Ecological monitoring of water bodies: bioindication, microalgae biodiversity indices

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Abstract. The paper presents data on biomonitoring the pollution state of aquatic environments through the development of microalgae. The presented results are based on the correlation of basic parameters of the aquatic environment state. This includes the determination of microalgae species composition, quantitative characteristics of abundance and biomass, as well as a number of hydrochemical parameters. Additionally, integral indices of biodiversity such as Serens-Cherkanovsky, Margalef, Shannon-Weaver, Simpson, and Pielou were calculated and cluster analysis of the basic aquatic environment state was performed. The comparison of trends revealed that the studied water bodies possess unique characteristics. Overall, these water bodies are able to handle anthropogenic stress, which is demonstrated through self-purification processes. However, this phenomenon is slowed down in the case of the Nizhnekalmius reservoir.

1 Introduction

The biological balance in aquatic ecosystems is maintained by diverse dynamic relationships between organisms and the environment. Anthropogenic impact disrupts this balance, primarily affecting the species composition of the biocenosis. Throughout the 20th and 21st centuries, there has been a constant deterioration in the quality of water bodies, leading scientists are searched for optimal methods of determining water quality [1-3].

Biological monitoring is the one method used to determine water quality. It allows for the identification of the consequences of single or multiple pollution events, which may not be detected through chemical or microbiological analysis alone. The results of such analyses only reflect the state of the water at the time the sample was taken. Biological monitoring enables the detection of anthropogenic pollution in a water body over an extended period of time [4,5]. The quality of water bodies is determined by the trophic regime, which is a crucial factor. Abiotic factors such as light, temperature, hydrodynamics, mineral composition, and water acidity, as well as biotic factors such as population development indicators, are determinants of the trophic regime [6,7].

The biomonitoring of aquatic environments by microalgae status is based on the analysis of morphological traits in combination with ecology and biogeography. Furthermore, biodiversity (as a list of species and as an indicator of the complexity of aquatic communities) reflects changes in indicators of the entire aquatic environment [8].

Rivers frequently exhibit a high degree of utilisation in human activities, which is often manifested in the regulation of river flows and the construction of reservoirs, resulting in the accumulation of (relatively) large amounts of nutrients and organic matter. The increase in the content of all forms of mineral nitrogen in water and, as a consequence, the average annual concentrations of almost all mineral elements and organic substances significantly. This subsequently causes uncontrolled development of microalgae (phytoplankton). The distribution of micro- and macroelements, as well as organic matter, within individual reservoir sections is contingent upon the morphology and water exchange intensity [9-12]. Water stagnation can occur in areas with wind surges, shallow waters, and bays where water exchanging is slower. This can lead to an increase in the concentration of organic matter and the occurrence of outbreaks or so-called 'bloom' spots of microalgae. This phenomenon is known as anthropogenic eutrophication. Anthropogenic eutrophication often leads to an increase in the proportion of cyanobacteria in the total microalgae population [13-16]. As nutrient levels continue to rise, the ecosystem may experience a loss of biodiversity, resulting in a decrease of dominant communities and a succession of microalgae. Microalgae communities develop according to a standard scheme, progressing from the dominance of diatoms and green algae to the dominance of cyanobacteria. Cyanobacterias are the oldest prokaryotes and have a high degree of adaptation to oxygen deficiency and excess light. They also fix atmospheric nitrogen which is dissolved in water [17, 18].

Therefore, ecological research is necessary to evaluate the consequences of anthropogenic impact and regulate river discharge in order to create a reservoir.

2 Materials and Methods

Samples collected in 2017-2023 in the Starobeshevo and Nizhnekalmius reservoirs, located on the Kalmius River, served as the material for the work. During the monitoring studies, 216 phytoplankton samples were collected at 9 monitoring points with varying degrees of anthropogenic impact. The sites in the middle section of the Kalmius River were used as controls. Species composition was determined under a Zeiss Primo Star microscope. The number of phytoplankton cells was determined by the counting method using a Goryaev chamber, biomass was determined by the stereometric method [19]. Commonly used identifiers [19] were used for species identification. Statistical processing was performed in Statistica 10.

Donbass is a region with a high degree of industrial use, which, as it well known, primarily affects the quality of natural water resources. The main water artery of Donbass is the Kalmius River, which has four regulated reservoirs. The Upper Kalmius Reservoir is formed in the upper reaches of the river and is classified as a water body with minimal industrial use. It provides drinking water to Donetsk [20]. The Lower Kalmyk and Starobeshiv reservoirs have been formed on the middle stretch of the river. The Lower Kalmyk reservoir, which is 3.3 km long, flows through the centre of Donetsk. The reservoir is adjacent to the districts of urban and industrial development and discharges about 7 million cubic meters of excess water to the city's industrial enterprises. It receives over 9 million cubic meters of water annually from rain and mine water.

The Starobeshevo reservoir is a cooling reservoir of the Starobeshevo TPP, its it's 15 kilometres long. The Kalmius River and the Gruzskaya River form the water balance of the Starobeshevo reservoir. The reservoir is surrounded by agricultural land, which provides a constant flow of water,

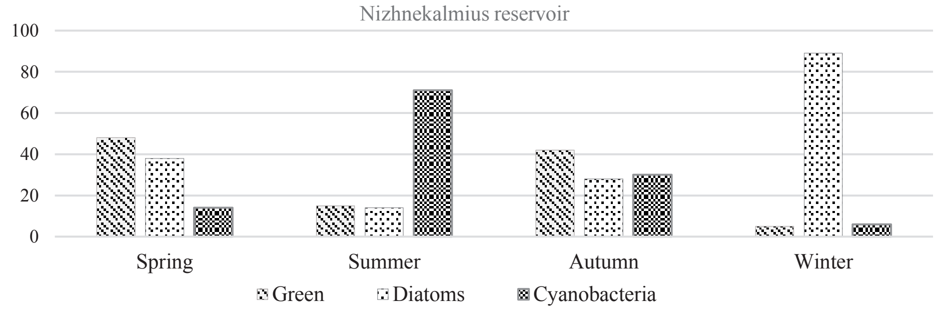
In the lower part of the Kalmyk River, 30 km from the Sea of Azov, there is the Pavlopolskoye reservoir, which is 25 km long. The Pavlopolskoye reservoir is intensively used for agriculture. The water is characterized by high mineral content, as well as elevated levels of nutrients and pesticides [20].

The ongoing biomonitoring of the state of pollution of the aquatic environment is based on the creation of a unified system based on the integrity of the aquatic ecosystem, taking into account a number of related factors, including: determination of species composition, quantitative characteristics, abundance and biomass, as well as a number of hydrochemical parameters to correlate the determination of the state of the baseline environment. The data obtained were used to calculate the Serens-Cherkanovsky, Margalef, Shannon-Weaver, Simpson and Pielou integral indices, followed by cluster analyses of the initial state of the aquatic environment. The trends compared have the dynamics of change in the current period and also for subsequent periods, since phytoplankton are the first to react to changes in the state of the aquatic environment and any changes in parameters are often manifested in changes in quantitative characteristics [21].

3 Results and discussion

At the primary stage, the study determined the species composition of microalgae and compiled a checklist of species inhabiting the waters of the Kalmius River basin [9]. The analysis of species diversity revealed that Starobeshevo reservoir had the highest taxonomic richness among the investigated points of the Kalmius River, with 371 identified species. Nizhnekalmius reservoir had a smaller number of identified species, with 216. The middle section of the Kalmius River contained 128 species of microalgae.

Analysis of their distribution by systematic structure revealed that they belong to 8 divisions, 17 classes, 42 orders, 66 families, and 105 genera. *Bacillariophyta* and *Chlorophyta* were the dominant divisions, accounting for 32.65% and 28.18% of the total number of species, respectively. The diversity of *Cyanobacteria* species was significantly lower, accounting for only 18.90% of the total number of species. The *Euglenophyta* and *Ochrophyta* divisions combined accounted for 14.09% of the total number of species. The *Cryptophyta, Dinophyta,* and *Charophyta* departments each had only one species, making up 6.18% of the total number of species. The distribution of the species composition of the dominant departments by season is shown in Fig. 1.



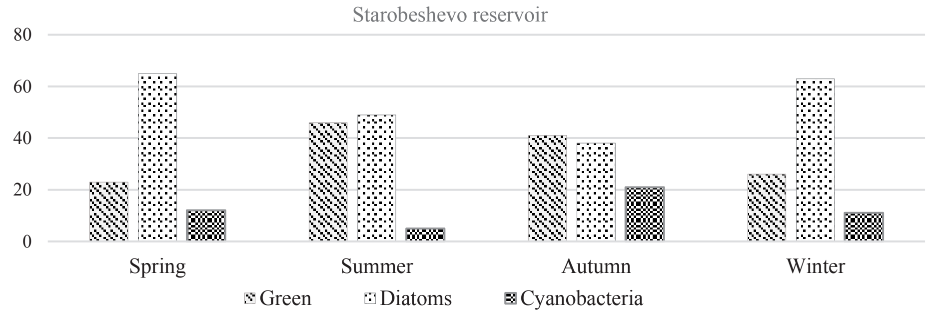
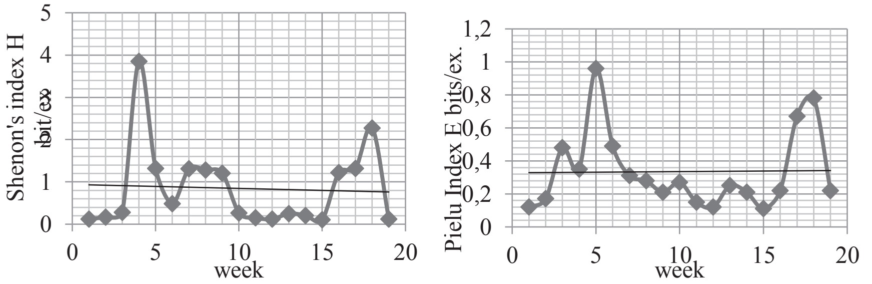


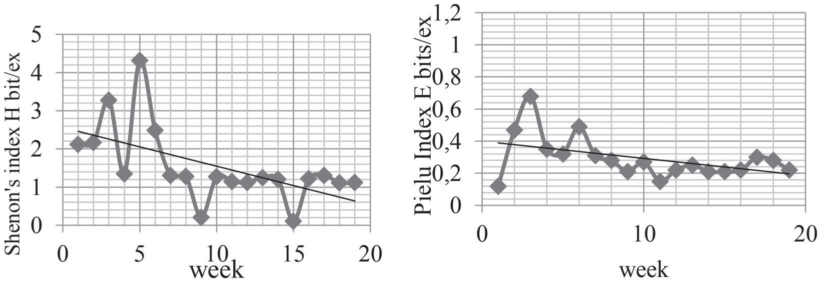
Fig. 1 Dynamics of microalgae development in the reservoirs of the Kalmius River

A comparative analysis of the Shenonne-Weaver biodiversity indices for Starobeshevo reservoir revealed a significant variation in the index, ranging from 0.10 bits/ex (in winter) to 4.26 bits/ex (in summer). The highest index value was observed in October 2019, indicating the formation of the most complex phytoplankton structure during this period. The Pielu biodiversity index ranged from 0.01 bp/ex to 0.68 bp/ex, indicating a high degree of phytoplankton variability. The Simpson index ranged from 0.02 bp/ex to 0.79 bp/ex on average. The minimum values were observed during the summer period (0.02-0.07 bp/ex), indicating the absence of dominance by any individual species. Therefore, no dominant group was identified in the Starobeshevskoye reservoir based on the index ratio, and there is a tendency for the phytoplankton communities to level out.

The Shenonne-Weaver diversity index for the Nizhnekalmius reservoir ranged from 0.6 bits/ex to 3.86 bits/ex in terms of phytoplankton abundance. The minimum values were observed during the summer period, which is characterized by a monodominant community structure. The maximum values of the index were observed during the spring period. The Pielu index varied from 0.1 bp/ex to 0.97 bp/ex, with minimum values observed during the spring period and maximum values during the summer period. On average, Simpson's index ranged from 0.01 to 0.96 bp/ex.



A) Nizhnekalmius reservoir



B) Starobeshevo reservoi

Fig.2 Microalgae biodiversity dynamics of the studied reservoirs from April to September 2022

The dynamics of phytoplankton biodiversity in the Lower Kalmius reservoir suggests an imbalance in taxonomic composition with significant differences in the number of individuals among dominant divisions. Seasonality is also evident with a dominant group present mainly during the summer period.

The presence of distinct dominant groups of cyanobacteria in the Lower Kalmius reservoir is directly linked to the reservoir's trophic balance. Research has shown that periods of maximum cyanobacteria abundance are associated with higher concentrations of biogenic elements, specifically nitrogen and phosphorus [22]. The nitrogen to phosphorus (N:P) concentration ratio during the summer period ranged from 3:1 to 1:1 (NO_2 2.01 mg/dm^3 and PO_4 1.87 mg/dm^3, respectively). It is important to note that the standard MAC for total nitrogen, as defined by ISO 6777:1984, NEQ, should not exceed 1.0 mg/dm3, and for phosphorus, it should not exceed 0.01 mg/dm^3, as defined by ISO 6878:2004, NEQ. The MAC for phosphorus was exceeded in all seasons, and for nitrogen, it was mainly exceeded in summer and autumn. Therefore, based on the ratios of nutrient element concentrations, it can be concluded that the Nizhnekalmius reservoir is hypereutrophic [23]. Water quality is related to the wastewater produced by livestock complexes. In these conditions, there is an exponential increase in the abundance of cyanobacteria, and the population density fluctuates, decreasing from week 6 to week 16. This decrease is most likely caused by the depletion of consumed biogens. Therefore, the dynamics of the N:P ratio indicates uncontrolled development of cyanobacteria caused by the volley of biogens at the expense of phosphates and nitrates.

4 Conclusions

The results obtained are based on the correlation of basic parameters of the aquatic environment, taking into account a number of associated factors. These include the determination of microalgae species composition, quantitative characteristics of abundance and biomass, as well as a number of hydrochemical parameters. Additionally, integrated indices of biodiversity, such as Serens-Cherkanovsky, Margalef, Shannon-Weaver, Simpson, Pielou, and cluster analysis of the basic state of the aquatic environment. The general analysis of biodiversity revealed that microalgae develop in accordance with the standard cycle observed in freshwater bodies of the temperate zone. However, the high concentration of cyanobacteria in the Lower Kalmius reservoir, attributed to anthropogenic increases in biogenic matter, necessitates the highlighting of the presence of summer succession, which is characterized by a significant decline in biodiversity levels. This, in turn, affects the self-purification of the reservoir.

Comparable trends indicated that the studied reservoirs exhibited distinctive characteristics. In general, the studied reservoirs demonstrated the capacity to cope with anthropogenic load, which manifested in self-purification processes. However, this phenomenon was not consistently observed in the Nizhnekalmius reservoir.

The task has been completed within the framework of the youth laboratory "Diagnostics and mechanisms of adaptation of natural and anthropogenically transformed ecosystems of Donbass" (№ 1023110700153-4-1.6.19;1.6.11;1.6.12).

References

1. A. Safonov, BIO Web Conf. **43**, 03002 (2022)
2. A. Safonov, Diversity of plant world **1**, 1 (2019)
3. V. Korniyenko, V. Kalaev, Contemporary Problems of Ecology **15**, 7 (2022)
4. B.Sun, C.Tang, N.Yang, P.He, Aquatic Ecology **55**, 2 (2021)

5. E. P. Odum, Basic ecology 215-257 (1983)
6. I. Zinicovscaia, K.N. Vergel, A.I. Safonov, N.S. Yushin, A.V. Kravtsova, O. Chaligava, Ecosystem Transformation **6**, 3 (2023)
7. N.S. Mirnenko, Forestry Bulletin **26**, 6 (2022)
8. S. Barinova, Indicator algae in environmental quality assessment **6,** (2000)
9. E.I. Mirnenko, Ecosystem Transformation **5**, 2 (2022)
10. J.C., Michalak A.M., Pahlevan, Nature **590,** 7846 (2021)
11. J.J. Karlusich, F.M. Ibarbalz, C. Bowler, Journal of Plankton Research **42**, 6 (2020)
12. J.Padisák, L. Naselli-Flores, Hydrobiologia **848**, 1 (2021)
13. K. Dong, K.O. Kvile, N.C. Stenseth, L.C. Stige, Marine Ecology Progress Series **635,** (2020)
14. K.M. Lewis G.L. Van Dijken, K.R. Arrigo Science **369**, 6500 (2020)
15. M. Lürling, Hydrobiologia **848,** 1 (2021)
16. P.D.Klochenko, T.F.Shevchenko, I.M. Nezbrytska, Hydrobiological Journal **57,** 3 (2021)
17. Md.S. Islam, Aquatic Bioresources & Environment **4**, 3 (2021)
18. S.V. Bespalova, S.M.Romanchuk, S.V. Chufitskiy, V.V.Perebeinos, B.A.Gotin, Biophysics **65,** 5 (2020)
19. G.S.Fomin Water. Control of chemical, bacterial and radiation safety according to international standards 245-315 (2000)
20. V.P. Styopkin Complete history of Donetsk **560, (**2008)
21. R.M. Gorodnichev, L.A. Pestryakova, L.A. Ushnitskaya, S.N. Levina, P.V. Davydova Methods of ecological research. Basics of statistical data processing **94**, (2019)
22. T. Priest, B. Fuchs, R. Amann, M.Reich, Environmental Microbiology, **23**, 1 (2021)
23. Y.Saeiam, P.Pichitkul, I.Wudtisin, U. Nedtharnn, International Journal of Agricultural Technology **16,** 3 (2020)