Analysis of Spatiotemporal Dynamics of Phytoplankton in the Upstream of the Yenisei River (Krasnoyarsk)*

Yulia Ponomareva[0000-0002-6427-2457] and Anna Korobko[0000-0001-5337-3247]

Institute of Computational Modeling of the Siberian Branch
of the Russian Academy of Sciences, 50/44 Akademgorodok, Krasnoyarsk, 660036, Russia
ponomarevayulia@mail.ru

Abstract. This paper presents modern materials on the phytoplankton of the downstream of the Krasnoyarsk hydroelectric power station. Intellectual analysis methods, which provide multidimensional analysis and reveal structural features, have been applied to the data of hydrobiological studies. It has been established that diatoms prevailing in plankton in all seasons of the year, form the basis for the floristic list in the Yenisei River. The main regularities of the spatiotemporal dynamics of rheophilic phytoplankton in the area of the Yenisei above and below Krasnoyarsk have been revealed. Despite the small diversity of truly planktonic species, they form the main phytoplankton biomass throughout the studied riverbed. In terms of the species composition, total abundance and biomass, the phytoplankton of the main channel is similar to the phytoplankton of the left-bank stations. The characteristics of the right-bank complexes have inherent traits due to the air supply system. Data clustering by the principal component values reveals the differences between the stations on the river banks and the channel part. Along the longitudinal profile of the river downstream from the dam, a decrease in the number and biomass of planktonic algae has been observed, which occurs due to the runoff from the upper reach of the reservoir.

Keywords: Cluster Analysis, Phytoplankton, Yenisei River.

1 Introduction

The Yenisei River is one of the greatest rivers in the world and largest Siberian waterway, where high-pressure dams and large reservoirs are located. At present, extensive material has been accumulated concerning the algal flora of lakes, water reservoirs, and lowland rivers [1, 2]. Compared to limnic ecosystems, the species composition and structure of rheophilic phytoplankton communities have been studied to a much lower extent [3]. The priority area today is the assessment of the spatiotemporal structure of phytoplankton, which reflects the main changes in environmental conditions and plays an important role in understanding the functioning of the ecosystem. Moreover, systematic algological analysis in the areas of drinking water supply sources allows one to establish the degree of pollution of the domestic water supply and adjust the operating regime of water treatment plants [4, 5].

Under the conditions of high flow rates, phytoplankton develops weakly or does not develop at all and it is a mixture of phytoperiphyton species and allochthonous algae, and in regulated rivers it is a mixture of phytoplankton of reservoirs which is discharged from the catchment area of the hydroelectric power station [6]. An important part of any hydrobiological study is the use of statistical tools, which makes it possible to obtain quantitative characteristics of the distribution of organisms which are suitable for comparison, to numerically describe and substantiate the results obtained, and also to reveal the relationship between individual variables characterizing the habitat. Various mathematical and statistical methods are widely used to process data from hydrobiological (ecological) studies [6].

Earlier it was found that on the Yenisei River, 34 km downstream from the dam of the Krasnoyarsk hydroelectric power station, where an open-type water intake is located, in the spring and summer period there is an annual increase in the quantitative indicators of phytoplankton, which significantly complicates the operation of filtering and treatment facilities. The number of filter flushes increases, and the sanitary condition of the structures deteriorates [7]. According to our previous studies, the dominant complex of the river algae during this period is similar to that at the 20–40 m horizon in the upstream [8]. Overall, 240 species have been recorded in the phytoplankton of the Krasnoyarsk reservoir [9], but three planktonic species develop most intensively: *Aulacoseira islandica* (O. Müll.) Sim., *Cyclotella radiosa* (Grun.) Lemm. and *Fragilaria crotonensis* Kitt., entering the downstream from the Krasnoyarsk reservoir. Hocewever, the fate of the limnic algae further downstream is currently unknown. Possibly, by analogy with zooplankton, limnic algae are eliminated from the water column in the river flow [10], and consequently, the degree of their negative influence during water treatment decreases.

The aim of the research is to study the spatiotemporal dynamics of phytoplankton in the downstream of the Krasnoyarsk hydroelectric power station using statistical and mathematical procedures and to assess the “fate” of limnic phytoplankton in the fast-flowing river.

2 Methods and Materials

The material for the study was a year-round collection of phytoplankton in 2016–2017. The part of the Yenisei River upstream and downstream from the city of Krasnoyarsk was studied to obtain comparative materials. Along the river bed, phytoplankton samples were taken every ten days at five sites located 27 km (Section 1), 34 km (Section 2), 37 km (Section 3), 51 km (Section 4), and 65 km (Section 5) downstream from the dam. Each section included three stations (at the right and left banks and in the middle of the river).

The procedure for collecting and processing the material corresponded to standard methods, which are described in more detail in [11]. The nomenclature for algae was adopted taking into account taxonomic transformations in accordance with the system from the International Algological Database (http://www.algaebase.org). What conditions of the existence are appropriate to algae was determined according to [12], the Serensen floristic similarity coefficient (FSC) was estimated according to [13]. The degree of complexity of phytoplankton communities was determined by calculating the Shannon species diversity index (by biomass) [14]. The dominant algae included the species making the main contribution to the total phytoplankton biomass.

Statistical data processing was performed using the nonparametric Kolmogorov-Smirnov criterion and Mann-Whitney U-criterion. In the figures, the data are presented as an arithmetic mean with the mean-square error. For cluster analysis, an initial dataset of 34 parameters was used (for example, total abundance and total biomass of phytoplankton, average cell volume, abundance and biomass of diatoms, abundance and biomass of green algae, and other parameters) and 75 observations, which were aggregated by the date of the study with the calculation of the average values of the parameters characterizing the sampling sites. The parameters were standardized with respect to the expectation value and standard deviation. Factor analysis by the method of principal components made it possible to move to the five main components while maintaining 80% of the information content. When forming clusters, the distance between them was calculated by the Weighted Pair Group Method with Arithmetic Mean (WPGMA method). Analytical data processing was performed in the PyCharm environment in the Python language using the libraries: pandas (https://pandas.pydata.org/), sklearn (https://scikit-learn.org/), scipy (https://scipy.org) and matplotlib (https://matplotlib.org/).

3 Results and Discussion

In total, 109 species and varieties of algae were found in the plankton of the river, belonging to 7 divisions, 14 classes, 31 orders, 45 families and 66 genera. Bacillariophyta (76 taxa with a rank below the genus) and Chlorophyta (17) played a special role in the formation of the phytocenosis of the studied area of the river.

For all the studied communities (both between the stations within the same site, as well as between the sites), in general, a fairly high floristic similarity coefficient (FSC) (up to 0.74) was established. The Shannon species diversity index (H_b) ranged from 1.37 to 3.96. Decreased H_b values were noted in early spring and summer. High H_b values were obtained in late spring and autumn. It was established that the species composition of the downstream algae was dominated by cosmopolitan species, benthic group, alkaliphiles and alkalibionts, and with respect to the degree of water salinity - oligohalobes. Despite the species richness of the benthic algae raised from the bottom of the river by its rapid current, their number in the entire study area was significantly lower than the number of planktonic species, and the biomass was significantly higher.

During two years of observation, the general course of phytoplankton development in the entire investigated area of the river Yenisei had a similar character (Fig. 1). The indices of abundance, biomass and total diversity of algae at all the stations increased in late spring - early summer (in May-June), and then, decreased in autumn and winter. A similar pattern was typical for aquatic ecosystems [15]. At the left-bank stations, sharp fluctuations in the quantitative indicators of phytoplankton were observed. The total number ranged from 0.09 to 5.31 mln. cells/L, biomass – from 0.04 to 5.98 mg/L. The concentration of algae at the right bank stations varied over a wider range: from 0.06 to 7.02 mln. cells/L, biomass –from 0.03 to 17.19 mg/L. The dynamics of the quantitative indicators of phytoplankton in the main channel was similar to the left-bank stations. The total abundance did not exceed 6.42 mln. cells/L, biomass – 5.11 mg/L.

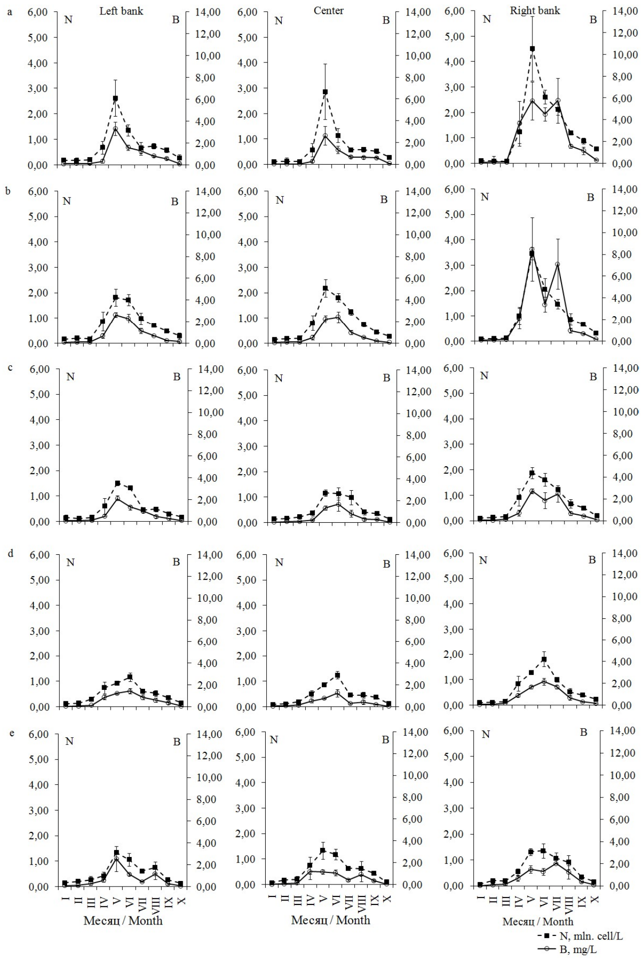

Fig. 1. Seasonal dynamics of the total abundance (N, mln. cells/L) and the total biomass (B, mg/L) of phytoplankton in 2016–2017 (a – Section 1; b – Section 2; c – Section 3; d – Section 4; e – Section 5).

The obtained differences in the algae biomass along the right bank of Sections 1 and 2 are due to the significant quantitative predominance of large-celled benthos algae washed out by the current from pebble soils, and, apparently, by the influence of the right-bank tributaries (Mana and Bazaikha). This is consistent with the concept of the river continuum that the river plankton is formed not only under the influence of the upstream areas, but also by the adventitious system [16].

Preparation of the observation data for mining analysis consisted in performing a homogeneous relational sampling including the results of research for the considered period. The complete data sampling contained fifty-two columns, three of them ("Date", "Section" and "Shore") characterized the spatiotemporal component of the sampling points, and all the other included the measured and calculated parameters.

Most data processing methods do not work for data with gaps, so the sampling was limited to those parameters and observation dates which allowed us to form a dense data sampling. Several different combinations of data processing methods were tested during the study and a sequence, which gave more visual and interpretable presentation of the study data, was established (Fig. 2).

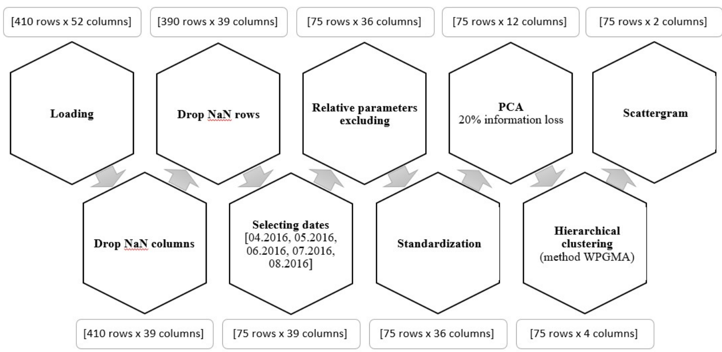

Fig. 2. Proposed sequence of the data processing stages.

Factor analysis performed by the PCA method allowed us to go into the space of the principal components corresponding to the directions of the greatest scatter of the values of the considered parameters. For data sampling without aggregation by dates, nine main components were identified, provided that the loss of the information content was no more than 20%. The first two components were the most informative.

Figure 3 shows a list of the analyzed initial parameters and their contribution to the principal components. Blue color shows the contribution of each parameter to the first component, and orange color - to the second one. The overlapping areas of different colors means that the contribution to the components is different in sign. For example, the parameter "Biomass of benthic" is included in the first component with a "+" sign, and in the second - with a "-" sign. This means that the greater the first component value for the considered sampling site and time is, the greater is the value of the parameter "Biomass of benthic". And vice versa, the higher the value of the site coordinates along the axis of the second component is, the lower is the value of the parameter. The greater the difference between the areas of different colors on the graph is, the more different is the contribution of the parameters to the principal components.

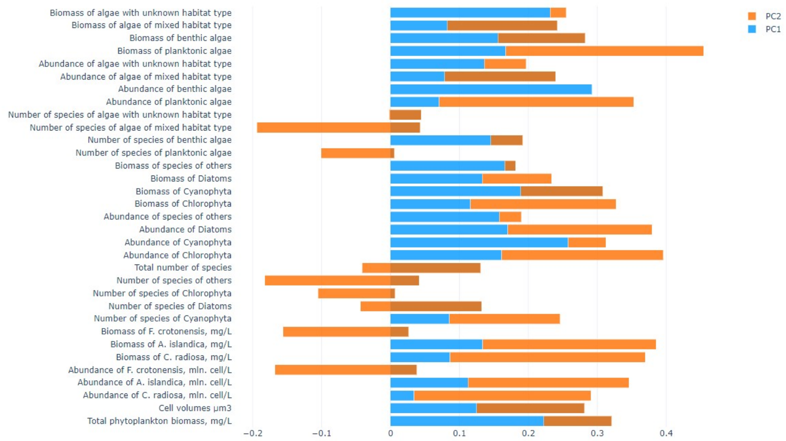

Fig. 3. Contribution of the initial parameters to the first two principal components.

The dendrogram of the spatiotemporal distribution of the studied sampling points, without aggregating the sampling by dates, is shown in Figure 4.

Using the factor analysis of the observed parameters by the method of principal components and agglomerative hierarchical clustering of data, four main clusters were identified: “Green”, “Red”, “Cyan” and “Magenta”. The “Cyan” cluster combines mainly the results of measurements in April and June as related to the sampling points on the left and right banks. The “Green” cluster includes June measurements at all points of Section 1 and in the center of Section 2. The “Red” cluster contains the data obtained in Section 5 in April and July. The data obtained in May, July and August fall into the “Magenta” cluster. Blue color shows the samples characterized by the extreme values of the parameters and were not assigned to any of the clusters. These are the measurements obtained for the sites of the right bank of Sections 1 and 2 at different times.

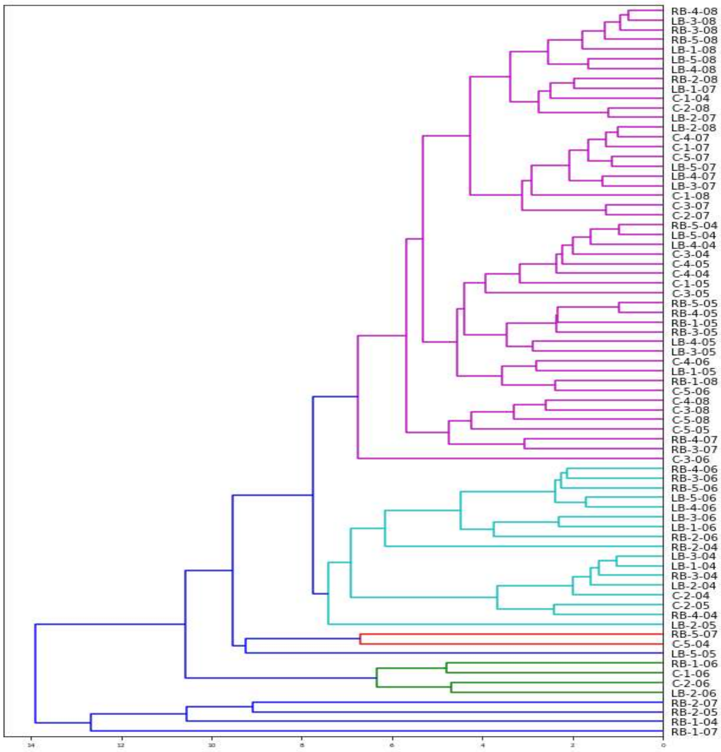

Fig. 4. Result of hierarchical clustering of the spatiotemporal distribution of phytoplankton (LB – left bank, RB – right bank, C – center; 1–5 – section number; 04 – April, 05– May, 06 – June, 07 – July, 08 – August).

To determine the values characterizing the identified clusters, the scattergram of the studied values on the plane of the first and second principal components should be analyzed (Fig. 5).

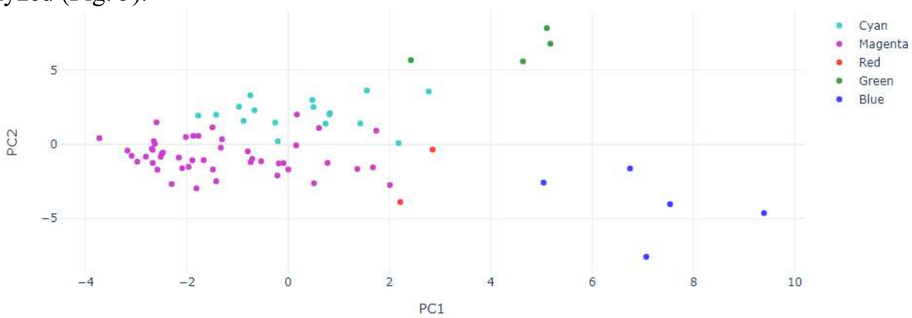

Fig. 5. Scattergram for the observation results on the plane of the first and second principal components (PC1, PC2).

Taking into account the contribution of the initial parameters to the principal components and the scatter diagram, it was found that:

- the right banks of the first and second sections in April, May and July were characterized by high biomass of benthic forms and diatom algae, as well as by the total number of species;
- in June, in Sections 1 and 2, a slight decrease in the biomass of benthic and diatom species and an increase in the biomass of plankton, green and blue-green species were recorded;
- data for May, July and August were characterized by a significant decrease in the parameters of benthic and diatom species and by an increase in plankton-benthic species and *F. crotonensis*;
- in April and June the sampling points on the left and right banks show relatively high values of the abundance of plankton species, biomass of green algae and blue-green algae, as well as an increase in the abundance and biomass of *A. islandica* and *C. radiosa*.

The horizontal distribution of the most common representatives of the reservoir phytoplankton (*C. radiosa*, *A. islandica*, and *F. crotonensis*) decreased moving downstream the river from the dam.

4 Conclusion

In the period from 2016 to 2017, 109 species and varieties of algae from seven divisions were found in the plankton of the Yenisei River. The obtained FSC values indicate a high degree of similarity of the dominating phytoplankton complex of the studied sections and stations. In terms of the species composition, total abundance, and biomass, the phytoplankton in the center of the channel was similar to the phytoplankton of the left-bank stations. The characteristics of the right-bank complexes have inherent traits, apparently due to the supply system. The species composition of the algae in the downstream of the Krasnoyarsk hydroelectric power station at a distance of 65 km downstream from the dam was dominated by cosmopolitan species, algae of the benthic type of habitat, alkaliphiles and alkalibionts, with respect to the degree of water salinity by oligogalobes. The algological regime of the Yenisei in the downstream of the Krasnoyarsk hydroelectric power station is largely determined by the development of algae fouling and benthos, as well as by the right-bank tributaries, and to a lower extent - by the discharges from the Krasnoyarsk reservoir. A large species diversity of benthic algae in the plankton of the Yenisei River is due to the richness of the microphytobenthos raised from the pebble-rocky bottom of the river by its rapid current. Data clustering by the principal component values reveals the differences between the stations on the river banks and the channel part. Due to high turbulence, going away from the dam, the abundance and biomass of limnic species always decreased and, 65 km downstream from the dam, was closer or equal to zero.

References

1. Piirsoo, K., Pall, P., Tuvikene, A., Viik, M.: Temporal and spatial patterns of phytoplankton in a temperate lowland river (Emajo˜gi, Estonia). J. Plankton Res. **30(11)**, 1285–1295 (2008)
2. Gajsina, L., Fazlutdinova, A., Muhina, O., Ahmadeeva, L., Rogozin, D., Bul'hin, A. et al.: Ecological features of cyanobacteria and algae communities of the littoral of the meromictic Lake Shira (Khakassia Republic, Russia). Theoretical and applied ecology **1**, 47–50 (2020). doi: 10.25750/1995-4301-2020-1-047-050
3. Sabater, S., Artigas, J., Duran, C. Pardos, M., Romani, A.M., Tornes, E. et al.: Longitudinal development of chlorophyll and phytoplankton assemblages in a regulated large river (the Ebro River). Sci. Total Environ **404(1)**, 196–206 (2008). doi: 10.1016/j.scitotenv.2008.06.013
4. Zhou, S., Huang, X., Cai, Q.: Temporal and spatial distributions of rotifers in Xiangxi Bay of the Three Gorges Reservoir, China. Int. Rev. Hydrobiol. **94(5)**, 542–559 (2009). doi: 10.1002/iroh.200811107
5. Ponomareva, Y., Andrianova, A.: Application of hydrobiological analysis for improving the efficiency of water treatment at the water intake Gremyachiy Log. In: MIP Engineering 2019: Advanced Technologies in Material Science, Mechanical and Automation Engineering, p. 62040. Institute of Physics and IOP Publishing Limited, Krasnoyarsk (2019). doi: 10.1088/1757-899X/537/6/062040
6. Montero, P., Daneri, G., Tapia, F., Iriarte, J.L., Crawford, D.: Diatom blooms and primary production in a channel ecosystem of central Patagonia. Latin American Journal of Aquatic Research **45(5)**, 999–1016 (2017)
7. Sonmez, F., Kutlu, B., Sesli, A.: Spatial and temporal distribution of phytoplankton in Karkamis dam lake (Sanliurfa/Turkey). Fresenius Environmental Bulletin **26(10)**, 6234–6245 (2017)
8. Ponomareva, Y., Ivanova, E.: Ratio between living and dead cells and the size structure of the Yenisei River phytoplankton downstream of the Krasnoyarsk Hydroelectric Power Station. Contemporary Problems Ecology **9(5)**, 582–589 (2016). doi:10.15372/SEJ20160508
9. Krasnoyarsk Water Reservoir: monitoring, biota, water quality. Siberian Federal University, Krasnoyarsk (2008) (in Russian)
10. Gladyshev, M., Dubovskaya, O., Makhutova, O.: Alive and dead limnic zooplankton in head-water and tail-water the dam of the Krasnoyarsk hydroelectric power station. Academy of Sciences reports **390(4)**, 571–573 (2003) (in Russian)
11. Ponomareva, Y., Shchur, L.: Seasonal and Interannual Dynamics of phytoplankton of the Yenisei River in the area of the Gremyachii Log water intake facilities. Inland Water Biology **7(1)**, 34–36 (2014) (in Russian)
12. Barinova, S., Medvedeva, L., Anisimova, O.: Environmental algae biodiversity. PiliesStudio, Tel'-Aviv (2006) (in Russian)
13. Method for studying biogeocenoses of inland water bodies. Nauka, Moscow (1975) (in Russian)
14. Alimov, A.: On some problems of modern hydrobiology. Inland Water Biology **1**, 7–13 (1996) (in Russian)
15. Allan, J., Castillo, M.: Stream ecology: Structure and function of running waters (2nd ed.). Chapman & Hall: London (2007)
16. Vannote, R., Minshall, G., Cummins, K., Sedell, J., Cushing, C.: The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences **37**, 130–137 (1980)