Трансформация экосистем
Ecosystem Transformation

ISSN 2619-0931 Online
www.ecosysttrans.com

DOI 10.23859/estr-220816
EDN HGBFHT
УДК 574.583

Article

Interannual dynamics of the Ural River phytoplankton and different-type stretches of the Iriklinsky reservoir in spring

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Abstract. Our study revealed that water temperature and total atmospheric precipitation played the leading role in the interannual dynamics of phytoplankton in the unregulated section of the Ural River in spring of 2016–2019. With rise in water temperature, the concentration of nutrients and organic matter increased. In the Iriklinsky reservoir, the phytoplankton development depended on arrival of substances from the catchment, however, the cumulative effect of the ratio of major hydrological parameters and the total atmospheric precipitation was crucial. Due to this, the periods of the maximum quantitative development of the communities in each stretch differed in time. Phytoplankton transformation was diverse and hinged on the influence of the main river, including morphometric parameters of sites. For instance, most statistically significant changes in the studied parameters were recorded in the river and the upper reaches, while the least – in the low reaches of the reservoir.

Keywords: algae, weather conditions, hydrological characteristics, specific number of species, biomass, mixotrophic phytoflagellates, average single-cell mass, organic matter, nutrients

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Acknowledgements: We express our gratitude to the colleagues of the Saratov Branch of the Federal State Budgetary Scientific Institution "VNIRO" V.A Kolozin, L.V. Grishina, E.G. Kuzina, S.A. Mosiyash, I.G. Filimonova, as well as specialists from IBIW RAS L.G. Korneva, E.G. Sakharova, V.S. Vishnyakov and A.I. Tsvetkov for assistance in the collection of primary material, hydrochemical studies, identification of taxa and statistical processing.

To cite this article: Dzhayani, E.A., Shashulovskaya, E.A., 2023. Interannual dynamics of the Ural River phytoplankton and different-type stretches of the Iriklinsky reservoir in spring. *Ecosystem Transformation* **6** (3), 53–85. https://doi.org/10.23859/estr-220816

Received: 16.08.2022
Accepted: 13.09.2022
Published online:18.08.2023

DOI 10.23859/estr-220816
EDN HGBFHT
УДК 574.583

Научная статья

Межгодовые изменения фитопланктона реки Урал и разнотипных плесов Ириклинского водохранилища весной

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Аннотация. Показано, что ведущая роль в межгодовых изменениях фитопланктона незарегулированного участка р. Урал весной 2016–2019 гг. принадлежала температуре воды и сумме атмосферных осадков, при увеличении которой в воде повышалась концентрация биогенных элементов и органического вещества. В Ириклинском водохранилище развитие фитопланктона зависело от поступления веществ с водосбора, однако степень его воздействия в разных плесах определялась совместным влиянием суммы атмосферных осадков и соотношения основных гидрологических параметров. Благодаря этому в каждом плесе периоды максимального количественного развития сообществ имели временные различия. Фитопланктон исследованных участков отличался разной глубиной трансформации: наибольшее количество статистически значимых изменений изученных показателей характерно для реки и верхнего плеса водохранилища, наименьшее – для нижних плесов, что определялось степенью влияния главной реки и морфометрическими параметрами участков.

Ключевые слова: водоросли, погодные условия, гидрологические характеристики, удельное видовое богатство, биомасса, миксотрофные фитофлагелляты, средняя индивидуальная масса, органическое вещество, биогенные элементы

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Благодарности: Выражаем признательность коллегам Саратовского филиала ФГБНУ «ВНИРО» В.А. Колозину, Л.В. Гришиной, Е.Г. Кузиной, С.А. Мосияш, И.Г. Филимоновой, а также специалистам ИБВВ РАН Л.Г. Корневой, Е.Г. Сахаровой, В.С. Вишнякову и А.И. Цветкову, оказавшим неоценимую помощь в сборе первичного материала, гидрохимических исследованиях, определении ряда таксонов и статистической обработке.

Для цитирования: Джаяни, Е.А., Шашуловская, Е.А., 2023. Межгодовые изменения фитопланктона реки Урал и разнотипных плесов Ириклинского водохранилища весной. *Трансформация экосистем* **6** (3), 53–85. https://doi.org/10.23859/estr-220816

Поступила в редакцию: 16.08.2022
Принята к печати: 13.09.2022
Опубликована онлайн:18.08.2023

Introduction

Clearly, all types of water bodies are unique, but of special note are built from the ancient times such quasi-natural ecosystems as reservoirs. The first-ever reservoir was created in 2950–2750 BC in Egypt. In Russia, man-made water bodies appeared not long ago, i.e. in 1701–1709 during the Vyshnevolotsk water system construction. In the 20th century, the reservoirs were built all over the world (Datsenko, 2007). Their significance in shaping biological diversity, resources and water quality of large river ecosystems, as well as in solving important economic and social problems is beyond question. Hence, studying biological regimes of reservoirs is among topical issues of fundamental and applied science.

Along with a technogenic component, the influence of natural regime of the main river and its tributaries also play a large role in the formation of hydrological regimes of reservoirs (Datsenko, 2007; Datsenko et al., 2017; Edelshtein et al., 2017). Climate change brings to transformation of water regime of Russia and world rivers (Frolova et al., 2022; Pozdniakov et al., 2022; Rets et al., 2022; Wang et al., 2021) including hydrological, hydrochemical and biological regimes of the regulated river sections in different natural zones. The most vulnerable are the water bodies in the forest-steppe and steppe areas, where in the short run aridization is expected (Edelgerieva, 2019; Magritsky and Kenzhebaeva, 2017). They cover a significant territory of the Ural River basin, including the moderately and slightly desertificated sites in the Orenburg region (Zonn et al., 2004).

The Ural River is among top-three longest watercourses of Europe (2428 km); its ecological state is dependent on such anthropogenic factors as tillage, industrial and municipal wastewater, deposits development, and a regulated flow as well (Chibilev et al., 2006; Solovykh et al., 2003). In the Russian part of the river basin, there are 11 reservoirs. The largest Iriklinsky (Chibilev et al., 2006) is located in the low part of the upper reaches of the Ural River. Here, geology, topography, soils, vegetation and climate have formed a peculiar hydrological river regime, which is characterized by low water, low runoff rate, insignificant groundwater supply, and large-scale variations of interannual runoff. The water content in high- and low-water years differs by 8–10 times (Magritsky and Kenzhebaeva, 2017; Magritsky et al., 2018; Sivokhip, 2014; Solovykh et al., 2003). From these river features, it is feasible to identify the tendencies in dynamics of the aquatic community structure of its regulated sections under different water conditions.

It is worth noting that the reservoir water area includes extremely heterogeneous sites with different hydrological and morphometric characteristics, decisive for water balance peculiarities. With predominance of the horizontal component of external water exchange, the catchment role is most important, while at vertical – inner water body processes are in the lead (Datsenko, 2007). From this we assume that changes in aquatic communities in different-type reaches of the Iriklinsky reservoir influenced by considerable interannual variations of abiotic factors have specific features, which can be most pronounced in spring when runoff of the Ural river accounts for 65–80% (up to 90%) per annum (Chibilev et al., 2006).

Phytoplankton is the primary link in the food chain and a key element in the processes of the biotic cycle and water self-purification. Phytoplankton characteristics serve as indicators of the ecological state of various aquatic ecosystems, including reservoirs (Datsenko, 2007; Datsenko et al., 2017; Edelshtein et al., 2017; Korneva, 2015; Okhapkin, 1997).

The literature presents the data on phytoplankton from the middle and low reaches of the Ural River mainly devoted to the analysis of the species composition of communities and saprobic characteristics of waters (Blumina, 1962; Drabkin and Blumina, 1963; Fokina, 1968; Gidrobiologiia reki Url, 1971; Kiselev, 1954; Poryadina, 1971, 1973a, b; Poryadina and Ergashev, 1975). Information on phytoplankton of the upper river reaches, where the Iriklinsky reservoir is located, is limited. For instance, V.N. Baturina (1970b) reports only about low abundance of phytoplankton above the reservoir. The studies (1960s) of the Iriklinsky reservoir phytoplankton are evidence of the highest species composition, number and biomass in its upper reaches. In May, the phytoplankton biomass varied here from 0.1 to 14 mg/l. In the low reaches, phytoplankton was almost completely absent (Baturina, 1970a, b; Poryadina and Zhovnir, 1983); any data on the long-term averages do not exist (Eremkina, 2020). To perform a comparative analysis of phytoplankton in different-type sections of the reservoir with different water content is hardly possible because of scarce and fragment data on the quantitative characteristics of phytoplankton (Solovykh et al., 2003).

The purpose of this work is to study the interannual dynamics of the quantitative characteristics and phytoplankton structure in different-type reaches of the Iriklinsky reservoir under interannual variations of weather, hydrological and related hydrochemical factors in spring of 2016–2019.

Material and methods

Brief description of the reservoir

The filling of the regulated channel-type reservoir began in 1955. Its normal headwater level (NHL) was reached in 1966 (Chibilev et al., 2006). At NHL of 245 m, its volume is 3.25 km^3, the area – 260 km^2, and the length – 73 km. Release of the reservoir is under 6 m, water exchange takes place once every two years, and the catchment area of the reservoir makes up 36900 km^2. The reservoir has several channel reaches and a number of large lateral bays (Fig. 1). The upper among the studied reaches – Chapaevsky, covers an area of 26 km^2, its maximum width and depth – 2 km and 15 m; the reaches Sofinsky, Tanalyk-Suunduksky and Priplotinny – 23 km^2, 3 km, 15 m; 61 km^2, 7 km, 28 m; 3 km^2, 0.8 km, 36 m, respectively (Solovykh et al., 2003).

Weather and hydrological conditions

According to the data from the open sources available at (http://rp5.ru; https://www.meteoblue.com/ru/climate-change), the highest air temperature was recorded in May of 2016 and 2018, the largest total precipitation – in 2017 and the least – in 2019 (Table 1). Similar to input volumes in 2016, water level and escapages of the reservoir in 2017 were maximum, whereas the minimum indicators of these parameters were noted in 2018 and 2019, respectively (Table 2).

Sampling and processing methods

Phytoplankton was collected in May of 2016–2019 from transverse sections (left and right banks, midstream) of the Ural River and the reaches of the reservoir (more than 70 in total) (Fig. 1). Sampling was carried out by standard methods. Algae, fixed with the Utermel solution and formalin, were further concentrated by the sedimentation method (Metodicheskie rekomendatsii..., 1984).

We defined water transparency using a Secchi disk, measured the surface water temperature and analyzed the content of dissolved oxygen, organic matter and nutrients in the samples taken for hydrochemical studies. To do that, the generally accepted methods of titrimetric and photometric analysis described in detail in E.A. Shashulovskaya et al. (2020a) were used.

Algae were studied with the use of a Micromed-3 light microscope in the Uchinskaya-2 chamber of 0.01 ml, and biomass was calculated via the counting-volume method. Species with a biomass of ≥ 10% were identified as dominant. The phytoplankton state was assessed due to specific number of species per sample, biomass, average single-cell mass, and biomass of mixotrophic phytoflagellates (cryptophytes, dinophytes, chrysophytes, euglenoids). The trophic status of the water body was identified by phytoplankton biomass (Kitaev, 2007), whereas the water quality – using the Pantle-Bukk saprobity index modified by Sladeček (Sládeček, 1973) in accordance with the indicator significance of species from the Wegl lists (Wegl, 1983). We employed the STATISTICA 13 software package for statistical data processing, verification of distribution normality, determination of the Pearson correlation coefficient ($p < 0.05$), and evaluation of statistical significance of means' difference via one-way ANOVA ($p < 0.05$) and Tukey's HSD test.

Results

Physical and chemical characteristics of water

The content of dissolved oxygen during the study period varied as 95–125%. In 2016, it was lower (75–94%). Oxygen concentrations were high in all reaches of the reservoir; supersaturation in most samples was, probably, induced by developing bioproduction processes.

Water temperature ranged within 8.4–16.3 °C. In 2016, the water area of the reservoir was least heated (average: 11.5 °C). During the warmest year of 2019, water temperature exceeded the average by 1.3 °C. In all years of observation, a drop in water temperature was noted in the direction from the upper to low reaches of the reservoir due to faster warming of the shallow Chapaevsky reach in spring.

Water transparency and water color index changed as 1.1–2.7 m and 12.3–43.4°, respectively. Maximal transparency was in the deep-water Priplotinny reach. The highest values of the water color index, on the contrary, were observed in the upper reaches of the reservoir most influenced by the Ural waters (Shashulovskaya et al., 2017). Depending on the content of humic substances of terrigenous

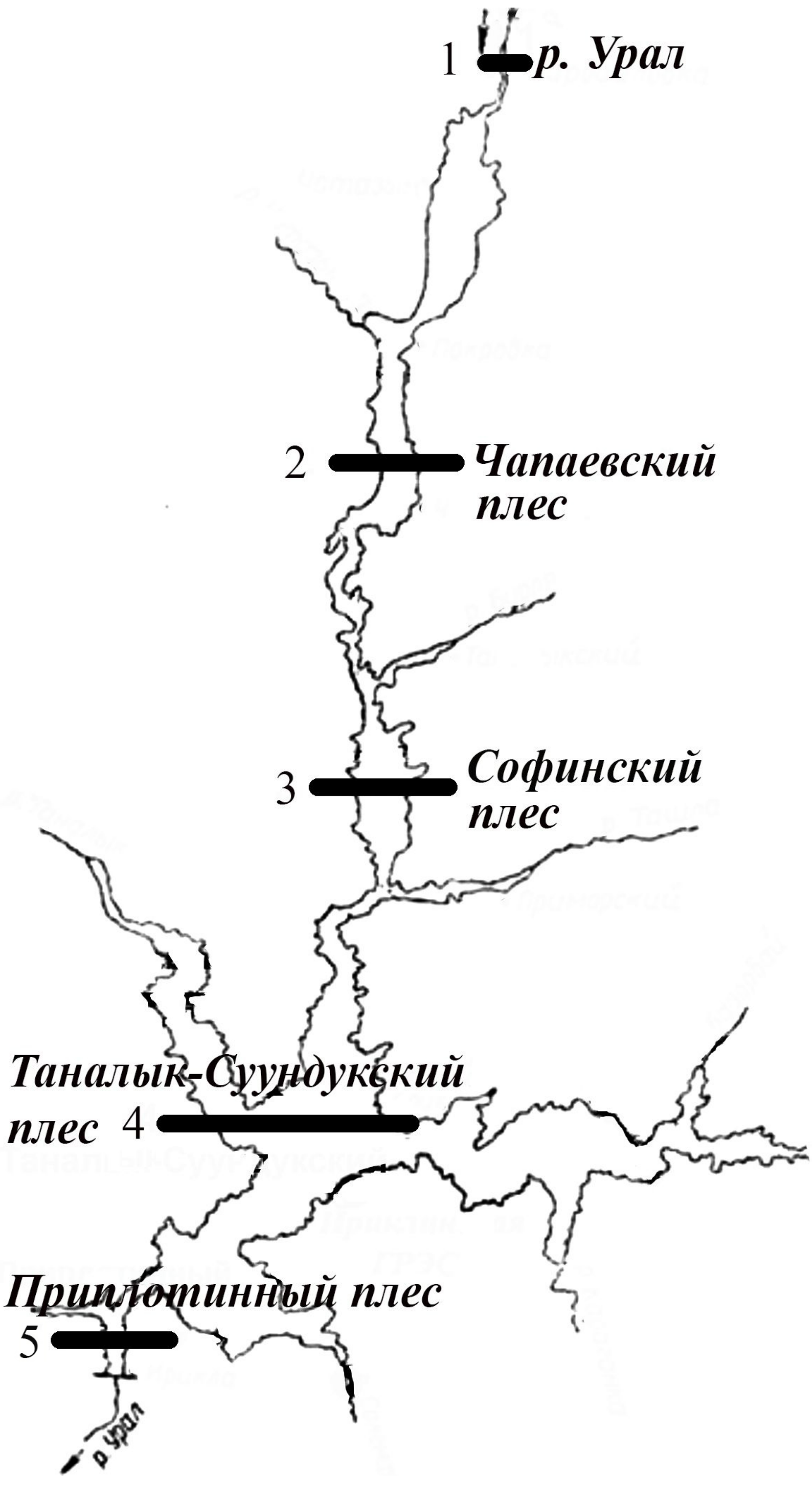

Fig. 1. Schematic map of the Iriklinsky reservoir; 1–5—sampling sites.

Table 1. Air temperature and total atmospheric precipitation near the Iriklinsky reservoir.

Month	Air temperature, °C				Total precipitation, mm			
	2016	2017	2018	2019	2016	2017	2018	2019
IV	8.5	6	5.6	5.1	32.7	21.1	24.5	26.0
V	15.1	13.7	15.1	14.7	29.4	58.2	22.6	15.0

Table 2. Fluctuations in water level, inflow and escapage volumes of the reservoir.[1].

Month	Water level, m				Input volume, m^3/s				Discharge volume, m^3/s			
	2016	2017	2018	2019	2016	2017	2018	2019	2016	2017	2018	2019
IV	242.7	243.5	243.1	242.4	278.5	276.2	202.7	61.2	25.7	48.8	19.2	15.0
V	244.6	244.9	244.0	242.6	175.8	104.4	83.2	54.1	37.5	67.8	15.0	24.2

origin (Zobkova et al., 2015), this indicator had its peak in 2017 despite the reduced (compared to 2016) spring inputs. Obviously, water color intensity during this period was induced by the maximum total precipitation in the reservoir catchment (Table 1). Permanganate oxidizability (PO) characterized the content of allochthonous organic matter (Lozovik et al., 2017); distribution of its values and color variations well correlated. We noted higher PO values in the Chapaevsky and Sofinsky reaches with its further drop along the longitudinal axis of the reservoir. In 2017, PO concentrations and color intensity were the greatest in the waters of the Chapaevsky and Sofinsky reaches. In 2019, allochthonous organic matter was minimal because of low input volumes and total precipitation.

The content of total (COD) and easily oxidized (BOD_5) organic matter varied within 25–38 mgO/L and 0.9–5.2 mgO_2/L, respectively (Table 3). These indicators slightly differed both for the sites along the longitudinal axis of the reservoir and interannual data.

The distribution of compounds of mineral nitrogen (greatly contributing to eutrophication) along the longitudinal axis of the Iriklinsky reservoir was similar to water color dynamics. The upper reaches (Chapaevsky and, in some years, Sofinsky) were distinguished by much higher concentrations of ammonium nitrogen, nitrites, and nitrates. Peak concentrations of ammonium nitrogen were recorded in 2016, and nitrates – in 2017 (Table 3). It should be noted that in 2017, color values were also maximal in the reservoir, suggesting the predominance of a terrigenous source in the genesis of nitrates. The concentration of nitrites was negligible (< 6 μg/l) that is typical for unpolluted water bodies with a sufficient oxygen content. The average concentrations of ammonium were 2.8 times lower in 2019 than in 2016, and those of nitrate – 6.8 times less than in 2017.

Unlike allochthonous matter and mineral nitrogen compounds, the distribution of mineral phosphorus (the second most important nutrient) along the longitudinal axis of the reservoir was more uniform. A significant gradient of its concentrations was noted only in 2017–2018, being almost two times greater than in the Tanalyk-Suunduk and Priplotinny reaches. As stated earlier in (Shashulovskaya et al., 2020b), the inner aquatic processes (diffusion from bottom sediments, sedimentation, turnover rate) are essential for dynamics of phosphates, therefore, the role of climatic and hydrological factors in their balance is less as compared to nitrogen compounds.

In all years of observations, the reduced concentrations of silicon and iron in the waters were marked in the direction from the Chapaevsky to the Priplotinny reach. In the dry year of 2019, the concentrations of these elements and other compounds were the lowest.

An analysis of the correlation coefficients suggests that input volume (r = 0.76), water level (r = 0.89) and discharge volume (r = 0.97) positively relate with the total atmospheric precipitation. The latter

[1] Operations Department of the Iriklinskoye Reservoir, 2009–2023. Web page. URL: http://ueiv.ru (accessed: 16.04.2020).

Table 3. Mean values (m) and standard deviation (SD) of physicochemical water parameters for the water area sites studied in May 2016–2019. *F* is the Fisher criterion; *p* – the level of significance; statistically significant differences between the studied years according to ANOVA ($p < 0.05$) are in bold; * – statistically significant differences between the study years averages (a–d) according to Tukey's HSD test ($p < 0.05$). I is the unregulated section of the Ural River, II – Chapaevsky reach, III – Sofinsky reach, IV – Tanalyk-Suuduksky reach, V – Priplotinny reach.

Indicator	Site	2016[a]		2017[b]		2018[c]		2019[d]		*F*	*p*
		m	*SD*	*m*	*SD*	*m*	*SD*	m	SD		
Indicator, °C	I	13.1^{*b-d}	0.0	14.8^{*d}	0.1	15.1^{*d}	0.1	13.8	0.6	**29.7**	**0.000**
	II	13.1^{*b,d}	0.1	16.3^{*c,d}	0.2	13.5^{*d}	0.3	14.6	0.3	**63.1**	**0.000**
	III	12.6	0.1	12.5	0.2	12.6	1.1	11.4	0.6	1.0	0.428
	IV	9.7^{*d}	0.5	8.4^{*c,d}	0.4	11.4	0.4	12.4	2.1	**5.9**	**0.020**
	V	10.7^{*d}	0.6	10.9^{*d}	0.2	10.8^{*d}	0.7	12.7	0.5	**4.3**	**0.043**
Transparence, m	I	0.4	0.1	0.5	0.1	0.6	0.1	0.6	0.2	1.0	0.414
	II	1.1	0.1	1.3	0.1	1.1	0.1	1.1	0.2	1.5	0.278
	III	1.4^{*d}	0.1	1.3^{*d}	0.1	1.6	0.0	1.7	0.2	**5.9**	**0.020**
	IV	2.5	0.5	2.1	0.4	2.2	0.3	1.8	0.8	0.4	0.728
	V	2.7^{*b-d}	0.1	1.6^{*d}	0.1	1.8^{*d}	0.0	2.1	0.2	**43.1**	**0.000**
Water color index, °	I	25.8	–	29.6	–	23.0	–	22.0	–	–	–
	II	27.0^{*b,d}	0.5	41.6^{*c,d}	3.5	33.0^{*d}	2.2	19.0	1.0	**21.0**	**0.000**
	III	27.9^{*b,d}	0.4	43.4^{*c,d}	0.6	26.8^{*d}	0.5	13.3	1.2	**463.7**	**0.000**
	IV	14.4^{*b}	0.9	22.9^{*c,d}	3.3	15.7	0.2	12.3	0.6	**7.3**	**0.011**
	V	13.2^{*b}	0.9	18.7^{*d}	2.0	16.0	0.4	13.0	1.0	**5.4**	**0.026**
O_2, mg/l	I	8.7	–	10.0	–	10.6	–	11.5	–	–	–
	II	9.3^{*b-d}	0.3	11.9^{*d}	0.5	11.4	0.1	10.7	0.5	**13.0**	**0.002**
	III	8.1^{*b-d}	0.2	12.2^{*d}	0.5	11.5	0.3	10.9	0.5	**27.2**	**0.000**
	IV	9.4^{*b-d}	0.4	13.1^{*c,d}	0.4	11.3	0.3	11.5	1.0	**13.0**	**0.002**
	V	8.7^{*b-d}	0.2	12.9^{*c,d}	0.3	11.8^{*d}	0.1	11.1	0.4	**68.9**	**0.000**

Indicator	Site	2016[a]		2017[b]		2018[c]		2019[d]		*F*	*p*
		m	*SD*	*m*	*SD*	*m*	*SD*	m	SD		
PO, mgO/l	I	7.8	–	8.2	–	5.9	–	5.3	–	–	–
	II	7.4*[b,d]	0.2	8.4*[c,d]	0.1	7.6*[d]	0.3	5.2	0.2	**51.1**	**0.000**
	III	7.2*[b-d]	–	8.2*[c,d]	–	5.9*[d]	0.2	5.3	0.0	**226.2**	**0.000**
	IV	5.9	–	6.1	1.1	4.4	0.3	5.2	0.2	1.8	0.225
	V	5.4*[d]	0.1	4.5	0.2	5.0	0.2	4.4	0.8	2.7	0.118
COD, mgO/l	I	38	–	37	–	39	–	47	–	–	–
	II	38*[b-d]	–	30*[d]	1	30*[d]	–	27	0	**60.9**	**0.000**
	III	30*[b-d]	–	27	1	25	–	25	0	**15.4**	**0.001**
	IV	31*[c]	–	28	2	25	–	28	0	**5.5**	**0.024**
	V	27*[c]	–	29*[d]	2	31*[d]	–	26	0	**9.1**	**0.006**
BOD_5, mgO_2/l	I	–	–	2.3	–	3.2	–	1.6	–	–	–
	II	3.7*[d]	0.7	3.6*[d]	–	3.6*[d]	–	2.1	0.0	**4.5**	**0.040**
	III	5.2*[c,d]	1.6	3.3	–	0.9	–	2.3	0.0	**5.0**	**0.031**
	IV	3.7	0.7	3.2	–	2.8	–	3.4	0.0	1.1	0.406
	V	2.0*[b]	0.7	3.8*[c]	0.2	2.9	–	2.2	0.0	**4.9**	**0.032**
$N\text{-}NH_4$, mg/l	I	0.26	–	0.12	–	0.30	–	0.10	–	–	–
	II	0.22*[d]	0.04	0.19*[d]	0.01	0.19*[d]	0.02	0.10	0.00	**5.0**	**0.030**
	III	0.29*[b-d]	0.01	0.19*[c,d]	0.01	0.14*[c,d]	0.01	0.08	0.00	**113.2**	**0.000**
	IV	0.25	0.12	0.11	0.02	0.19	0.05	0.09	0.00	1.3	0.352
	V	0.14*[b-d]	0.02	0.05	0.01	0.05	0.01	0.04	0.00	**26.0**	**0.000**

Indicator	Site	2016[a]		2017[b]		2018[c]		2019[d]		*F*	*p*
		m	*SD*	*m*	*SD*	*m*	*SD*	m	SD		
$N\text{-}NO_2$, µg/l	I	17	–	10	–	15	–	10	–	–	–
	II	14*[b,d]	3	23*[c,d]	2	12	0	<6	–	**26.9**	**0.000**
	III	18*[c,d]	3	23*[c,d]	–	9*[d]	1	<6	–	**28.8**	**0.000**
	IV	<6*[c]	–	10*[c,d]	0	<6	–	<6	–	**4.3**	**0.043**
	V	<6*[b,c]	–	<6*[d]	–	<6*[d]	–	<6	–	**5.7**	**0.022**
$N\text{-}NO_3$, mg/l	I	0.82	–	1.45	–	1.31	–	0.66	–	–	–
	II	0.34	0.04	0.44*[c,d]	0.05	0.28*[d]	0.03	0.10	0.00	**16.5**	**0.001**
	III	0.39*[b,d]	0.03	0.75*[c,d]	0.02	0.46*[d]	0.09	0.04	0.00	**41.3**	**0.000**
	IV	0.10	0.01	0.16	0.09	0.06	0.02	0.05	0.00	1.1	0.420
	V	0.06*[b]	0.03	0.28*[c,d]	0.07	<0.02	–	0.05	0.00	**10.2**	**0.004**
$P\text{-}PO_4$, mg/l	I	0.035	–	0.11	–	0.13	–	0.10	–	–	–
	II	0.036*[b-d]	0.000	0.064*[d]	0.007	0.073*[d]	0.006	0.019	0.000	**32.4**	**0.000**
	III	0.034*[b-d]	0.003	0.077*[c,d]	0.002	0.10*[d]	0.01	0.010	0.000	**71.3**	**0.000**
	IV	0.040*[c,d]	0.000	0.040*[d]	0.000	0.050*[d]	0.010	0.013	0.000	**21.5**	**0.000**
	V	0.021*[b,c]	0.005	0.043*[d]	0.007	0.057*[d]	0.004	0.016	0.000	**17.2**	**0.001**
Si, mg/l	I	3.7	–	3.6	–	1.4	–	2.6	–	–	–
	II	2.9*[d]	0.2	3.3*[d]	0.2	2.7*[d]	0.3	1.1	0.0	**29.3**	**0.000**
	III	3.5*[c,d]	0.1	3.6*[c,d]	0.1	2.8*[d]	0.1	1.2	0.0	**229.9**	**0.000**
	IV	1.6*[c]	0.1	1.8*[c]	0.1	2.1*[d]	–	1.8	0.0	**7.0**	**0.013**
	V	1.1*[b-d]	0.0	1.8*[c,d]	0.1	2.5*[d]	0.1	2.1	0.0	**74.7**	**0.000**
Fe, mg/l	I	0.26	–	0.15	–	0.17	–	0.24	–	–	–
	II	0.27*[d]	0.02	0.26*[d]	0.03	0.23*[d]	0.02	0.13	0.00	**10.3**	**0.004**
	III	0.25*[d]	0.02	0.21	0.01	0.23	0.04	0.17	0.00	2.8	0.106
	IV	0.21*[b-d]	0.02	0.15*[c]	0.01	0.07	0.01	0.12	0.00	**14.0**	**0.002**
	V	0.09*[b]	0.01	0.13*[c,d]	0.01	0.06	0.02	0.09	0.00	**7.6**	**0.010**

contributed to the surface runoff of biogenic and organic matter from the basin. As a result, most chemical parameters of water well correlated with the total precipitation, water level, input and discharge volumes (Table 4). The best and most numerous correlations were revealed for the upper part of the reservoir, i.e. the Chapaevsky and Sofinsky reaches (most affected by the main river) and the Tanalyk-Suunduksky reach (connected with its two largest tributaries – the rivers Tanalyk and Suunduk).

The Ural River phytoplankton

In 2017, the specific number of phytoplankton species was the highest; it significantly exceeded that for 2016 ($p = 0.005$), 2018 ($p = 0.011$) and 2019 ($p = 0.001$) (Fig 2**A**) due to diatoms, greens and dinophyte algae (Table 5). This indicator was the lowest for greens and cryptophytes species in 2016 and for diatoms – in 2019. In 2018–2019, cyanobacteria was not detected in phytoplankton at all.

The highest phytoplankton biomass was recorded in 2018, being statistically much higher than in 2016, 2017, and 2019 (p = 0.000, 0.048, and 0.000, respectively). At the same time, in 2016 and 2019, biomass was lower than in 2017 ($p = 0.000$ and $p = 0.005$) (Fig. 3**A**). In 2017–2018, diatoms prevailed in phytoplankton biomass and cryptophytes, dinophytes and euglenoids in 2017 (Table 5). Diatoms formed the basis for biomass, with the maximum share in 2018 and the minimum one – in 2017 (Table 5). As compared to other years of observations, the share of green algae reached its maximum in 2019; euglenoids – in 2017; cryptophytes – in 2019 and 2017; *Ulnaria ulna* (Nitzsch) Compère (21.3%) dominated in 2016; *Euglena viridis* (O.F. Müller) Ehrenberg (16.9%), *Ulnaria ulna* (10.8%), *Surirella brebissonii* var. *kuetzingii* Krammer & Lange-Bertalot (10.0%); *Ulnaria ulna* (60.8%)

Table 4. Correlation coefficients between weather conditions (April–May), hydrological parameters (April–May), and hydrochemical characteristics of the Iriklinsky reservoir reaches in 2016–2019. Designations are given as in Table 3. Statistically significant ($p < 0.05$) coefficients are in bold.

Indicator	Site	O_2	PO	COD	BOD_5	$N\text{-}N_H4$	$N\text{-}NO_3$	$P\text{-}P_O4$	Si	Fe
Total precipi-tation	II	0.20	**0.77**	0.39	0.50	0.47	**0.86**	0.39	**0.76**	**0.68**
	III	0.17	**0.99**	0.47	0.45	0.65	**0.84**	0.33	**0.83**	0.19
	IV	0.32	0.50	0.30	0.09	0.02	0.53	0.37	−0.39	0.52
	V	0.22	0.04	0.09	0.51	0.22	**0.78**	0.19	−0.51	**0.69**
Water level	II	0.28	**0.96**	0.44	**0.71**	**0.66**	**0.92**	**0.71**	**0.94**	**0.83**
	III	0.22	**0.90**	0.39	0.25	**0.69**	**0.95**	**0.69**	**0.96**	0.44
	IV	0.23	0.29	0.05	−0.10	0.16	0.45	**0.73**	−0.07	0.28
	V	0.25	0.20	0.46	0.54	0.24	**0.58**	0.53	−0.29	0.39
Input volume	II	−0.23	**0.80**	**0.84**	**0.72**	**0.77**	**0.82**	0.39	**0.86**	**0.86**
	III	−0.26	**0.82**	**0.71**	**0.60**	**0.95**	**0.73**	0.45	**0.97**	**0.53**
	IV	−0.26	0.35	0.39	0.13	0.38	0.37	**0.64**	−0.33	**0.60**
	V	−0.30	0.49	0.20	0.14	**0.70**	0.31	0.19	**−0.66**	0.24
Discharge volume	II	0.31	**0.62**	0.16	0.33	0.28	**0.74**	0.28	**0.60**	0.50
	III	0.29	**0.93**	0.34	0.38	0.46	**0.75**	0.19	**0.66**	0.02
	IV	0.49	0.51	0.26	0.09	−0.13	0.52	0.18	−0.40	0.45
	V	0.36	−0.15	−0.01	0.56	0.02	**0.87**	0.11	−0.41	**0.79**

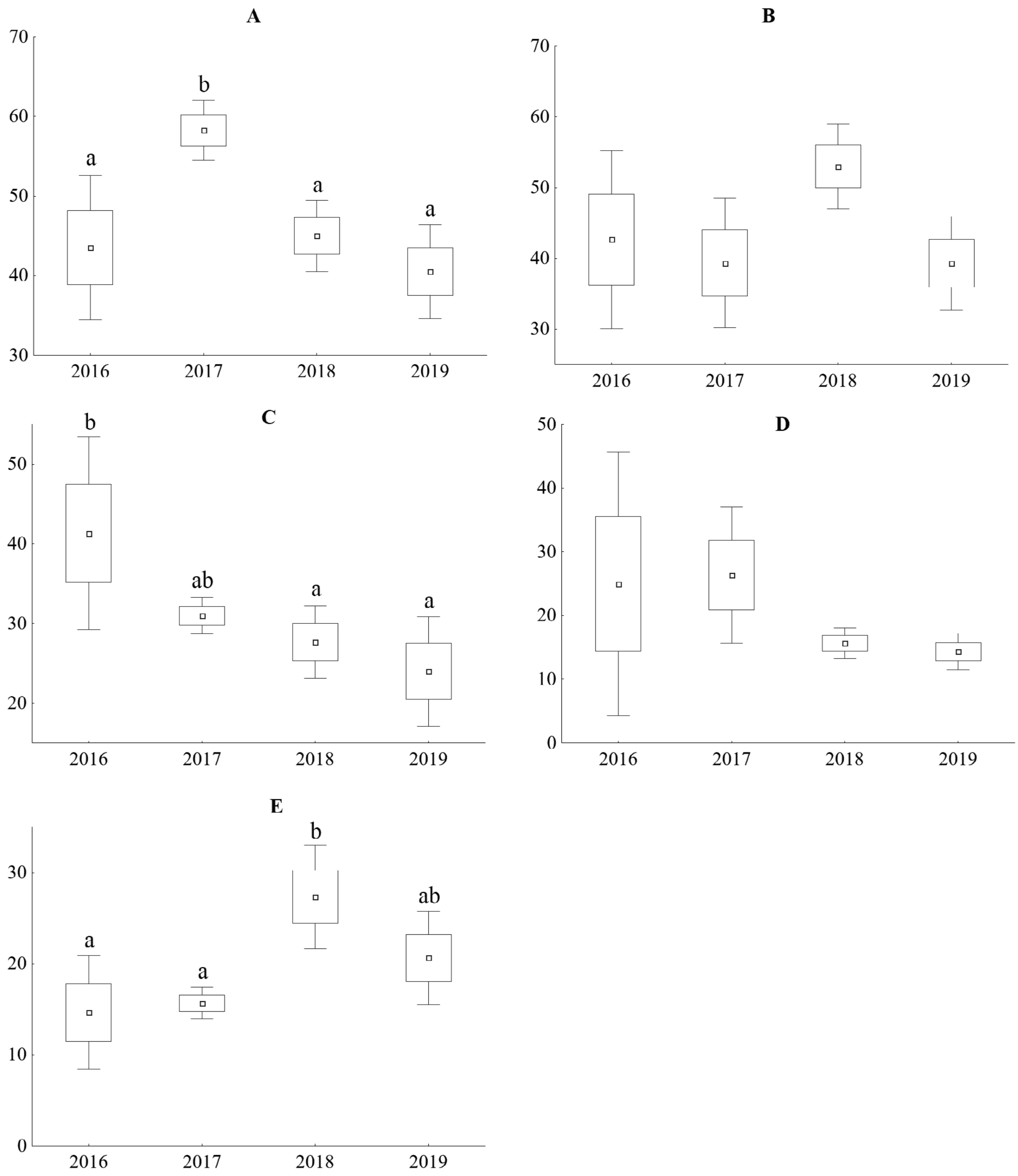

Fig. 2. Specific number of phytoplankton species of the Ural river (**A**), Chapaevsky (**B**), Sofinsky (**C**), Tanalyk-Sunduksky (**D**) and Priplotinny (**E**) reaches of the Iriklinsky reservoir (May 2016–2019).

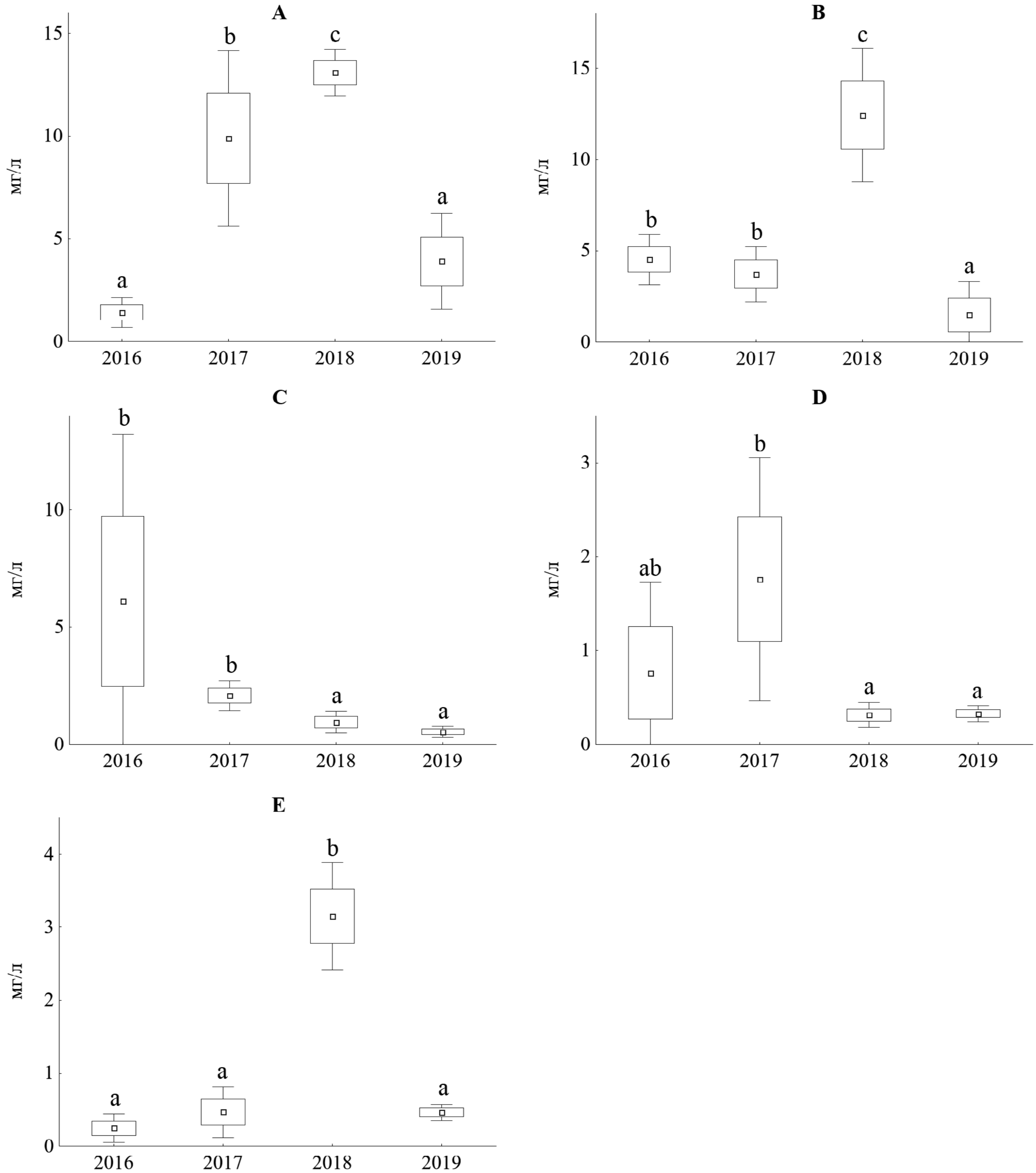

Fig. 3. Phytoplankton biomass of the Ural river (**A**), Chapaevsky (**B**), Sofinsky (**C**), Tanalyk-Sunduksky (**D**) and Priplotinny (**E**) reaches of the Iriklinsky reservoir (May 2016–2019).

Table 5. Mean values (*m*) and standard deviation (*SD*) of phytoplankton indicators in the unregulated section of the Ural River in May 2016–2019. *Sp* is the number of species per sample; *B* – biomass; *Bmix* – the mixotrophs biomass; *H* – the Shannon index; *S* – the saprobity index; *AICM* – the average single-cell mass; *F* – the Fisher's test, *p* – the significance level. Statistically significant differences between the studied years according to ANOVA ($p < 0.05$) are in bold; * – statistically significant differences according to Tukey's HSD test ($p < 0.05$).

Indicator	Taxon	2016[a]		2017[b]		2018[c]		2019[d]		*F*	*p*
		m	*SD*	*m*	*SD*	*m*	*SD*	m	SD		
Sp	Bacillariophyta	23.5*[b,d]	2.5	29.8*[c,d]	1.8	23.3*[d]	1.7	16.0	3.9	**8.0**	**0.003**
	Cyanobacteria	0.5	0.3	0.5	0.3	0.0	0.0	0.0	0.0	2.0	0.168
	Chlorophyta	12.5*[b-d]	1.0	19.3*[c]	0.5	15.8	0.5	18.3	2.9	**10.1**	**0.001**
	Cryptophyta	2.5*[b-d]	0.6	4.3	0.5	4.5	0.3	4.0	0.0	**4.4**	**0.026**
	Dinophyta	0.0*[b]	–	1.3*[c,d]	0.3	0.0	–	0.3	0.5	**11.3**	**0.001**
	Euglenophyta	2.3	0.9	2.0	–	1.3	0.3	0.8	1.5	1.4	0.291
B, mg/l	Bacillariophyta	1.06*[b,c]	0.29	6.13*[c,d]	1.42	11.96*[d]	0.55	2.46	1.55	**31.7**	**0.000**
	Cyanobacteria	0.00	0.00	0.01	0.00	0.00	–	0.00	0.00	1.1	0.396
	Chlorophyta	0.20*[b-d]	0.03	1.31	0.28	1.26	0.74	1.16	0.74	1.4	0.281
	Cryptophyta	0.04*[b,c]	0.02	0.50	0.09	0.34	0.09	0.22	0.09	**7.8**	**0.004**
	Dinophyta	0.00*[b-d]	–	0.13*[c,d]	0.04	0.00	–	0.01	0.02	**10.9**	**0.001**
	Euglenophyta	0.07*[b-d]	0.03	1.78*[c,d]	0.49	0.27	0.11	0.03	0.06	**10.9**	**0.001**
Share in total *B*, %	Bacillariophyta	74.2*[b-d]	1.4	60.8*[c]	3.4	86.7*[d]	4.6	62.2	6.4	**12.9**	**0.000**
	Cyanobacteria	0.3	0.2	0.1	0.03	0.0	–	0.0	0.0	1.6	0.235
	Chlorophyta	15.6*[d]	2.0	13.3*[d]	0.2	8.8*[d]	5.0	29.7	4.2	**9.6**	**0.002**
	Cryptophyta	2.6*[d]	0.8	5.6*[c]	1.1	2.5*[d]	0.7	6.3	2.6	**3.9**	**0.038**
	Dinophyta	0.0*[b]	–	1.4*[c,d]	0.4	0.0	–	0.1	0.2	**13.1**	**0.000**
	Euglenophyta	4.4*[b]	1.5	18.4*[c,d]	2.7	1.9	0.8	0.8	1.7	**25.1**	**0.000**
Bmix, mg/l		0.144*[b]	0.048	2.414*[c,d]	0.581	0.608	0.132	0.268	0.085	**12.4**	**0.001**
H, bit/mg		4.09*[c]	0.21	4.21*[c]	0.10	2.36*[d]	0.07	4.00	0.15	**47.0**	**0.000**
S		2.09*[b]	0.05	2.34*[c]	0.04	2.13	0.03	2.16	0.23	2.6	0.099
AICM, 10^{-9} g		0.33*[c]	0.02	0.22*[c]	0.02	1.13*[d]	0.10	0.35	0.07	**60.2**	**0.000**

Table 6. Mean values (*m*) and standard deviation (*SD*) of phytoplankton indicators in the Chapaevsky reach in May 2016–2019. Designations are given as in Table 5.

Indicator	Taxon	2016[a]		2017[b]		2018[c]		2019[d]		*F*	*p*
		m	*SD*	*m*	*SD*	*m*	*SD*	m	SD		
Sp	Bacillariophyta	17.3^{*d}	1.8	16.3^{*d}	1.5	16.0^{*d}	1.5	8.3	1.5	**8.3**	**0.008**
	Cyanobacteria	0.7^{*c,d}	0.3	1.3^{*c,d}	0.3	3.3	0.3	4.3	1.5	**10.5**	**0.004**
	Chlorophyta	16.0	3.5	13.7	1.8	18.7	2.2	16.0	4.0	0.7	0.603
	Cryptophyta	5.0^{*b}	0.6	0.0^{*c,d}	–	4.0	1.0	3.3	0.6	**13.0**	**0.002**
	Dinophyta	0.7	0.7	1.3	0.3	1.0	0.6	1.3	0.6	0.4	0.752
	Euglenophyta	2.3^{*c}	0.3	4.7^{*c}	1.2	8.3^{*d}	1.2	4.0	1.7	**6.4**	**0.016**
B, mg/l	Bacillariophyta	3.756^{*c,d}	0.379	2.873^{*c}	0.695	10.53^{*d}	1.57	0.459	0.468	**23.4**	**0.000**
	Cyanobacteria	0.001	0.001	0.035	0.015	0.024	0.004	0.042	0.040	1.6	0.269
	Chlorophyta	0.402	0.293	0.246	0.062	0.399	0.086	0.180	0.156	0.5	0.709
	Cryptophyta	0.187	0.012	0.000	–	0.232	0.053	0.136	0.142	**4.2**	**0.047**
	Dinophyta	0.070	0.070	0.168	0.054	0.079	0.044	0.052	0.036	1.1	0.415
	Euglenophyta	0.092^{*c}	0.024	0.359	0.130	1.117	0.235	0.613	0.894	2.2	0.160
Share in total *B*, %	Bacillariophyta	84.3^{*d}	5.5	76.3^{*d}	2.6	84.7^{*d}	1.4	32.2	2.2	**61.6**	**0.000**
	Cyanobacteria	0.04^{*d}	0.02	1.1	0.6	0.2^{*d}	0.03	7.0	6.7	2.8	0.106
	Chlorophyta	7.6	4.7	7.0	2.0	3.3^{*d}	0.8	14.2	3.2	2.7	0.115
	Cryptophyta	4.2^{*b,d}	0.4	0.0^{*d}	–	1.9^{*d}	0.4	9.7	4.1	**11.8**	**0.003**
	Dinophyta	1.2	1.2	4.4	0.5	0.6	0.4	6.8	7.1	1.8	0.230
	Euglenophyta	2.2^{*d}	0.7	10.4	3.8	8.8^{*d}	0.8	28.2	19.0	3.6	0.064
Bmix, mg/l		0.350	0.088	0.531	0.123	1.428	0.283	0.805	1.022	2.0	0.197
H, bit/mg		3.10^{*d}	0.38	3.42^{*c}	0.13	2.54^{*d}	0.05	3.90	0.27	**7.1**	**0.012**
S		2.32^{*d}	0.11	2.38^{*d}	0.06	2.54^{*d}	0.01	2.13	0.14	**5.5**	**0.024**
AICM, 10^{-9} g		0.678^{*d}	0.11	0.983^{*d}	0.29	0.695^{*d}	0.06	0.133	0.099	**5.0**	**0.031**

and *Stephanodiscus hantzschii* Grunow (15.1%) – in 2018; *Stephanodiscus hantzschii* (24.1%) and *Chlamydomonas reinhardtii* P.A. Dangeard (10.9%) – in 2019.

In 2018, the lowest Shannon index and the highest average single-cell mass were noted. Peak in biomass of mixotrophic phytoflagellates was recorded in 2017 (Table 5). By the saprobity index, the river waters during the study period were characterized as β-mesosaprobic, with its maximum in 2017 (Table 5). In 2016, the Ural waters had the status of α-mesotrophic, in 2017 and 2018 – β-eutrophic, and in 2019 – β-mesotrophic waters according to the Kitaev scale (2007).

Atmospheric precipitation amount was responsible for major changes in phytoplankton. With growing precipitation, specific number of phytoplankton species (r = 0.87), as well as Bacillariophyta (r = 0.80), Dinophyta (r = 0.79) and Cyanobacteria (r = 0.63), biomass of Cryptophyta (r = 0.61), Dinophyta (r = 0.82), Euglenophyta (r = 0.84), and mixotrophic phytoflagellates (r = 0.84) also increased. In addition, an increase in N-NO_3 and P-PO_4 concentrations, the total biomass of phytoplankton (r = 0.72 and 0.82) and biomass of Bacillariophyta (r = 0.62 and 0.92) increased as well. With growing P-PO_4, the average single-cell mass increased (r = 0.84), however, the Shannon index decreased (r = −0.87).

Phytoplankton of the Chapaevsky reach

The highest specific richness of phytoplankton was recorded in 2018, though statistically confirmed interannual differences were not found (Fig. 2**B**). At the same time, a statistically significant increase in the number of euglena algae species was noted (Table 6). In 2018 and 2019, the growth of the specific species richness of cyanobacteria and the reduction in the number of diatoms species per sample in 2019 were noted.

The highest phytoplankton biomass was detected in 2018; it was statistically much higher than in 2016 (p = 0.001), 2017 (p = 0.000) and 2019 (p = 0.000) due to diatoms (Fig. 3**B**, Table 6). The lowest biomass was observed in 2019. In all years, diatoms dominated, but in 2019 their share decreased. That year the share of cyanobacteria, greens, cryptophytes, dinophytes, and euglena algae increased (Table 6). In 2016, among the dominants were *Cyclotella meneghiniana* Kützing (34.1%) and *Ulnaria ulna* (21.8%), in 2017–2018 – *Stephanodiscus hantzschii* (46 and 62%, respectively), and in 2019 – *Trachelomona* sp. (31%).

The Shannon index was the highest in 2019; it was statistically much greater than in 2016 and 2018 (Table 6). The average single-cell mass in 2019 was statistically much less than in other years of observations (Table 6). We did not reveal any statistically confirmed differences in biomass of mixotrophic phytoflagellates during the study period; its highest value was registered in 2018, the lowest − in 2016 (Table 6). By the water saprobity index, the reach was characterized by β-mesosaprobic waters in 2016, 2017 and 2019. In 2018, this index reflected the transitional status of the reservoir waters from β-meso- to α-mesosaprobic conditions (Table 6). According to the Kitaev scale (2007), the trophic status of this stretch in 2016 corresponded to α-eutrophic, in 2017 − β-mesotrophic, in 2018 − β-eutrophic, and in 2019 to α-mesotrophic waters.

Fluctuations in water level played the significant role in the interannual dynamics of phytoplankton. With its increase, the number of Bacillariophyta species (r = 0.77) and the average single-cell mass (r = 0.80) also increased; however, the number of Cyanobacteria species (r = −0.71), their share in the total biomass (r = −0.60), as well as the share of Cryptophyta (r = −0.86) and Euglenophyta (r = −0.60) reduced. With growing concentrations of P-PO4, which positively correlated with atmospheric precipitation, input volume, water level, total biomass of phytoplankton (r = 0.75), number of Bacillariophyta species per sample (r = 0.65), including their biomass (r = 0.77) and the share in total biomass (r = 0.72), average single-cell mass (r = 0.61) and saprobity index (r = 0.76) also increased, but the Shannon index decreased (r = −0.64).

Phytoplankton of the Sofinsky reach

In 2016, the number of phytoplankton species per sample was statistically much higher than in 2018 (p = 0.033) and 2019 (p = 0.011) (Fig. 2**C**). In addition, the maximum number of diatoms species was noted in 2016, while of Cyanobacteria − in 2019. (Table 7).

The highest phytoplankton biomass falls on 2016, the lowest − on 2019 (Fig. 3**C**). Biomass of euglenophytes and dinophytes was abundant in 2016 and 2019, respectively. In contrast to 2016−2017, biomass of cryptomonads dropped in 2018−2019 (Table 7). Diatoms in 2016−2018, while cryptophytes and dinophytes in 2019 dominated in biomass (Table 7). The share of greens (2018−2019) and euglena

Table 7. Mean values (*m*) and standard deviation (*SD*) of phytoplankton indicators in the Sophinsky reach in May 2016–2019. Designations are given as in Table 5.

Indicator	Taxon	2016[a]		2017[b]		2018[c]		2019[d]		*F*	*p*
		m	*SD*	*m*	*SD*	*m*	*SD*	m	SD		
Sp	Bacillariophyta	$19.7^{*b\text{-}d}$	3.8	10.7^{*d}	0.7	8.0	1.5	2.7	2.5	**10.3**	**0.004**
	Cyanobacteria	0.3^{*d}	0.3	$0.3^{*b\text{-}d}$	0.3	0.3^{*d}	0.3	3.3	0.6	**20.3**	**0.000**
	Chlorophyta	10.7	1.8	10.7	0.7	11.3	1.2	11.3	2.1	0.1	0.962
	Cryptophyta	4.7^{*b}	0.7	6.7^{*d}	0.3	5.3	0.3	5.0	1.0	3.1	0.091
	Dinophyta	0.3	0.3	0.3	0.3	0.7	0.3	1.3	0.6	2.0	0.193
	Euglenophyta	3.7^{*d}	1.5	1.3	0.3	1.3	0.7	0.3	0.6	2.9	0.103
B, mg/l	Bacillariophyta	4.595	3.237	1.073	0.200	0.500	0.254	0.028	0.024	1.6	0.258
	Cyanobacteria	0.000	0.000	0.007	0.007	0.001	0.001	0.005	0.003	0.7	0.555
	Chlorophyta	0.128	0.014	0.145	0.010	0.146	0.045	0.090	0.060	0.8	0.551
	Cryptophyta	$0.874^{*c,d}$	0.271	$0.789^{*c,d}$	0.191	0.208	0.065	0.226	0.119	**4.3**	**0.045**
	Dinophyta	0.005^{*d}	0.005	0.014^{*d}	0.014	0.011^{*d}	0.007	0.175	0.103	**7.2**	**0.011**
	Euglenophyta	$0.467^{*b\text{-}d}$	0.208	0.039	0.017	0.046	0.029	0.009	0.015	**4.3**	**0.044**
Share in total *B*, %	Bacillariophyta	65.1^{*d}	9.7	51.7^{*d}	4.6	44.7^{*d}	16.4	4.3	3.7	**7.0**	**0.012**
	Cyanobacteria	0.0	0.0	0.3^{*d}	0.3	0.2^{*d}	0.2	1.0	0.3	3.9	0.056
	Chlorophyta	$3.7^{*c,d}$	1.6	$7.3^{*c,d}$	0.9	18.7	6.9	16.5	6.2	**4.5**	**0.043**
	Cryptophyta	20.9	8.3	37.5	5.3	25.1	10.5	43.4	15.5	1.5	0.280
	Dinophyta	0.0^{*d}	0.0	0.6^{*d}	0.6	1.7^{*d}	1.3	33.4	12.3	**20.3**	**0.000**
	Euglenophyta	$9.5^{*b,d}$	2.0	2.3	1.4	4.5	3.2	1.4	2.4	2.9	0.102
Bmix, mg/l		$1.353^{*c,d}$	0.427	0.846	0.172	0.266	0.049	0.410	0.145	**4.3**	**0.043**
H, bit/mg		3.86^{*d}	0.05	3.48^{*d}	0.11	3.19	0.38	2.87	0.38	3.5	0.071
S		2.14	0.03	2.01	0.04	2.08	0.13	2.13	0.16	0.6	0.660
AICM, 10^{-9} g		1.27^{*d}	0.40	0.67	0.02	0.61	0.11	0.14	0.08	**4.9**	**0.032**

Table 8. Mean values (*m*) and standard deviation (*SD*) of phytoplankton indicators in the Tanalyk-Suunduksky reach in May 2016–2019. Designations are given as in Table 5.

Indicator	Taxon	2016[a]		2017[b]		2018[c]		2019[d]		F	p
		m	SD	m	SD	m	SD	m	SD		
Sp	Bacillariophyta	10.3	4.9	13.3	6.1	4.7	0.3	3.3	1.2	1.4	0.299
	Cyanobacteria	0.3*[d]	0.3	0.3*[d]	0.3	0.7	0.3	1.7	0.6	3.6	0.066
	Chlorophyta	8.0	3.5	6.0	1.0	5.3	0.3	4.0	1.0	0.8	0.525
	Cryptophyta	4.0	2.1	4.7	1.2	3.7	0.7	3.7	0.6	0.1	0.933
	Dinophyta	1.0	1.0	1.7	0.3	1.0	0.6	1.7	0.6	0.4	0.770
	Euglenophyta	0.3	0.3	0.0	–	0.3	0.3	0.0	0.0	0.7	0.596
B, mg/l	Bacillariophyta	0.231	0.183	0.473	0.314	0.065	0.012	0.055	0.047	1.1	0.388
	Cyanobacteria	0.000	0.000	0.004	0.004	0.001	0.001	0.001	0.001	0.6	0.615
	Chlorophyta	0.219	0.197	0.206	0.135	0.133	0.038	0.038	0.006	0.5	0.709
	Cryptophyta	0.265	0.134	0.684	0.359	0.092	0.036	0.094	0.035	2.1	0.180
	Dinophyta	0.021	0.021	0.392	0.281	0.012	0.007	0.138	0.078	1.5	0.280
	Euglenophyta	0.003	0.003	0.000	–	0.009	0.009	0.000	0.000	0.8	0.539
Share in total *B*, %	Bacillariophyta	46.6*[d]	21.5	38.8	19.2	23.8	7.9	16.7	11.8	0.8	0.531
	Cyanobacteria	2.0	2.0	0.7	0.7	0.6	0.3	0.4	0.2	0.4	0.730
	Chlorophyta	16.5*[c]	9.9	9.2*[c]	4.1	40.8*[d]	4.0	11.7	1.7	**6.4**	**0.016**
	Cryptophyta	28.9	17.6	29.6	12.4	26.7	7.9	29.1	8.0	0.0	0.998
	Dinophyta	3.6*[b,d]	3.6	21.4*[c]	8.8	3.3*[d]	2.0	42.1	20.7	**5.7**	**0.022**
	Euglenophyta	0.6	0.5	0.00	–	4.8	4.7	0.0	0.0	0.9	0.473
Bmix, mg/l		0.30	0.26	1.12	1.04	0.11	0.06	0.232	0.066	2.2	0.169
H, bit/mg		2.97	0.94	3.61	0.26	2.83	0.05	2.69	0.36	0.7	0.599
S		2.06	0.18	1.71	0.08	1.82	0.14	1.86	0.30	1.0	0.446
AICM, 10^{-9} g		0.15*[b,c]	0.10	0.39*[d]	0.07	0.43*[d]	0.18	0.103	0.024	**7.2**	**0.012**

algae (2016) considerably increased. *Ulnaria ulna* (30.1%) in 2016 and *Cryptomonas curvata* Ehrenberg (29.4 and 17.5%, respectively) in 2017−2018 were among the dominant species. In 2019, *Stephanodiscus hantzschii* (10 and 26%), *Surirella brebissonii* var. *kuetzingii (*13.2 and 15.7%), *Gymnodinium helveticum* Penard (31.4%), *Cryptomonas ovata* Ehrenberg (16.3%) and *Komma caudata* (L. Geitler) D.R.A. Hill (15.4%) prevailed.

The years 2016–2017 were distinguished by the highest values of the Shannon index, while 2019, on the contrary, by the lowest (Table 7). Similarly, the average single-cell mass also changed (Table 7). The maximum biomass of mixotrophic phytoflagellates was found in 2016 (Table 7). According to the saprobity index, the waters during the study period were characterized by β-mesosaprobic conditions (Table 7). By the Kitaev scale (2007), in 2016 they corresponded to α-eutrophic, in 2017 − to β-mesotrophic, and in 2018−2019 to oligotrophic conditions.

Correlation analysis revealed positive correlations of input volume and water level with specific number of phytoplankton species (r = 0.76), the number of Bacillariophyta species (r = 0.84), Cryptophyta biomass (r = 0.78), and the Shannon index (r = 0.70). For the specific number of Cyanobacteria species (r = −0.88), Dinophyta biomass (r = −0.76), and biomass of mixotrophic phytoflagellates (r = −0.76) they were negative. The total phytoplankton biomass positively correlated with BOD_5 (r = 0.87) at increasing input volumes.

Phytoplankton of the Tanalyk-Suunduk reach

Statistically confirmed interannual differences in the specific number of phytoplankton species were not found, however, the highest values were noted for 2016−2017, and the lowest − for 2019 and 2018. (Fig. 2**D**). In 2019, the number of cyanobacteria species was statistically much higher (Table 8).

In 2018−2019, phytoplankton biomass was lower than in 2017 (p = 0.038 and 0.040, respectively) (Fig. 3**D**). In 2019, biomass of almost all taxonomic groups dropped significantly (Table 8). The share of diatoms in the total phytoplankton biomass was the greatest in 2016−2017; for greens and dinophytes this indicator was maximal in 2018−2019 (Table 8). *Rhodomonas lens* Pascher & Ruttner (18.6%), *Tetraselmis cordiformis* (H.J. Carter) F. Stein (14%) prevailed in 2016, *Gymnodinium helveticum* (15.9%), *Rhodomonas lens* (12.5%), *Cryptomonas curvata* (10.3%) − in 2017, not identified to the species representatives of the family Volvocaceae (28.6%), *Cryptomonas curvata* (25.5%), *Asterionella formosa* Hassall (10.6%) − in 2018, *Gymnodinium helveticum* (21.8%), *Ceratium hirundinella* (O.F. Müller) Dujardin (18.3%), *Komma caudata* (11%) and *Monoraphidium contortum* (Thuret) Komárková-Legnerová (10.3%) − in 2019.

There were no statistically significant differences in the Shannon index, however, its highest value was registered in 2017, and the lowest in 2019 (Table 8). In 2018−2017, phytoplankton had the greatest average single-cell mass, in 2019 − the lowest (Table 8). The biomass of mixotrophic phytoflagellates did not differ greatly; its highest and lowest indicators were noted in 2017 and 2018, respectively (Table 8). By the saprobity index, the waters were β-mesosaprobic with its maximum in 2016 and minimum in 2017 (Table 8). According to the Kitaev scale (2007), the trophic status of waters in the stretch in 2016 corresponded to oligotrophic, in 2018 and 2019 − to ultraoligotrophic, in 2017 − to α-mesotrophic conditions.

The specific number of Bacillariophyta species (r = 0.59), the total biomass (r = 0.68), and Cryptophyta biomass (r = 0.64) increased with rise in the total atmospheric precipitation. At the same time, the number of Cyanobacteria species reduced (r = −0.71). Mixotrophic phytoflagellates biomass correlated positively with water color index (r = 0.55) and PO (r = 0.72), whereas the saprobity index demonstrated negative correlation with O_2 content (r = −0.58).

Phytoplankton of the Priplotinny Reach

The specific number of phytoplankton species in 2018 was statistically much higher than in 2016 (p = 0.008) and 2017 (p = 0.012) (Fig. 2**E**) due to growing number of diatoms species (Table 9). As compared to other observation periods, phytoplankton in 2019 was distinguished by the highest specific number of green algae species. However, this indicator did not differ statistically from that for the years 2017 and 2018.

The phytoplankton biomass in 2018 was higher than in 2016, 2017 and 2019 (p = 0.000) (Fig. 3**E**) due to Bacillariophyta and Chlorophyta (Table 9). In 2016, biomass was represented by Cryptophyta

Table 9. Mean values (*m*) and standard deviation (*SD*) of phytoplankton indicators in the Priplotinny reach in May 2016–2019. Designations are given as in Table 5.

Indicator	Taxon	2016^{a}		2017^{b}		2018^{c}		2019^{d}		*F*	*p*
		m	*SD*	*m*	*SD*	*m*	*SD*	m	SD		
Sp	Bacillariophyta	5.7^{*c}	1.7	4.0^{*c}	0.6	15.7	3.0	9.7	3.1	**7.2**	**0.012**
	Cyanobacteria	1.3	0.3	0.7	0.3	1.0	0.6	0.3	0.6	1.1	0.400
	Chlorophyta	2.3^{*d}	0.7	3.3	0.7	4.3	0.3	5.7	2.1	3.3	0.078
	Cryptophyta	4.7	1.2	5.7	0.3	4.7	0.3	3.7	1.2	1.3	0.350
	Dinophyta	0.7^{*b}	0.3	2.0	–	1.3	0.3	1.3	0.6	3.6	0.067
	Euglenophyta	0.0	–	0.0	–	0.0	–	0.0	0.0	–	–
B, mg/l	Bacillariophyta	0.058$^{*b\text{-}d}$	0.019	0.050^{*c,d}	0.012	0.726^{*d}	0.124	0.152	0.014	**26.2**	**0.000**
	Cyanobacteria	0.000	0.000	0.015	0.012	0.005	0.003	0.000	0.000	1.3	0.351
	Chlorophyta	0.010^{*c}	0.006	0.023^{*c}	0.003	2.006^{*d}	0.305	0.064	0.026	**41.8**	**0.000**
	Cryptophyta	0.157	0.065	0.252	0.086	0.288^{*d}	0.026	0.071	0.074	2.7	0.117
	Dinophyta	0.021	0.019	0.129	0.082	0.121	0.062	0.174	0.054	1.4	0.311
	Euglenophyta	0.000	–	0.000	–	0.000	–	0.000	0.000	–	–
Share in total *B*, %	Bacillariophyta	28.8^{*b}	7.3	11.9^{*d}	2.1	22.8	1.5	33.7	7.2	**4.6**	**0.038**
	Cyanobacteria	0.2	0.1	4.2	3.8	0.2	0.1	0.0	0.0	1.1	0.398
	Chlorophyta	4.2^{*c,d}	1.2	5.8^{*c,d}	1.3	63.4^{*d}	3.1	13.7	3.7	**177.9**	**0.000**
	Cryptophyta	59.1^{*c,d}	10.1	55.6^{*c,d}	4.9	9.5	1.4	13.9	11.9	**16.0**	**0.001**
	Dinophyta	7.7^{*d}	4.3	22.5	7.2	4.2^{*d}	2.0	38.6	13.5	**7.3**	**0.011**
	Euglenophyta	0.0	–	0.0	–	0.0	–	0.0	0.0	–	–
Bmix, mg/l		0.178	0.076	0.381	0.168	0.409	0.086	0.246	0.078	1.1	0.398
H, bit/mg		2.95	0.30	3.18^{*c}	0.15	2.34	0.22	2.90	0.49	2.1	0.175
S		1.91	0.11	1.81	0.08	1.73	0.06	1.90	0.11	1.2	0.364
AICM, 10^{-9} g		0.18$^{*b\text{-}d}$	0.08	0.13	0.03	0.42	0.02	0.098	0.033	**10.1**	**0.004**

and Bacillariophyta, in 2017 − by Cryptophyta and Dinophyta, in 2018 − by Chlorophyta, in 2019 − by Dinophyta and Bacillariophyta (Table 9). In 2016, among the dominant were the species of the genus Cryptomonas (41.5%), in 2017 − *Komma caudata* (15.2%), *Cryptomonas curvata* (12.4%), *Rhodomonas lens* (12%), *Ceratium hirundinella* (19.5%), in 2018 − representatives of the Volvocaceae family (61.9%), in 2019 − *Gymnodinium helveticum* (36.5%) and *Monoraphidium contortum* (10.8%).

In 2017, phytoplankton was characterized by the maximum Shannon index, and in 2018 − by the minimum one (p = 0.042) (Table 9). In 2018, the average single-cell mass was statistically much higher than in 2016, 2017 and 2019 (Table 9). In 2018, phytoplankton was represented by maximum biomass of mixotrophic phytoflagellates that was not confirmed statistically (Table 9). Interannual changes in the saprobity index were not revealed. During the study period, the waters were characterized by β-mesosaprobic conditions (Table 9). In terms of phytoplankton biomass, the trophic status corresponded to β-mesotrophic only in the year of 2018, while in 2016, 2017 and 2019 − to ultraoligotrophic waters (Kitaev, 2007).

Involvement of discharge volumes in the change of phytoplankton parameters was very high; their rise contributed to reduction of the specific number of phytoplankton species (r = −0.62), the number of Bacillariophyta species (r = −0.69), the total biomass (r = −0.58), biomass of Bacillariophyta (r = −0.66) and Chlorophyta (r = −0.60). The total biomass of phytoplankton (r = 0.76), biomass of Bacillariophyta (r = 0.67), Chlorophyta (r = 0.74), and Cryptophyta (r = 0.69) increased with growing concentrations of $P\text{-}PO_4$. The biomass of mixotrophic phytoflagellates positively correlated with total precipitation (r = 0.93).

Discussion

Interannual fluctuations in weather and hydrological conditions in spring made impact on phytoplankton dynamics. However, major factors for the study sites differed that resulted in the formation of maximum quantitative characteristics of microalgae in various years.

In the unregulated section of the Ural River, phytoplankton was abundant in biomass due to Bacillariophyta and Chlorophyta that is often observed in highly trophic watercourses (Okhapkin, 1997). It should be noted that the studies conducted in the 1960s characterized the quantitative development of the river phytoplankton as poor (Baturina, 1970b); in the middle reaches, its biomass varied within 0.11–0.92 mg/l showing its maximum near large cities (Poryadina, 1973a, b). Our data allow to assume that the increased load on the river catchment was responsible for extra input of nutrients and organic matter. This was most clearly manifested under maximum surface runoff of 2017. As a result, concentrations of nutrients in the water, biomass of phytoplankton, cyanobacteria and mixotrophic phytoflagellates increased. Besides, among the dominants appeared *Euglena viridis* – an indicator species of polysaprobic waters. The saprobity index increased, the average single-cell mass and the Shannon index, on the contrary, decreased.

The leading role in the interannual dynamics of the river phytoplankton was also played by water temperature. Its maximum rise in 2018 brought to an increase in the community biomass and trophic status of waters, as well as to the appearance of the dominant species *Stephanodiscus hantzschii*, an indicator of α-mesosaprobic conditions. At minimum water temperatures in 2016, the phytoplankton biomass was the lowest even at higher total precipitation and input than in 2018.

In the upper stretch Chapaevsky, the most trophic conditions were formed in 2018 that is evidenced by the maximum phytoplankton biomass and the saprobity index, the lowest Shannon index, the reduced number of dominant species and appeared *Stephanodiscus hantzschii (*the indicator of α-mesosaprobic conditions), the share of which in the total phytoplankton biomass was the largest. Apparently, in 2018, changes in the ratio of input and discharge volumes, including water level, ensured the greatest accumulation of nutrients from the Ural waters. A drastic drop in discharge and input volumes at the optimum water level, contributing to location of the boundary of the variable backwater zone in the Chapaevsky reach, determined the maximum input and accumulation of substances transported by the river here. The highest indicators of some chemical water characteristics provide support for this view.

The Mozhaisk reservoir studies revealed that the large flood runoff supplied nutrients from the basin and was responsible for the pronounced increase in phytoplankton abundance (Datsenko et al., 2017). However, in the spring of 2017, the Chapaevsky reach with its maximum water level, total precipitation, input and discharge volumes, including maximum water temperatures and high concentrations of nutrients did not see a tangible increase in phytoplankton biomass. We believe that the tendency in the community dynamics depends on the ratio of a number of factors, i.e. external inputs from the catchment, waters of the main river and its tributaries, as well as diffuse exchange of bottom layers with surface ones. Studies of water bodies in Kazakhstan have revealed both direct and reverse relationships between water level and quantitative indicators of plankton (Krupa, 2012; Krupa et al., 2013). A direct relationship was observed when the amount of substances accumulated in the reservoir was less than that supplied from the basin; the reverse relation was observed under opposite conditions. Thus, in the Chapaevsky reach, the amount of substances accumulated in the bottom sediments was higher than that transported from the catchment, and rise in water level (2017) induced the effect of "dilution". The assumption that availability of biogenic and organic substances would increase at the least depth was disproved: in 2019, the total phytoplankton biomass was minimum at the lowest water level, total atmospheric precipitation, and input volume. On the contrary, biomass and the share of cyanobacteria, cryptophytes and euglenoids in the total biomass showed their maximum. These indicators for diatoms, as well as the average single-cell mass reached the minimum. Consequently, a drop in water level and nutrients removal from the bottom to the surface of the reservoir in the Chapaevsky reach had only a limited effect on the phytoplankton structure, in contrast to the Moskvoretsk reservoirs with the pronounced biomass growth (Datsenko et al., 2017; Goncharov and Abdullaeva, 2014; Goncharov and Datsenko, 2002).

All this brings us to assumption that the phytoplankton biomass did not increase in 2017 at the highest water level, maximum precipitation, high volumes of input and discharge because the area of the greatest accumulation of allogeneic matter was shifted within the boundaries of the variable backwater zone, consisting of its upper (episodic backwater), middle (regular periodic backwater), and low (deep long-term backwater) subzones (Berkovich, 2012; Lin et al., 2007; Makkaveev et al., 1958). The Chapaevsky reach is situated mainly within the middle and low subzones, where most substances (transported by the main river and its tributaries) is accumulated due to reduced flow. As compared to other stretches, its waters are characterized by maximum temperatures. It is obvious that high concentrations of nutrients and water temperature ensure the formation of phytoplankton distinguished by the greatest quantitative characteristics. At the maximum water level in 2017, the zone of the highest accumulation of allogenic substances could be located above the Chapaevsky, i.e. in the uppermost Urtazymsky reach that is the upper (episodic) subzone. Unfortunately, in this place no sampling was made.

A large role in the formation of quantitative characteristics of phytoplankton belongs not only to water level fluctuations, but also to input volumes. It is associated with the flow rate of the main river and its tributaries; with its increase, waters may reach the middle reach. As a result, in the Sofinsky reach in 2016, we observed maximum total biomass and mixotrophic phytoflagellates biomass with its largest input volume and water level less than in 2017, including reduction in the number of dominant species at significant biomass of *Ulnaria ulna*.

In the Tanalyk-Suunduk stretch, the formation of phytoplankton hinged on the total atmospheric precipitation and discharge volumes providing the increased horizontal water movement along the longitudinal profile of the reservoir. As a result, the highest biomass of phytoplankton and mixotrophic phytoflagellates was found under maximum total precipitation and discharge volumes in 2017 and at maximum input volume and high atmospheric precipitation in 2016. In these years, flood waters of the Ural, Tanalyk, and Suunduk rivers delivered most nutrients, thus contributing to the formation of favorable conditions for phytoplankton development.

Table 10. Correlation coefficients of phytoplankton indicators with its total biomass in May 2016–2019 Designations are given as in Table. 5. Statistically significant ($p < 0.05$) coefficients are in bold.

Indicator	Phytoplankton biomass				
	I	II	III	IV	V
Sp	**0.50**	**0.77**	**0.93**	**0.88**	**0.87**
H	−0.17	**−0.84**	**0.69**	**0.79**	−0.36
B_{mix}	**0.83**	**0.64**	**0.88**	**0.80**	**0.82**
S	0.39	**0.75**	0.05	−0.45	**−0.65**
AICM	0.25	**0.53**	**0.84**	**0.50**	**0.72**

The maximum specific number of species and biomass of phytoplankton, the share of Chlorophyta in the total biomass, the average single-cell mass, the reduction in the number of dominant species, and the minimum Shannon index were recorded in the Priplotinny reach in 2018. This phenomenon was due to the lowest runoff volume during the whole period of our study when nutrients arrived from the catchment during flooding and retained; the water was characterized by maximum values of COD, $P\text{-}PO_4$ and Si concentrations.

An increase in the phytoplankton biomass in different-type sections indicated an increase in the trophic status of waters, which in the river (β-eutrophic), reaches Chapaevsky (β-eutrophic) and Sofinsky (α-eutrophic) was higher than in the Tanalyk-Suunduksky (α-mesotrophic) and Priplotinny (β-mesotrophic) ones.

With increase in the phytoplankton biomass, its other characteristics acting as indicators of organic and biogenic load also changed. In most areas, with the formation of the best trophic conditions, the specific number of phytoplankton species was maximum. Thus, we may conclude that the previously identified regularity on species richness reduction in very clean and very dirty waters (Barinova, 2000; Barinova et al., 2006) is also true for the specific number of phytoplankton species. Therefore, the euphotic layer of the studied areas of the Iriklinsky reservoir was characterized by a relatively high quality of the habitat. Positive correlation coefficients between the specific number of species and the total phytoplankton biomass were revealed for all studied areas (Table 10).

With maximum increase in the phytoplankton biomass in the Ural River, the Chapaevsky and Priplotinny reaches, the Shannon index decreased, but in the reaches Sofinsky and Tanalyk-Suunduksky it increased. This index was the lowest for both clean and dirty waters (Barinova, 2000; Barinova et al., 2006). At the same time, no regularities of its change related with eutrophication was found since it reflects to a greater extent stability disturbance under extreme conditions than the trophic state of water bodies (Trifonova, 1990). We believe that with growing volumes of external inputs of substances from the catchment this index dynamics depends on their concentrations and initial trophic status of a water body or its site. For example, in the Ural River, the increased nutrient and organic load in 2018 brought to the decreased Shannon index due to a growing share of *Ulnaria ulna* (60.8% of the total). The upper among the investigated reaches, Chapaevsky, the first received the river waters rich in nutrients and organic substances. However, just the specific ratio of water level, input volume and total precipitation formed the best trophic conditions in 2018. The Shannon index was the lowest and *Stephanodiscus hantzschii* (62.2% of the total biomass) prevailed. The obtained correlation coefficients reflect the tendency in dynamics of the Shannon index with increase in the total phytoplankton biomass in different-type sites. (Table 10).

The data on dynamics of mixotrophic phytoflagellates are used to determine the transformation of the phytoplankton communities at the input of organic and biogenic substances. It is known that with trophic status increase, the quantitative characteristics of mixotrophs grow as well (Goryunova, 2006; Korneva, 1999, 2009; Rosowski, 2003; Safonova, 1987; Sládečeková and Sládeček, 1993). This is most clearly manifested in ecosystems where the main flux of suspended and organic matter is provided by external inputs (Alimov, 1982; Hodkinson, 1975; Margalef, 1992; Mordukhai-Boltovskoy and Rivier, 1977). In these conditions, the color of water, the amount of suspended matter, and the number of bacteria in the water column increase (Kopylov et al., 2000; Tsvetkov et al., 2015) that favors the development of flagellar phagotrophs. In the studied areas of the Iriklinsky reservoir, biomass of phytoflagellates and the total biomass of phytoplankton showed positive correlation (Table 10).

In contrast to the Priplotinny reach, in the Chapaevsky, the saprobity index positively correlated with phytoplankton biomass (Table 10). However, in most cases, interannual dynamics of this index was within β-mesosaprobic water conditions, and only in the spring of 2018 in the Chapaevsky reach it corresponded to α-mesosaprobic waters. Consequently, the most noticeable changes in the saprobity index occurred with an increase in organic and nutrient load in the section of the highest annual nutrient intake.

Predominance of large or small forms of algae cells indicates the changes in the trophic status of the reservoir, though this issue remains open for discussion. It is known that the smaller the algae cell size, the better their metabolism and efficiency of solar energy assimilation are (Gutelmacher, 1986). A high ratio of the cell surface area to its volume and a thinner diffuse boundary layer ensure the ability of small cells to absorb nutrients more efficiently in conditions of their deficiency. In contrast to small cells, large ones are able to store nutrients better. This provides a competitive advantage for small forms at low and for large forms at high trophicity and sharp fluctuations on the nutrient content in the water as well (Cloern, 2018; Edwards et al., 2011). However, the study of phytoplankton in the eutrophic reservoirs of the Volga and Belorussia lakes showed increased abundance of small-celled species (Korneva, 2015; Mikheeva, 1992). At the same time, it was noted that at a highly eutrophic and hypertrophic state, the share of nanoplankton in the phytoplankton composition reduced, and large-scale colonial forms of cyanobacteria and large dinophyte algae dominated (Datsenko, 2007; Mikheeva and Lukyanova, 2006). Dynamics of the ratio of major biogenic substances, providing a shift in the dominance of small and large forms (Fogg, 1965; Sommer, 1985, cited in: Trifonova, 1990), also was of great importance. Interestingly, the observations of the lake phytoplankton during eutrophication did not reveal any pronounced patterns of cell size changes. Therefore, it casts doubt on the use of this characteristic as an indicator of the trophic status dynamics of water bodies (Trifonova, 1990). In spring, the highest average single-cell mass in all sections of the Iriklinsky reservoir was observed in the years with maximum phytoplankton biomass that was evidenced by positive correlation coefficients between the considered indicators (Table 10).

Conclusion

Our study suggests that meteorological and hydrological conditions played a significant role in the interannual fluctuations of quantitative characteristics of phytoplankton from the unregulated section of the Ural River and different-type stretches of the Iriklinsky reservoir. Dynamics of the phytoplankton biomass in the Ural River greatly depended on precipitation providing nutrients supply from the catchment. Water temperature was also important. In the reservoir, the phytoplankton development hingered on arrival of substances from the catchment, which in different reaches was determined using as the total precipitation as the ratio of major hydrological parameters, i.e. input and discharge volumes, including water level. As a result, the periods of maximum quantitative development of phytoplankton in different sites did not coincide. In the reaches Chapaevsky and Priplotinny, the highest phytoplankton biomass was found in 2018 when average water level, discharge and input volumes were the lowest. In the Sofinsky reach, a high biomass of algae was recorded in 2016 due to maximum input of most nutrient-enriched waters from the Ural River and its tributaries. In the Tanalyk-Suuduk Reach, connected with two large tributaries (Tanalyk and Suunduk), the highest phytoplankton biomass was recorded in 2017 and 2016 at the increased total precipitation and input volume. In each stretch, interannual dynamics of phytoplankton was specific. The largest number of statistically significant changes in the analyzed phytoplankton parameters was noted in the river (72.7%). The share of such changes for the reservoir was the following: 50.0% for Chapaevsky, 45.5% for Sofinsky, 13.6% for Tanalyk-Suunduksky, and 31.8% for Priplotinny reaches. Thus, two low reaches subject to the least impact of the main river, having the greatest depths, large area (Tanalyk-Suunduksky reach) and canyon-like profile (Priplotinny reach) demonstrated the most stable state of phytoplankton and environmental conditions. The highest trophic status of the waters was observed in the unregulated section of the Ural River, the Chapaevsky and Sofinsky reaches of the reservoir.

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