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HYDROCHEMICAL CONDITIONS OF PHYTOPLANKTON DEVELOPMENT IN ZAPORIZHIAN (DNIPRO) RESERVOIR

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Phytoplankton development directly depends on environmental conditions. Clarification of the relationship between environmental changes and phytoplankton communities is necessary for understanding and predicting the impact of human activity on freshwater ecosystems, particularly reservoirs. Zaporizhian (Dnipro) reservoir is the first of the artificial reservoirs in the cascade on the Dnipro, which at the present stage of existence is subject to increased anthropogenic load. This load primarily affects the indicators of phytoplankton as a primary component of hydroecosystems. The study on hydrochemical indicators of the Zaporizhian reservoir in the summer of 2019 has shown that the content of ammonia, sulfates, indicators of permanganate oxidizability, and in certain areas the content of dissolved oxygen exceeded the regulatory limits. Phytoplankton, depending on the selection points, was represented by blue-green algae, which formed 76–98% of abundance and 30–70% of the biomass. According to the Pearson correlation coefficients, it has been found that the main hydrochemical indicators affecting the development of quantitative indicators of phytoplankton in the Zaporizhian reservoir are water temperature, indicators of permanganate oxidizability and phosphate content.

Key words: phytoplankton, Zaporizhian (Dnipro) reservoir, hydroecosystems, hydrochemical conditions.

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INTRODUCTION

Monitoring of various components of aquatic ecosystems is a prerequisite for clarification of their functional state (Li et al. 2019). The chemical regime of water plays a crucial role in the life of hydrobionts and is one of the main factors affecting the development of the natural food supply and fish productivity (Hryhorenko et al. 2019).

Being the primary component of any aquatic ecosystem, phytoplankton determines the developmental variation and dynamics of all subsequent trophic levels and therefore is an integral component of monitoring (Stelmakh et al. 2019). The productivity of phytoplankton directly depends on environmental conditions, such as the availability of light and nutrients, temperature, mineralization, the content of biogenic elements, etc. (Varkey et al. 2018, Kozak et al. 2015, Yuan et al. 2017, Sabater-Liesa et al. 2018, Mishra et al. 2019).

Environmental changes can strongly influence phytoplankton and lead to undesirable changes in its qualitative and quantitative indicators (Bukin et al. 2020). Therefore, clarification of the relationship between environmental changes and phytoplankton communities is vitally important for understanding and predicting the impact of human activity on freshwater ecosystems. This is particularly topical for reservoirs that are subject to increased anthropogenic impact (Znachor et al. 2020).

Zaporizhian (Dnipro) reservoir is the first of the artificial reservoirs in the cascade on the Dnipro River, which during its existence has undergone several transformations caused by changes in hydrological and hydrochemical regimes in the process of hydraulic construction and under the influence of increased anthropogenic pressure (Fedonenko & Nikolenko, 2019). It is a multi-purpose reservoir, but due to the increased anthropogenic pressure, one of the main areas of modern research is the compliance of hydrochemical and hydrobiological parameters for fishery purposes. Changes in phytoplankton complexes directly impact the ecological state of the reservoir and the number of trophic levels in the food chain and therefore may be essential to biodiversity at higher trophic levels (Varkey et al. 2018, Dickman et al. 2008)

Recently, there has been an intensive development of blue-green algae during the summer period. These algae cause water blooming and produce cyanotoxins that have a detrimental effect on living organisms and water quality (Sharamok et al. 2019, Teneva et al. 2020).

The purpose of the work is to study the hydrochemical regime and phytoplankton abundance, biomass, species diversity and occurrence in the Zaporizhian reservoir in the summer of 2019.

MATERIALS AND METHODS

Phytoplankton samples were collected according to generally accepted methods (Arsan et al., 2006) with a Ruttner`s bathometer from the surface horizon (0.25 m) into plastic containers (0.5 dm^3), every two weeks during the summer of 2019 at 5 sites along the riverbed of the Zaporizhian reservoir; these sites are different in hydrological and hydrochemical conditions (Fig. 1): Samara Bay (48°5340.21 N; 35°1873.20 E), Festival Wharf (48°4671.74 N; 35°0659.38 E), Monastyrskyi island (48°4540.40´´N; 35°0874.76E), the entry of the Mokra Sura River (48°3258.21´´N; 35°1394.38E), and the lower part of the reservoir near the Viyskove village (48°2230.75´´N; 35°2080.05E).

Fixation, concentration, and laboratory investigation of samples were performed following generally accepted hydrobiological methods (Arsan, 2006; Romanenko, 2006). The samples were fixed by 40 % formalin (1:100), concentration of samples was performed by sedimentation. The phytoplankton composition was determined in Najott's chamber at × 100-400. Biomass was determined by the volume

Fig. 1. Scheme of the Zaporizhian (Dnipro) reservoir.

calculation method. Taxon names are given according to Raznoobrazie vodoroslei Ukraine, 2000.

Simultaneously, from the surface horizon (0.25–0.5 m) into plastic containers (2.5 dm^3) the following indicators were determined at the same sites in the water of the Zaporizhian reservoir following generally accepted hydrochemical methods (Alekin et al. 1973, Romanenko 2006): temperature, pH, the content of dissolved oxygen, ammonia, sulfates and chlorides, biogenic elements, also determined the N inorg / P inorg ratios, the amount of dissolved organic matter by indicators of permanganate oxidizability. In situ measurements of temperature, pH and dissolved oxygen by planar optodes. Indicators of the chemical composition of water were compared with the current fish farming standards (Voda rybohospodarskykh pidpryiemstv 2006).

The Pearson correlation coefficient (R) was applied to identify and establish the level of correlation between hydrochemical indicators and indicators of the abundance and biomass of phytoplankton.

The Shannon-Wiener index, was calculated by the following formula:

$$H = -\sum_{i=1}^{n} \frac{Ni}{N} \log 2 \frac{Ni}{N} \text{ or } H = -\sum_{i=1}^{n} \frac{Bi}{B} \log 2 \frac{Bi}{B}, \text{ where}$$

H - Shannon's index
Ni (Bi) - an estimate of the "significance" of the i-th type, that is, the number (biomas) of the i-th type;
N (B) - the outward estimate of "significance", that is, the outward number (biomas) of phytoplankton;
n - number of species and internal species taxa
Statistical processing of the obtained results was carried out under generally accepted methods of variational statistics.

RESULTS

Analysis of the results of the study on the hydrochemical regime obtained during the study period has shown that with relation to most of the studied indicators, the water in the Zaporizhian reservoir met the standard values (Table 1). Following indicators exceeded the permissible concentrations: 2–11 times – in ammonia content, in all studied areas, except for the lower section of the reservoir, the highest values were recorded in the area of the Festival Wharf; 1.5–2 times – in sulfate content, there is a tendency to decrease their content downstream. The content of readily oxidizable organic substances was consistently high throughout the summer period, as evidenced by the indicators of permanganate oxidizability, which exceeded the lower limit of standard values by 1.05–1.5 times. The content of dissolved oxygen was changing significantly. Thus the highest values at all sampling points were recorded in June, in the area of the lower part of the reservoir – 6,98 mg/dm^3; the lowest values were recorded in August, in the area of the Festival Wharf –4.15 mg/dm^3 and the entry of the river – 3.35 mg/dm^3, which is 1.2–1.5 times less than the standard values.

The Ninorg/ Pinorg ratios varied significantly at different selection points: from 2:1 in the area of the Samara Bay and the entry of the Mokra Sura River to 180:1 in the area of the Monastyrskyi island.

During the study, phytoplankton of the Zaporizhian reservoir numbered 51 species and intraspecific taxa, which can be attributed to 5 divisions: Chlorophyta (24), Bacillariophyta (14), Cyanophita (10), Euglenophyta (2), Chrysophyta (1). The greatest taxonomic diversity (27 i.s.t.) was recorded in August at the entry of the Mokra Sura river; the lowest one – in the Samara Bay (11 i.s.t.).

The abundance of phytoplankton in the study period ranged from 32315.29±133.53 thous. cells/dm^3 near the Monastyrskyi island to 94857.11±571.29 thous. cells/dm^3 in the Samara Bay (Fig. 2). At all sampling points, the basis

Table 1. Average values of hydrochemical indicators of the Zaporizhian reservoir in the summer period of 2019

Indicator	Samara Bay	Festival Wharf	Monastyrskyi isl.	Entry of the Mokra Sura River	The lower part of the reservoir	Standard values
Temperature °C	23.4±0.05	23.1±0.06	22.9±0.04	23.2±0.04	22.9±0.05	≤ 28
pH	7.8±0.05	7.6±0.04	6.92±0.05	7.8±0.06	7.9±0.04	6.5–8.5
Oxygen content mg/dm³	4.8±0.05	4.9±0.05	6.54±0.05	4.25±0.05	5.7±0.65	≤5
Permanganate oxidizability mg/dm³	14.9±0.62	14.2±0.54	13.10±0.45	14.1±0.64	10.5±0.46	≤10–15
Ammonia mg/dm³	0.31±0.0008	0.58±0.0009	0.2±0.0007	0.11±0.0008	0.01±0.0005	0.05
Nitrites mg/dm³	0.007±0.00045	0.008±0.00032	0.1±0.004	0.05±0.002	0.0048±0.00024	0.1
Nitrates mg/dm3	0.42±0.019	0.28±0.017	1.49±0.059	0.39±0.016	0.27±0.012	≤ 2
Phosphates mg/dm³	0.38±0.021	0.01±0.0004	0.01±0.0005	0.25±0.01	0.01±0.0004	0.5
Sulfates mg/dm³	96.05±2.01	95.25±0.47	87.60±0.47	82.40±0.47	78.09±1.63	50–70
Chlorides mg/dm³	42.6±0.48	42.2±0.47	42.2±0.47	41.85±0.47	41.58±0.47	50–70

Remark.± – standard deviation

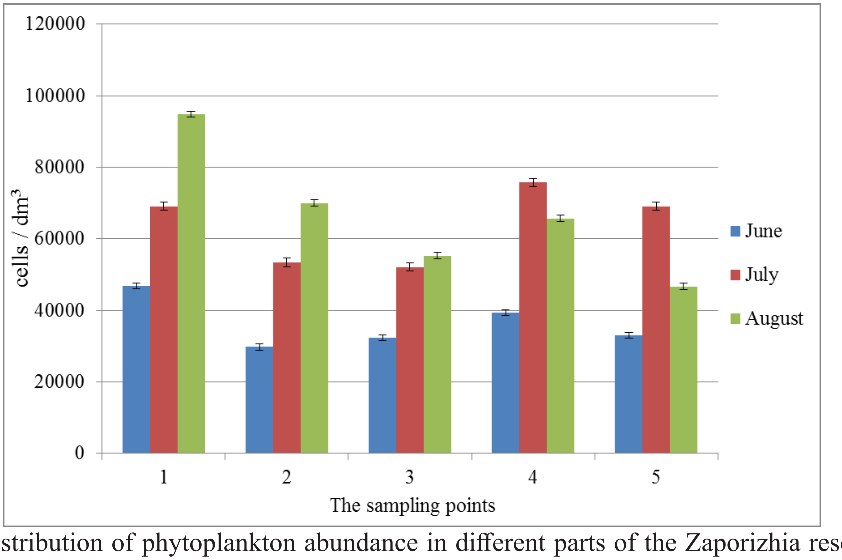

Fig. 2. Distribution of phytoplankton abundance in different parts of the Zaporizhia reservoir: 1 – Samara bay; 2 – Festival Wharf; 3 – Monastyrskyi island; 4 – the entry of the Mokra Sura river; 5 – the lower part of the reservoir (Viyskove village).

of abundance (85–98 %) and biomass (30–77 % (Fig. 3)) was formed by representatives of Cyanophyta, in particular the genus *Microcystis*. The maximum values are recorded in the Samara bay, and the minimum in the lower part of the reservoir.

Biomass values ranged from 7.99±0.024 mg/dm^3 in the lower part to 13.10±0.091 mg/dm^3 in the Samara Bay (Fig. 3), which is consistent with recent studies on phytoplankton in the Zaporizhian reservoir (Sharamok et al. 2019, Yakovenko et al. 2017) and may stem from both increased eutrophication of the Samara Bay and high concentrations of heavy metals, which contributed to a decrease in biodiversity with a relative increase in the vegetation of some representatives of Cyanophita. In June the formation of biomass in the area of the Festival Wharf and the entry of the Mokra Sura River was dominated by Chlorophyta representatives by 4% ($P < 0.05$).

The basis of abundance and biomass was formed by the genera *Microcystis* Kütz, 1833, *Aphanizomenon* A.Morren ex Bornet & Flahault, 1888, *Anabaena* Bory ex Bornet and Flahault 1886, to a lesser extent – *Pediastrum* Meyen, 1829, *Scenedesmus* Meyen, 1829.

For more relevant quantitative characterization of phytoplankton, it is necessary to use specific informative indices, for example, the Shannon index. The Shannon index indicates the

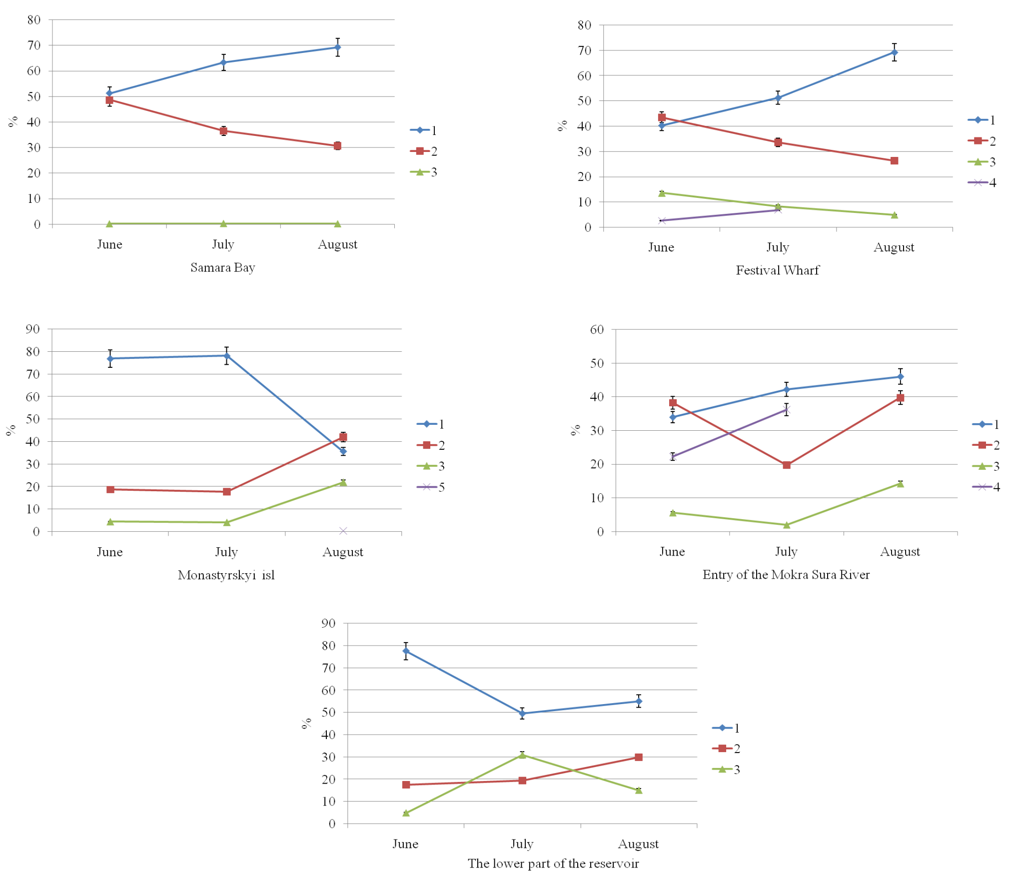

Fig. 3. Changes in the biomass (%) of the phytoplankton community in different parts of the Zaporozhye reservoir : 1 – Cyanophyta ; 2 – Chlorophyta; 3 – Bacillariophyta; 4 – Euglenophyta; 5 – Chrysophyta.

degree of diversity of phytoplankton structure (Romanenko 2006, Semeniuk 2004).

Indicators of the Shannon biodiversity index by the abundance (biomass) of phytoplankton of the Zaporizhian reservoir during the study period varied from 0.47 (1.30) bits/ind. to 1.44 (2.16) bits/ind.

It has been found that the main hydrochemical indicators affecting the abundance of summer phytoplankton of the Zaporizhian reservoir are the water temperature (R=0.89; p=0.05), the content of chlorides (R=0.71; p=0.05), indicators of permanganate oxidizability (R=0.70; p=0.05), the content of phosphates (R=0.66; p=0.05) and sulfates (R=0.64; p=0.05), while those affecting the biomass are water temperature (R=0.95; p=0.05), indicators of permanganate oxidizability (R= 0.78; p=0.05) and the content of phosphates (R= 0.77; p=0.05), which is consistent with many studies on the influencing factors of phytoplankton community structure (Liu et al. 2021, Fadel et al. 2015, Gogoi et al. 2020). However, a positive correlation is also observed for other hydrochemical parameters studied, which indicates their effect on the total abundance and biomass of summer phytoplankton (Wang et al. 2020).

DISCUSSION

The level of phytoplankton development depends significantly on the ratio of inorganic forms of nitrogen and phosphorus because algae with high nitrogen and low phosphorus content, or vice versa, are unable to fully synthesize proteins, ATP, ADP, NADP, and nucleic acids (Perin, et al., 2021; Pasichnaya et al., 2015). In the Samara Bay and the entry of the Mokra Sura River a high concentration of inorganic phosphorus induces increased eutrophication, which leads to the development of phytoplankton, water blooming, an increase in the amount of organic substance, oxygen deficiency, and during certain periods – to the "starvation" of fish and other aquatic organisms, a decrease in biodiversity (Hans et al. 2020,Tang, et al. 2020).

Taking into account most indicators, the worst water quality was in the Samara Bay, relatively high water quality was observed in the area of the Viyskove village, which may be due to both a decrease in industrial and household discharges and the self-cleaning capacity of the reservoir.
In general, taking into account hydrochemical indicators, there was a tendency to deterioration of water quality in the Zaporizhian reservoir from

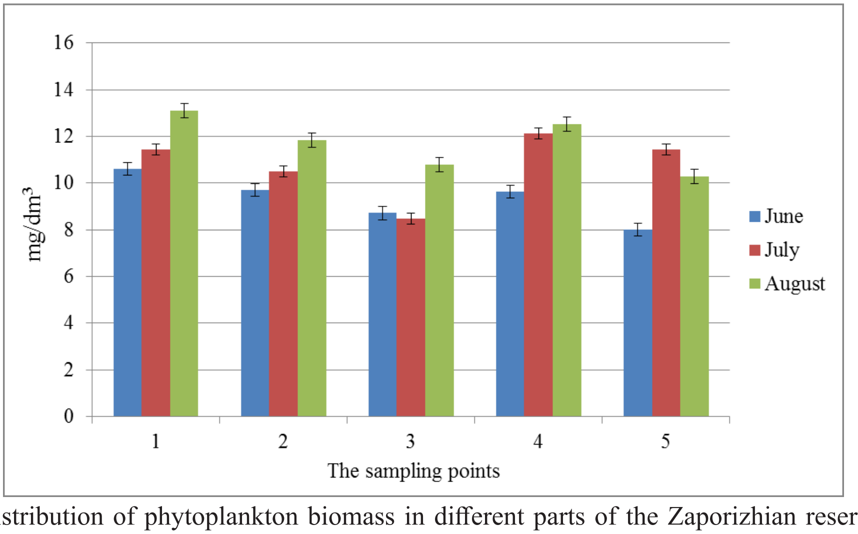

Fig. 4. Distribution of phytoplankton biomass in different parts of the Zaporizhian reservoir: 1 – Samara bay; 2 – Festival Wharf; 3 – Monastyrskyi island; 4 – the entry of the Mokra Sura river; 5 – the lower part of the reservoir (Viyskove village).

June to August. The latter is mainly associated with an increase in water temperature, which leads to the intensification of anthropogenic effects on the eutrophication state of reservoirs during a certain period. It is generally known that eutrophication occurs most strongly in warm and illuminated shallow areas, which occupy up to 39% of the Zaporizhian reservoir (Dembowska, 2018, Obukhov, 2006). The latter contributes to the development of planktonic algae, a decrease in water transparency, and as a result, leads to a deterioration in the trophic state of reservoirs and biological contamination. Biological contamination of water bodies is caused by the accumulation of biogenic substances in the water mass (Kim et al., 2021). These are phosphorus and nitrogen compounds, which lie behind a sharp decrease in the oxygen content in water, higher pH, precipitation of calcium carbonate, magnesium hydroxide (Pichura 2016).

The lowest taxonomic diversity in the Samara Bay substantially occurs due to abnormally high water temperatures in the Samara Bay in late July–August (≥25^{o}C), which contributed to a decrease in biodiversity with increased vegetation of Cyanophyta in the surface layer (Glibert 2020). In addition, there are high concentrations of zinc and copper in Samara Bay, which are the most toxic to algae (Sharamok et al. 2019).

There is a trend to decrease in the Shannon index from the beginning of June to the end of August, which is related to the dominance of representatives of blue-green algae, caused by an increase in water temperature and the ratio of various forms of nitrogen and phosphorus, as well as a high content of readily oxidizable organic substances. The maximum values of the Shannon index for the abundance and biomass of phytoplankton were recorded in the first half of June near the entry of the Mokra Sura River. They were slightly lower in the area of Monastyrskyi island and Festival Wharf.

Information diversity of phytoplankton by its abundance may indicate a transition of the phytoplankton structure from a polydominant to an oligo - and monodominant complex (Wang et al. 2020, Semeniuk 2004). However, the Shannon biomass index indicates high biodiversity of algae in June, as the cells of the *Microcystis aeroginosa* species, which forms the basis of the abundance, have insignificant volumes and due to hydrochemical conditions during this period do not reach the peak of their abundance and, accordingly, biomass. The minimum values were recorded in August, in the Samara Bay, which indicates the simplicity of a phytoplankton community, owing to the dominance of blue-green algae.

Analysis of quantitative indicators of phytoplankton has shown that the abundance and biomass of algae increased with water temperature and reached its maximum at abnormally high temperatures (≥25^{o}C), recorded in late July–August, and were formed mainly by blue-green algae.

Similar relationships between phytoplankton biomass and both temperature and ortho-phosphorus were also reported by Suresh et al. (2013), Deyab et al. (2019) and Bukin et al. (2020).

CONCLUSIONS

The results of studies performed in the summer period of 2019 have shown that the development of phytoplankton of the Zaporizhian reservoir directly depends on hydrochemical parameters and their ratio. A high positive correlation was noted between the quantitative indicators of phytoplankton of the Zaporizhian reservoir and water temperature, indicators of permanganate oxidizability, the content of chlorides, phosphates and sulfates.

According to hydrochemical indicators, there was a tendency to deterioration of water quality in the Zaporizhian reservoir from June to August.

The maximum abundance and biomass of

phytoplankton, with minimal taxonomic richness, has been recorded in the Samara Bay, which corresponds to its hydrochemical state; the minimum one has been recorded near Monastyrskyi Island and Viyskove village, where hydrochemical indicators are the most optimal for fisheries activities.

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