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Comparative analysis of the structure of planktonic algae of the Volga and Kama rivers before their confluence in the Kuibyshev reservoir (the Republic of Tatarstan, RF)

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ABSTRACT

The article presents the results of comparative analysis of the structure of planktonic algae in the Volga and Kama rivers, as well as the assessment of the trophic state of these water bodies, which form the Kuibyshev reservoir at their confluence. The hydrochemical regime of the Kuibyshev reservoir is nonhomogeneous and is determined by the chemical properties of the Volga and Kama, differing in the ratio of ions and mineralization. The ionic compositionin Kama is often dominated by sulfates. Its mineralization ranges from 168 to 674 mg L^{-1}, depending on the season and dryness of the year. The Volga contains calcium hydrocarbonate and display a lower degree of mineralization (120-130 mg L^{-1}). Different composition of the incoming water, runoff rate, the degree of volume drawdown, intra-basin processes and groundwater inflows exhibit a direct impact on the conditions for the existence of planktonic algae. During the growing season of 2012, 123 algae taxa were identified among the phytoplankton of the Volga and Kama rivers (the areas before their confluence in the Kuibyshev reservoir). In terms of species diversity, diatoms and green algae were prevalent. The Volga exhibits higher species diversity (107 species), while the phytoplankton in Kama displays less diverse (77 species). In the seasonal dynamics of phytoplankton in both areas, two peaks of abundance and biomass are observed, i.e., at the middle and at the end of summer. The studied areas of Volga River are characterized by a phytoplankton complex of blue-green, diatoms and green algae, while diatom phytoplankton predominates in Kama River. In the summer-autumn period, the "blooming" of water in both rivers is connected with massive development of blue-green algae of the genera *Aphanizomenon, Microcystis, Anabaena* and *Oscillatoria*. During most of the growing season, the waters of Volga and Kama rivers belong to the mesasaprobic type and correspond to the moderately-polluted zone. Moreover, the waters of Kama River are characterized by higher saprobity indices. The trophic status of studied rivers mostly corresponds to eutrophic type, and in the periods of maximum development of planktonic algae - to hypereutrophic type.

Keywords: Algocenosis, Phytoplankton, Algae, Volga River, Kama River, Kuibyshev reservoir.
Article type: Research Article.

INTRODUCTION

The Kuibyshev reservoir (the Republic of Tatarstan, Russia) was formed as a result of the damming of Volga by the Volzhskaya HPP in the area of Togliatti, and was designed for seasonal flow regulation. The length of the reservoir from the Cheboksary hydroelectric complex to the Kuibyshev hydrosystem is 480 km along Volga and 201 km along Kama. The latter flows into Volga at the Kama bay of the reservoir. At the confluence of the Volga and Kama rivers, the Kuibyshev reservoir forms a lake-like extension, i.e., the Volga-Kama reach. The hydrochemical regime of Kuibyshev reservoir is nonhomogeneous in terms of the chemical composition of water

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masses. Due to the earlier flood in spring, water masses of Volga fills the Volga-Kama and almost the entire Tetyushsky reaches of the reservoir, and then the waters of the Kama reach add there. Pushing aside the Kama and Volga winter waters to the west, they spread along the shallow left bank of both reaches. The frontal zone of the Volga and Kama spring water masses is clearly observed even visually, and their different genesis is reflected in the physical and chemical properties of water. According to the hydrochemical indicators, the following water masses are distinguished: waters of Volga, Kama, Volga-Kama, Cheremshan and Kuibyshev reservoir. The Kama waters are more turbid and less transparent than the Volga ones. The chemical composition of water in the Kuibyshev reservoir is determined, first of all, by the chemical properties of the Volga and Kama waters, which differ in the ratio of ions and mineralization. The ionic composition of Kama River is often dominated by sulfates, and its mineralization ranges from 168 to 674 mg L^{-1}, depending on the season and dryness of the year. The Volga waters are calcium hydrocarbonate and have a lower degree of mineralization (120-130 mg L^{-1}; Kuibyshev Reservoir 2008). In general, water in Kuibyshev reservoir belongs to the hydrocarbonate class, the calcium group, the second and the third types, and is nonhomogeneous in terms of mineralization. The hardness of water ranges from 2 to 5 mg-equ L^{-1}; the content of calcium, magnesium and chlorides does not exceed the established norms; the active reaction of the medium is normal (pH 6.5 - 8.5). The water level in Kuibyshev reservoir is regulated by the dam of the hydroelectric power station, which has an annual, seasonal and daily regulation. The nature of anthropogenic impact and pollution along the entire length of the reservoir are also of great importance. Since the reservoir occupies an intermediate position in the system of reservoirs of the Volga cascade, it is characterized by transboundary transfer of pollutants from the upstream areas of the Volga and Kama rivers. At the same time, some of them accumulate and transform in the reservoir, while some are transferred to the lower areas and can serve as a source of pollution of downstream reservoirs. Large tributaries, river transport, local industrial, agricultural and municipal wastewaters, etc. also make a significant contribution to water pollution (Pautova 1989). There are several studies about plankton communities around the world (Shumilov *et al.* 2005; Ershad Langerudi *et al.* 2010; Jafari *et al.* 2015). Different composition of the incoming water, runoff rate, the degree of volume drawdown, intra-basin processes and groundwater inflows have a direct impact on the conditions for the existence of aquatic organisms, and primarily, planktonic algae - phytoplankton (Khaliullina *et al.* 2009; Khaliullina & Yakovlev 2015). The purpose of the work is to make a comparative analysis of the species composition and seasonal dynamics, as well as to determine the trophic state of the coastal shallow waters of the Volga and Kama rivers, which form the Kuibyshev reservoir at their confluence.

MATERIALS AND METHODS

The investigations of planktonic algae were carried out during the growing season of 2012 on the Volga river (middle part of the Kuibyshev reservoir) in the area of the settlement Borovoe Matyushino (observing station 1), and on the Kama river (5 km downstream of Nizhnekamsk) (observing station 2). The location map of the sampling stations is shown in Fig. 1. Phytoplankton samples were taken from a depth of 0.5-2.5 m, at the coastal zone, with an interval of once a week. A total of 72 qualitative and quantitative samples were collected. Sampling and laboratory investigation of phytoplankton samples were carried out according to the generally accepted methods (Wasser 1989; Krammer 1991a,b; AlgaBase 2000; Sadchikov 2003; Pröschold & Leliaert 2007; Cantonati 2017).

All quantitative samples by a volume of 0.5 L were fixed with a 4% formalin solution. Fixed samples were concentrated by sedimentary method to 7-10 mL for qualitative and quantitative assessments of phytoplankton. Also, PVF-35/ NB vacuum filtration device for hydrobiological studies in water was used to thicken phytoplankton. Vladipor membrane filters MFAS - OS - 2 and MFAS - OS - 3 with pore sizes of 0.45 and 0.8 μm were used for the concentration of phytoplankton. The organisms were counted according to the generally accepted method in the Goryaev chamber.

The volumetric-counting method was used to determine the biomass. The trophic state index (ITS) was calculated for each sample, using the Milius block, according to the formula $Ib = 44.87 + 23.22 \times \log B$ (Andronikova 1993). The Pantle–Buck saprobity index (S), modified by Sladecek, was calculated to define the degree of saprobity of water bodies (Sladecek 1973). Over the entire period of research, meteorological conditions and hydrological features of the rivers (water level, transparency, weather conditions, etc.) were recorded.

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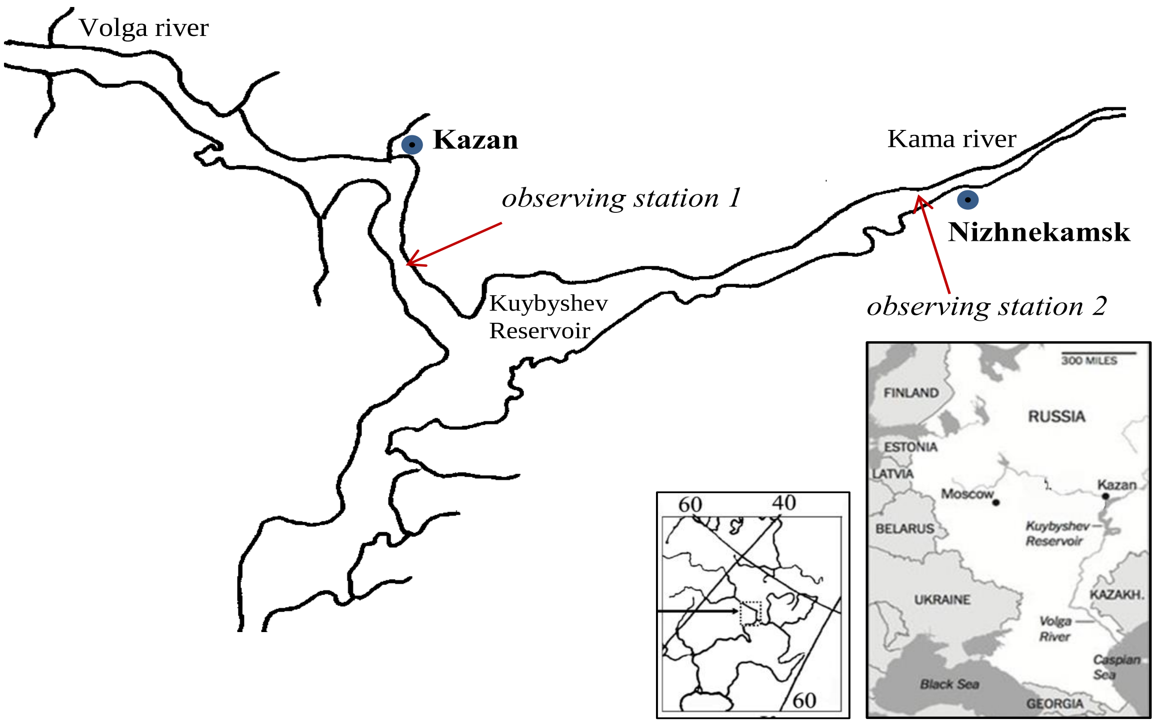

Fig. 1. The schematic map of the research area location on the Volga and Kama rivers in 2012.

RESULTS AND DISCUSSION

3.1. Composition and ecological - floristic characteristics of algae

During the observation period, 123 taxa of planktonic algae from 7 phyla were defined among the phytoplankton of the studied areas. Since the objective of given study was the phytoplankton of the water column, the species diversity in our observations was low. The data on the taxonomic structure of phytoplankton are presented in Table 1.

Table 1. The number of taxa in certain groups of phytoplankton of the Kuibyshev reservoir, 2012 (the number of species in the Volga/Kama rivers is in brackets).

Phylum	Class	Order	Genus	Species
Cyanophyta	2	3	9	16 (16/9)
Cryptophyta	1	1	1	2 (2/1)
Dinophyta	1	2	4	7 (6/4)
Chrysophyta	1	2	3	3 (3/2)
Bacillariophyta	2	5	26	48 (34/45)
Euglenophyta	1	1	4	9 (9/0)
Chlorophyta	3	4	24	38 (37/16)
Total	11	18	71	123 (102/77)

The largest number of taxa of the rank order was defined in the phyla of green algae and diatoms. In terms of species diversity, the general list was dominated by the representatives of algae including Bacillariophyta (41%) and Chlorophyta (32%). Other groups were less diverse: Cyanophyta (14%), Euglenophyta (8%), Chrysophyta (3%), Dinophyta (2%), and Cryptophyta (2%; Fig. 2). The most frequent occurrence at the station 1 was characteristic for the genera of blue-green algae including *Merismopedia, Aphanizomenon, Microcystis,* cryptophyta algae such *Cryptomonas*, diatoms including *Cyclotella, Synedra, Stephanodiscus, Nitzschia*, dinophytes *Peridinium*, euglena such as *Trachelomonas* and green algae including *Chlamydomonas, Carteria, Tetraedron, Scenedesmus, Grucigenia, Dictyosphaerium, Coelastrum, Monoraphidium.* The genera of blue-green algae such as *Aphanizomenon* and diatoms including *Cyclotella, Synedra, Stephanodiscus, Nitzschia, Aulacoseira* were most often found at the station 2.

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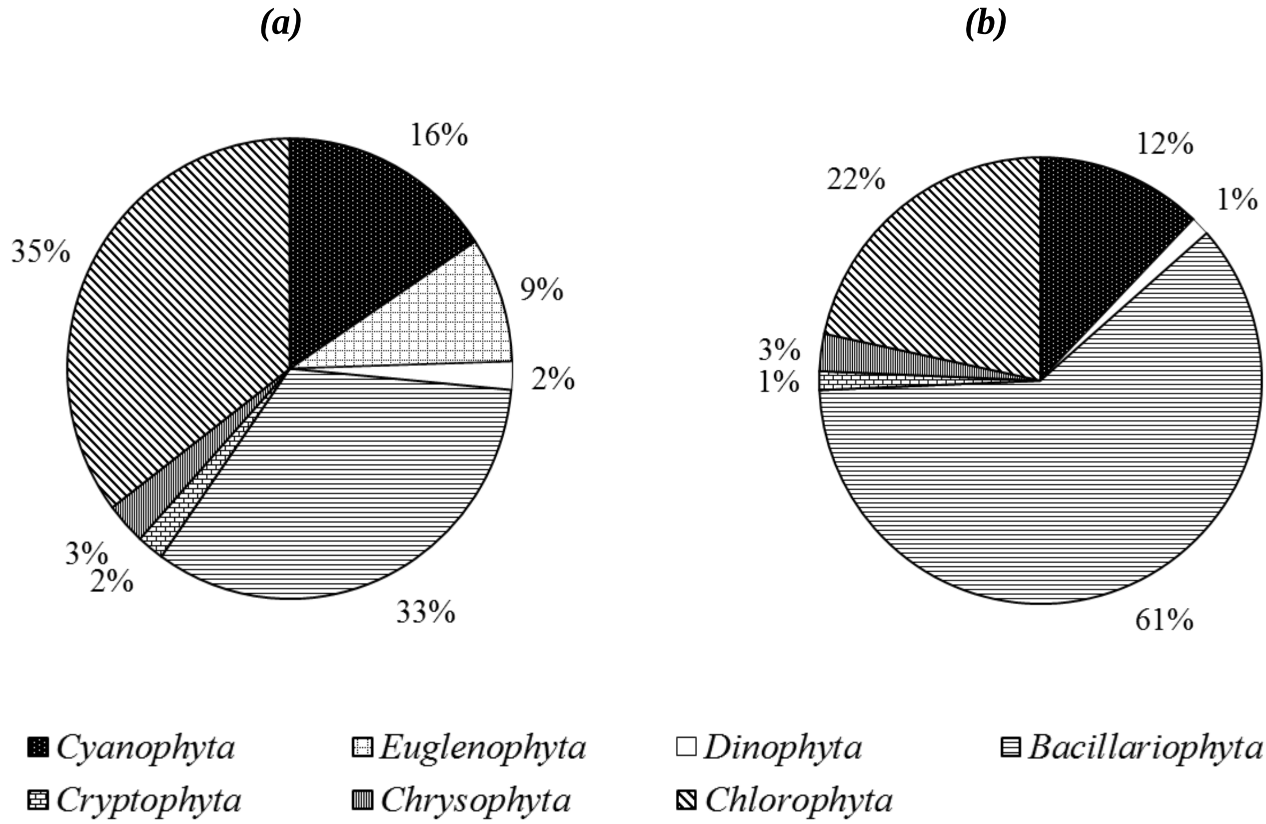

Fig. 2. The number of taxa in certain groups of phytoplankton of the Kuibyshev reservoir, Volga River (a) and the Kama River (b) in 2012.

Plankton algae in the studied areas were represented by several ecological groups, differing in species composition, growing conditions, development dynamics, etc. They included the algae of phytoplankton, epipelon, epiphyton and free floating filaments or swarming of filamentous algae. In terms of species diversity, green algae and diatoms prevailed at the station 1, approximately in equal proportions. At the station 2, diatoms were the most diverse (61%). Many species were identified only in qualitative samples, since they were few.

At the beginning of summer, the phytoplankton communities of coastal shallow waters were dominated by algal species with a wide ecological spectrum, which can also inhabit plankton and benthos. These are mainly species of filamentous centric and pennate diatoms, sphaeropleales algae. The genera *Cyclotella, Synedra, Stephanodiscus, Nitzschia, Scenedesmus* were distinguished by the highest species diversity. Furthermore, they were joined by the species of epipelon and epiphyton (large species with a heteropolar structure of cells or colonies). These were the species of heavy diatoms, scraps of green filamentous and desmidiales algae. In addition, blue-green, euglena and green algae began to develop en masse.

3.2. Seasonal dynamics of phytoplankton in 2012

In 2012, during the growing season of algae, the average monthly air temperatures were higher than the norm by 2-3 °C. Unstable weather conditions were observed with significant fluctuations in air temperature. Abundant rainfall and thunderstorms, which were unevenly distributed over the territory and in time, alternated with long periods of calm, hot and dry weather. In contrast to previous years, the water level in the reservoir was very high, close to 53 - 54 m, during the entire ice-free period. At the beginning of the growing season (May), the total number of species of planktonic algae per sample at the station 1 ranged from several to 16 species (Fig. 3). In terms of species diversity, diatoms and green algae prevailed (50 and 31%), and blue-green algae were also found

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up to 19% of the total. The most abundant species were diatoms *Aulacoseira islandica* o. Mill., *Aulacoseira italica* (Ehr.) Kiitz., *Aulacoseira granulata* (Ehr.) Ralfs., *Stephanodiscus hantzschii* Crun., *Nitzschia acicularis* W.Sm. Green algae were represented by sphaeropleales. *Aphanizomenon flos-aquae* (L.) Ralfs., *Oscillatoria planctonica* Wotosz prevailed among blue-green algae.

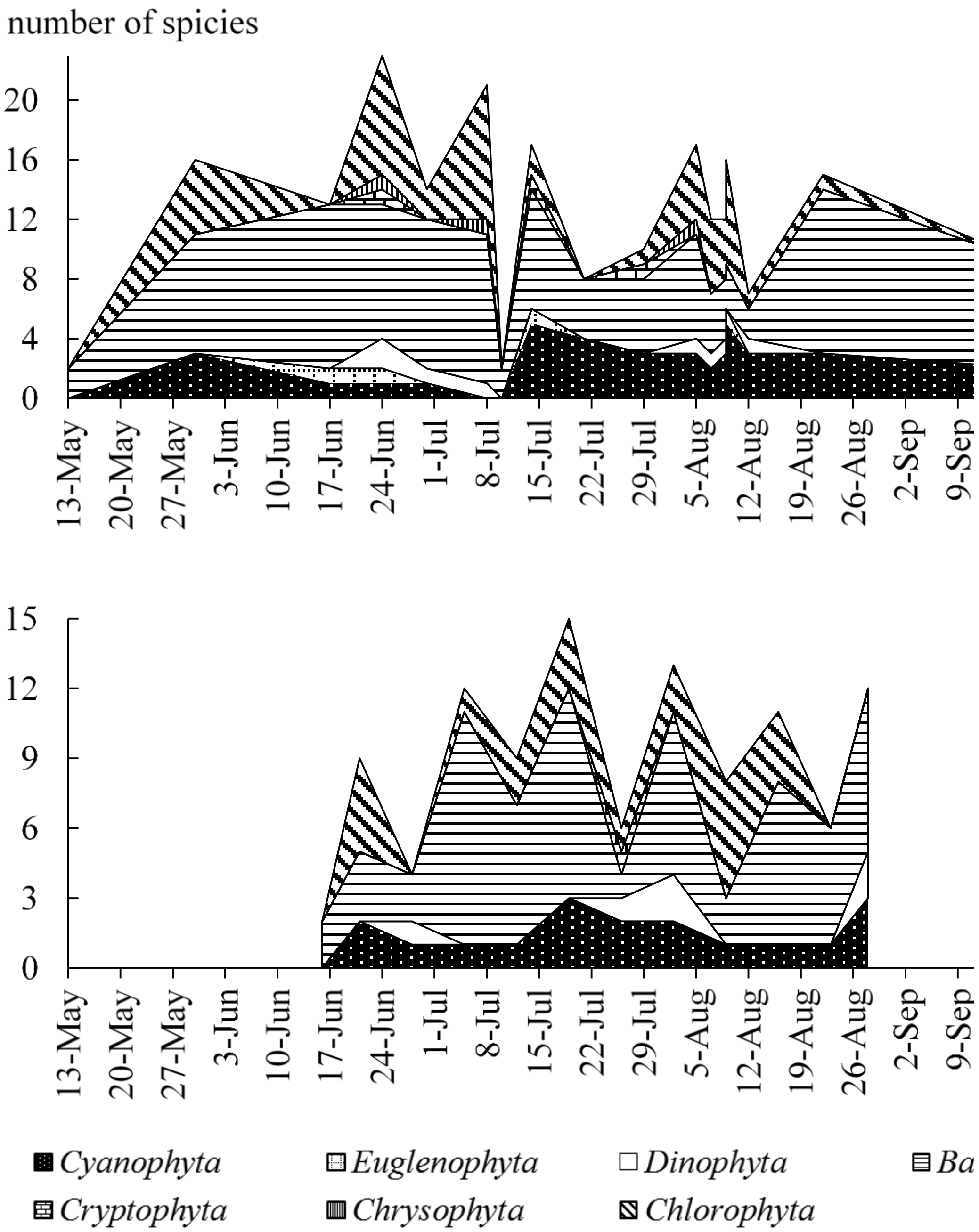

Fig. 3. Seasonal dynamics of the number of phytoplankton taxa per sample from the Kuibyshev reservoir, Volga River (a) and Kama River (b) in 2012.

The number of species decreased by the beginning of June. However, by the late June, the number of algae at both stations was more than doubled and reached to 23 species at the station 1, and 9 species at the station 2. In terms of species diversity, diatoms and green algae prevailed at the station 1. At the beginning of June, diatoms accounted for 85%, by the middle of June reached to 40%, and at the end of the month to 71%. Green sphaeropleales constituted up to 35% of the total number of species. *Aulacoseira islandica* (O. Mill.), *Aulacoseira italica* (Ehr.) Kiitz were the dominant species. At the station 2, diatoms accounted for 33-50% of the total number

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of the planktonic algae species, and green sphaeropleales for 35%. In addition, by the end of June, dinophytes (25%) and blue-green algae (25%) began to occur. At this station, from the second half of June, the centric diatom *Stephanodiscus hantzschii* Crun was dominated, forming in some places up to 84% of the total abundance and 99% of the total biomass. From the middle of summer at the station 1, the species diversity of diatoms began to decrease, and until autumn it was kept within 30 - 50%. Furthermore, their diversity increased only at the end of August to 70%. The above mentioned species of centric diatoms prevailed.

During the summer period at this station, a high diversity was observed among green (29-44% until mid-August) and blue-green algae (29-50% until October). Green volvocales *Pandorina morum* (Mill.) Bory., *Chlamydomonas* sp., *Carteria globosa* Korschik joined to green sphaeropleales and developed en masse. At the station 1, blue-green algae of the genera *Aphanizomenon flos-aquae* (L.) Ralfs., *Oscillatoria planctonica* Wotosz., *Microcystis aeruginosa* Kutz., *Anabaena flos - aquae* Breb., *Anabaena scheremetievi* Elenc. developed massively until September. So, from the middle of July the "blooming" of water began on the entire area of the reservoir. The phenomenon of water blooming in the Kuibyshev reservoir often continues until the end of September. However, in that high-water and cool summer year, those phenomena did not last long, and since September massive outbreaks of blue-green algae development were not observed, even in Volga River.

The station 2 differed from the station 1 with lower values of all indicators. Since the second half of summer at the station 2, the species diversity did not exceed 15 species per sample. During the entire period of observation, centric and pennate diatoms prevailed (60 - 80%). *Stephanodiscus hantzschii* Crun was the dominant specie; *A. islandica* O. Mill., *Aulacoseira italica* (Ehr.) Kiitz., *Aulacoseira granulata* (Ehr.) Ralfs. also developed abundantly. Green algae (up to 28 - 63%) were recorded in the first half of August and were represented by sphaeropleales and volvocales *Chlamydomonas* sp. The maximum values of blue-green algae (up to 25 - 33% of species number per sample) were defined in mid-July and August. In general, diatom complex of algae was characteristic for the waters of Kama River during the growing season. Green and blue-green algae in such a high-water year were not typical for that station. In terms of quantitative indicators, the considered sections of the rivers were strikingly different (Figs. 4 and 5). In addition, in terms of biomass and abundance, blue-green algae prevailed in Volga River at the station 1. Diatoms were the dominant group only at the beginning of the growing season. The maximum quantitative indicators of phytoplankton in that area were observed by mid-July (at the beginning of "blooming") and by mid-August. At that time, the total abundance of phytoplankton was 2471.19 and 2380.86 million cells L^{-1}, and in both cases, blue-green algae formed up to 99.6% and 99.8% of the total abundance respectively. The total maximum biomasses during these peaks were 168.71 and 160.29 mg L^{-1} respectively. Blue-green algae also formed up to 97% and 98% of the total biomass respectively.

As shown by the results of investigations, carried out in 2012, diatoms *Stephanodiscus hantzschii*, *Aulacoseira islandica* o. Mill., *Aulacoseira italica* (Ehr.) Kiitz., *Aulacoseira granulata* (Ehr.) Ralfs. dominated among the phytoplankton of Volga River in spring-summer period, according to quantitative indicators. In summer - autumn period the following algae prevailed: blue-green *Aphanizomenon flos – aquae* (L.) Ralfs., *Oscillatoria planctonica* Wotosz., *Microcystis aeruginosa* Kutz., *Anabaena flos - aquae* Breb., *Anabaena scheremetievi* Elenc.; green sphaeropleales *Actinastrum hantzschii* var. sp., *Crucigenia tetrapedia* (Kirchn.) W. et. W., *Crucigenia rectangularis* (A. Br.) Gay., *Pediastrum duplex* Meyen., *Scenedesmus guadricauda* (Turp.) Breb., *Scenedesmus acuminatus* (Lagerh.) Chod.; green volvocales *Pandorina morum* (Mill.) Bory., *Chlamydomonas* sp., *Carteria globosa* Korschik.; diatoms *Aulacoseira italica* (Ehr.) Kiitz.

In the waters of Kama River at the station 2, diatoms predominated in terms of both biomass and abundance. Blue-green algae prevailed in biomass only in early and late August, causing small blooming spots. By analyzing the dynamics of phytoplankton abundance in this area, it can be concluded that blue-green algae predominate in abundance during the entire observation period, which is caused by the small size of cells of planktonic blue-green algae. However, it cannot be said that they dominate in this area, since these algae do not even exceed 5% by biomass. The maximum quantitative indicators of phytoplankton in that area were observed by mid-June and by the end of July to August. During the first maximum, caused by the development of diatoms, the total phytoplankton abundance was 11.44 million cells L^{-1} (diatoms formed up to 65% of the total abundance). The total biomass during that period was 44.03 mg L^{-1} (diatoms formed 99% of the total biomass). The same biomass during that period was observed at the station 1.

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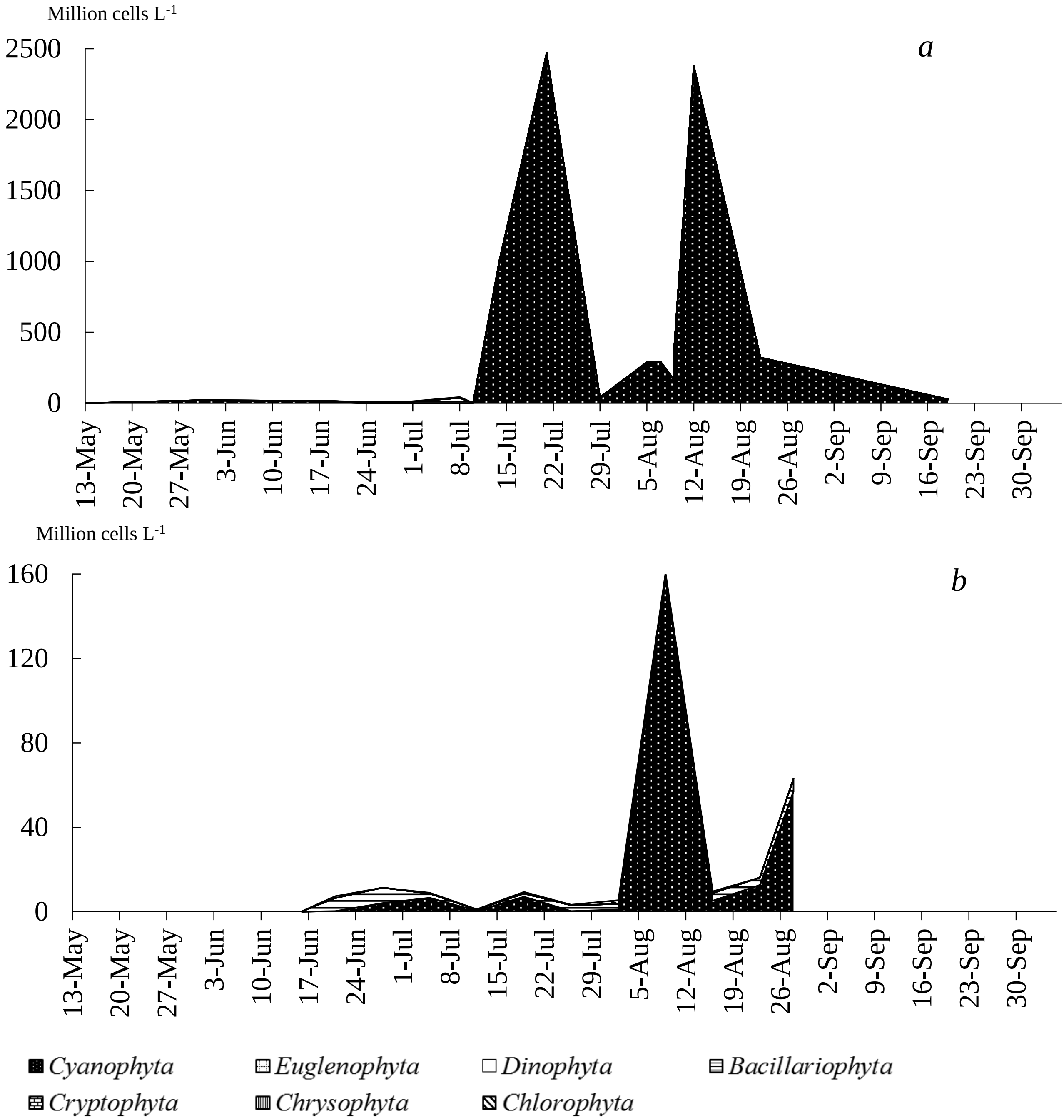

Fig. 4. Seasonal dynamics of phytoplankton abundance (million cells L^{-1}) in Kuibyshev reservoir, Volga River (a) and Kama River (b) in 2012.

Due to blue-green algae (99%), the total abundance and total biomass of phytoplankton amounted to 160.61 million cells L^{-1} and 13.74 mg L^{-1} at the beginning of August. Blue-green algae dominated for a very short period, and since mid-August, diatoms began to prevail in water again, and by the end of August they formed 63.07 million cells L^{-1} and 11.85 mg L^{-1} (90 and 84%, respectively). Diatoms *Stephanodiscus hantzschii*, *A. islandica* O. Mill., *A. italica* (Ehr.) Kiitz., *Aulacoseira granulata* (Ehr.) Ralfs. dominated among the phytoplankton of Kama River in the spring-summer period, according to quantitative indicators. In the summer - autumn period the following algae prevailed: blue-green *Aphanizomenon flos – aquae* (L.) Ralfs., *Anabaena flos - aquae* Breb.; diatoms *Stephanodiscus hantzschii*, *A. islandica* O. Mill., *A. italica* (Ehr.) Kiitz., *A. granulata* (Ehr.) Ralfs.; green algae *Crucigenia rectangularis* (A. Br.) Gay., *Scenedesmus guadricauda* (Turp.) Breb., *Scenedesmus acuminatus* (Lagerh.) Chod.; green volvocales *Chlamydomonas* sp.

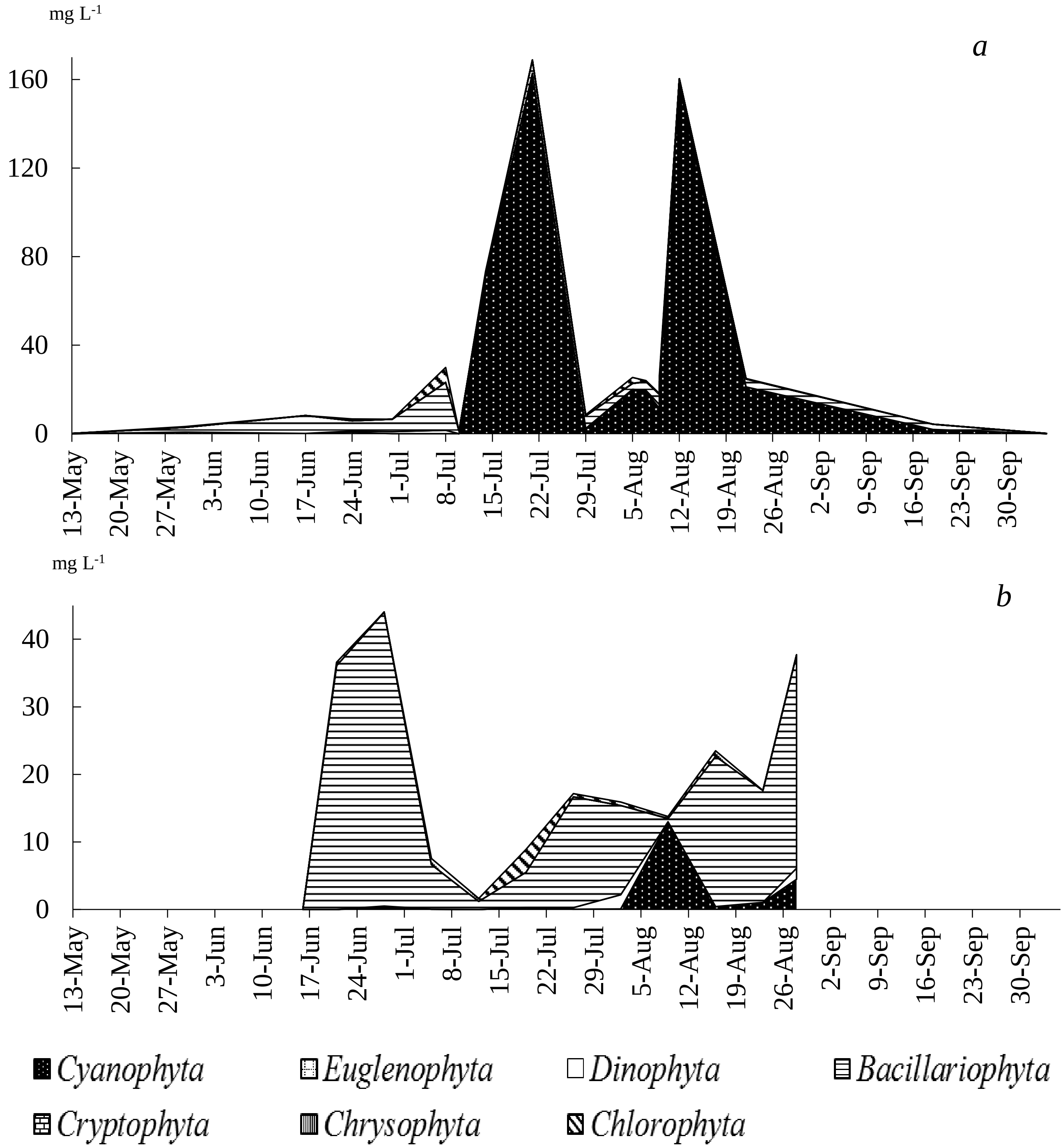

Fig. 5. Seasonal dynamics of phytoplankton biomass (mg L^{-1}) in the Kuibyshev reservoir, the Volga river (a) and the Kama river (b) in 2012.

In the seasonal dynamics of phytoplankton in both areas, there were two peaks of abundance and biomass i.e., in summer and in the summer-autumn period, during which the maximum values of abundance and biomass were reached. In the latter period, the "blooming" of water was connected with the massive development of blue-green algae of the genera *Aphanizomenon* and *Microcystis*. During most of the growing season, the waters of the Volga and Kama rivers belonged to the mesasaprobic type and corresponded to the moderately polluted zone (Fig. 6). Moreover, the waters of Kama River were characterized by higher saprobity indices. The trophic status of studied rivers mostly corresponded to the eutrophic type, and in the periods of maximum development of planktonic algae – to the hypereutrophic type (60 – 79: eutrophic, 80 – 100: hypereutrophic).

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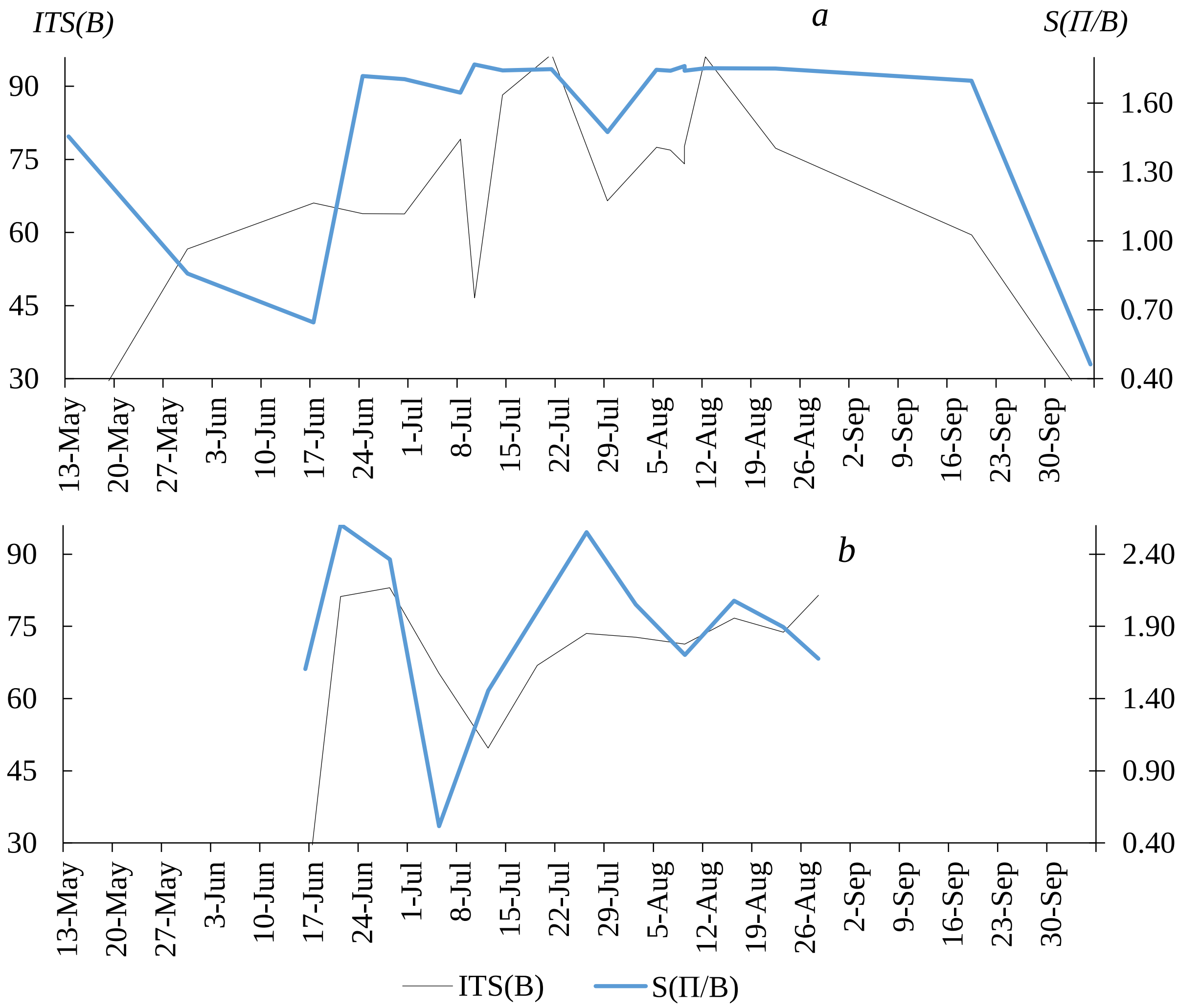

Fig. 6. The dynamics of the indices of trophic state (ITS, B) and saprobity (S, P/B) according to the phytoplankton biomass of the Kuibyshev reservoir, Volga River (a) and Kama River (b) in 2012.

SUMMARY

During the growing season of 2012, 123 taxa of algae, belonging to 7 phyla, were identified among the phytoplankton of the flowing regions of the Volga and Kama rivers (the areas before their confluence in the Kuibyshev reservoir). In terms of species diversity, diatoms and green algae were prevalent. The Volga waters exhibited higher species diversity (107 species), while the phytoplankton of Kama River was less diverse (77 species). In the seasonal dynamics of phytoplankton in both areas, two peaks of abundance and biomass were observed, i.e. at the middle and end of summer. The waters of the studied areas of the Volga River were characterized by a phytoplankton complex of blue-green, diatoms and green algae, while diatom phytoplankton predominated in Kama River. In the summer-autumn period, the "blooming" of water in both rivers was connected with massive development of blue-green algae of the genera *Aphanizomenon*, *Microcystis*, *Anabaena*, *Oscillatoria*. During most of the growing season, the waters of the Volga and the Kama rivers belonged to the mesasaprobic type and correspond to the moderately polluted zone. Moreover, the waters of Kama River are characterized by the higher saprobity indices. The trophic status of studied rivers mostly corresponds to the eutrophic type, and in the periods of maximum development of planktonic algae – to the hypereutrophic type.

CONCLUSIONS

The study of the biology and structure of phytoplankton communities in aquatic ecosystems is the basis for monitoring and control over the quality of natural waters. The comparative analysis of water quality by the indicators of planktonic algae of the Volga and Kama rivers, before their confluence in the Kuibyshev reservoir, can be used in the work of environmental and fishing organizations, in the assessment of the state of rivers, flowing

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into the Kuibyshev reservoir, as well as in the process of development of practical recommendations for improvement the quality of aquatic environment in the reservoir. The results obtained in this work will be applied in monitoring and predictive research of the rivers of the Republic of Tatarstan, as well as in the study of biological diversity of the Republic of Tatarstan and the Russian Federation.

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