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Environmental preferences of Cyanobacteria in the gradient of macroclimatic factors and pollution

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The article describes the distribution of the diversity of cyanobacteria in 51 Eurasian floras in the gradient of environmental factors. Environmental factors in order to analyze the strength of their impact on the community of cyanobacteria were divided into two main groups. The first group represents local factors that are distinguished by the instability of exposure, short duration, and wide amplitude. This group includes organic and toxic anthropogenic pollution and temperature. They are related to the seasonality and the intensity of using the catchment area. Cyanobacteria increases in productivity but reduces the species richness in the gradient of increasing influence of the first group of factors. The second group combines factors of global long-term macroecological stability associated with the latitude and altitude of the aquatic habitat. We took for analysis cyanobacterial floras in a latitudinal gradient from Israel to the Arctic, as well as in a gradient of height from 4 to 4213 m above sea level in the Caucasus and the Pamir. A group of global climatic factors, such as a decrease in the average annual temperature at high latitudes, an increase in insolation at high altitudes, has a stimulating effect on the diversity of cyanobacteria and at the same time increases their intraspecific variability. The index of intraspecific variation (Ssp/Sp Index) increase in the gradient of the latitude of habitat and altitude that indicates the release of intraspecific variability and can serve as an indicator of climatic stress and the surviving of cyanobacteria under climatic instability and local pollution.

Keywords: Cyanobacteria, species richness, climatic gradients, altitude, pollution, Eurasia.

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Экологические предпочтения цианобактерий в градиенте макроклиматических факторов и загрязнения

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В статье описывается распределение разнообразия цианопрокариот в 51 евразийской флоре, как части водного сообщества, в градиенте факторов окружающей среды. Факторы среды в целях анализа силы их воздействия на сообщества цианобактерий были разделены на две основные группы. Первая группа представляет собой факторы, которые отличаются нестабильностью проявления, короткой продолжительностью и широкой амплитудой. К этой группе отнесены локальные факторы, такие как органическое и токсическое антропогенное загрязнение, а также температура, которые связаны с сезонностью и характером местного климата и интенствностью использования площади водосборного бассейна. Первая группа факторов повышает продуктивность цианобактерий, но уменьшет богатство видов в градиенте усиления воздействия. Вторая группа объединяет факторы глобальной долгосрочной макроэкологической стабильности, связанные с широтностью и высотностью местообитания. Для анализа были взяты флоры цианобактерий в широтном градиенте от Израиля до Арктики, а также в градиенте высоты от 4 до 4213 м над уровнем моря на Кавказе и Памире. Окалось, что цианобактерии реагируют на изменения глобальных климатических факторов, таких как снижение среднегодовой температуры в высоких широтах, и увеличение инсоляции на больших высотах. Эти факторы оказывают стимулирующее влияние на разнообразие цианобактерий и в то же время увеличивают их внутривидовую изменчивость. Ранее нами разработан индекс внутривидовой изменчивости (Индекс Ssp/Sp), рассчитываемый на основе известного видового богатства флоры водорослей и цианобактерий (Sp) и числа присутстующих в списке флоры таксонов рангом ниже вида (Ssp). В результате расчётов и анализа было выявлено возрастание индекса в градиенте широты местообитания и высоты над уровнем моря, что свидетельствует о высвобождении внутривидового полиморфизма на границе ареала и может служить индикатором климатического стресса и выживания цианобактерий в условиях климатической нестабильности и локального загрязнения.

Ключевые слова: цианобактерии, видовое богатство, климатические градиенты, высота над уровнем моря, загрязнение, Евразия.

The factors affecting the species richness of cyanobacteria and the quantitative indicators of their communities can be divided into two main groups: 1) on local scale like a reservoir or basin of a small river, and 2) on global scale like a large administrative or floristic region, a large river basin, and a part of the continent. In the first case, to determine the degree of reaction of the communities of cyanobacteria, beta- and alpha-diversity are analyzed. In the second case, diversity is combined from large floristic or geographical regions, and alpha- and gamma-diversity can be analyzed. Factors of the first group, such as local water temperature, nutrient saturation, are represent a group of rapidly changing indicators with a large amplitude. At the same time, macroclimatic factors can be considered relatively stable compared to the scale of development of algal communities.

Factors such as the latitude or altitude gradient [1] are associated not only with the main climatic characteristics but also with key players in the formation of biota diversity factors that were established at the current stage of biome evolution. The study of the diversity of cyanobacteria of continental water bodies and the patterns of response of their communities to the influence of various factors, both local and macroclimatic, was the aim of this work.

The aim of present work was the identification of the response of cyanobacterial communities in water bodies of various regions in Eurasia to the climatic and local state of its habitats in latitude and altitude gradients using comparative floristic and new statistical methods.

Material and Methods

The material for this study comes from our own and with the co-authors long-term studies in rivers and lakes of Eurasia [2, 3] (Fig. 1). A total of 95 floras were studied, with 2985 taxa, among them 70 floras contain cyanobacteria. The studied algal diversity for current analysis included 599 genera from 51 floras.

The main approach to the analysis of data on the floristic diversity of algae, including cyanobacteria, was made from [3] to determine the main models for the distribution of species richness by climatic and local environmental gradients.

Similarity calculation was performed using the BioDiversity Pro 2.0 program and network analyses in JASP on the botnet package in R Statistica package of [4].

Results and Discussion

We revealed 92 genera of cyanobacteria in 51 Eurasian aquatic floras. There is represented of 23 flora contains 17 genera with more than 3 species, and 16 floras contain 10 species-rich common cyanobacterial genera (Table 1).

Fig. 1. Studied algal floras in the waterbodies of Eurasia

Table 1

Ten most species rich cyanobacteria genera in studied aquatic floras of Eurasia. Abbreviated: FE – Russian Far East; IS – Israel; TJ – Pamir; Si – Siberia; STJ – South Tajik depression, Panj River tributaries basin

Genus	FE-1	FE-3	FE-5	FE-9	FE-11	IS-1	IS-2	TJ-1	TJ-2	TJ-3	TJ-4	TJ-5	Si-1	STJ-4	STJ-5	STJ-6
Phormidium	0	6	3	0	1	1	16	4	4	5	3	4	4	10	3	4
Oscillatoria	4	1	1	0	0	3	14	9	13	10	12	7	3	4	0	0
Microcystis	5	7	2	3	12	7	9	4	3	3	3	2	5	3	2	1
Merismopedia	2	4	4	1	3	6	5	4	2	2	4	5	3	6	4	5
Gloeocapsa	2	1	0	0	2	0	6	6	3	4	5	6	0	7	1	2
Dolichospermum	0	3	2	5	6	2	0	2	4	3	3	1	0	1	1	1
Chroococcus	0	3	1	0	7	1	7	1	2	1	2	2	2	1	0	1
Aphanotece	1	5	1	4	4	1	8	2	2	0	2	1	1	1	0	0
Aphanocapsa	0	4	1	2	6	4	8	1	1	1	1	1	1	1	0	0
Anabaena	6	1	3	5	6	1	4	6	6	6	8	6	3	3	0	1

A diversity of cyanobacteria and its distribution have been studied in various regions with a climatic gradient associated with latitude. The species richness of cyanobacteria and their contribution to algal communities were evaluated at the levels of alpha- and gamma-diversity [5].

Research on such a wide area using observations and experimentation has shown that temperature is one of the most important factors, both local and climatic, and that cyanobacterial communities respond to changes in water temperature, but sometimes this can only be seen through bioindication or floristic analysis. Some studies mentioned that cyanobacteria response to pollution impact could be used as indicators of toxicity in the northern areas [6]. In the boreal region of Eurasia, usually, there are three extremums in the development of algae, one of which is dominated by cyanobacteria, while in the more southern regions it has two, or south to one extremum only [3].

Seasonal fluctuations in environmental parameters and species richness of cyanobacteria can thus be attributed to local dependencies that link algae growth in relation to nutrient levels, temperature, and insolation [1, 3]. Moreover, the last two factors are already global, although on a local scale they appear in a "masked" form.

Thus, the relationship between the species richness of freshwater cyanobacteria in the rivers of Israel and the climatic parameters of the region from north to south in the direction of the temperature gradient and humidity of the climate turned out to be quite distinct. Analysis shows that in a semi-arid and desert climate, the anthropogenic influence (local factors) is masked by the influence of climatic (global) factors and hydrology. Therefore, diversity dramatically decreases from north to south [1, 3]. Figure 2 demonstrate dramatically decreasing of algae species richness after polluted sewage input to the Lower Jordan River and increasing the role of cyanobacteria after local anthropogenic impact on the algae diversity.

Comparison of the algae diversity of the characteristic of the rivers Oren in northern and Zin in southern Israel over a hundred years with trends in temperature and climate humidity showed that the effect of desertification is similar to anthropogenic, provokes an increase in salinity and can degrade the diversity of both cyanobacteria and the entire aquatic community [3]. The use of statistical methods for the algae flora of Israel showed that the species composition was divided into four groups corresponding to mountain, foothill, coastal habitats, and located in the rift valley [3], that is, it corresponds to the climatic characteristics of the studied territory.

The climate affected not only species richness in algal communities, but also such variables as the abundance and biomass of river phytoplankton in the water bodies of Ukraine and Kazakhstan [1, 7, 8]. This suggests that sunlight intensity and ambient temperature are the most important local regulatory factors for models of alpha diversity distribution.

Latitudinal climate change from the boreal region to the Arctic affects the distribution of cyanobacteria [1]. With an increase in climatic loads, their species richness correlated quite clearly with a decrease in the number of ice-free days in the direction of the north of the continent. That is the species richness of cyanobacteria increases in the latitude of the habitat and is asso-

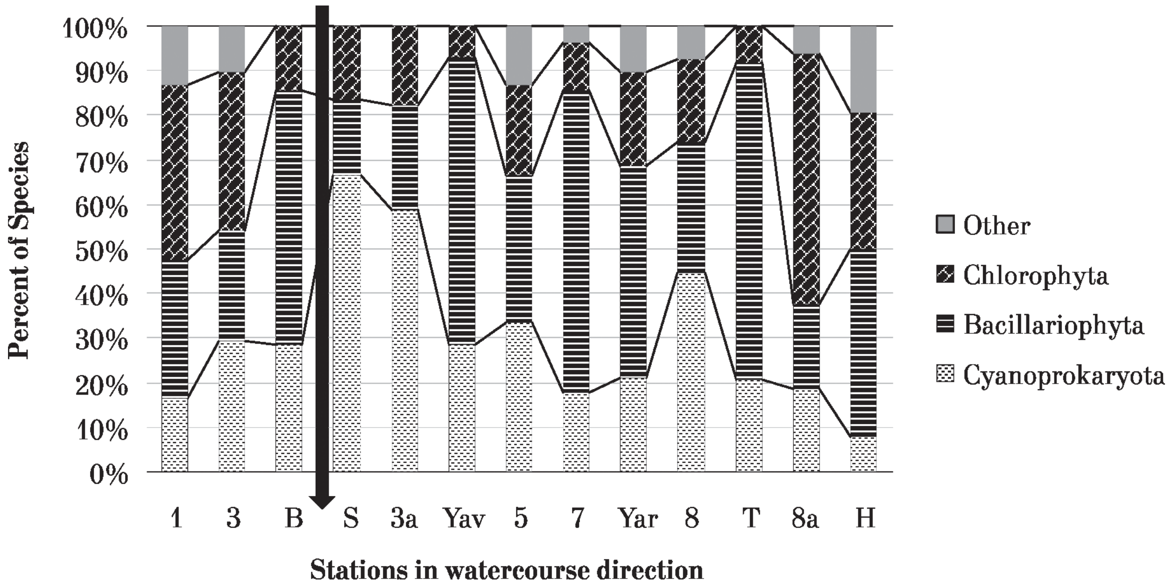


Fig. 2. Distribution of algae and cyanobacteria species in taxonomic divisions and increasing the role of cyanobacteria in the Lower Jordan River under strong anthropogenic impact (black arrow down)

ciated with a decrease in integral insolation, but does not detect a reaction to lower temperatures averaged over the growing season. Consequently, cyanobacteria under climatic stress are more competitive in comparison with algae of other taxonomic Division at high latitudes [1].

One of the widely known natural phenomena is the distribution of biological diversity by habitat altitude [1]. While plant communities are fairly well studied in this regard, the study of the distribution of freshwater algae, including cyanobacteria, is at the initial stage.

To identify patterns of distribution of cyanobacteria, the mountainous countries of the Caucasus (Fig. 3) and the foothills of the Pamirs, as well as in the regions of Kazakhstan and Israel were selected [1]. The results of the analysis showed that the proportion of cyanobacteria increases due to a decrease in the proportion of diatoms and other taxonomic Division of algae from a height of 200 to 2500.

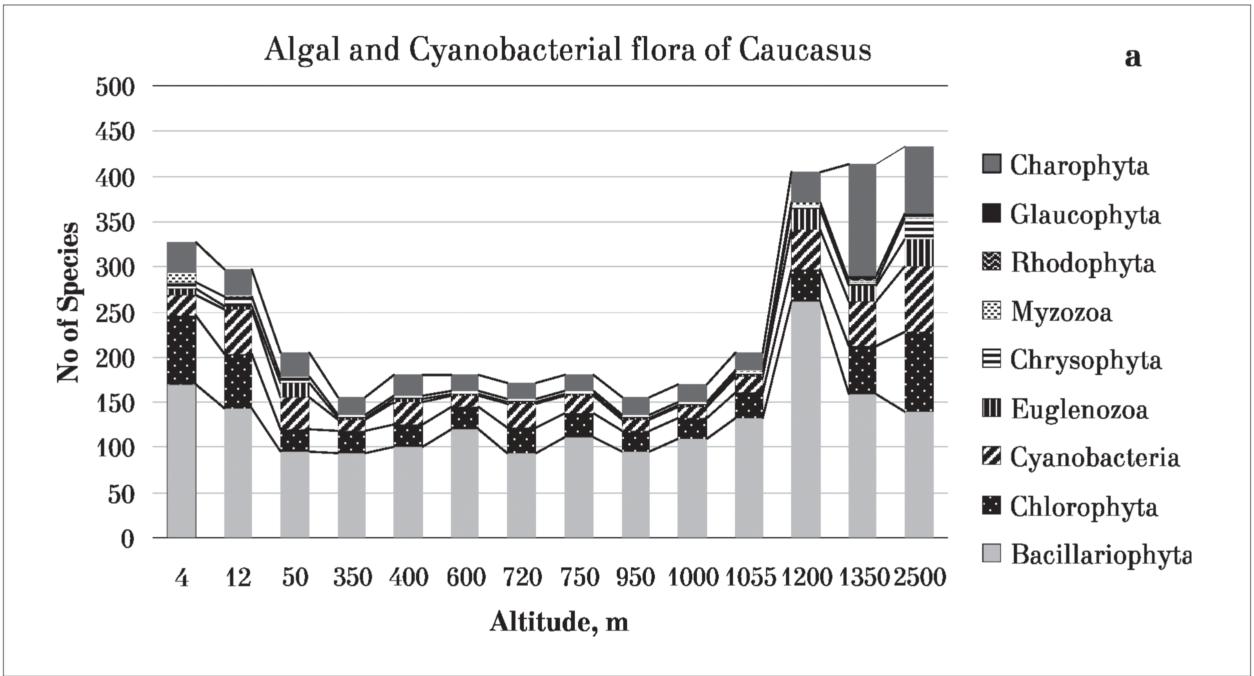
Adding analysis of the diversity of cyanobacteria in the foothills of the Hindu Kush and high mountains of the Pamirs showed a clear trend of an increase in the species richness of cyanobacteria at altitudes from 2500 to 4500 m. That is, with an increase in altitudinal and climatic stress in habitats above 2200 m above sea level, cyanobacteria remain more competitive compared to algae of other Division [1]. At the same time, the distribution of species richness in the regional flora of the high mountain tributaries of the Indus River according to the height gradient [1] showed a large participation of green algae and cyanobacteria, compared to diatoms.

A significant feature of the taxonomic structure of algae in the water bodies of the southern regions of Eurasia is a large proportion of monomorphic species. Such exceptionally low intraspecific variability may be associated with recent climatic instability and anthropogenic impacts that have destroyed habitat differentiation and contributed to the survival of highly resistant monomorphic populations.

To identify the degree of intraspecific variability, we developed the Ssp/Sp index as the ratio of the number of species, including intraspecific variations (Ssp), to the number of species (Sp) in each algal flora [1]. Thus, the index values in the aquatic flora of the Holarctic increase from south to north, which correlates with global climate changes. At the same time, for cyanobacteria of the high mountain habitats of the Pamirs, as well as the high-latitude Arctic, an increase in the Ssp/Sp index correlates with an increase in climate stress. Figure 4 show the correlation of the cyanobacteria species richness in 51 algal floras of Eurasia. Clusters combined the most similar cyanobacteria floras. The first cluster includes the Pamir high mountain habitats only. Second cluster combine cyanobacteria floras in Russian Far East, mountain Kazakhstan and Israel as well as the floras of

South-Tajik depression habitats in Pamir piedmonts. Cluster 3 represented mostly Russian North habitats and cyanobacterial floras of cold habitats in Russian Far East and mountain Israel and Kazakhstan. Four cluster includes different cyanobacterial floras from lowland habitats of Kazakhstan, Turkey, Georgia, India and South Tajik depression lowlands of the Panj River basin. So, we can see the climatic factors regulation in the distribution of cyanobacteria species richness in Eurasia.

Therefore, the trend of increasing intraspecific variability in cyanobacterial communities at high altitudes and high latitudes suggests that extreme living conditions play a major role in their polymorphism and may be a mechanism for protecting species from environmental stress for future survival and development.



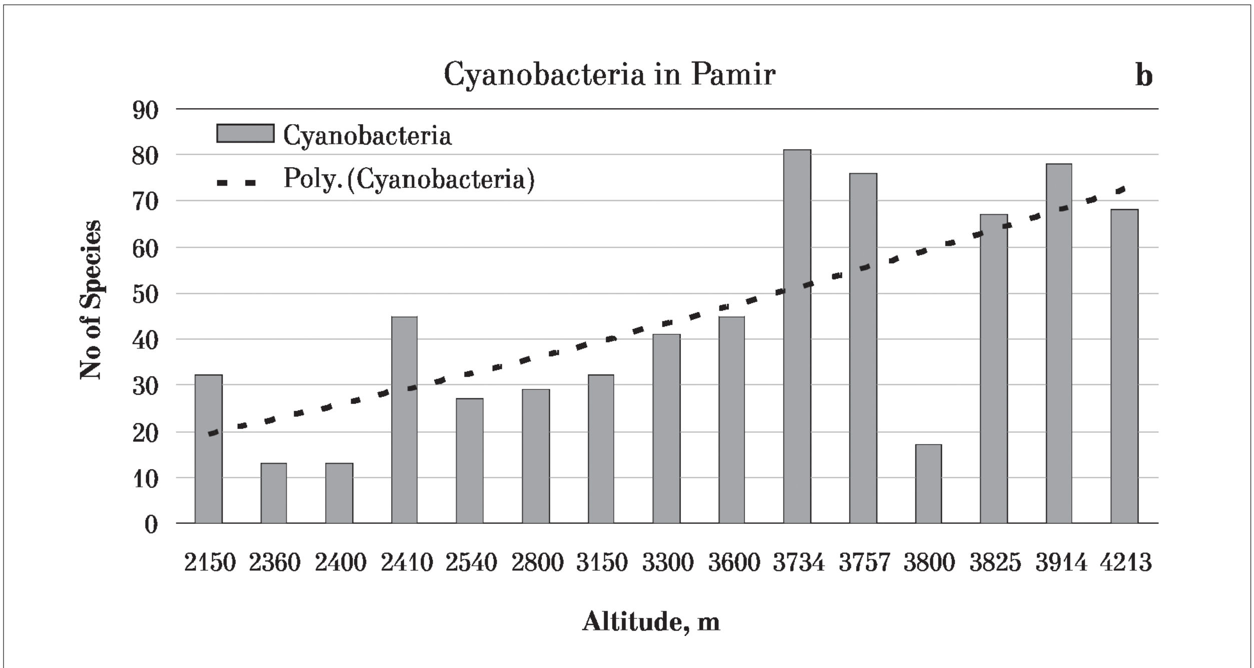


Fig. 3. Taxonomic distribution of algae and cyanobacteria species richness over the Caucasus Mountains (A) and cyanobacteria in Pamir (B) aquatic habitats and increasing the role of cyanobacteria species in high altitude communities. The dotted line is the polynomial trend line of the Cyanobacteria species number distribution over the altitude of its habitat

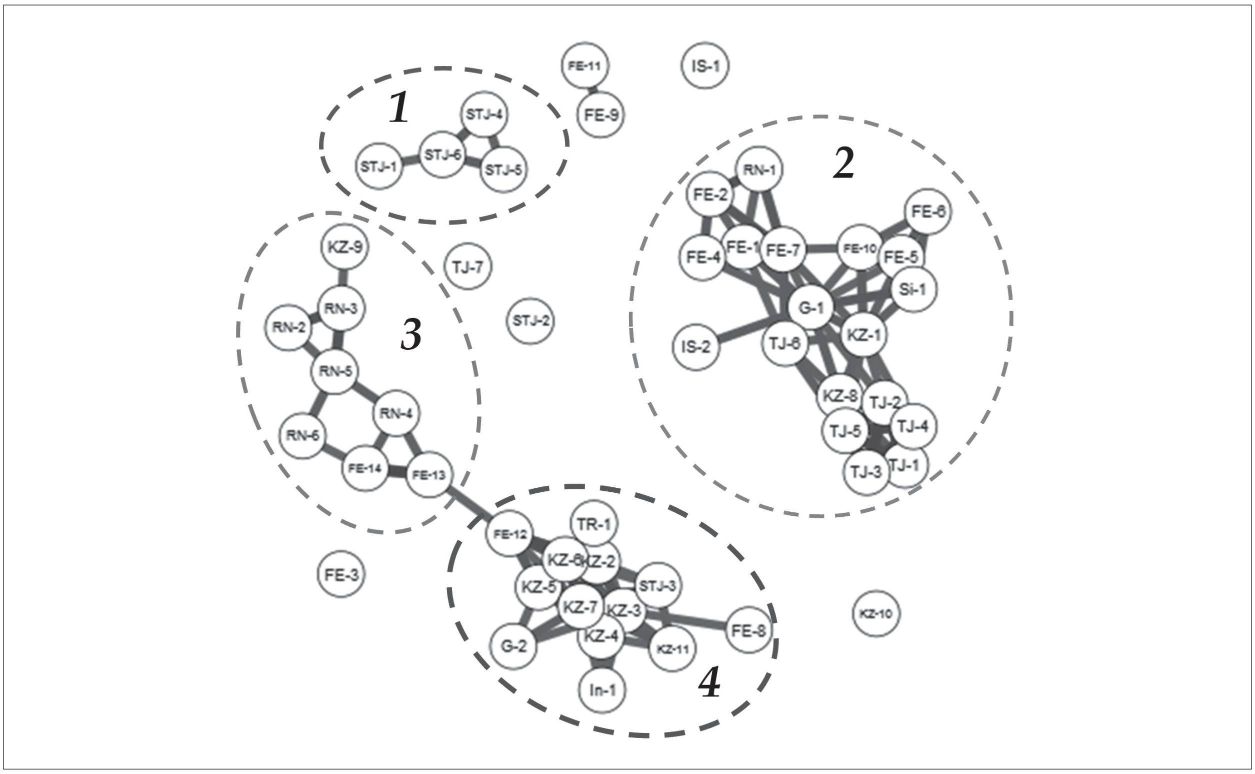


Fig. 4. JASP plot of correlation of the cyanobacteria species richness in 51 algal floras of Eurasia. The dashed colored lines are marked of the clusters with most similar floras. Abbreviations for the Eurasian algae and cyanobacteria floras: STJ, South Tajik Depression; FE, Far East; IS, Israel; KZ, Kazakhstan; TJ, Tajikistan, Pamir; RN, Russian North; G, Georgia; TR, Turkey

Conclusion

Based on our floristic material from 51 algae flora in continental water bodies of Eurasia, the influence of the main environmental factors on the distribution of the diversity of cyanobacteria was revealed. The first group represents local factors that are more related to local conditions and pollution, which are characterized by exposure instability, short duration and wide amplitude. The second group represents climate-related global factors, such as habitat latitude and altitude. Cyanobacteria respond to changes in local factors, such as temperature, associated with the seasonality of the climate, increasing their productivity, but reducing their species richness. A group of global climatic factors, such as a decrease in the average annual temperature at high latitudes, an increase in insolation at high altitudes, is reflected in the confinedness of the diversity of cyanobacteria to the amplitude of these factors in the region. At the same time, they have a stimulating effect on the diversity of cyanobacteria and increase their intraspecific variability. The intraspecific variability index increases its values with increasing latitude and altitude of the habitat of cyanobacteria. Thus, the Ssp/Sp index can serve as an indicator of climatic stress and, at the same time, as an indicator of the survival of cyanobacteria under conditions of climatic instability and local pollution.

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