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Article

State and dynamics of zooplankton in Kazan Bay of the Kuibyshev Reservoir in 2018

P.A. Lyubin

Institute of Ecology and Subsoil Management, Academy of Sciences of the Republic of Tatarstan, ul. Daurskaya 28, Kazan, 420087 Russia

plubin@mail.ru

Abstract. During the growing season of 2018, the composition and dynamics of zooplankton in the Kazan Bay of the Kuibyshev Reservoir were studied. In total, 69 zooplankton taxa were identified, the species richness of zooplankton was 9 ± 1 taxa per station, abundance, 221.9 ± 32.1 thous. ind./m^3, biomass, 1.6 ± 0.5 g/m^3, average daily production, 0.124 ± 0.034 g/m^3 per day. Two peaks were observed in the dynamics of quantitative characteristics of zooplankton (in June and in August), which was typical for mesotrophic lakes of temperate latitudes in accordance with Sommer's PEG model. Two-factor ANOSIM analysis, performed on the basis of the similarity of stations in terms of the contribution of species to total production, evidenced on the influence of the month of sampling ($R = 0.472$; $p = 0.001$) and distance from the lower boundary of bay mouth ($R = 0.279$; $p = 0.001$) on the structure of zooplankton communities. The factor of station location relative to the banks and riverbed did not have a significant effect on the composition of zooplankton ($R = -0.028$; $p = 0.94$). Pollution in the Kazan Bay in 2018 corresponded to the long-term average level in the β-mesosaprobic zone, which characterized the waters as moderately polluted.

Keywords: Kazanka River, spatial analysis, zooplankton succession, PEG model

ORCID:
P.A. Lyubin, https://orcid.org/0000-0002-2064-5127

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Научная статья

Состояние и динамика зоопланктона Казанского залива Куйбышевского водохранилища в 2018 г.

П.А. Любин

Институт проблем экологии и недропользования Академии наук Республики Татарстан (ИПЭН АН РТ), 420087, Россия, г. Казань, ул. Даурская, д. 28.

plubin@mail.ru

Аннотация. В вегетационный период 2018 г. исследованы состав и динамика зоопланктона Казанского залива Куйбышевского водохранилища. Выявлено 69 таксонов зоопланктона. За время наблюдений видовое богатство зоопланктона составило 9 ± 1 таксонов на станцию, численность – 221.9±32.1 тыс. экз./м^3, биомасса – 1.6 ± 0.5 г/м^3, среднее значение суточной продукции – 0.124 ± 0.034 г/м^3 в сутки. В динамике количественных характеристик зоопланктона выявлены два пика – в июне и августе, что характерно для мезотрофных озер умеренных широт в соответствии PEG-моделью Зоммера. Двухфакторный ANOSIM-анализ, выполненный на основании сходства станций по вкладу видов в общую продукцию, показал влияние на структуру зоопланктонных сообществ таких факторов, как месяц отбора проб ($R = 0.472$) и удаленность от нижней границы устья залива ($R = 0.279$) при уровне статистической значимости $p = 0.1\%$. Фактор расположения станций относительно берегов и русла не имел значимого влияния на состав зоопланктона ($R = -0.028$ при $p = 94.1\%$). Загрязнение Казанского залива в 2018 г. соответствовало среднемноголетнему уровню, β-мезосапробной зоне, что характеризовало воды как умеренно загрязненные.

Ключевые слова: река Казанка, пространственный анализ, сукцессия зоопланктона, PEG-модель

ORCID:
П.А. Любин, https://orcid.org/0000-0002-2064-5127

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Introduction

The Kazanka River is a left-bank tributary of the Kuibyshev Reservoir (Volga River) and is of great economic and recreational importance for the Western Cis-Kama region of the Republic of Tatarstan, Russia. The river flows through the territory of Kazan, Arsky and Vysokogorsky districts. According to the State Water Register[1], the length of the watercourse is 142 km, the drainage area is 2600 km^2. Fourteen small rivers flow into the Kazanka River. The lower course of the river locates in the backwater of the Kuibyshev Reservoir and forms an expanded part of the channel, the Kazan Bay, dividing the city of Kazan into two equal parts.

Since the second half of the XX century, the landscape adjacent to the river within the city has undergone major changes. In most of its part, natural territorial complexes were replaced by anthropogenic communities and man-made structures, which led to a transformation of the regime of the river itself (Mozzherin et al., 2012). Within the city of Kazan, the water area of the bay is blocked by four transport dams with bridges and so forms four sections, influenced to varying degrees by the waters of the Kazanka River and of the Kuibyshev Reservoir:

1. The site is most influenced by the waters of the Kuibyshev Reservoir. The shores of this water area are mainly formed by artificial embankments (dams with aquatic and semi-aquatic vegetation); the bank was reinforced with retaining walls made of monolithic reinforced concrete only in the eastern part of the water area;
2. The widest section of Kazan Bay. The banks of the site are mostly reinforced with concrete retaining walls; there are reclaimed areas of sandy beaches with little vegetation in the northern part only;
3. The site is characterized by the presence of a large number of islands and shallows, abundantly overgrown with aquatic vegetation. Artificial bank protection elements are present in a small part of the water area;
4. The site is most influenced by the Kazanka River. The water area of the bay here has two extensions. The shores are predominantly of natural origin, abundantly covered with semi-water and aquatic vegetation.

The depths and coastline of the Kazan Bay depend strongly on the level of the Kuibyshev Reservoir. At a normal backwater level, the maximum depth of the reservoir is 9 m, the average depth of the bay is 2.7 m, and the water area is 10.6 km^2 (Mozzherin et al., 2012). In 2018, the water temperature in the bay during the study period ranged from 13.8 to 18.0 °C in May and from 9.8 to 13.8 °C in September; in July the water warmed up to 24.5 °C.

Currently, the urban area around the bay is being actively developed with sports and other facilities, recreational infrastructure is being developed, and it is planned to create a natural landscape park “Kazanka Islands”. At the same time, environmental deterioration here is indicated by regular water blooms accompanied by the abundant development of blue-green algae (Abramova et al., 2020, 2021) and cases of mass fish death (Shagidullin et al., 2017).

Zooplankton is an important structural and functional part of water body ecosystems, participating in the self-purification of water bodies and serving as an indicator of their condition, sensitively responding to changes in both natural and anthropogenic factors. Therefore, in accordance with the Order of the Federal Agency for Fisheries[2], the state of zooplankton communities is usually considered as one of the criteria for assessing the consequences of the negative impact of human activities on the state of aquatic biological resources and their habitat. Economic activity in a modern metropolis is carried out almost year-round, with a particular intense increase in the summer months, which requires special attention to the state of the environment during this period. Previous studies on zooplankton in the Kazanka River revealed changes in the structure of zooplankton communities and significant fluctuations in its abundance and biomass in the summer season (Derevenskaya, 2017; Derevenskaya and Umyarova, 2017; Derevenskaya et al., 2015; Mingazova et al., 2013); however, the influence of biotopic conditions on plankton communities was not considered. It is known that local characteristics may affect the structure

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[1] Kazanka. State Water Register of Russia. Web page. URL: http://www.sur-base.ru/water-base/?show_obj=35287 (accessed: 03.06.2024).

[2] Order of Rosrybolovstvo dated May 6, 2020 No. 238 “On approval of the Methodology for determining the consequences of negative impacts during construction, reconstruction, major repairs of capital construction projects, introduction of new technological processes and other activities on the state of aquatic biological resources and their habitats and the development of measures to eliminate the consequences negative impact on the state of aquatic biological resources and their habitat, aimed at restoring their damaged state”.

and quantitative indicators of zooplankton, both the species populations and entire communities (Lyubin and Ziganshin, 2020). Transport dams, river runoff, and reservoir waters may have a particularly strong influence on the functioning of local plankton communities within the studied reservoir.

Survey studies were carried out during the growing season of 2018 in different areas of Kazan Bay to study the impact of the listed factors on zooplankton communities. The research objectives were to study the species composition and quantitative dynamics of zooplankton during the growing season, to determine the influence of the waters of the Kuibyshev Reservoir and the Kazanka River in different parts of the bay on the composition and structure of communities, as well as to assess the level of organic water pollution based on zooplankton indicators.

Materials and methods

Survey studies of zooplankton in the Kazan Bay were carried out from May through September 2018. Sampling was performed monthly in the water area at four sections corresponding to sections of the bay, with three stations at each (Fig. 1). The first station of each transect was located at the left bank, the second one, in the middle of the river, and the third one, at the right bank. Zooplankton samples were taken by filtering 20–30 liters of water from the surface through an Apstein plankton net (mesh size 0.093 mm) in accordance with standard hydrobiological methods (Metodicheskie rekommendatsii..., 1982; Rukovodstvo po metodam..., 1983). Samples were fixed with a 40% formaldehyde solution to a final concentration of 4% in the sample. For the taxonomic identification of zooplankton, generally accepted keys were used (Błędzki and Rybak, 2016; Opredelitel presnovodnykh bespozvonochnykh..., 1977; Opredelitel zooplanktona..., 2010). The zooplankton biomass was calculated using formulas for the dependence of the mass of organisms on body length (Chislenko, 1968; Metodicheskie rekommendatsii..., 1982).

For each species, the occurrence P_i (%) was determined according to the equation:

$$P_i = m_i/N_s \times 100,$$

where m_i is the number of stations at which species *i* was found; N_s – total number of stations.

To assess quantitatively the significance of species in classification constructions when assessing the similarity between stations, we applied the method of the express assessment of a certain species population production based on the average weight of its individuals (Manushin, 2008):

$$P = B \cdot 0.0019 \cdot (B/N)^{-0.9},$$

where *P* is the daily production of the species/taxon, g/m³ per day; *B* – biomass g/m^3; *N* – population density, ind./m^3.

Due to the large uncertainty of production parameters and the lack of data on the predators' diet, the total production of the zooplankton community (P_{tot}) was calculated as the total production of large (weighing > 10^{-5} g) zooplankters (Metodicheskie rekommendatsii..., 1982). The total production of smaller (weighing < 10^{-5} g) zooplankters was calculated separately and taken as the total production in the absence of large forms.

The Czekanovski index was used to compare stations according to the zooplankton community structure (Czeckanovski, 1909). Testing the statistical significance of the influence of factors (time, area, and sampling site) was performed by ANOSIM similarity simulation analysis in the Primer 5 program (PRIMER-E Ltd) (Clarke, 1993; Clarke and Gorley, 2001; Clarke and Warwick, 2001). In order to make this analysis more complete and to represent the faunal similarity of the stations to each other visually, the ordination of the latter was performed. The result was the MDS diagram in the axes of the first two non-metric scales, which showed the lowest level of stress (Clarke and Warwick, 2001). The dominant species were identified in accordance with the accepted scale (Lyubarsky, 1974).

As a generalized indicator of species diversity, we used Shannon species diversity index (*H*), an information measure widely used for these purposes (Shannon, 1948), calculated by the equation:

$$H = -\sum\left(\frac{n_i}{N}\log_2\left(\frac{n_i}{N}\right)\right),$$

where n_i – number of individuals of the i^{th} species/taxon in the sample; *N* is the total number of individuals in the sample.

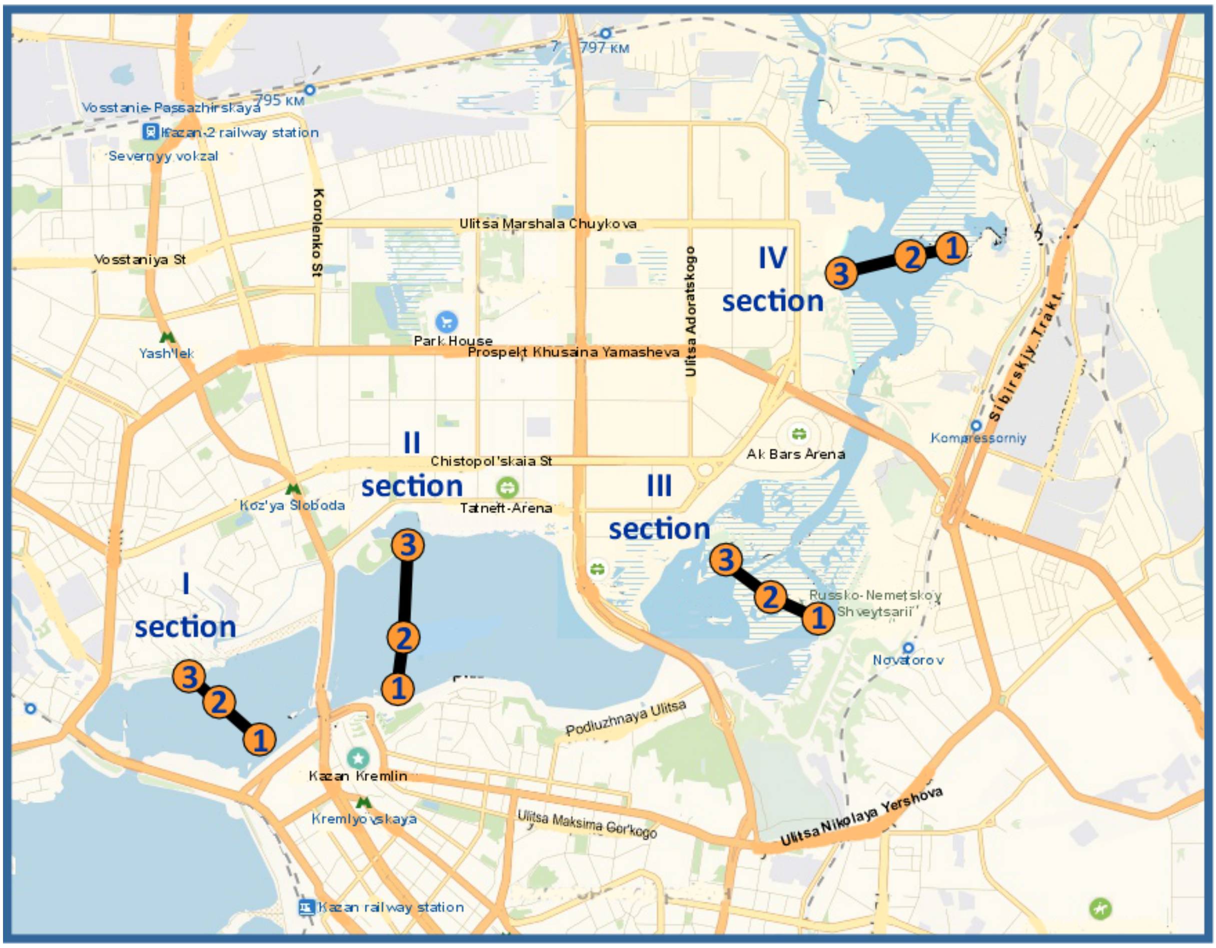

Fig. 1. Location of sampling stations in the Kazan Bay of the Kuibyshev Reservoir.

The index of the prevailing life strategy or ecological well-being (DE) was used to assess the general ecological state (well-being) of communities; it was based on a comparison of the information diversity of species by number and biomass and calculated using the equation (Denisenko, 2006):

$$D_E = [H'(B) - H'(N)]/\log_2(S),$$

where *H'(B)* and *H'(N)* are Shannon indices calculated by biomass and number of individuals; *S* – number of species in the sample.

We have successfully tested this index on zooplankton communities in the Volga-Kama region (Lyubin and Tokinova, 2021; Lyubin and Ziganshin, 2020; Lyubin et al., 2017).

Water quality was assessed by calculating the Pantle–Buck saprobity index (*S*) (Pantle and Buck, 1955) as modified by Sladěček (Sládeček, 1965, 1973).

Results and discussion

In the Kazan Bay, 67 species of zooplankton were found in May–September 2018, as well as nauplii and copepodite stages of copepods belonging to 42 genera, 23 families, 10 orders, 3 classes and 2 phyla (Table 1). The largest number of species (70%) accounted for rotifers (Rotifera), followed by cladocerans (Cladocera), 19%. Copepoda represented 11% of the total species list. The data obtained indicate a change in the taxonomic composition of communities comparing to the period of 1999–2015 (Derevenskaya, 2017; Derevenskaya et al., 2015; Mingazova et al., 2013). Previously, cladocerans dominated by biodiversity, constituting up to 45% of the total number of zooplankton species in the Kazanka River. The share of rotifers did not exceed 40% with a maximum of 36 species. Total species richness of zooplankton ranged from 58 to 95 species in 1999–2015.

The maximum number of species (17 taxa) was noted at stations II and III sections in August and September 2018. The minimum number of taxa (2 taxa per station) was registered in May at station no. 1 section III, on the left bank, opposite the “Russian-German Switzerland” park. In addition, in the sample taken at the station no. 2 section IV in September, there were no zooplankters at all, but their presence at stations nos. 1 and 3 of the same section means that this sample must be considered incorrectly selected and excluded from subsequent analysis. On average, during the observation period, species abundance was 9 ± 1 taxa per station.

The most frequently encountered species in the study area were rotifers Brachionus calyciflorus, Brachionus angularis, Keratella quadrata, nauplii and immature copepodites of copepods (Table 1). In June, rotifers Asplanchna priodonta, Filinia longiseta, and cladoceran Bosmina longirostris reached wide distribution and mass development in the study area. Consistently, from June to August, the frequency of occurrence of Daphnia cucullata were increasing.

The average zooplankton abundance was 221.9 ± 32.1 thous. ind./m^3 at the stations for the entire observation period. The minimum value (300 ind./m^3) was noted at station no. 2 section I in May, the maximum value (1072 thous. ind./m^3), at the same station in August. Biomass varied from 0.2 mg/m^3 to 28.758 g/m^3. The zooplankton biomass for the entire study period averaged 1.6 ± 0.5 g/m^3. The minimum and maximum biomass values corresponded to those observed for abundance. When analyzing quantitative data, there was a high correlation between zooplankton biomass (W) and its abundance (N), described by a power equation

$$W = 10^{-7} N^{1,3}$$

at $R^2 = 0.9$.

The obtained quantitative characteristics of zooplankton generally corresponded to the values indicated for zooplankton communities in the Kazan Bay for 1999–2015 (Derevenskaya, 2017; Derevenskaya et al., 2015; Mingazova et al., 2013). The only exception was maximum abundance and biomass at certain stations. In samples from 1999–2010, a record value of the total number of zooplankton was registered (8042 thous. ind./m^3), while the maximum biomass was 13.6 g/m^3 (Mingazova et al., 2013). The value of secondary daily production of zooplankton (P_{tot}) ranged as 0.0001–1.754 g/m^3 per day, on average, 0.124 ± 0.034 g/m^3 per day.

When analyzing the similarity of stations according to the contribution of species to the total production using the Czekanovski index (Czeckanovski, 1909), there was an average level of similarity found (16.6 ± 0.3%). At the 50% similarity level, about 1/3 of all sites were significantly different, the rest formed 14 clusters with an average of 3 stations each, the largest cluster included 7 stations. The MDS diagram constructed on the basis of the obtained similarity matrix allowed one to visually assess the influence on the composition and structure of zooplankton of such factors as the location of survey sites and the sampling time (Fig. 2).

According to Fig. 2, stations of the sections I and IV divide the MDS diagram area into two almost equal parts (“A” and “B”). Since the stations of section I are located in the area most influenced by the waters of the Kuibyshev Reservoir, and the stations of section IV are located in the area under the influence of the waters of the Kazanka River, we assume that the faunal complexes at these areas were formed under the influence of these water masses. Stations of the sections II and III occupied an intermediate position and, depending on the month of sampling, were associated with either the stations of bay apex (area “A”) or the mouth area (area “B”) (Fig. 2).

The results of two-factor ANOSIM analysis confirmed that the sampling month and the sampling area influenced zooplankton communities and its structure significantly. The lowest difference in fauna structure was observed between the May and July collections (Table 2). The stations of sections I and II, as well as stations of sections III and IV, were the closest to each other in composition and structure of zooplankton (Table 3).

The overall value of R for the factor of study period (months) was 0.472 ($p = 0.001$), d for the factor of study site (section), 0.279 ($p = 0.001$). This indicated a high statistical reliability of the level of influence of the selected factors (Tables 2, 3). The factor of station location relative to the channel (near the right, left bank, in the middle of the channel) did not have a significant effect on the composition of zooplankton ($R = -0.028$; $p = 0.94$).

The dynamics of total zooplankton production followed the dynamics of abundance and biomass and coincided with fluctuations in taxonomic richness. All parameters increased in June, followed by

Table 1. Species composition and frequency of occurrence (%) of taxa in Kazan Bay in May–September 2018. *S* – individual saprobity index of species. * – total number of registered taxa for the accounting period is indicated in parentheses.

Taxon	*S*	Month					Total
		May	June	July	August	September	
ROTIFERA							
Anuraeopsis fissa (Gosse, 1851)	1.2	16.7	0	0	0	0	3.4
Ascomorpha ecaudis Perty, 1850	1.3	8.3	0	0	0	0	1.7
Asplanchna brightwelli Gosse, 1850	2.3	0	8.3	0	8.3	18.2	6.8
Asplanchna girodi Guerne, 1888	1.4	0	16.7	0	0	0	3.4
Asplanchna herricki de Guerne, 1888	1	0	8.3	0	0	18.2	5.1
Asplanchna priodonta Gosse, 1850	1.6	0	100	8.3	58.3	45.5	42.4
Asplanchna sieboldi Leydig, 1854	1.5	0	8.3	16.7	8.3	27.3	11.9
Asplanchna sp.		16.7	0	0	8.3	0	5.1
Asplanchnopus multiceps (Schrank, 1793)	1.3	16.7	0	0	0	0	3.4
Brachionus angularis Gosse, 1851	2.5	41.7	100	83.3	66.7	45.5	67.8
Brachionus calyciflorus Pallas, 1776	2.5	58.3	100	41.7	75	100	74.6
Brachionus diversicornis (Daday, 1883)	2	0	50	0	0	0	10.2
Brachionus leydigii Cohn, 1862	2.3	0	41.7	0	8.3	0	10.2
Brachionus quadridentatus Herman, 1783	2.2	0	25	25	0	0	10.2
Brachionus urceus (Linnaeus, 1758)	2.3	0	25	0	0	0	5.1
Brachionus variabilis Hempel, 1896		0	0	0	8.3	0	1.7
Euchlanis deflexa (Gosse, 1851)	1.6	0	0	8.3	0	0	1.7
Euchlanis dilatata Ehrenberg, 1832	1.6	0	16.7	0	16.7	9.1	8.5
Filinia longiseta (Ehrenberg, 1834)	2.3	0	100	16.7	25	81.8	44.1
Filinia terminalis (Plate, 1886)	1.4	0	25	0	0	0	5.1
Kellicottia longispina (Kellicott, 1879)	1.4	0	0	0	8.3	0	1.7
Keratella cochlearis (Gosse, 1851)	1.9	0	66.7	0	58.3	54.5	35.6
Keratella quadrata (Müller, 1786)	1.7	50	100	8.3	50	100	61
Keratella testudo (Ehrenberg, 1832)	1.3	8.3	0	0	8.3	9.1	5.1
Keratella ticinensis (Callerio, 1921)	1.5	0	0	0	8.3	0	1.7
Lecane luna (Müller, 1776)	1.6	0	0	0	0	18.2	3.4
Lecane ungulata (Gosse, 1887)	1.5	0	0	0	8.3	0	1.7
Lepadella ovalis (Müller, 1786)	1.7	0	8.3	0	0	0	1.7
Mytilina ventralis (Ehrenberg, 1830)	1.2	0	0	0	8.3	0	1.7
Notholca acuminata (Ehrenberg, 1832)	1.5	16.7	8.3	0	0	0	5.1
Notholca squamula (Müller, 1786)	1.2	0	0	0	0	9.1	1.7

Taxon	*S*	Month					Total
		May	June	July	August	September	
Platyias patulus (Müller, 1786)	1.8	0	0	8.3	0	0	1.7
Polyarthra dolichoptera Idelson, 1925	1.3	0	0	0	0	63.6	11.9
Polyarthra euryptera Wierzejski, 1891	1.2	0	0	8.3	0	0	1.7
Polyarthra longiremis Carlin, 1943	1	8.3	0	0	0	0	1.7
Polyarthra major Burckhardt, 1900	1.2	0	0	0	50	18.2	13.6
Polyarthra remata Skorikov, 1896	1	0	16.7	8.3	0	0	5.1
Polyarthra vulgaris Carlin, 1943	2.1	8.3	58.3	0	25	9.1	20.3
Pompholyx sulcata Hudson, 1885	1.7	0	0	0	16.7	0	3.4
Proales sigmoidea (Skorikov, 1896)		0	8.3	0	0	0	1.7
Rotaria sp.		8.3	0	0	0	0	1.7
Synchaeta longipes Gosse, 1887	1.2	0	0	8.3	0	9.1	3.4
Synchaeta pectinata Ehrenberg, 1832	1.7	8.3	8.3	33.3	66.7	72.7	37.3
Testudinella incisa (Ternetz, 1892)	1.3	0	8.3	0	0	0	1.7
Trichocerca pusilla (Jennings, 1903)	1.6	0	0	8.3	0	0	1.7
Trichotria truncata (Whitelegge, 1889)	1.2	0	8.3	0	0	0	1.7
Rotifera gen. sp.		8.3	0	0	0	0	1.7
The average number of Rotifera species		**2.7 (14*)**	**9.1 (24)**	**2.8 (14)**	**5.9 (21)**	**7.1 (18)**	**5.5 (47)**
CLADOCERA							
Bosmina longirostris (Müller, 1785)	1.6	8.3	91.7	25	0	72.7	39
Bythotrephes brevimanus Lilljeborg, 1901		0	0	0	16.7	0	3.4
Ceriodaphnia megops Sars, 1862	1.4	0	0	0	8.3	0	1.7
Chydorus sphaericus (Müller, 1785)	1.8	0	0	25	75	63.6	32.2
Daphnia cristata Sars, 1862	1.1	0	0	0	0	9.1	1.7
Daphnia cucullata Sars, 1862	1.7	25	25	50	91.7	27.3	44.1
Daphnia longiremis Sars, 1862		0	0	16.7	16.7	27.3	11.9
Daphnia longispina O.F. Muller, 1785	2	0	0	16.7	0	18.2	6.8
Leydigia acanthocercoides (Fischer, 1854)	1.4	0	0	0	0	9.1	1.7
Macrothrix laticornis (Jurine, 1820)	1.7	0	8.3	0	0	9.1	3.4
Pleuroxus uncinatus (Baird, 1850)	1.4	0	0	0	0	9.1	1.7
Cladocera gen. sp.		8.3	0	0	8.3	0	3.4
The average number of Cladocera species		**0.4 (3)**	**1.2 (3)**	**1.3 (5)**	**2.1 (6)**	**2.4 (9)**	**1.5 (12)**

Taxon	*S*	Month					Total
		May	June	July	August	September	
COPEPODA							
Cyclops vicinus Uljanin, 1875	1.8	0	8.3	0	0	0	1.7
Eucyclops lilljeborgi (Sars G.O., 1918)		0	8.3	0	8.3	0	3.4
Eudiaptomus graciloides (Lilljeborg, 1888)	1.7	0	0	0	0	9.1	1.7
Mesocyclops bodanicola Kiefer, 1928		0	8.3	0	8.3	9.1	5.1
Mesocyclops leuckarti (Claus, 1857)	1.7	0	16.7	16.7	25	45.5	20.3
Thermocyclops oithonoides (Sars, 1863)	1.3	0	0	0	8.3	0	1.7
Nauplii Copepoda gen. sp.		91.7	100	91.7	100	72.7	91.5
Copepodides Calanoida gen. sp.		0	8.3	0	8.3	9.1	5.1
Copepodides Cyclopoida gen. sp.		0	8.3	8.3	0	0	3.4
Copepodides Maxillopoda gen. sp.		50	66.7	83.3	100	72.7	74.6
The average number of Copepoda species		**1.4 (2)**	**2.2 (8)**	**2 (4)**	**2.6 (7)**	**2.2 (6)**	**2.1 (10)**
The average number of total species		**4.6 (19)**	**12.6 (35)**	**6.1 (23)**	**10.6 (34)**	**11.7 (33)**	**9.1 (69)**

a decrease in July and an increase again in August. A similar picture of two peaks of zooplankton development is typical for eutrophic and mesotrophic lakes of temperate latitudes (Sommer et al, 1986). Previously, a one-time increase in the abundance of zooplankton in June or July was revealed for Kazanka River zooplankton in 2010–2012 (Derevenskaya et al., 2015).

According to the successional PEG (Plankton Ecology Group) by Sommer's model (Sommer et al., 2012), starting positions in the pelagic ecosystem are predetermined by the state of the zooplankton community during previous autumn and by the changes occurring during wintering (Cáceres, 1998; Sommer and Lewandowska, 2011). In our material, the initial stage is well described by the May data. In May, the minimum values of average zooplankton production were observed (0.032 ± 0.024 g/m^3 per day) with an average abundance of 48.6 ± 29.6 thous. ind./m^3, and average biomass of 0.174 ± 0.114 g/m^3 (Fig. 3). Species richness and Shannon species diversity index, calculated by abundance, were also minimal, averaging 5 ± 1 taxa per station and 1.7 ± 0.1 bit/ind. respectively. At most sites, naupliar and copepodite stages of copepods dominated. In bay apex, *Keratella quadrata* and *Asplanchnopus multiceps* dominated at some stations. In bay mouth, cladoceran *Bosmina longirostris* developed abundantly. Despite the rather wide variability of May samples and the low level of similarity between them (on average 15% on the matrix), there is a concentration of most of the stations in area "A" (Fig. 2). In our opinion, this indicates a certain influence of river waters on the zooplankton communities of Kazan Bay in the spring due to floods. However, under the influence of local biotopic features of the winter period, original variants of spring zooplankton communities are formed. The influence of the waters of the Kuibyshev Reservoir during this period is apparently minimal.

Warming water, increased insolation, and the availability of nutrients ensure high growth of small forms of phytoplankton from May to June and the subsequent development of small zooplankton organisms (Birge and Juday, 1922). Our study also traced an increase in zooplankton production in June to an average of 0.220 ± 0.066 g/m^3 per day per station. This occurred primarily due to the increase in the number of rotifers, which outpaces the increase in the number of crustaceans. As the relative abundance of rotifers increases, the relative abundance of younger copepods decreases, which may indicate indirect competition between these two groups (Fig. 4). Rotifers are more successful in competition for food items due to their high reproductive rate (Herzig, 1979). The average abundance of zooplankton in the study area in June was 418.9 ± 78.9 thous. ind./m^3 with an average biomass of 2.142 ± 0.536 g/m^3.

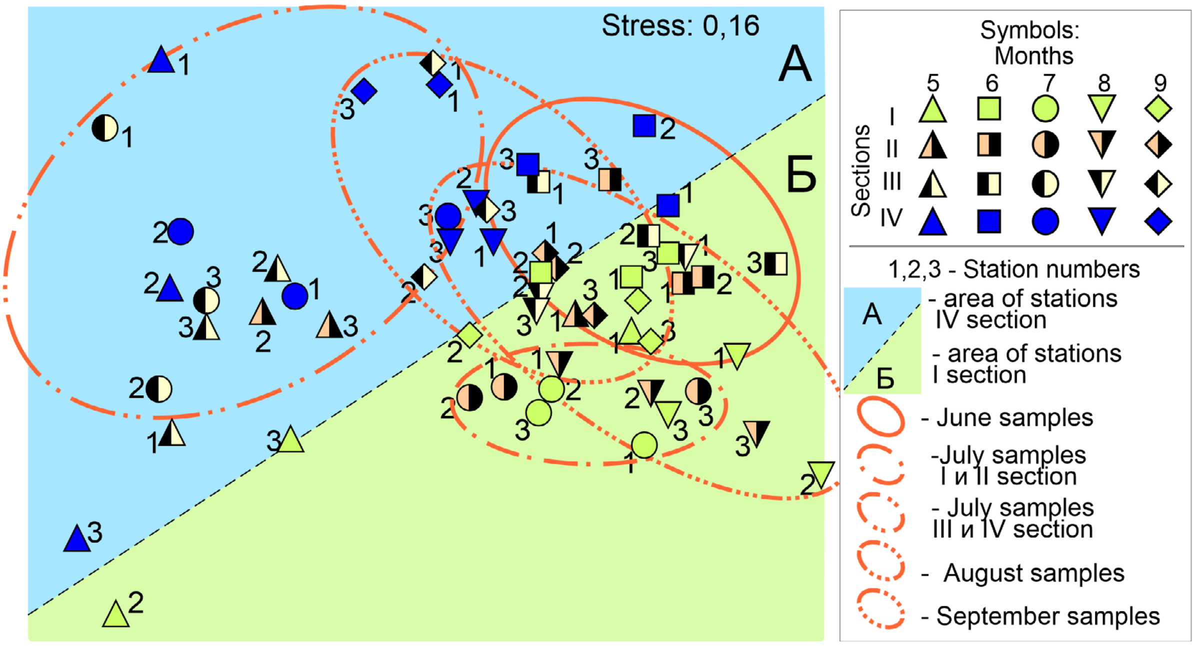

Fig. 2. MDS similarity diagram of Kazan Bay stations in May–September 2018 (based on the zooplankton production).

Species richness at stations has also increased to an average of 12 ± 1 taxa per station. The average level of biodiversity (*H*) was also maximum, 2.9 ± 0.1 bit/ind. The structure of zooplankton communities in June was quite similar in all areas. The average similarity coefficient between stations was 44% across the matrix. All stations were grouped in its upper right corner near the dividing line (Fig. 2). Rotifer *Asplanchna priodonta* was the dominant species at most of the stations. In the zone of influence of reservoir waters (stations of sections I and II), the subdominant forms were the younger copepodites of copepods, and in the zone of influence of river waters (stations of sections III and IV), rotifer *Brachionus calyciflorus* prevailed. Apparently, at this stage, the influence of river and reservoir waters faded into the background, and the prevailing factors were trophic relationships in the community.

The mass development of small planktonic phytophages leads to a decrease in the number and biomass of phytoplankton, which is expressed in the onset of the next stage of community development, so-called “clean water” phase (Birge and Juday, 1922; Deneke and Nixdorf, 1999; Sommer et al, 1986). Following the decrease in food supply, the abundance of zooplankters also decreases. According to our data, there was a significant decrease in zooplankton production in July (on average, down to 0.110 ± 0.056 g/m^3 per day). The average abundance of zooplankton at the stations in July was 84.7 ± 24.5 thous. ind./m^3, biomass, 0.788 ± 0.431 g/m^3. Species richness and biodiversity also decreased down to 6 ± 1 taxa per station and down to 1.6 ± 0.1 bit/ind. In fact, in July, a new, summer cycle of zooplankton succession starts; that is why the July indicators are similar to that obtained in May. Interesting changes are also occurring in the structure of zooplankton communities. Stations of sections I, II and stations of sections III, IV diverge quite far from each other, forming independent clusters (Fig. 2). The average similarity coefficient between stations of the first pair was about 40% according to the matrix, of the second pair, about 20%. The similarity between the monitoring stations of the first and second pairs averaged 7% according to the matrix. After a decrease in the number of rotifers in the lower half of the bay, younger copepodites of copepods became dominant forms; cladocerans *Daphnia cucullata* and *Daphnia longispina* were subdominants. In bay apex (section IV), the rotifers kept leading position in the structure of the zooplankton community; the rotifers *Brachionus calyciflorus*, *Asplanchna sieboldi*, *and Synchaeta pectinata* predominated there. At stations of section III, the naupliar stages of copepods were dominant, and the subdominants were the rotifers *Brachionus angularis* and *Brachionus calyciflorus*, and the cladoceran *Bosmina longirostris.* The high similarity between the stations of the first two sections and the dominance of crustacean representatives at them apparently indicates that the zooplankton fauna of Kazan Bay is largely influenced by the waters of the Kuibyshev Reservoir in July, during the low-water period of the Kazanka River, which may be traced even to stations of section III.

Table 2. Pairwise test of differences between stations and survey months (based on the averaged data across sections).

Cluster pairs	*R* Statistics	Significance level, %
May–June	0.630	0.1
May–July	0.111	15.0
May–August	0.620	0.1
May–September	0.435	0.3
June–July	0.657	0.1
June–August	0.574	0.1
June–September	0.595	0.2
July–August	0.380	1.6
July–September	0.494	0.3
August–September	0.585	0.1

Table 3. Pairwise test of differences between stations and sections (based on the average monthly data).

Cluster pairs	*R* Statistics	Significance level, %
I–II	–0.141	92.0
I–III	0.385	0.7
I–IV	0.543	0.2
II–III	0.267	1.7
II–IV	0.547	0.1
III–IV	0.052	30.0

At the next stage of succession, in accordance with Sommer's model (Sommer et al, 1986), a decrease in the pressure of phytophagous plankton provokes a repeated summer flowering of phytoplankton, which, in turn, leads to a repeated increase in the zooplankton abundance. This phenomenon was also observed in August, when average zooplankton production increased up to the values registered in June (0.262 ± 0.149 g/m^3 per day). The average zooplankton abundance was 378.3 ± 93.6 thous. ind./m^3, the average biomass, 3.964 ± 2.424 g/m^3. Species richness and biodiversity also increased in August up to 11 ± 1 taxa per station and up to 2.4 ± 0.1 bit/ind. The dynamics of zooplankton production separately across sections has a clear increase of zooplankton abundance in August (Fig. 5). The maximum amplitude of changes during this period occurred at stations in section I (0.794 g/m^3 per day) with subsequent decrease towards the bay mouth (section II, 0.194 g/m^3 per day; section III, 0.039 g/m^3 per day; section IV, 0.023 g/m^3 per day). A similar, but less pronounced peak was also observed in June, when the maximum was registered at stations of sections II and III. We assume that the presence of dams and bridges slows down succession in the pelagic communities of the Kazan Bay. At stations of the sections I and II, copepodite stages of copepods and cladoceran *Chydorus sphaericus* dominated. At stations of section III, nauplii of copepods and rotifers *Brachionus calyciflorus* predominated. Rotifers *Brachionus calyciflorus* and cladocerans *Daphnia cucullata* were dominant at stations of section IV. According to MDS diagram, stations of sections I, II and III are located in area "B". Stations of section IV, although located in area "A," locate quite close to the boundary line. In our opinion, indicates a significant influence on the composition and structure of zooplankton communities by the waters of the Kuibyshev Reservoir (Fig. 2).

According to Sommer's succession model (Sommer et al, 1986), multiple fluctuations in the abundance of phyto- and zooplankton may occur in summer, depending on the temperature regime of the

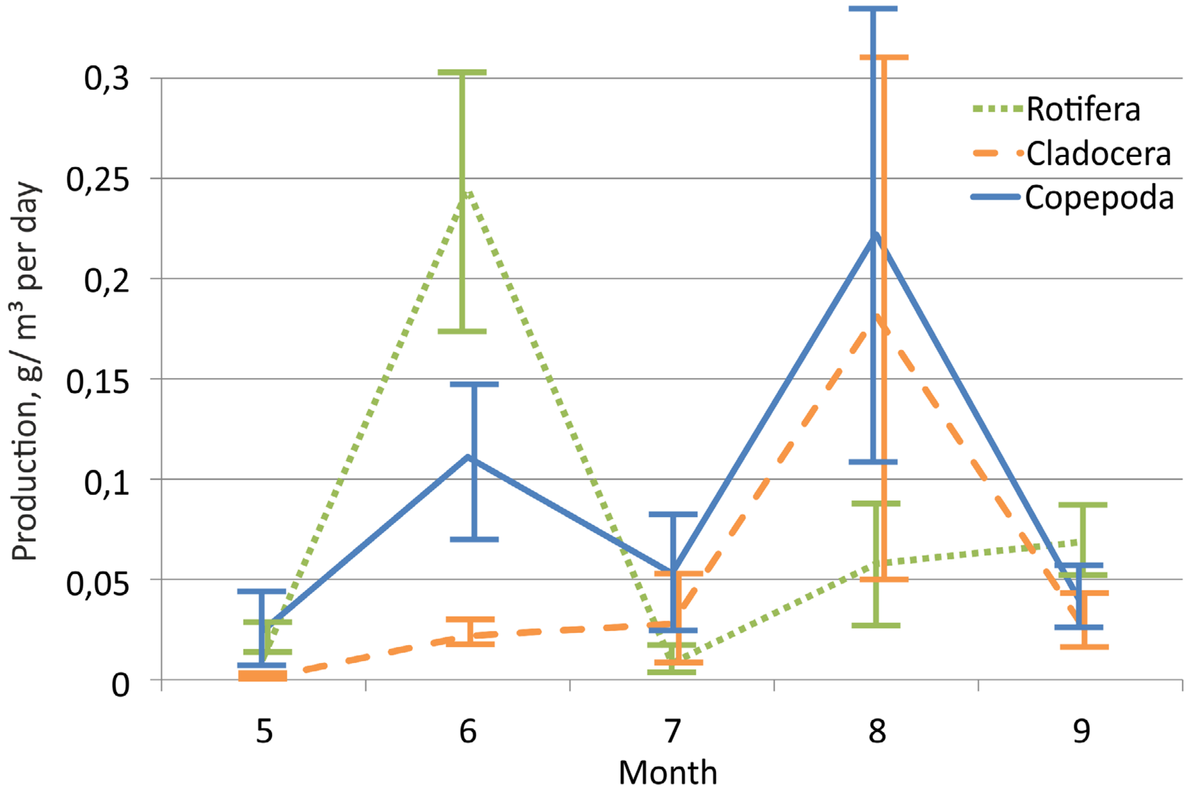

Fig. 3. Dynamics of absolute production of zooplankton taxonomic groups during the study period.

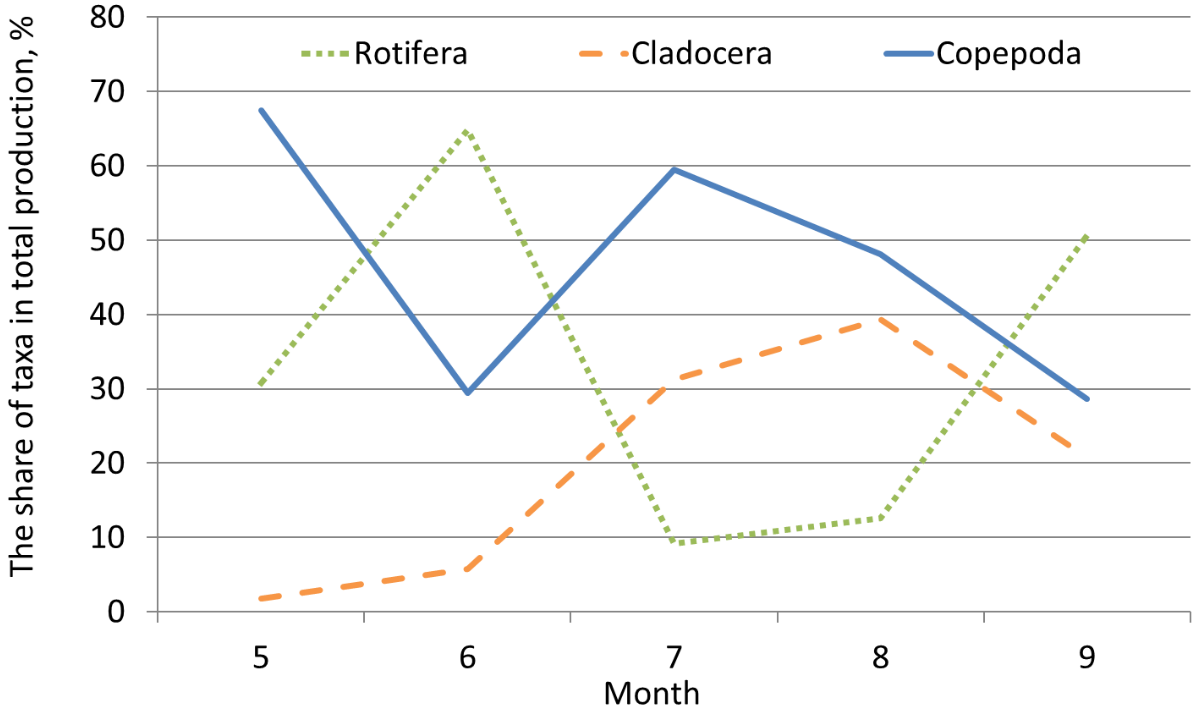

Fig. 4. Dynamics of relative production of zooplankton taxonomic groups during the study period.

reservoir and the availability of organic matter. However, in autumn, the intensity of ecological processes decreases along with a decrease in illumination and water temperature, which may be tracked by a drop in the zooplankton abundance and biomass. We noted an increase in the abundance of planktonic organisms after the “clean water” phase once in August; in September, an autumn decrease in zooplankton productivity was observed down to 0.059 ± 0.022 g/m^3 per day. This stage was most pronounced at the stations near the bay mouth. The average zooplankton abundance there was 175.1 ± 33.2 thous. ind./m^3, biomass, 0.894 ± 0.317 g/m^3. The number of taxa at stations was similar to that in June (12 ± 1 species per station), Shannon index averaged 2.6 ± 0.2 bit/ind. In general, Shannon index values we obtained for zooplankton communities in Kazan Bay for the entire growing season were consistent with previously published data (0.7–2.8 bit/ind.) for the Kazanka River (Mingazova et al., 2013). In contrast to August, in September the pattern has shifted towards the “A” region (Fig. 2). In our opinion, this indicates a significant influence of the Kazanka River waters. At stations of the sections II, III and IV, rotifers *Keratella quadrata* and *Brachionus calyciflorus,* and species of the genus *Asplanchna* dominate. At stations of section I, copepodite stages of copepods and cladoceran *Daphnia longiremis* predominate. Apparently, in September, as the reservoir water level decreases, the backwater boundary shifts and the influence of river water increases.

When analyzing the level of organic pollution using the Pantle–Buck method, the average saprobity index in 2018 was 1.8 ± 0.05; this corresponded to moderately polluted waters (β-mesosaprobic zone). Considering the dynamics of this index, it should be noted that the most favorable environment was observed in May and September (1.6 and 1.5), the least favorable, in July (1.9). We did not find any significant differences in the saprobity index in different areas of the Kazan Bay. The results obtained are fully consistent with the data of previous studies (Derevenskaya, 2017; Derevenskaya and Umyarova, 2017; Derevenskaya et al., 2015; Mingazova et al., 2013).

The well-being index (D_E), which describes the presence or absence of stress in zooplankton communities, varied from −0.5 to 0.4. The index value decreased with increasing productivity in June (from −0.08 ± 0.04 to −0.27 ± 0.03). An increase in the index was noted in July along with zooplankton abundance decline (−0.02 ± 0.04). A repeated decrease of the index was observed in August and September: −0.09 ± 0.03 and –0.11 ± 0.04, respectively. At the same time, a decrease of the index (i.e., of stress in the zooplankton community) was recorded during the period of the most active development of relatively large species. In the Kazan Bay of the Kuibyshev Reservoir, these were species of the genera *Asplanchna* (Rotifera) and *Daphnia* (Cladocera).

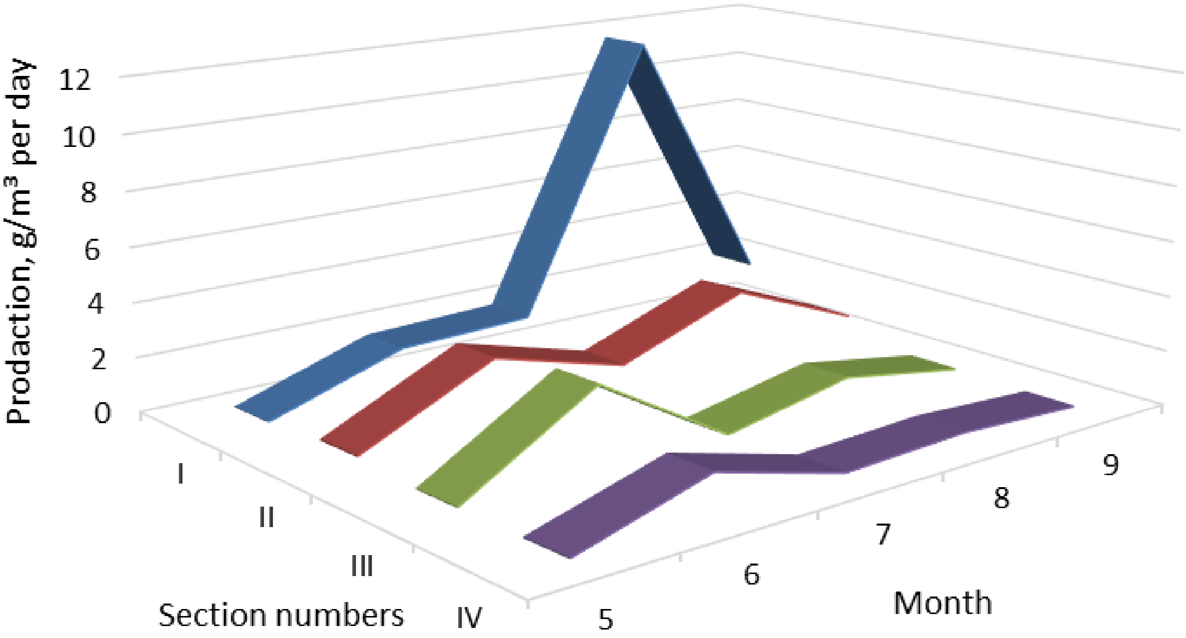

Fig. 5. Dynamics of total daily zooplankton production (P_{tot}) across the sections during the research period.

Conclusions

Research conducted in May–September 2018 made it possible to track the changes in the taxonomic composition of zooplankton in the Kazan Bay compared to data from 1999–2015, expressed in an almost twofold increase in the share of Rotifera in the species list. The abundance and biomass of zooplankton varied widely, but were generally consistent with the values obtained during previous studies (Derevenskaya, 2017; Derevenskaya et al., 2015; Mingazova et al., 2013). Two peaks in the quantitative development of zooplankton were observed, which corresponded to Sommer's successional PEG model (Sommer et al, 1986) characteristic of mesotrophic lakes of temperate latitudes. Statistical analysis revealed that the sampling month of (R = 0.472) and the distance of the site (section) from bay mouth (R = 0.279) influenced the structure of zooplankton communities. Dynamics of phenological events in the Kazan Bay has a saw shape due to the presence of a system of artificial dams that impede water exchange between sections of the bay, the waters of the Kuibyshev Reservoir, and the Kazanka River. Increase of the zooplankton abundance in May and August, when the reservoir water level was high, proceeded from the mouth areas to bay apex. The autumn decline of zooplankton abundance in September began from the bay apex under the influence of the Kazanka River waters. The increase in zooplankton abundance in June and August was accompanied by an increase in species diversity and a decrease in stress index values (negative D_E values), due to the appearance of larger forms (K-strategy species) in the community, which predetermined the system's tendency to stabilize. As a rule, cladocerans and copepods were the dominant species in communities formed under the influence of reservoir waters, rotifers, in communities affected by river waters. The degree of organic pollution calculated by Pantle–Buck method was the highest in mid-summer with a more favorable picture in May and September. In general, in 2018, the saprobity index of the Kazan Bay water area, determined by indicator species of zooplankton, corresponded to the long-term average level of moderately polluted waters (Derevenskaya, 2017).

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