to sodium in the Eastern Balkhash where the TDS is more than 2,000 mg/dm^3. The ratios of K^+/Ca^{2+}, Mg^{2+}/Ca^{2+} also increased sharply when the TDS reached about 2,000 mg/dm^3 (Fig. 2b).

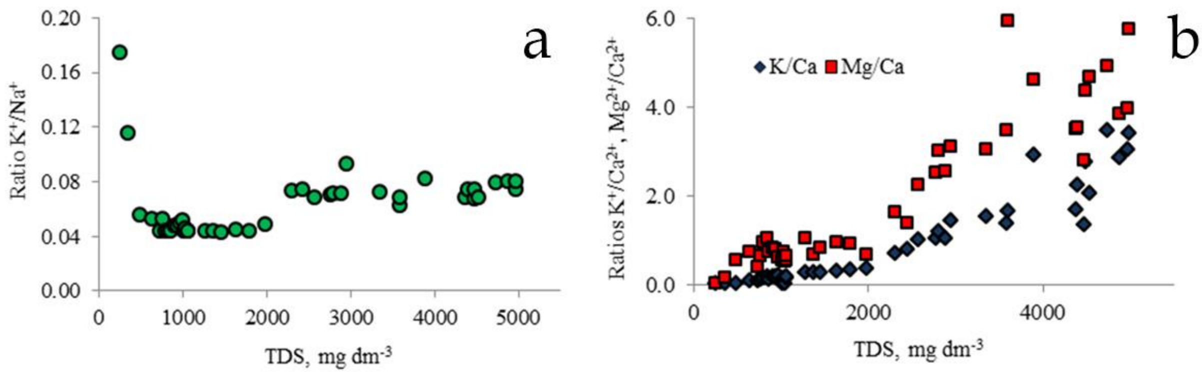

Fig 2: Changes in the ratios of metal ions within the TDS gradient of the Balkhash Lake water, summer 2004

Phytoplankton was represented by 91 species of which Chlorophyta prevail with 29 species, Bacillariophyta – 26, Cyanobacteria – 21, Charophyta and Euglenophyta – 4 of each, Dinophyta – 3, Chrysophyta – 1 species. The quantitative variables of algal communities were relatively low (Table 3). Cyanobacteria dominated the community of the lake according to the average abundance and biomass of phytoplankton. Bacillariophyta was on the second place according to abundance. Bacillariophyta and Euglenophyta shared second place in terms of the biomass.

Table 3: Quantitative variables of phytoplankton of the Balkhash Lake, summer 2004

Part of the lake	Bacilla-riophyta	Charo-phyta	Chloro-phyta	Chryso-phyta	Cyano-bacteria	Dino-phyta	Eugleno-phyta	Total
abundance, mln.cells m^{-3}								
Western Balkhash	87.0	6.0	52.3	2.0	658.4	16.3	67.4	889.5
Eastern Balkhash	186.5	5.7	92.3	0.0	776.1	12.6	46.3	1119.4
average	135.8	5.6	72.0	1.0	716.2	14.5	57.1	1002.4
biomass, gm^{-3}								
Western Balkhash	0.150	0.015	0.039	0.004	0.353	0.020	0.211	0.796

Eastern Balkhash	0.243	0.008	0.041	0.000	0.404	0.023	0.093	0.812
average	0.211	0.011	0.043	0.002	0.394	0.022	0.167	0.853

No statistically significant relationship was found between the total quantitative variables of algal communities and TDS (Table 4). The phytoplankton abundance was slightly stimulated by the growth of K^+/Na^+ and Mg^{2+}/Ca^{2+} ratios. The chemical composition of water influenced the development of algae in all divisions except of Bacillariophyta. The concentration of individual ions excluding calcium as well as K^+/Na^+, K^+/Ca^{2+}, Mg^{2+}/Ca^{2+} ratios, the quantitative variables of Chrysophyta, Dinophyta, and Euglenophyta decreased within the TDS gradient, whereas the abundance of Cyanobacteria increased.

Table 4: Spearman rank-order correlations between the quantitative variables of phytoplankton and the hydrochemical parameters of the Balkhash Lake, at p <0.05

Paired variables	Spearman Rank Order Correlations	Paired variables	Spearman Rank Order Correlations
ChrysophytaAb – HCO_3^-	-0.399	DinophytaAb – Na^+	-0.318
ChrysophytaAb –SO_4^{2-}	-0.340	DinophytaAb – K^+	-0.334
ChrysophytaAb – Cl^-	-0.407	Total Ab – K^+/Na^+	0.408
Chrysophyta Ab – Na^+	-0.399	Total Ab – Mg^{2+}/Ca^{2+}	0.313
ChrysophytaAb – K^+	-0.399	ChrysophytaBi – HCO_3^-	-0.397
ChrysophytaAb – K^+/Ca^{2+}	-0.388	ChrysophytaBi – Cl^-	-0.406
ChrysophytaAb – K^++Na^+	-0.371	ChrysophytaBi – TDS	-0.369
ChrysophytaAb – TDS	-0.366	ChrysophytaBi – Na^+	-0.399
CyanobacteriaAb – Mg^{2+}	0.338	ChrysophytaBi – K^+	-0.398
CyanobacteriaAb – K^++Na^+	0.370	ChrysophytaBi – K^+/Ca^{2+}	-0.396
CyanobacteriaAb – HCO_3^-	0.369	DinophytaBi – K^+	-0.328
CyanobacteriaAb – Cl^-	0.325	DinophytaBi – Na^+	-0.310
CyanobacteriaAb – TDS	0.310	DinophytaBi – Cl^-	-0.326
CyanobacteriaAb – K^+	0.328	EuglenophytaBi – Mg^{2+}	-0.372
CyanobacteriaAb – K^+/Na^+	0.431	EuglenophytaBi – HCO_3^-	-0.543
CyanobacteriaAb – K^+/Ca^{2+}	0.352	EuglenophytaBi – SO_4^{2-}	-0.459
CyanobacteriaAb – Mg^{+2}/Ca^{2+}	0.375	EuglenophytaBi – Cl^-	-0.550
EuglenophytaAb – K^++Na^+	-0.393	EuglenophytaBi – TDS	-0.495
DinophytaAb – Mg^{2+}	-0.310	EuglenophytaBi – Na^+	-0.541
DinophytaAb – HCO_3^-	-0.322	EuglenophytaBi – K^+	-0.537
DinophytaAb – SO_4^{2-}	-0.306	EuglenophytaBi – K^+/Na^+	-0.357
DinophytaAb – Cl^-	-0.331	EuglenophytaBi – K^+/Ca^{2+}	-0.544
DinophytaAb – TDS	-0.327	Euglenophyta Bi – Mg^{2+}/Ca^{2+}	-0.418

Three-dimensional graphs showed the complex nature of the variability of phytoplankton in dependence on abiotic factors. Algal accumulations were recorded in the most heated areas with increased TDS of water as well as in the freshened zones with minimum temperature values in the Western Balkhash (Fig. 3a). Two unequal extremums of phytoplankton abundance were recorded across the entire TDS gradient in the Eastern Balkhash: one at high, the second at low water temperature (Fig. 3b). Generally, the total biomass of plankton algae within the TDS gradient and the water temperature changed in the similar way as the abundance.

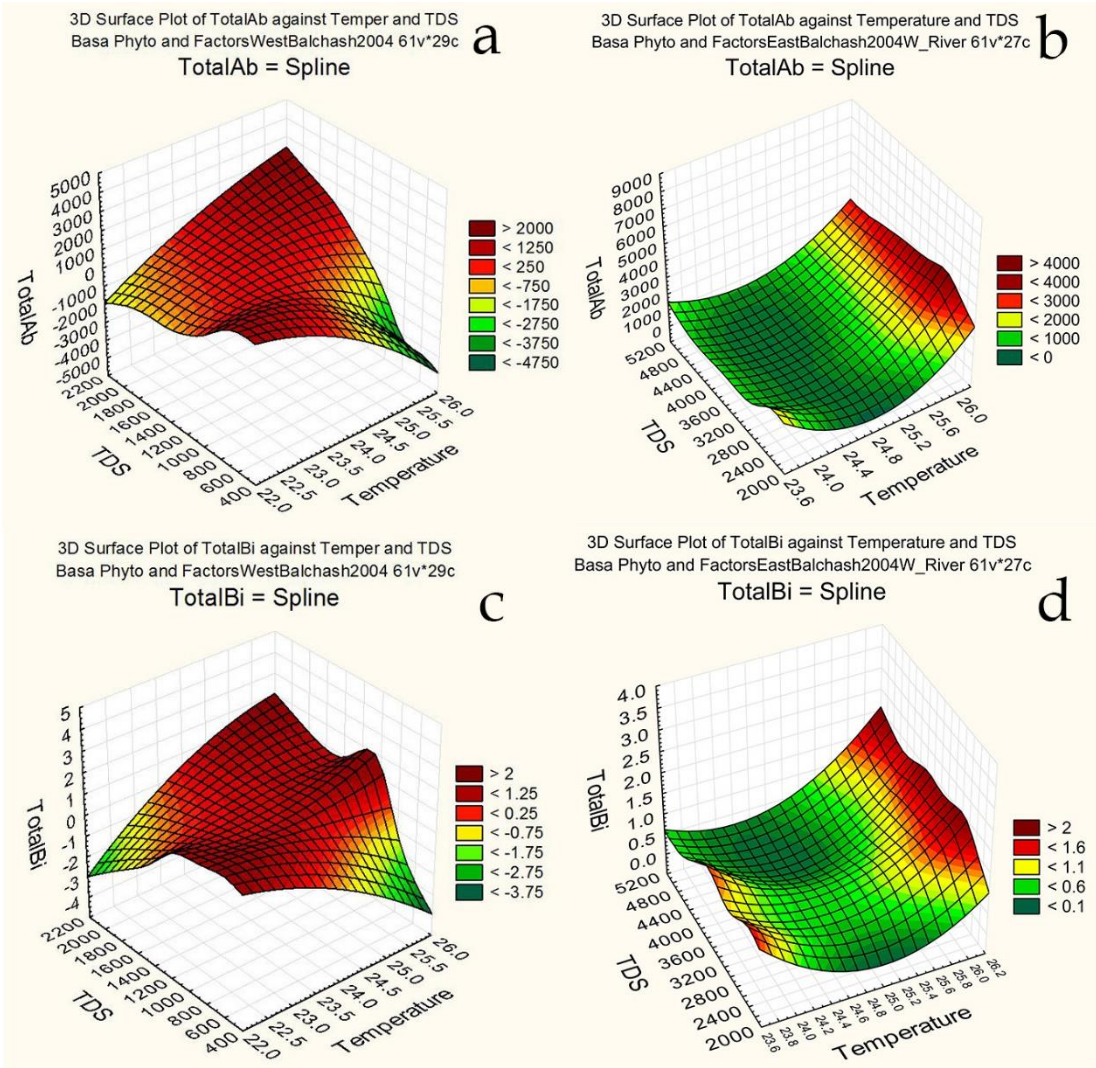

Fig 3: Distribution of abundance and biomass of phytoplankton depending on the temperature and the TDS of water in the Western (left, a, c) and Eastern Balkhash (right, b, d), summer 2004

The increase of both, TDS and K^+/Na^+ ratio, had an adverse effect on phytoplankton abundance in the Western Balkhash (Fig. 4a). The increase in the K^+/Na^+ ratio was unfavorable for algae only when TDS value is 2,000-3,000 mg/dm^3 in the eastern part of the lake. The relative content of metal ions did not negatively affect the phytoplankton abundance when the amount of dissolved solids in water was maximal (Fig. 4b).

The total biomass of planktonic algae increased with the increase in the TDS of water from 400 to 2,000 mg/dm^3 in the Western Balkhash (Fig. 4c), and decreased with water salinity of the Eastern Balkhash growing from 2,200 to 5,000 mg/dm^3 (Fig. 4d). An increase in the K^+/Na^+ ratio stimulated an increase in the biomass of planktonic algae in the most desalinated zones of the western part of the lake with TDS up to 1,600 mg dm^{-3} (Fig. 4c). The increase in the K^+/Na^+ ratio had a negative effect on the biomass of phytoplankton community with a further increasing in the TDS from 1,600 to 2,500 mg/dm^3 whereas in the zone of maximum salinity the dependence was again positive (Fig. 4d). Thus, two vectors of variability of total quantitative parameters of phytoplankton communities were traced: one was related to the dynamics of the TDS, the second – to the ratio K^+/Na^+. It should be emphasized that the increase in the K^+/Na^+ ratio was unfavorable for planktonic algae, mainly at the TDS of about 2,000 mg/dm^3.

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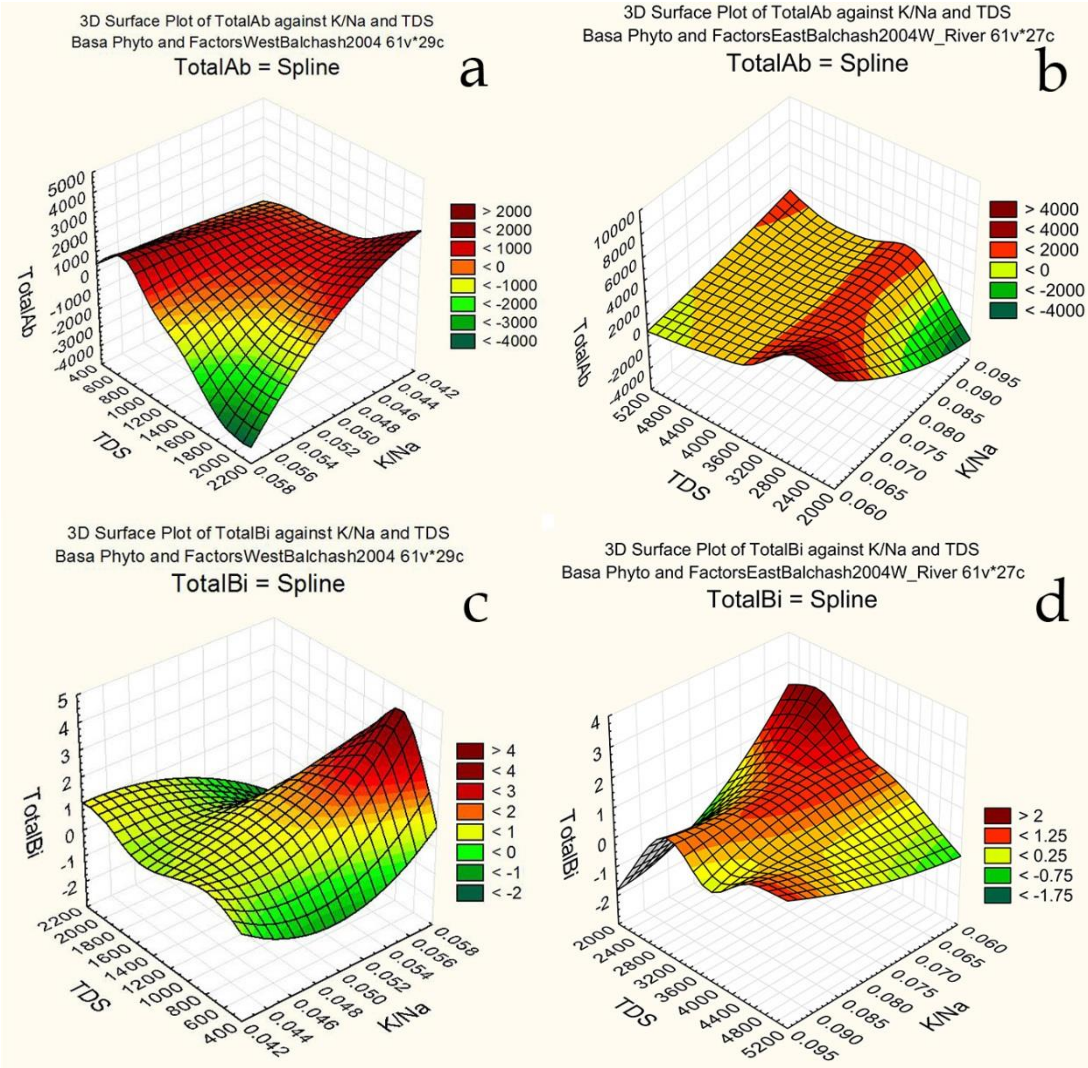

Fig 4: Distribution of abundance and biomass of phytoplankton depending on the TDS of water and K^+/Na^+ ratio in the Western (left, a, c) and Eastern Balkhash (right, b, d), summer 2004

The distributions of the abundance and biomass of dinophytes, cyanobacteria, diatoms, and chrysophytes abundance in the Western Balkhash within the TDS gradient and the K^+/Na^+ ratio followed the patterns described for the entire phytoplankton community (Fig. 4a,c). As well as the total quantitative variables of phytoplankton (Fig. 4b,d) within the TDS gradient and the K^+/Na^+ ratio, the abundance of charophytes, euglenophytes, abundance and biomass of diatoms and blue-greens in the Eastern Balkhash varied in the same manner.

Variability of quantitative variables of charophytic and green algae on the both parts of the lake was differing from the picture described above. Favorable conditions for Charophyta developed where K^+/Na^+ ratio was high in desalinated areas in the Western Balkhash (Fig. 5a,c). The K^+/Na^+ ratio was favorable for this species' abundance when the TDS was about 2,400-2,600 mg/dm^3 in the Eastern Balkhash and with the further increase in the Total Dissolved Solids in water the K^+/Na^+ ratio did not matter (Fig. 5b). The biomass of the charophytes was maximal in the saline areas together with increased values of the K^+/Na^+ ratio and also at the minimal values of K^+/Na^+ ratios when the TDS being about 3,200 mg/dm^3 (Fig. 5d).

The variability of Chlorophyta's abundance depending on the TDS was represented by a concave surface (Fig. 5e,f). This parameter decreased in the Western Balkhash with an increase of the TDS from 400 to 2,000 mg/dm^3. The abundance of green algae increased again with a further increase in the TDS in the eastern part of the lake to 5,000 mg/dm^3. The negative influence of the K^+/Na^+ ratio on Chlorophyta's abundance was mainly observed when the TDS was about 2,000 mg/dm^3 in the both parts of the water area.

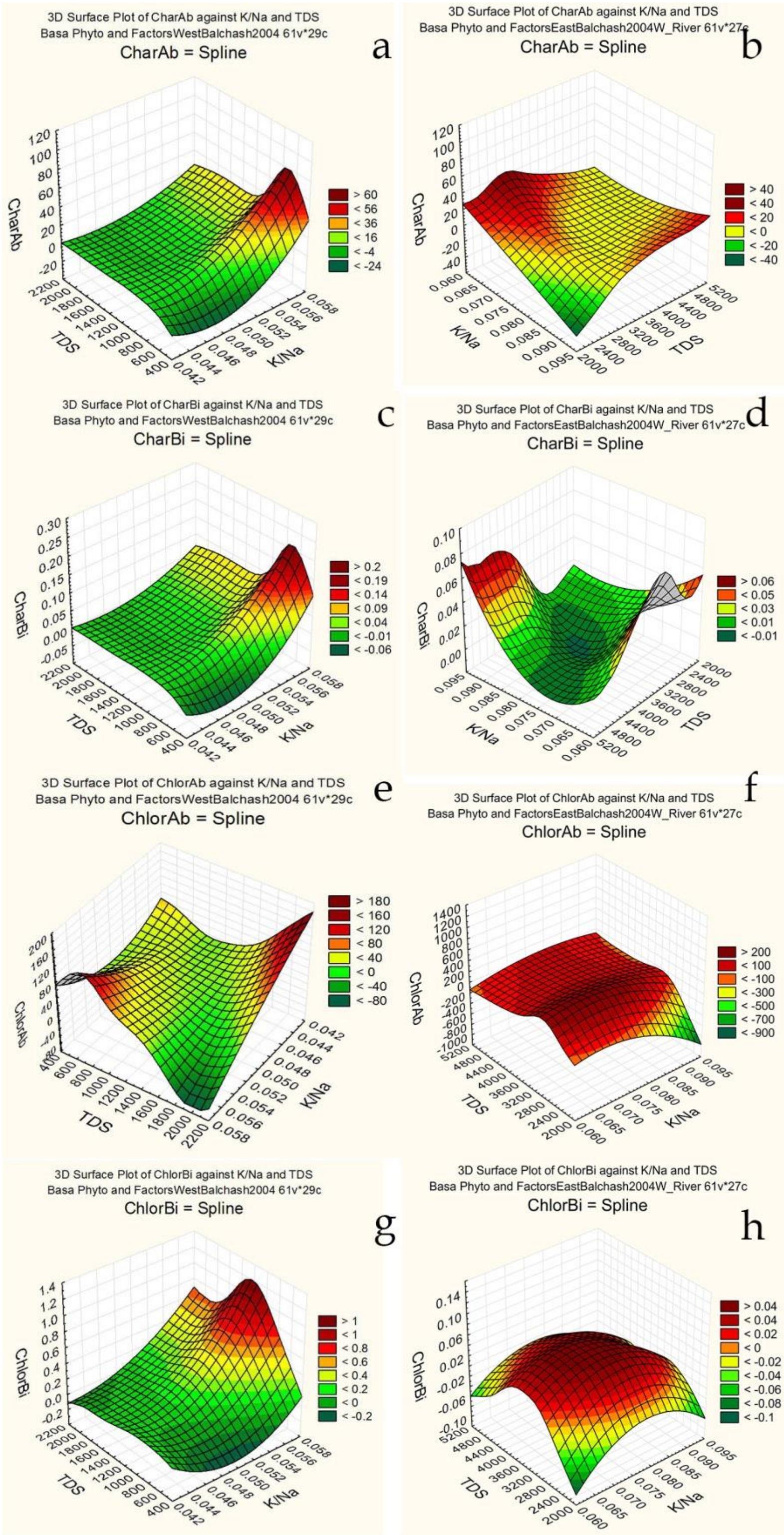

Fig 5: Distribution of abundance and biomass of Charophyta and Chlorophyta depending on the TDS of water and K^+/Na^+ ratio in the Western (left, a, c, e, g) and Eastern Balkhash (right, b, d, f, h), summer 2004.

The increase in Chlorophyta's biomass in the Western Balkhash was stimulated by an increase in the K^+/Na^+ ratio at the TDS values of about 1,200 mg/dm^3 (Fig. 5g). The value of this parameter varied non-linearly in the eastern part of the lake within the gradient of K^+/Na^+ and the TDS (Fig. 5h).

The oppression of algal communities was recorded in the Eastern Balkhash in areas with TDS at about 2,000 mg/dm^3 and high K^+/Ca^{2+} ratio (Fig. 6b, d). The variability of the quantitative variables of phytoplankton under the influence of chemical factors was non-linear in the western part of the lake. The leading role was played by the TDS but the relative content of potassium and calcium in water was less substantial (Fig. 6a, c).

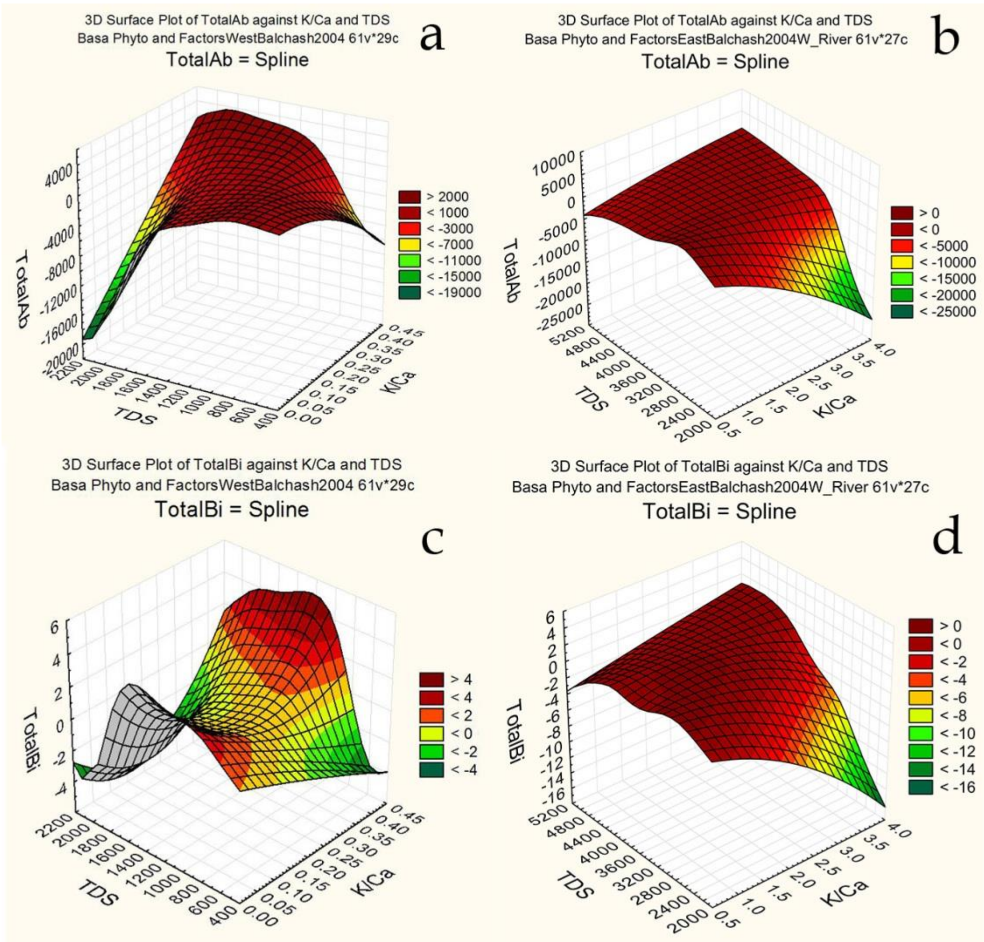

Fig 6: Distribution of phytoplankton abundance and biomass depending on the TDS water and K^+/Ca^{2+} ratio in the Western (left, a,c) and Eastern Balkhash (right, b, d), summer 2004

The distribution of the abundance and biomass of blue-green, diatom, charophyte, and green algae in the TDS gradient and the K^+/Ca^{2+} ratio in the water of the Western Balkhash was governed by the patterns described for the total quantitative variables of phytoplankton (Fig. 6a). The spatial variability of the abundance and biomass of greens, blue-greens, diatoms and charophytes in the Eastern Balkhash was synchronous and within the framework of above-mentioned trends (Fig. 6b, d).

There was two peaks of abundance of chrysophytes, abundance and biomass of dinophytes and euglenophytes in the Western Balkhash unlike for other divisions: at maximum of water TDS and minimum values of K^+/Ca^{2+} as well as with minimum TDS of water and maximum values of K^+/Ca^{2+} (Fig. 7a,b,c). Opposite trends were established for the spatial dynamics of the chrysophytes biomass (Fig. 7d).

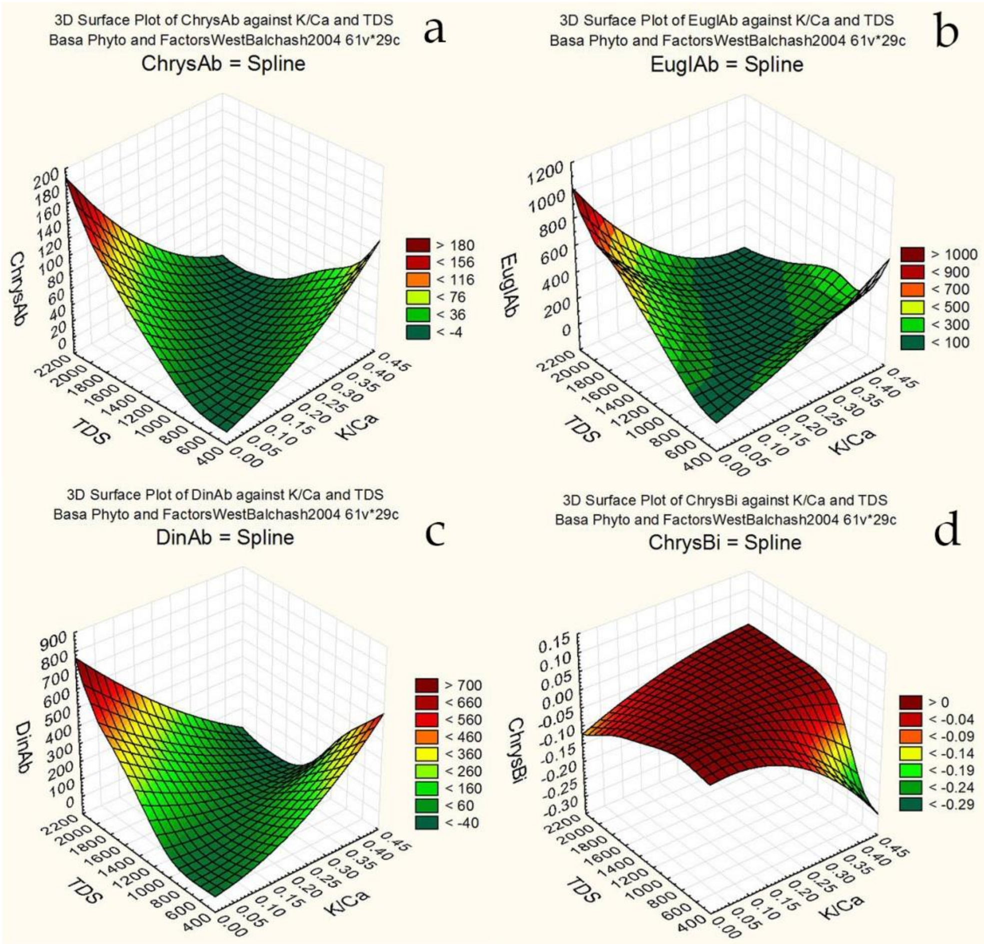

Fig 7: The distribution of Chrysophyta biomass, and abundance of Euglenophyta, Dinophyta and Chrysophyta depending on water TDS of and K^+/Ca^{2+} ratio in the Western Balkhash, summer 2004

The most apparent effect of K^+/Ca^{2+} ratio on the quantitative variables of Dinophyta in the Eastern Balkhash was observed at TDS of about 2000 mg dm^{-3} with the optimal ratio of K^+/Ca^{2+} being about 2.5 (Fig. 8a). The surface of Euglenophyta biomass (Fig. 8b) was bent at the same value of K^+/Ca^{2+} ratio, but in the opposite direction.

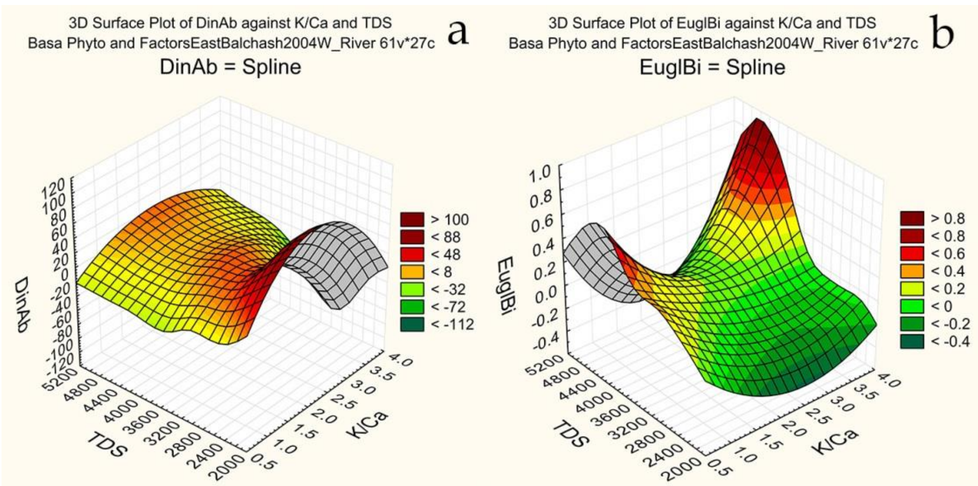

Fig 8: Distribution of abundance of Dinophyta (a) and biomass of Euglenophyta (b) depending on the water TDS and K^+/Ca^{2+} ratio in the Eastern Balkhash, summer 2004

The influence of Mg^{2+}/Ca^{2+} ratio on the phytoplankton communities of the Balkhash Lake was also observed mainly at Total Dissolved Solids in water of about 2,000 mg/dm^3 (Fig. 9a,b). The abundance of unicellular algae varied non-linearly when the Mg^{2+}/Ca^{2+} values increased from 0.3 to 4.0 and then decreased. The Mg^{2+}/Ca^{2+} ratio had no significant effect on the total abundance of algal cells at low (<2,000 mg/dm^3) and high TDS values (> 3,200 mg/dm^3).

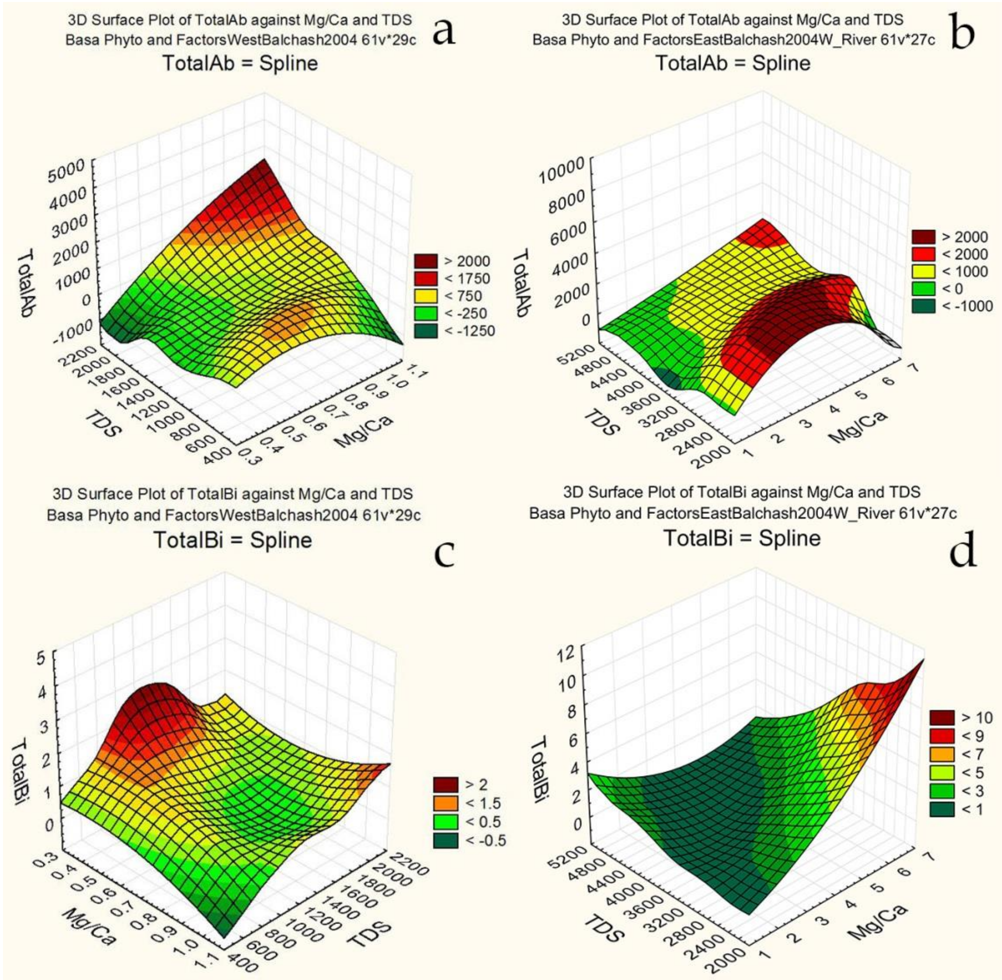

Fig 9: Distribution of abundance and biomass of phytoplankton depending on the TDS of water and Mg^{2+}/Ca^{2+}ratio in the Western (left, a, c) and Eastern Balkhash (right, b, d), summer 2004

A positive relationship was observed between the biomass of algae and the TDS in the Western Balkhash, while favorable conditions for algal communities were formed at low Mg^{2+}/Ca^{2+} ratios (Fig. 9d). The phytoplankton biomass increased almost linearly within the gradient of the Mg^{2+}/Ca^{2+} ratio in the Eastern Balkhash with a weaker positive bond with the TDS (Fig. 9c).

The distribution of algal abundance and biomass of all divisions in the Western Balkhash within the gradient of TDS and Mg^{2+}/Ca^{2+} ratio followed the patterns described for the total quantitative variables of phytoplankton (Fig. 9a,c). The spatial variability of quantitative variables of cyanobacteria, diatoms, charophyte, green, and euglenophyte algae in the Eastern Balkhash also complied with the general trends (Fig. 9b, d). In other words, the TDS of water being at about 2,000 mg/dm^3, the abundance and biomass of algal divisions increased within the gradient of Mg^{2+}/Ca^{2+} values ranging from 0.3 to 4.0, and with further growth of Mg^{2+}/Ca^{2+} ratio it decreased. The total abundance of algal cells of these divisions did not react to the changes in the Mg^{2+}/Ca^{2+} ratio at low (<2,000 mg/dm^3) and high TDS values (>3,200 mg/dm^3).

High values of Mg^{2+}/Ca^{2+} ratio along with the TDS of water were positively affected the abundance of euglenophytes in the Eastern Balkhash (Fig. 10a). The dinophytes abundance changed in a dome-shaped way within the gradient of Mg^{2+}/Ca^{2+} ratio demonstrating complex nature of its dependence on the TDS of water (Fig. 10b).

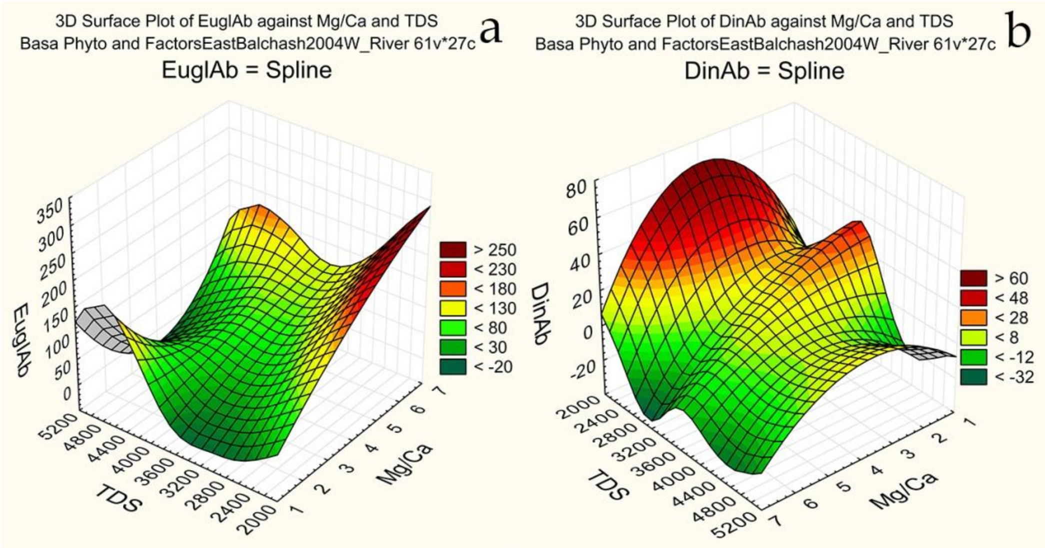

Fig 10: Distribution of abundance of Euglenophyta and Dinophyta depending on the TDS of water and Mg^{2+}/Ca^{2+}ratio in the Eastern Balkhash, summer 2004

DISCUSSION

Our results analysis revealed statistically significant but weak links between quantitative variables of phytoplankton communities and chemical composition of the water in the Balkhash Lake. Water salinity and related increase in the relative content of potassium, sodium and magnesium ions had a positive effect on Cyanobacteria but inhibited the abundance of species of other divisions except Bacillariophyta that was usually dominant in waters with high TDS. Differences between the spatial dynamics of the total abundance, total biomass of phytoplankton within the gradient of TDS and the chemical composition of the Balkhash Lake water illustrated internal changes in the communities. These changes occur mainly due to the species of Chrysophyta, Chlorophyta, Dinophyta, and Charophyta the variability of the quantitative variables of which did not follow the patterns of the whole phytoplankton communities.

Low values of rank correlation coefficients are caused by the non-linear nature of variability of phytoplankton variables in dependence on chemical factors. Our research showed that the influence of K^+/Na^+, K^+/Ca^{2+} and Mg^{2+}/Ca^{2+} ratios on the abundance and biomass of plankton algae in the Balkhash Lake was manifested most strongly when the TDS of water were approximately 2,000-2,200 mg/dm^3. This is due to the fact that in the conditions of the Balkhash Lake this value of TDS comes with an abrupt change in the relative content of cations: the concentration of calcium decreases, and the content of potassium, sodium and magnesium increases but with different intensities (Fig. 2). Similar results were obtained when analyzing of our data on different types of inland water bodies in Kazakhstan. Based on this our unpublished research, Fig. 11 shows that the absolute content of calcium in the water of Kazakhstan's inland water bodies increased in the direction from ultra-fresh water to waters with TDS of about 1,800-2,000.0 mg/dm^3, and with further growth of salinity, it decreased.

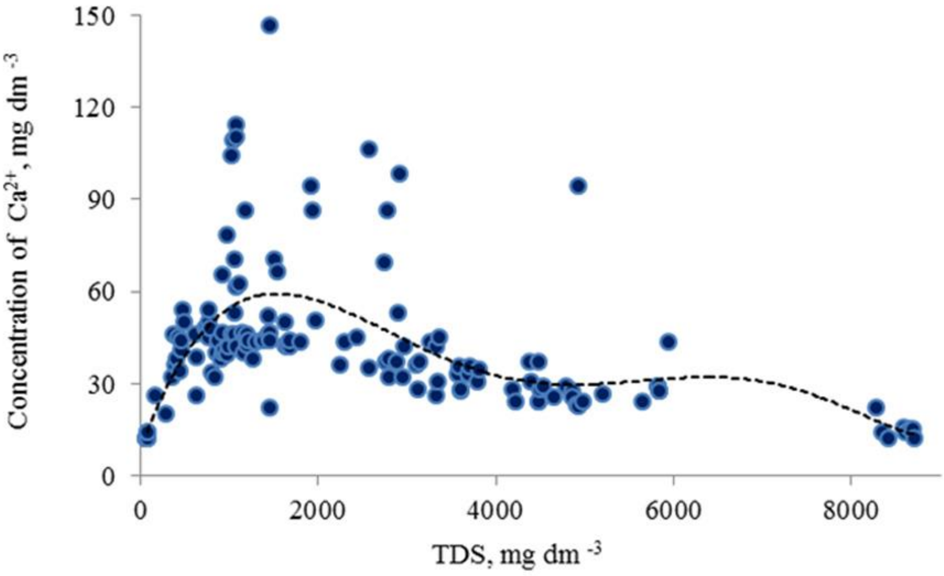

Fig 11: Change in calcium content depending on TDS of water in Kazakhstan's water bodies

Our results correspond to the theory of critical salinity proposed by A. Remane [5] and developed by follow investigations [6-13]. The concept of relativity and multiplicity of zones of barrier salinity was formulated [14] as part of the further development of the theory of critical salinity. According to this concept, the absolute values of barrier salinity zones depend on the chemical composition of water and osmoregulatory abilities of hydrobiontes.

The Balkhash Lake, the largest water body of arid zone in Kazakhstan after the Aral and Caspian seas, has a unique chemical composition of water (Table 5). The relative content of sodium, magnesium, calcium is lower, and the relative content of potassium is higher in the eastern saline part of the Balkhash Lake than in the ocean and the Aral Sea. The K^+/Na^+ and K^+/Ca^{2+} ratios in the Eastern Balkhash were higher due to higher relative potassium content, but ratio of Mg^{2+}/Ca^{2+} was close to that in ocean water. The maximum values of K^+/Na^+ ratio are characteristic of fresh river waters (Clark values) (Table 5), while the absolute content of potassium and sodium is at a very low level. High values of K^+/Na^+ ratio close to the Clark values were recorded in the fresh rivers Aksu and Lepsy feeding the Eastern Balkhash, and the Ili River, which flows into the Western Balkhash. This can explain the sharp decrease in the value of K^+/Na^+ ratio in the western part of lake (Fig. 2) with the gradual growth of water salinity in the direction from the zone of inflow of the Ili River towards the east. However, at the TDS more than 2,000 mg/dm^3 the K^+/Na^+ ratio increased again, which was observed in the eastern part of the Balkhash Lake.

Table 5: The TDS, the absolute content of cations, the ratios of K^+/Na^+, K^+/Ca^{2+}, Mg^{2+}/Ca^{2+} in the water of some water bodies in Kazakhstan based on our data and ** Blinov [33], and the Clark values *[32] of these variables in river and ocean water

Object	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	K^+/Na^+	K^+/Ca^{2+}	Mg^{2+}/Ca^{2+}
river water (Clark values)*	-	5.0	2.0	12.0	2.9	0.400	0.167	0.242
ocean water (Clarkvalues)*	34900.0	10670.0	396.0	408.0	1280.0	0.037	0.971	3.137
Aral Sea**	8780.0	2900.0	170.0	640.0	1200.0	0.059	0.266	1.875
Western Balkhash	1080.0	193.8	8.8	48.8	35.0	0.046	0.196	0.749
Eastern Balkhash	3437.0	692.4	51.0	32.4	98.4	0.080	1.725	3.235
Aksu River (Eastern Balkhash)	375.1	20.0	2.3	38.1	6.1	0.115	0.060	0.160
Lepsy River (Eastern Balkhash)	254.1	6.9	1.2	32.1	1.2	0.174	0.037	0.038
Ili River (Western Balkhash)	405.0	40.3	5.5	37.7	19.5	0.136	0.146	0.517

The chemical composition of water affected the phytoplankton communities at low (less than 2,000 mg/dm^3) and high (more than 2,000 mg/dm^3) TDS values, that is, in the Western and Eastern Balkhash, respectively, it manifested in different ways. Evidently, the Total Dissolved Solids at 1,800-2,000 mg/dm^3 can be considered a barrier separating the freshwater and brackish-water fauna and flora for the Balkhash Lake and for other inland waters in Kazakhstan. This value for oceanic waters is 0.5-2.0, for Caspian Sea – 0.5-2.5, and for Aral Sea – 0.5-3.0‰ [13]. Our results are consistent with some of the data obtained in the references earlier. So, the minimum number of species and abundance of mollusks were found in the shallow lagoons of the Baltic Sea at salinity of 0.5-2.0 ‰, with a general salinity gradient up to 8.9 ‰ [2]. The Figure 9 presented in [12], demonstrates that the minimum number of species in zooplankton was noted at a salinity of about 2.0 ‰.

The complex nature of the relationship between quantitative variables of phytoplankton communities and relative content of calcium, sodium, potassium and magnesium in the water of the Balkhash Lake is caused by the fact that an excess of ions of metals is as dangerous for water organisms [17, 20] as their deficiency [31]. The ratio K^+/Na^+ is 0.034 in the extracellular fluid of freshwater, marine and terrestrial animals [16], which is close to that in oceanic water ratio 0.037 [30]. We have shown that the crucial role for the populations of the dominant euryhaline species of planktonic crustaceans of the Balkhash Lake was played not by the TDS but also the value of the K^+/Na^+ ratio [34]. Abundance of the dominant species of plankton crustaceans was decreased when K^+/Na^+ values were greater than 0.067-0.080, i.e., it became critical when the outer environment reached the level twice as high as the intracellular fluid. Sharp changes in the total quantitative variables of green and charophytic algae took place only within the critical salinity zone of 1,800-2,000 mg/dm^3 as Fig. 5 illustrates with a similar K^+/Na^+ value about 0.075.

Therefore, the floristic parts and hydrochemical regions of the water area of the Balkhash Lake are differed substantially. Despite the fact that the lake is divided into 8 hydrochemical regions, the distribution of planktonic algae made it possible to discern 3 floristic regions only – with the TDS value of less than 1,800 mg/dm^3, a critical salinity zone of 1,800-2,200 mg/dm^3 and an increased salinity zone, with the TDS of more than 2,200 mg/dm^3. Spatially, the first area includes the greater part of the water surface of the Western Balkhash (the 1-3rd hydrochemical regions), and the third region unites the greater part of the Eastern Balkhash water surface (6-8th hydrochemical regions). The critical salinity zone is transitional and located in the central part of the lake on both sides to the east and west of the Strait Uzynaral (4th and 5th hydrochemical regions).

The results outlined here are preliminary to a certain extent and indicate the need for further studies of the ways the chemical composition of water affects the phytoplankton of the Balkhash Lake, with an emphasis on the spatial variability of the dominant algal species.

CONCLUSION

Correlation statistical analysis of the data from year 2004 revealed weak links between the quantitative parameters of phytoplankton communities and the chemical composition of the water of the Balkhash Lake. The water salinity and related changes in the relative content of main metal ions were favorable for Cyanobacteria but oppressed the abundance of species of other divisions except Bacillariophyta. Low values of the rank correlation coefficients are conditioned by the non-linear nature of the variability of phytoplankton parameters within the gradient of chemical variables. The influence of K^+/Na^+, K^+/Ca^{2+} и Mg^{2+}/Ca^{2+} ratios on the abundance and biomass of the plankton algal divisions of the Balkhash Lake was noted predominantly with the water TDS of about 2,000-2,200 mg/dm^3. This is due to the fact that in the conditions of the Balkhash Lake as well as in other inland water bodies in Kazakhstan at the TDS value as indicated above there is an abrupt change in the ratio of water cations to calcium concentration, while the content of potassium, sodium, and magnesium increases with different intensities. Our results correspond to the main points of theory of critical salinity by Remane – Khlebovich as well as to the concept of the relativity and multiplicity of zones of barrier salinities by Aladin. Evidently, the Total Dissolved Solids at the level of 1,800-2,200 mg/dm^3 is a barrier for the inland water bodies in Kazakhstan separating the freshwater and brackish-water fauna and flora. Further studies of the influence of ionic composition of water on biotic communities will make it possible to define this barrier more precisely. The floristic and hydrochemical divide of water area of the Balkhash Lake differed substantially. The distribution of plankton algae made it possible to identify only three floral regions from 8 hydrochemical regions: with a TDS value of less than 1,800 mg/dm^3 (1-3rd hydrochemical regions), a critical salinity zone of 1,800-2,200 mg/dm^3 (4-5th hydrochemical regions), and the zone of increased salinity with TDS more than 2,200 mg/dm^3 (6-8th hydrochemical regions).

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