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Climate Impact on Freshwater Biodiversity: General Patterns in Extreme Environments of North-Eastern Siberia (Russia)

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Authors' contributions

This work was carried out in collaboration between all authors. Author SB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VG and OG managed the analyses for the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aims of the current study are to reveal the response of high latitude riverine planktonic algal communities in northeastern Siberia to extreme climatic conditions of its habitats.
Study Design: We implemented diverse statistical methods, which represent some new approaches in freshwater algal diversity analysis.
Place and Duration of Study: Institute of Evolution, University of Haifa, Israel, Institute for Biological Problems of Cryolithozone SB RAS, Russia, between June 2008 and January 2014.
Methodology: We collected 800 samples of phytoplankton from 400 sites of 12 northeastern Siberian rivers in gradients of climatic and chemical variables that we analyzed. New indices - Geo-associated and Dynamic Habitat Index were included in this

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analysis. Statistical methods for comparative floristic analyses were used for calculating the similarity of algal communities among the sampling stations. Multiple regression stepwise statistical analysis on phytoplankton including chemical and climatic variables data was performed. Species diversity in algal communities and their environmental variables relationships were calculated.

Results: As a result, 1283 species (1637 taxa of species and infraspecies) from six taxonomic divisions were identified in phytoplankton communities. Species richness as a whole increased to the north. Abundance and biomass were highly correlated. Two types of phytoplankton communities were identified: a southern community with increasing diatoms and a northern group with decreasing diatoms to the north. Diatoms prevailed but were replaced by green algae in high mountains or by green and *Chrysophyta* algae and *Cyanobacteria* in the Arctic. We revealed major variables that considered stimulating or stress factors with helps of statistical prorgams.

Conclusion: Statistical analyses of phytoplankton in 12 large rivers revealed an increase in species richness to the north with community structure changing under stimulation of air temperature, ice-free periods, humidity, and trophic variables were stimulants and water transparency and speed flow were considered stress factors.

Keywords: Freshwater algae; diversity; ecology; climate adaptation; Northern Siberia.

1. INTRODUCTION

Relationships between freshwater algal biodiversity and environmental conditions can be determined as adaptation levels between the species and the community as a whole. Bio-indication and related integrative methods for aquatic environment sustainable assessment are based on the principle of congruence between community composition and the complexity of environmental factors. In any case, freshwater biodiversity is still a much underestimated component of global biodiversity [1] but can be estimated using diverse methods to measure major climatic variables [2,3]. However, there are still many problems in defining the role of climatic factors in predicting the community's response to environmental changes. In an analysis of freshwater algae diversity we encountered certain difficulties. First, it is difficult to determine the scope of communities involved, as well as to define the scope of research tasks and the relevance of operative approaches [4]. The effects of major climatic variables, such as temperature and altitude, on freshwater algae distribution is widely discussed in recent literature [5-13] but still remains a problem. We planned this study because there is a lack of detailed distributional information for most freshwater organism groups and an absence of distribution-climate models; therefore, studies should be aimed at increasing our knowledge about these aspects of the ecology of freshwater organisms [14]. We know only one relevant study for bio-diversity assessment over large gradient of latitude in South America [15] but it has been do on the lake secosystems. Many studies about planktonic algal communities in boreal lakes has been do for revealing gamma-diversity response to climatic variables [16] and importance of phytoplankton studies [17] with conclusion that diversity is the best predictor for resource use efficiency of phytoplankton communities across considerable environmental and climatic [18] gradients. Riverine communities studies under Far East climatic gradient up to now has been in initial stage [19].

The freshwater algal communities' comparisons experience allows us to use a productive approach when there are visible climatic responses in the ecoregional, riverine basin floras, and infra-specific generalization levels for comparison.

The aims of the current study are to reveal the response of high latitude riverine planktonic algal communities in northeastern Siberia to extreme climatic conditions of its habitats. Thus, we tried to implement diverse statistical methods, which represent some new approaches in freshwater algal diversity analysis.

2. MATERIALS AND METHODS

2.1 Sampling and Laboratory Studies

Samples for the study were collected in the summer low water season of June-August 2008 – 2011 from 12 large East Siberian Rivers: Anabar, Olenek, Indigirka, Yana, Kolyma, Aldan, Amga, Vilyui, Lena, Vitim, Olekma, and Chara (Fig. 1). The study areas are located on territories of Yakutiya, Buryatiya, Zabaykalskiy Kray and Magadanskaya, Amurskaya, and Irkutskaya Oblast.

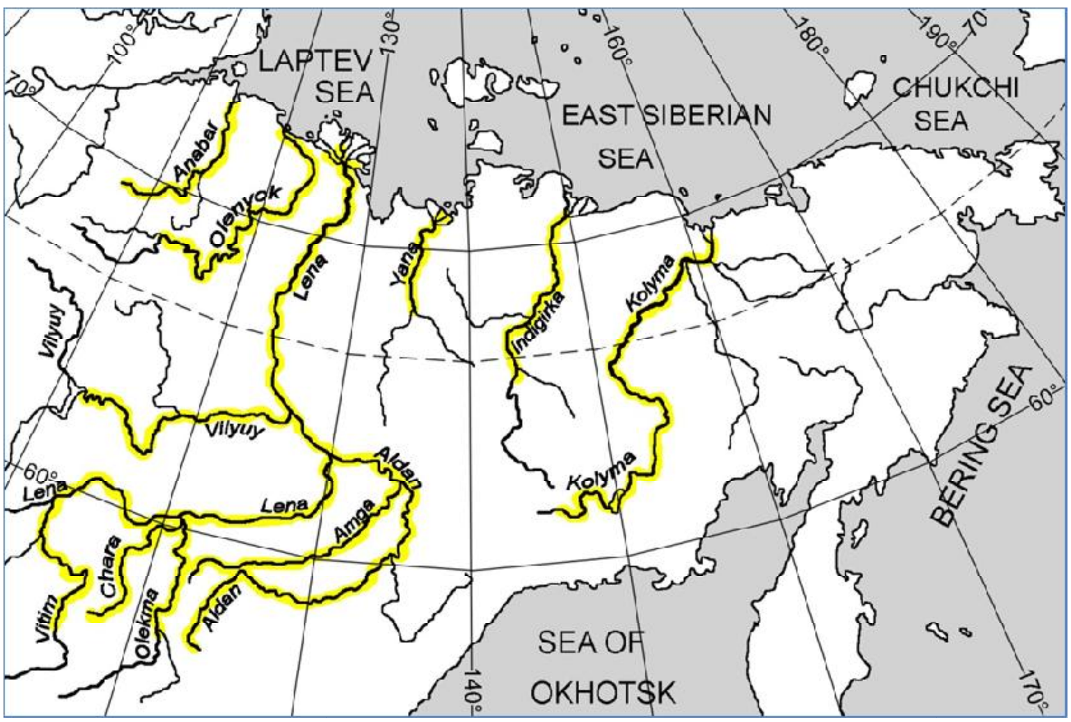

Fig. 1. Map of the studied (yellow) rivers in north-eastern Siberia

A total of 303 water samples and 800 phytoplankton samples were collected for hydrochemical and algological analyses, respectively. Some samples were collected from the littoral and others from the fairway of the rivers (from the 0 – 0.3 m depth in both cases).

Samples for chemical analysis were taken in 2.5 L dark glass bottles and transported to the laboratory during two days in an ice box with 4ºC. Water chemical analyses followed standard methods set out in [20,21]. Gas regime components (CO_2, O_2, and BOD_5) and Secchi disk depth, were determined in situ. Concentrations of other chemicals were determined in the laboratory.

One and a half liter water samples for phytoplankton quantitative analyses were concentrated on Sartorius membrane filters (pore size 1.2 µm) by pressure filtration, using the phytoplankton concentrator of our own design [22]. Samples for qualitative analyses were collected with an Apstein plankton net (SEFAR NITEX filter fabric, mesh size 30µm) and fixed in 4% neutral formaldehyde solution. Microscopy was performed with an Olympus BH2 microscope under magnification 600 – 1000. Algal cells were counted in a Nageotte counting chamber (volume 0.01 cm^3). Biovolumes of different taxa were calculated by approximating the cell shape to simple geometrical shapes, using our own linear measurements of cells. The volume to specific weight conversion factor was assumed to be a unity. Diatom shells were studied in 2500 permanent slides with Bio mount media. No less than 100 cells of each abundant species were calculated from each quantitative sample.

2.2 Taxonomic Analysis and Functional Classification

For taxonomic identification a common international handbook series were used. Modern species' names in our work come from Algaebase [23], employing the common system nomenclature derived from Cavalier-Smith [24].

The mean phytoplankton community cell size was estimated from the ratio between total biovolume and total abundance according to [25].

The Shannon's diversity index [26], which reflects the degree of abundance equality among the species in the community and is correlated to the entropy of the ecosystem [27], was calculated as:

$$\bar{H} = -\sum_{i=1}^{s} \frac{n_i}{N} \log_2 \frac{n_i}{N} \tag{1}$$

Where: H – Shannon species diversity index, bit, N – common individuals abundance, s – species number; n_i – the number of individuals in each species.

2.3 Statistical Analysis

Statistical methods for comparative floristic analysis were used for calculating the similarity of algal communities among the sampling stations on the basis of Sørensen's similarity indices that automatically calculated with GRAPHS Program [28].

Statistical analysis of correlation between species diversity and major climatic condition variables was calculated by distance-weighted least squares using the Statistica 7.1 Program.

Multiple regression Stepwise statistical analysis on phytoplankton, including chemical and climatic variables' data, was performed via the Statistica 7.0 software in order to determine the variables with strongest influence on the algal communities in studied rivers.

2.4 Description of Study Site

Eastern Siberia is the Asian territory of the Russian North-East, from the Yenisei basin to the Chukotsky peninsula [29]. Our study area with a large amplitude of latitude, altitude, temperature, and precipitation range [30] (Fig. 1) is bounded on the north by seas Laptev and East Siberian, on the west by the watershed of the Central Siberian Plateau, from the south by the mountain plateau of Stanovoy Ridge, from the southeast by the Yudoma-Maisky highlands and southern spurs of the Verkhoyansk Range, and from the east by the Kolyma Range [31]. Studied rivers are from the Lena 608 and Kolyma 609 ecoregions in the Freshwater Ecoregions of the World (FEOW) [32].

The territory of the region is represented by all forms of relief: mountains, plateaus, intermountain valleys (basins) and lowlands, and are distributed over two natural geographic zones – arctic and subarctic, and three natural zones - tundra, forest tundra and taiga, and mountain landscapes. Eastern Siberia is characterized by almost universal distribution of permafrost - continuous (integral) in the northern latitude of Vilyui River and intermittent in the southern half of the area. Power permafrost in the central part of the region is 350 – 450 m, the maximum depth found in the river basin Olenyok and reach 1,500 m [33]. In the south of the region power permafrost decreases; there are more or less significant areas devoid of permafrost (taliks) [34]. A climatic condition of Eastern Siberia is largely determined by its geographical location within the Asian continent and is protected by mountains from the Atlantic and Pacific Oceans. The main features of the climate of Eastern Siberia – a clear, severe, with little snow, stable and long winters and fairly dry, short, and hot summers. The studied water bodies represent twelve of the largest rivers of Eastern Siberia and belong to the basin of the Arctic Ocean. Our study area extends in a longitudinal direction of 106º53'E to 160º58'E, and in latitude – from 56º13' to 73º10'N. The total length of all studied rivers sites reaches more than 17,000 km.

2.5 Floristic Materials

The regional freshwater algal flora is represented in the main monographs of Vassilyeva-Kralina et al. [35,36] and Vasilyeva et al. [37]. Our papers are focused on the floristic diversity and community structure of phytoplankton in twelve major rivers of Eastern Siberia [38-48]. Freshwater algal diversity and ecology under anthropogenic impact study are represented in [49-52].

2.6 Environmental Data

Environmental and Dynamic Habitat Index, DHI [53] data we compiled from the Institute for Biological Problems of Cryolithozone SB RAS, Yakutsk meteorological data base (see Appendix as supplementary file). The DHI index is an important variable which correlated with the latitude of the sampling sites is calculated as a result of landscape variation and sensitivity to climate change for the North America from central part of U.S.A., Canada and to the Polar. Climatic parameters have been taken from http://worldclim.org/. Geo-association classes of the river basin placement are created by us as:

1 – Large transitional rivers;
2 – Rivers flows mainly in the latitudinal direction;
3 – River located in the south of the region;
4 – Rivers of the central part of the region;
5 – Most of the river basin is located north of the Arctic Circle;
6 – River basin is located north of the Arctic Circle.

3. RESULTS

We revealed 1,283 species (1,637 taxa of species and infraspecies) of algae and cyanobacteria in 800 samples collected during 2008 – 2011 from 12 rivers and 400 sampling stations (See Appendixas supplementary file). The *Bacillariophyta* prevail in six taxonomic divisions. Species richness varied from 9 – 146 taxa in different stations and represent diverse algal communities even in each studied river.

Studied rivers have mostly flow in a northerly direction. They are covered with ice most of the year (See Appendix as supplementary file) with ice free days from 112 (Anabar) to 149 (Amga), and the average water temperature in summer ranges from 3.8 to 23ºC. Speed of the flow varies from 0.28 to 3.61 m sec^{-1}, and water transparency from 0.04 to 4.50 m. Waters are mostly alkaline with pH from 6.68 to 9.28, fresh (TDS 13–452 mg L^{-1}), well oxygenated (6.0 – 13.6 mg O_2 L^{-1}) with CO_2 saturation of 0-8.8 mg L^{-1}. Nutrients concentration varied in nitric nitrogen (0 – 2.16 mg L^{-1}), phosphorous (0-0.36 mg L^{-1}), Si (0.4 – 4.63 mg L^{-1}), and Fe (0 – 3.0 mg L^{-1}) in quantity enough for algal biomass development. The elements that defined water quality such as ammonia (0.020 – 1.88 mg L^{-1}), nitrites (0 – 0.034 mg L^{-1}), and BOD (0.04 – 4.94 mg L^{-1}) reflect wide range of water quality but cannot be interpreted as unfavorable for survival of algae.

Therefore, we can analyze major biological variables such as species richness, abundance, and biomass changing over stations in a northern direction to reveal algal preferences in extreme climatic zones.

Climatic characteristics of the region form the system of complex interactions. Precipitation correlated with DHI (Pearson 0.60, $P<.01$), decreasing to the north, but their abundance is also associated with the number of days of open water, that is, with the temperature and light intensity (Fig. 2). Maximal values of rainfall are in the southern region, where the ice-free period is longer as well as in the northern sites where there are more days of open water. The DHI index is an important variable which correlated with the latitude of the sampling sites. It can be seen that DHI is lower for the northern habitats (Fig. 3).

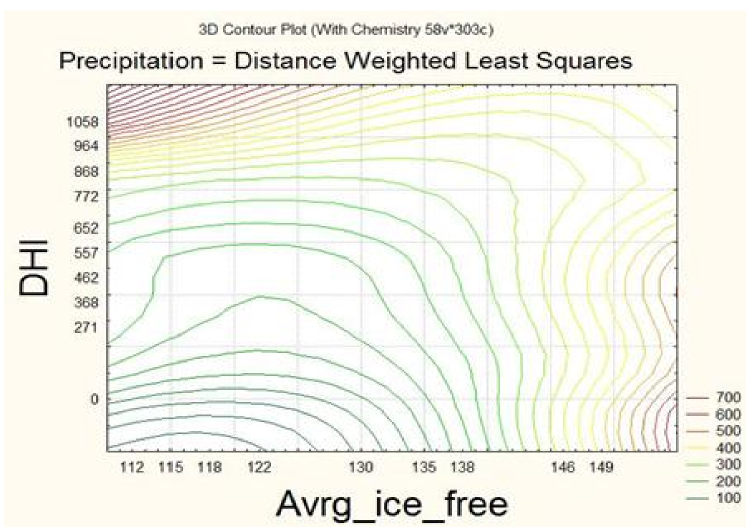

Fig. 2. Plot of precipitation distribution over the ice-free periods (Avrg_ice_free) and Dynamic Habitat Index (DHI)

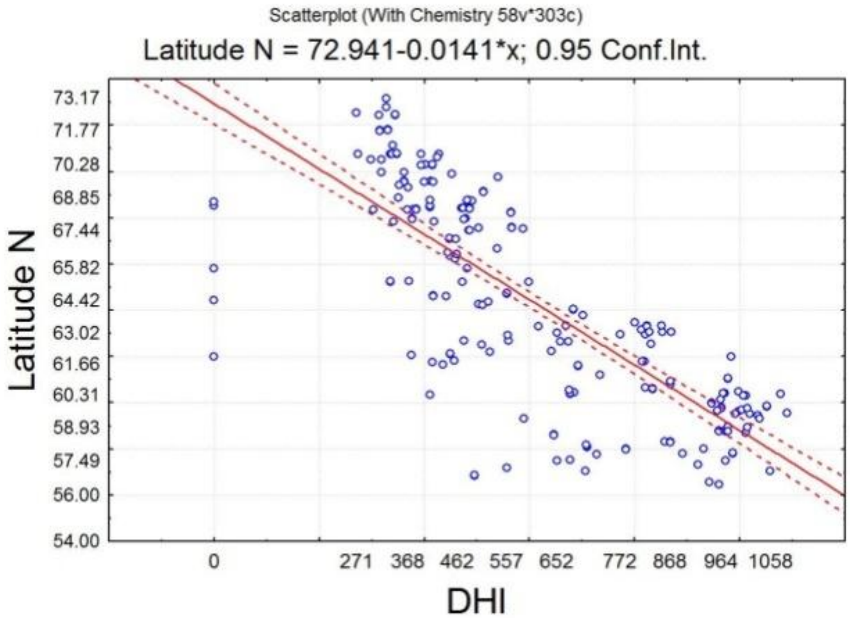

Fig. 3. Distribution of DHI over latitude of studied habitats

In rivers, species richness increased to the north excluding the southernmost river Vitim. Diatoms usually increased to the north, but in the middle of the studied area, they were replaced by *Chlorophytes* (Amga, Vilyui, Kolyma). *Chrysophyta* species number increased to the river mouth in the Indigirka River and changed of *Cyanobacteria* in the northernmost area of the river Anabar. Abundance and biomass of phytoplankton varied widely in the lowermost part of the northern Anabar River (58.9 cell L^{-1}; 0.0002 mg L^{-1}) and were higher in the largest rivers: Lena, Kolyma, Aldan, and Vilyui (more than one million cells per liter and about one mg L^{-1}). That means that the strongest climatic impact can be seen in the northern area rivers where the environment is unfavorable for algal communities. This expectation can be confirmed by data about community complexity. The average cell volume is the lowest in the northern stations but in the largest rivers it is highest, which correlated with the Shannon index of complexity: up to 5.76 in the rivers Lena, Vilyui, Vitim, and Kolyma. The average cell volume has a negative correlation with Shannon index in the studied communities and therefore both variables reflect the community's structure complexity fluctuation under climatic impact.

Abundance and biomass of phytoplankton usually have positive correlation (Pearson coefficient 0.30 – 0.94) with statistical significance (P = .04 – 2 10^{-8}). Each river can be characterized by its own productivity variables, but we revealed some tendencies in community structure over latitude. So, in the southernmost rivers Vitim, Olekma, Chara, Amga, and Aldan, which belong to the Lena River tributaries, diatoms prevail in abundance and biomass (Fig. 4). Northern rivers of the Lena Basin – Lena and Vilyui, changed abundance from diatom to diatom-*Chlorophyta* but in biomass diatoms still prevail. Other studied rivers in the north have more structural complexity of its communities. Usually diatom replaced to diatom-*Chrysophyte*-*Cyanobacteria* communities to the north. It is remarkable that in the Olenek and Anabar rivers whole basins of which are located above the Arctic Circle, the role of *Chlorophyta* and *Chrysophyta* algae is increased in communities to the mouth (Fig. 5). In the Olenek communities increased also cyanobacteria in abundance and biomass (See Appendixas supplementary file). The major tendency in the communities increase in abundance and biomass of phytoplankton in the north direction in most rivers, except in the Vilyui, Olekma and Aldan where these parameters were slightly decreased, and the Anabar River where there are significant decreases in abundance and biomass. Usually this tendency is correlated with species number except in the Anabar River.

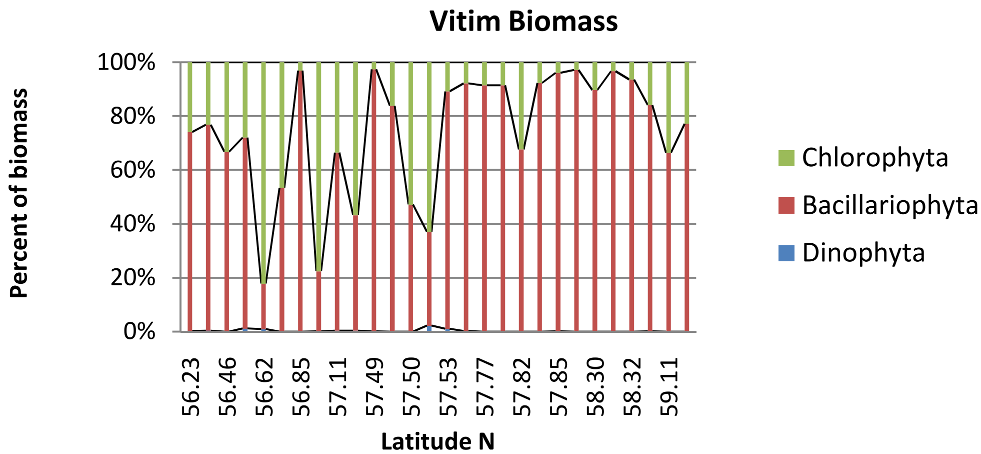

Fig. 4. Distribution of species richness in communities over latitude for typical southern rivers – the Vitim River

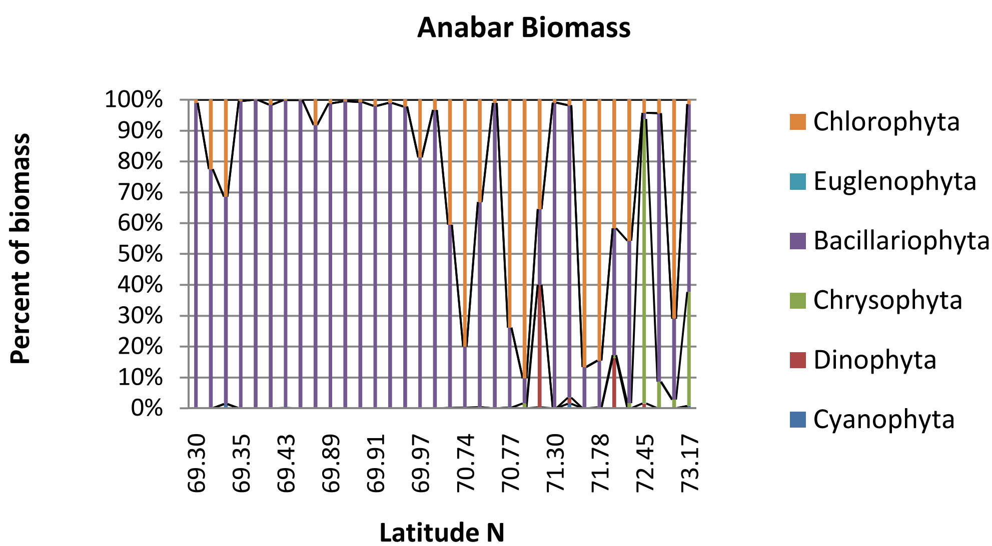

Fig. 5. Distribution of species richness in communities over latitude for typical northern rivers – the Anabar River

Therefore, we chose major community variables (species richness, abundance, biomass, average cell volume) to calculate the relationships with environmental data from (See Appendixas supplementary file). In the first step of calculation we implemented the multiple regression stepwise statistical analysis. (Table 1) show that the most important variables are (in Step 1 column) temperature, ice-free days, trophic variables, and flow speed. Species richness has been influenced by climatic variables – air temperature, precipitation, and ice-free period. Temperature and sunlight stimulate algal abundance and biomass whereas of water transparency and silica suppress algal development. Communities have been enriched by large-celled species and have more complexity in the low mineralized water with low transparency as can be seen in calculating the Biovolume and Shannon index H. Diatom and *Chrysophyte* algae were stimulated by temperature. Ammonia was important for *Cyanobacteria, Chlorophyta*, *Dinophyta*, and *Euglenophyta* whereas water transparency usually suppressed algal communities. Light stimulated cell abundance in diatoms; euglenoids were most abundant in temperate, mineralized, and polluted waters with low transparency, but phosphorous concentrations were important for green algae abundance. Algal biomass was stimulated by the light in green algae and by temperature and water pollution in euglenoids, whereas in diatoms high air temperature had negative influence.

Species richness as a whole increases with increases of water temperature (Fig. 6). Distance-weighted least squares correlation shows that species richness as a whole increases with decreasing DHI to the north as well as with the number of the open-water days (Fig. 7).

Fig. 8 shows the trend of increasing the number of species over the site position. Species richness is higher in the river basin in the north compared to the habitat coordinates. Precipitation plays an important role in increasing species richness in plankton communities, and in how the multi-specific communities form under high rainfall at low latitudes and under lower precipitation at high latitudes (Fig. 9).

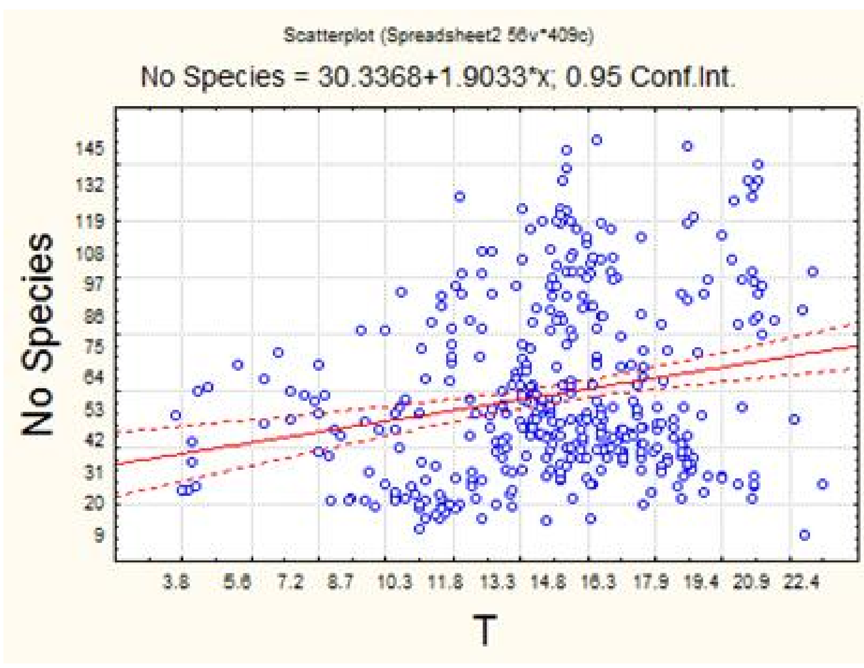

Fig. 6. Distribution of species richness in phytoplankton communities of studied rivers over temperature gradient

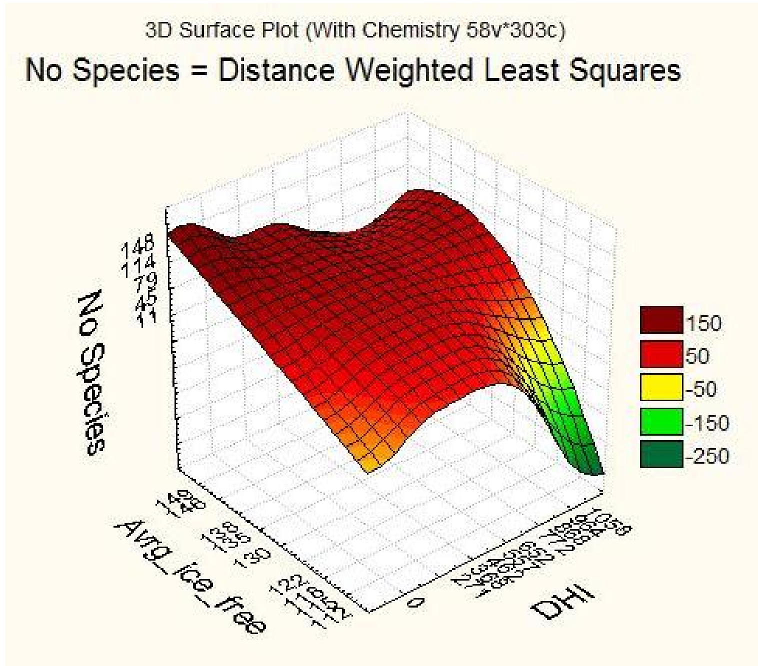

Fig. 7. Distribution of species richness in phytoplankton communities of studied rivers over gradient of DHI and ice-free period

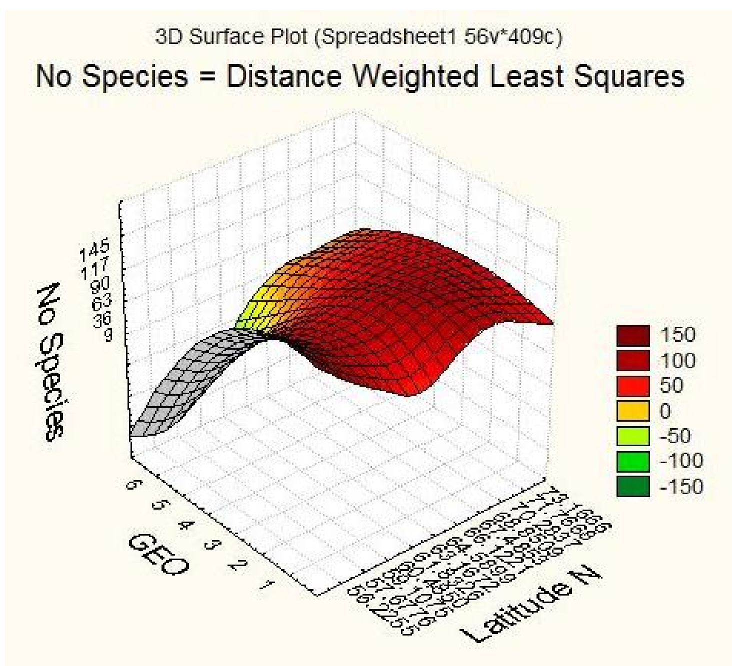

Fig. 8. Distribution of species richness in phytoplankton communities of studied rivers over latitude and gradient of the river basin placement

Table 1. Multiple regression stepwise statistical analysis results for the phytoplankton communities of the north-eastern Siberia Rivers. Abbreviations are gives as in appendix

Depen-dent variable	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
No. of Species	T_dry; Ice_free; **T_max**; Precip 0.434***	T_dry; **T_max**; Precip0.372***	T_dry; **T_max** 0.304***	T_dry 0.244***	-	-	-	-
Abundance	**Secchi**; **Si;**T_wat 0.267**	T_wat; **Si** 0.220**	**Si** 0.199*	T_wat 0.165*	T_wat 0.141*	-	-	-
Biomass	**Secchi**; Ice_free 0.264***	**T_max** 0.160**	**T_max** 0.138**	**T_max** 0.111**	-	-	-	-
Bio-volume	**Ice_free**; **TDS**; Secchi 0.161**	-	-	-	-	-	-	-
Cyano-phyta	Ptot; NH4 0.394***	Ptot; PO4; NH4; **Si** 0.372***	Ptot; **PO4**; NH4; **Alt** 0.348***	Ptot; **PO4**; T_dry 0.298***	Ptot; T_dry; **Alt** 0.260***	T_dry; **Alt** 0.217***	T_dry; **Alt** 0.184***	T_dry 0.091***
Bacilla-riophyta	T_mean_D; T_dry; **Secchi** 0.488 ****	T_mean_D; T_dry 0.362****	T_mean_D 0.234****	-	-	-	-	-
Chloro-phyta	**Secchi**;Ice_free; **Si**; T_wat; **T_dry**; NH4 0.712*****	T_wat; NH4; **Si**; **Secchi** 0.446****	T_dry; T_wat; NH4; **Si** 0.382****	T_dry; T_wat 0.318****	T_dry; T_wat 0.269****	T_dry 0.152***	-	-
SpChlo/ SpCyano	T_wat 0.199***	T_wat; T_ min 0.175***	T_wat; T_ min 0.098***	-	-	-	-	-
Dinophyta	NH4; **Si**; **pH** .329***	**Si**; **pH** 0.297***	CO2; **Si**; **pH** 0.254***	CO2; **Si** 0.169***	CO2 0.096**	-	-	-
Chryso-phyta	T_dry 0.399***	**T_wet**; T_dry **T_max** 0.322***	T_dry 0.288***	T_dry 0.252***	**T_wet** 0.211***	**T_wet** 0.152***	-	-
Eugleno-phyta	NH4 0.181**	NH4 0.157**	NH4 0.126**	NH4 0.091**	-	-	-	-

Table 1 continued…………………

N-Cyano-phyta	-	-	-	-	-	-	-	-
N-Dino-phyta	-	-	-	-	-	-	-	-
N-Chryso-phyta	-	-	-	-	-	-	-	-
N-Bacilla-riophyta	Ice_free; **Secchi** 0.248***	-	-	-	-	-	-	-
N-Eugleno-phyta	BOD; T_wat; Flow; TDS; Secchi0.277***	BOD; Flow 0.191**	BOD; T_wat; Flow 0.162**	BOD 0.102**	-	-	-	-
N-Chloro-phyta	Ptot 0.164**	Ptot; T_wat 0.147**	Ptot 0.078**	-	-	-	-	-
B-Cyano-phyta	**Si**; T_wat 0.192*	T_wat 0.159*	-	-	-	-	-	-
B-Dino-phyta	-	-	-	-	-	-	-	-
B-Chry-sophyta	-	-	-	-	-	-	-	-
B-Bacilla-riophyta	**T_max** 0.152 ***	-	-	-	-	-	-	-
B-Eugle-nophyta	BOD; T_wat; Flow 0.238**	BOD; T_wat 0.218**	BOD; T_wat 0.197**	BOD; T_wat 0.149**	BOD 0.079**	-	-	-
B-Chlo-rophyta	**Flow**; **Secchi**; Ice_free 0.203**	-	-	-	-	-	-	-
Shannon H	Ice_free; **Secchi** 0.804****	Ice_free 0.798****	-	-	-	-	-	-

*Note: Negatively influenced variables are bold; **, ***, **** = statistically significant at P < .01, P < .001; P < .0001 respectively*

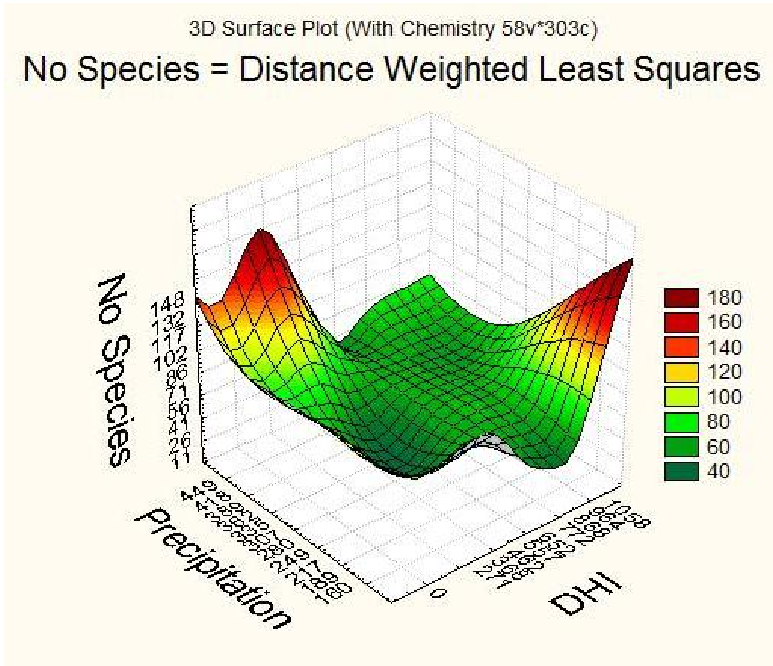

Fig. 9. Distribution of species richness in phytoplankton communities of studied rivers over gradient of DHI and precipitation

Abundance and biomass of phytoplankton in studied rivers correlate, but are not connected directly to each other as seen in (Fig. 10) where an upward trend in both variables in higher latitudes are seen with the change in plankton type. (Fig. 11) reflects the barely noticeable impact of the illumination on the productive variables of phytoplankton, but it is clear that a change in sunlight intensity is a function of ice-free periods; therefore we can see three types of communities.

Diatom biomass as the main part of the studied communities, formed in multi-specific communities, thrived in low-light conditions associated with fewer days in the open ice period (Fig. 12). It is remarkable that the revealed diatom biomass distribution is comparable to precipitation distribution (Fig. 2) in studied regions. This means that climatic variables, such as precipitation, and associated play major roles in increasing species richness and biomass of phytoplankton. At the same time, there is a tendency for the number of species to increase with the growth of the biomass of diatoms under well-lit conditions (Fig. 13).

As can be seen from the distribution of species composition in the typical south and typical north rivers (Figs. 4, 5), except the dynamics of diatoms, an important distinctive role in the northern habitats were made up of green algae and cyanobacteria; we therefore calculated this ratio for the studied communities. Precipitation increases with altitudes of habitats and (Fig. 14) shows that the number of cyanobacteria in the mountainous communities decreases, giving more benefits to the green algae. With increasing latitude and rainfall, the role of blue-green algae also decreased in comparison to the greens (Fig. 15).

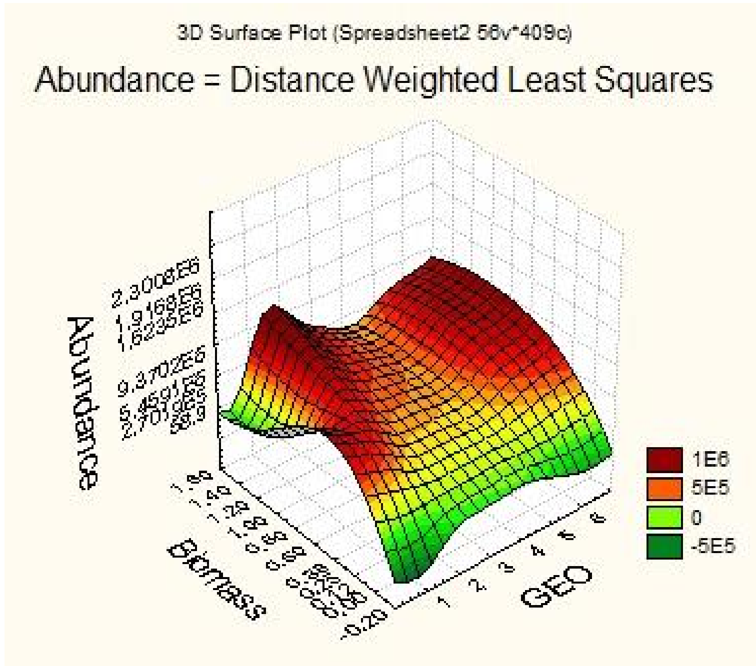

Fig. 10. Distribution of cell abundance in phytoplankton communities of studied rivers over the gradient of its biomass and the river basin placement

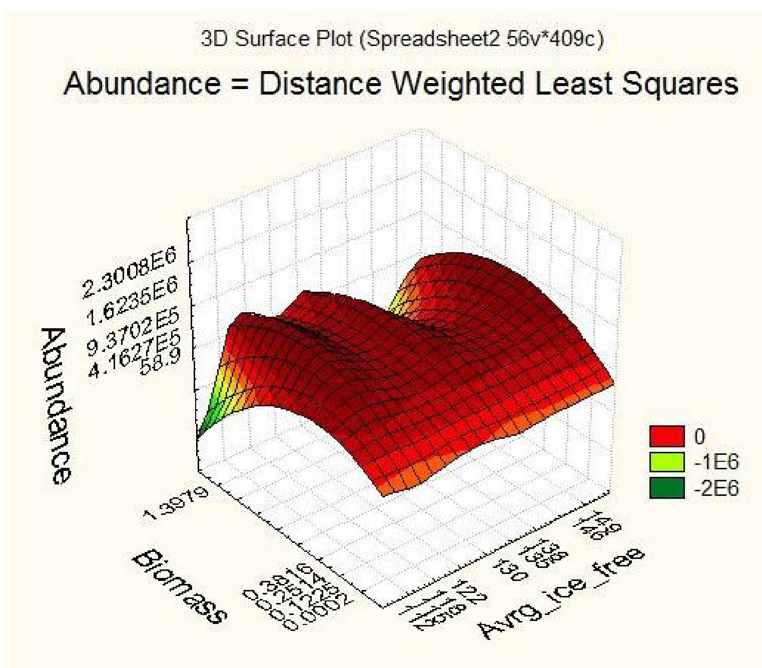

Fig. 11. Distribution of species richness in phytoplankton communities of studied rivers over the gradient of its biomass and ice-free period

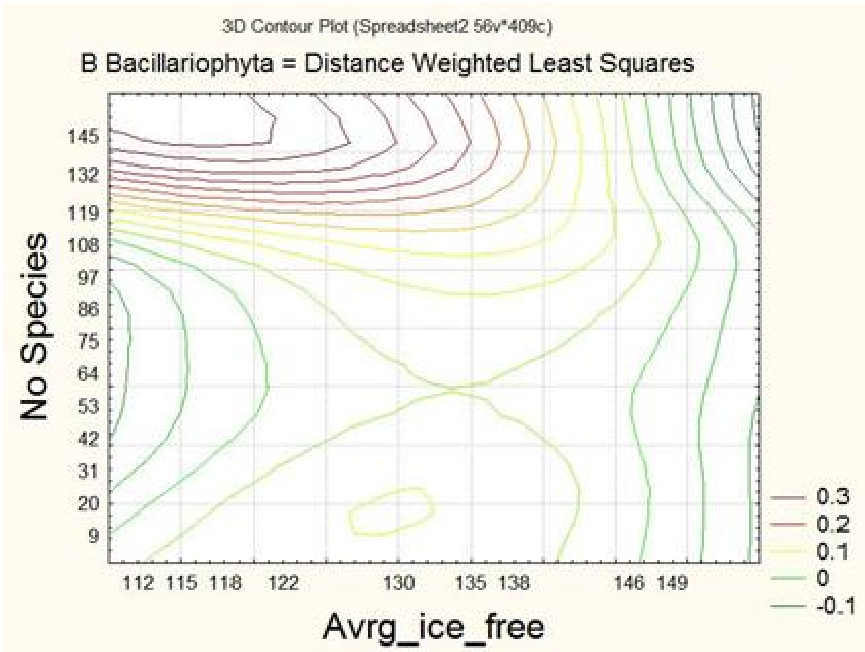

Fig. 12. Distribution of diatom biomass in phytoplankton communities of studied rivers over gradients of species richness and ice-free period

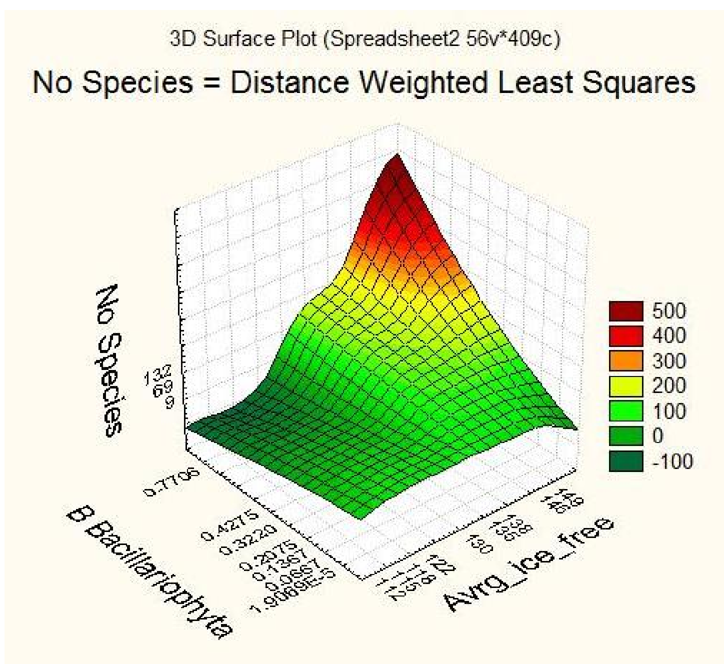

Fig. 13. Distribution of species richness in phytoplankton communities of studied rivers over diatom biomass and ice-free periodgradient

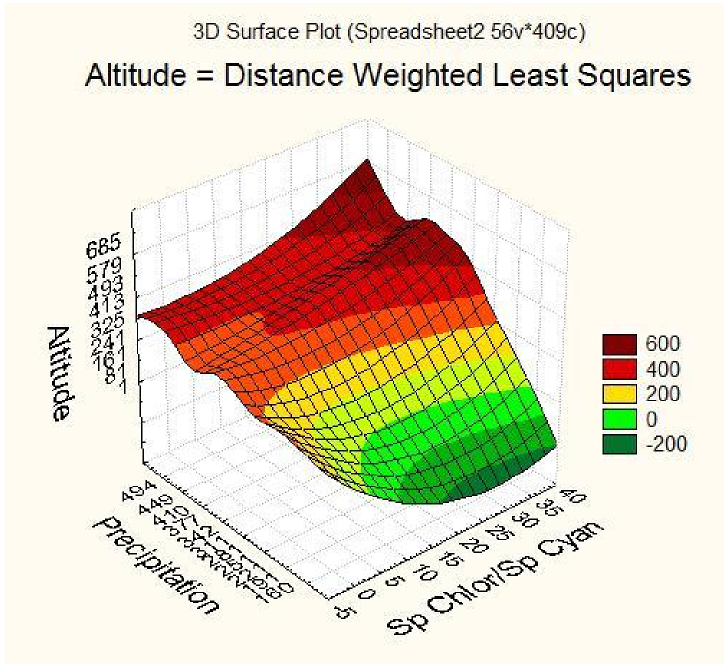

Fig. 14. Altitude, precipitation and *Chlorophyta*/*Cyanobacteria* ratio relationships in the studied rivers

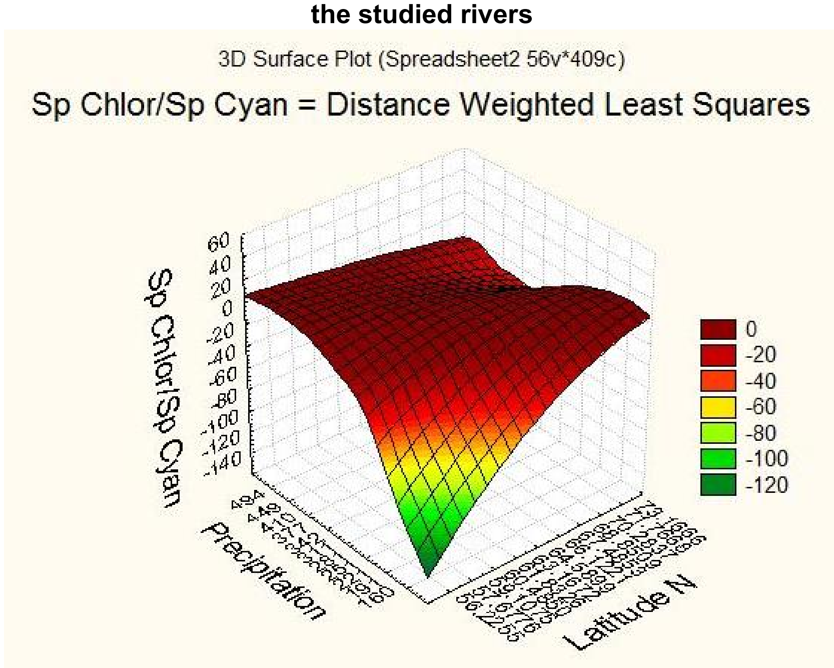

Fig. 15. *Chlorophyta*/*Cyanobacteria* ratio and precipitation relationships over the latitude of the studied rivers

4. DISCUSSION

Earlier we discussed the system of organizing the data to analyze the diversity of freshwater algal communities [4], which was hierarchical and limited at the top level of the river basin. Here, we used a new approach in which the data are combined at the regional level, thus increasing the level of generalization. Another new approach in our materials was to use not only hydrochemical but also regional climate data. We have also expanded the range of statistical analysis software with Program Graphs and modern version of Statistica.

We chose the same type of community that is only a summer phytoplankton of major rivers; the current of these major rivers predominantly ran from a south-to-north direction, which eliminated non-climate-related fluctuations. We analyzed a large number of samples from 400 sites resulting in the identification of 1283 species (1637 taxa of species and infraspecies) in phytoplankton communities, which is consistent with the Willis pattern [54], pointing to the completeness of the identified material. The studied rivers are mostly alkaline, ice-covered about half of the year with an average water temperature in summer from 3.8 to 23ºC and have no limitation for algal biomass development. We included environmental variables from two new indices: The DHI index [48] which strongly decreased with latitude, and the Geo-association index that we created for the river basin placement characteristic.

As a result of statistical programs applied to such large data numbers, our analysis shows the relationships between biological and climate-related variables. We revealed air temperature, ice-free periods, trophic variables, and flow speed as major variables that influenced phytoplankton communities. In contrast, water temperature was proposed as the major factor that influenced freshwater diversity [55] and therefore could be used as an indicator of global climate change [14], which wasn't included as an important variable in the studied Arctic rivers. Rivers in the north-eastern Siberia have two types of phytoplankton communities: southern with increasing diatoms to the north and northern with decreasing diatoms to the north. Species richness as a whole increased to the north and correlated with air temperature, precipitation, and ice-free periods. It is very interesting and non-trivial result which is invisible when only diatom communities have been studied in the climatic gradient [12] where diversity represents only one taxonomic group, such as diatoms [56]. In the Caucasian Mountains and Golan Heights freshwater communities we revealed a similar dynamic in community structure with decreases in diatoms in high-altitude habitats [9,10], which is similar to the Himalayas [56] with increases of *Chlorophyta* species [12]. At the same time anthropogenic factors also regulate the freshwater algal community structure and the distribution over the climatic gradient [11,12]. But our approach in this study suggested the removal of influence of human activities because the selected region is poorly populated and the rivers are large. Studies like this used some new approach that compared data in respect of sampling point latitude and was doing in first time. Whereas general patterns of diversity and productivity in aquatic communities of the lakes are rather developed [52], the riverine phytoplankton is poorly studied in hard climatic gradient. Our results reflect the same diversity-productivity pattern as for a large sequence of lakes [15,57] in climatic gradient.

5. CONCLUSION

Our study conclusions reveal strong environmental stress in high altitude and high latitude climatic conditions. Diatoms in both cases are replaced by green and red algae (in high mountains) or by green and *Chrysophyta* algae and *Cyanobacteria* (in the Arctic). That allows us to conclude that for climatic impact assessments on freshwater algal diversity can be studied the multidivisional communities under large amplitude climatic gradients. A multidivisional approach helps identified factors that regulated freshwater community dynamics over a climatic gradient, such as altitude [10] or latitude (present study), especially in the northern regions [14]. Usually, the assessment and prediction of freshwater diversity dynamics indicate water temperature as a major regulating factor [14,15,57]. But our analysis of large based algal communities and environmental variable relationships revealed the importance of other climatic related factors such as latitude, altitude, ice-free periods, air temperature, and humidity. These factors are stimulated in phytoplankton communities, while water transparency and flow speed are stress factors. Water temperature, on the contrary, is not revealed as an important regulating factor in the distribution of freshwater phytoplankton communities.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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