

INDICES OF ZOOPLANKTON IN ASSESSING THE ECOLOGICAL STATE OF LAKE ILINSKOE (RUSSIA)

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ABSTRACT

The results of long-term (from 1998 to 2016) studies of Lake Ilinskoe are presented in the paper. The lake is located in the protective zone of Volzhsko-Kamsky State Natural Biosphere Reserve, therefore, the anthropogenic impact on it is limited. The evaluation of lake's trophic status was made, using physico-chemical and zooplankton indicators. The following indicators of zooplankton community were defined: the average weight of zooplankton (w); the ratio of biomass of Cyclopoida to Calanoida (B_{Cycl}/B_{Cal}); the ratio of crustaceans biomass to rotifers biomass (B_{Cr}/B_{Rot}); the ratio of number of crustaceans to rotifers (N_{Cl}/N_{Cop}); the ratio of number of eutrophic species to oligotrophic species (E/O); the ratio of Rotifera: Cladocera: Copepoda; Shannon-Weaver biodiversity index.

It has been revealed, that the lake is eutrophic for trophic status. Rotifers predominate in the number of species among the zooplankton. The dominant species are characteristic of eutrophic water bodies. The tendency to decrease in the share of Copepoda in the community, and the increase in the share of Rotifera has been revealed. The indices of B_{Cycl}/B_{Cal} , B_{Cr}/B_{Rot} , N_{Cl}/N_{Cop} showed a tendency to increase. This is typical for eutrophic water bodies. The ratio of number of eutrophic species to oligotrophic (E/O), as well as the value of the individual mass of zooplankton, corresponded to eutrophic water bodies. The values of Shannon's diversity index were unrepresentative; they corresponded to the water bodies of the lower trophic level. The results of this study showed, that the potential of zooplankton, as a bioindicator of trophic status, is very high.

Keywords: zooplankton, lake, bioindication, eutrophication, indices, reserve.

INTRODUCTION

Lake ecosystems during their natural existence undergo regular changes in the direction of increasing their trophic status. In the modern period, there is a significant acceleration of this process, due to the anthropogenic pressure on water bodies. Any aquatic ecosystem, being in balance with environmental factors, has a complex system of mobile biological connections, which are disturbed by anthropogenic factors. First of all, the influence of anthropogenic factors, and in particular, pollution is reflected in the species composition of aquatic communities, and the ratio of quantitative indices of their constituent species.

Zooplankton is one of the most significant components in aquatic ecosystems. It participates in the transfer of matter and energy. It consumes organic matter, formed in water bodies and brought from outside; it is responsible for self-purification of water bodies and streams, forms the basis for feeding most of fish species. Being closely connected with other components of aquatic ecosystems, zooplankton can be used as an indicator for water quality assessment. Previous studies have shown quite high indicators of zooplankton communities in assessing the trophic status and the level of lakes' pollution. Various structural and functional indices of zooplankton communities are used for the purpose of bioindication [1-7].

We assume that Lake Ilinskoe is subjected to the eutrophication process, and various indicators of zooplankton community reflect the trophic status of the reservoir. Specific objectives of the research were the following: 1) to identify the biodiversity of zooplankton; 2) to find the tendencies in the change of long-term values of quantitative indicators of zooplankton; 3) to test the hypothesis that the zooplankton community is indicative in assessing ecological changes and trophic state of water bodies; 4) to determine the characteristics of zooplankton, which can serve as indicators, facilitating future monitoring of zooplankton in the Ilinskoe and other lakes of Volzhsko-Kamsky State Natural Biosphere Reserve.

MATERIAL AND METHODS

Volzhsko-Kamsky State Natural Biosphere Reserve is located on the left-bank terraces of the Volga River in the Middle Volga region (Russia). The climate of the region is moderately continental, with sharp temperature fluctuations and uneven precipitation. The area of Lake Ilyinsky is 21.7 hectares, maximum depth - 17.1 m, average depth - 4.4 m, water volume - 1275.9 thousand m³, by the nature of water exchange it is running. The river Sumkadisgorges into the lake. It has a great influence on the ecological state of Lake Ilinskoe, as it flows through agricultural lands. During the spring flood, it brings suspended and polluting substances into the reservoir. In this regard, the relevance of research is obvious.

Lake Ilinskoe was investigated in June-August of 1998-2016. In summer, the development of zooplankton is maximal and is determined mainly by trophic conditions [2, 7]. Zooplankton samples were taken from 1-3 stations, using the Jedi net (mesh size - 100 µm), on horizons, located in accordance with the stratification of water by temperature. Cameral processing included the determination of species composition, number and biomass of zooplankton. The calculations of abundance and biomass were carried out in accordance with generally accepted hydrobiological methods [8]. Shannon-Weaver index was calculated to estimate the biodiversity of zooplankton [9]. The following indicators of zooplankton community were also defined: the average weight of zooplankton (w); the ratio of biomass of Cyclopoida to Calanoida (B_{Cycl}/B_{Cal}); the ratio of crustaceans biomass to rotifers biomass (B_{Cr}/B_{Rot}); the ratio of number of crustaceans to rotifers (N_{Cr}/N_{Cop}); the ratio of number of eutrophic species to oligotrophic species (E/O).

At the same time, abiotic parameters were analyzed, including Secchi transparency, temperature, electrical conductivity, pH, the content of dissolved oxygen, carbon dioxide, PO_4^{3-} , NH_4^+ , NO_3^- , NO_2^- , organic substances (according to BOD₅ (biological oxygen demand)). Secchi transparency was used to calculate Carlson's trophic state index (TSI) [10]. Samples for the hydrochemical analysis were taken separately from the surface and bottom layers of water, using the bathometer Molchanova GR-18, and were analyzed, according to the methods, generally accepted in the ecological analysis [11-13].

RESULTS OF THE RESEARCH

Lake Ilinskoe is characterized by low water transparency - on average 0.48 ± 0.27 m, the color is greenish-yellow (Table 1). The values of Carlson's index (TSI) characterize the reservoir as eutrophic. In summer, the surface layers of water are saturated with oxygen. An oxygen deficiency is noted in the near-bottom layers, sometimes there is hydrogen sulphide. In the last decade, the oxygen content in the surface layers of water has increased, and in the bottom layers it has decreased. The amount of free carbon dioxide in summer is significant only at depth, in the surface layers of water it is absent. The active reaction of water corresponds to neutral - slightly alkaline, but during the blooming of water, pH increases sharply - up to 9.0 - 10.0. According to the hydrochemical classification of O.A. Alekin [11-12], water refers to the hydrocarbonate class of calcium group, with small and medium mineralization. It was noted the exceeding of maximum permissible concentrations (MPC) of biogenic and organic substances. During the period of investigations, the concentrations of ammonium ions and phosphates have been increasing. In the near-bottom layers of water, the concentrations of ammonium ions sometimes were 3.2 MPC. In the surface layers of water there was a tendency for nitrites grow. The exceedances of MPC for BOD₅ were noted.

Table 1. Mean values \pm standard deviation (n = 17) of abiotic parameters of water in Lake Ilinskoe

Index	Surface layer	The bottom layer
Secchi disc visibility, m	0,48 \pm 0,27	7,50 \pm 3,73
TSI _{SD}	72,57 \pm 8,25	-
pH	8,94 \pm 0,92	7,57 \pm 0,51
Dissolved oxygen, mg dm ⁻¹	13,31 \pm 4,79	4,10 \pm 2,22
BOD, mg O dm ⁻¹	6,87 \pm 2,75	4,01 \pm 1,85
NH ₄ ⁺ , mg dm ⁻¹	0,261 \pm 0,326	1,461 \pm 0,459
PO ₄ ³⁻	0,031 \pm 0,054	0,474 \pm 0,516

The quality of water in Lake Ilinskoe varied from the category of "completely clean waters" to "slightly polluted waters". The specific features of the hydrochemistry of lake, in particular, its intensive eutrophication, are connected with the influence of tributaries. Pollution of lake occurs the most intensively during the spring flood [14].

Thus, the tendency of increasing the content of biogenic elements in the lake water, the low oxygen content in the bottom layers of water, and the presence of hydrogen sulphide were revealed. Supersaturation of surface water layers with oxygen, alkaline reaction of the medium, high concentrations of easily oxidized organic matter are the indirect signs of water blooming, caused by phytoplankton. Physico-chemical studies of water indicate the intensive process of eutrophication of Lake Ilinskoe. Now, it is necessary to reveal the most characteristic features, peculiar to the zooplankton community of the eutrophic lake.

During the period of research, 61 species were identified in the composition of pelagic zooplankton, of which Rotifera - 36 species (59%), Cladocera - 18 (30%), Copepoda - 7 (11%). Rotifers significantly prevail in the number of species over the other groups of zooplankton.

The following species were the most frequently dominated in number: *Daphnia* (*Daphnia*) *cucullata* Sars, 1862, *Brachionus diversicornis* (Daday, 1883), *B. angularis* Gosse, 1851, *Thermocyclops oithonoides* (Sars, 1863), *Keratella cochlearis* (Gosse, 1851), *Filinia longiseta* (Ehrenberg, 1834). The dominant complex was usually formed by 5-6 species. *D. (D.) cucullata*, *T. oithonoides*, *Daphnia* (*Daphnia*) *cristata* Sars, 1862, *Asplanchna priodonta* Gosse, 1850 were dominated in biomass. The species composition is typical for eutrophic lakes of the Middle Volga region.

The number of zooplankton varied annually from 41.15 thousand specimens/m³ to 980.12 thousand ex/m³ (Figure 1). On the average it was 347.38 \pm 69.13 thousand specimens/m³. The biomass varied from 0.12 to 17.1 g/m³, on the average it was 2.82 \pm 1.07 g/m³. Rotifers prevailed among the zooplankton groups (55% of the mean values of abundance and biomass). Summer values of abundance and biomass were highly variable year-wise, but there was the growth in biomass in 2013-2015.

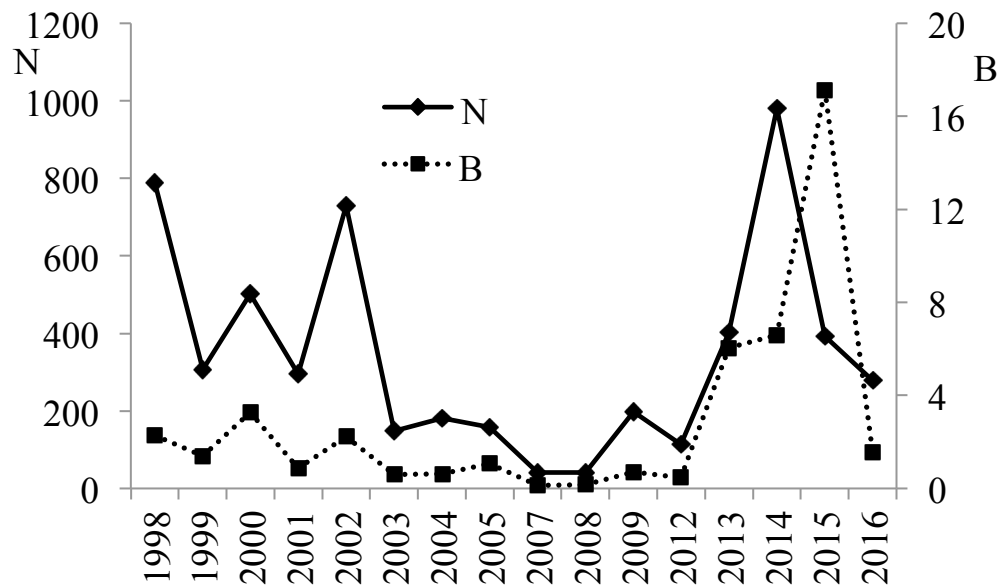


Fig. 1. Mean values of abundance (N, thousand specimens/m³) and biomass (B, g/m³) of zooplankton of Lake Ilinskoe (according to summer data).

The zooplankton community of Lake Ilinskoe is characterized by vertical heterogeneity in the distribution of zooplankton (Figure 2). This can be due to the intense oxygen regime in the bottom layers of water.

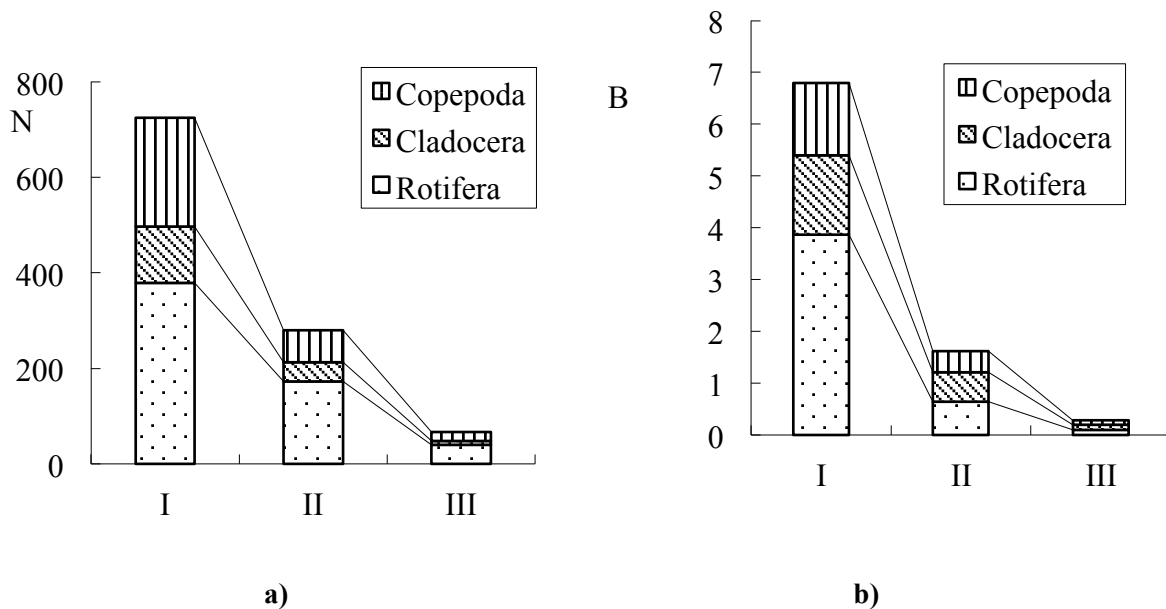


Fig. 2. Mean values of abundance (N, thousand specimens/m³) and biomass (B, g/m³) of zooplankton of Lake Ilinskoe in the epilimnion (I), metalimnion (II) and hypolimnion (III).

Long-term studies have shown a tendency to decrease in the share of Copepoda and the increase in Rotifera in the total number of zooplankton (Figure 3).

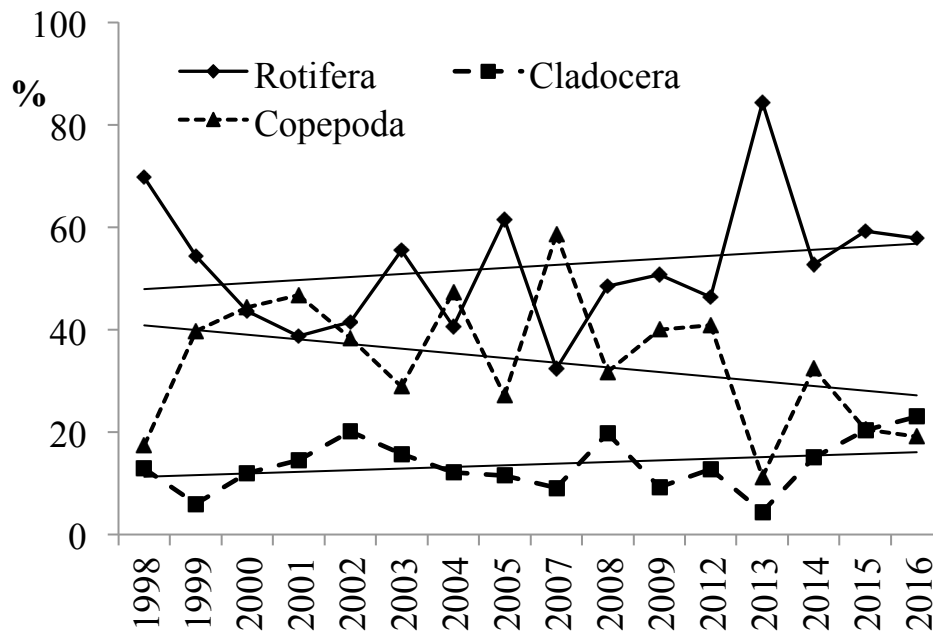


Fig. 3. Shares (%) of taxonomic groups of zooplankton in the total abundance and trend line

DISCUSSION OF THE RESULTS

The composition of zooplankton species in a water body is formed under the influence of a complex of abiotic and biotic factors and reflects its trophic status. Thus, the presence of rotifers *Brachionus*, high abundance of *Keratella* and *Filinia*, as well as *T. oithonoides*, are characteristic of water bodies with a high level of trophicity [1, 15]. In Lake Ilinskoethese species dominate.

Eutrophic lakes are characterized by a high number of rotifers [2]. This is also observed in Lakellinskoe. But here, the share of rotifers is very significant not only in abundance, but also in biomass, due to the massive development of rotifers *Asplanchna*, which have a large individual mass. These rotifers are facultative predators, feed on both animal food and algae [16], and probably the plenitude of food in this eutrophic lake is favorable for their development. In addition, it was previously noted, that in the process of lakes' eutrophication, the share of rotifers increased in the ratio Rotifera: Cladocera: Copepoda, due to a decrease in the share of crustaceans [3, 5, 7]. Similar picture was observed in our studies (Fig. 3).

The total values of abundance and biomass of zooplankton varied widely. It is also characteristic of high-trophic water bodies [1].

In the process of eutrophication, there is a change in the ratio of the main taxonomic groups of zooplankton. Thus, the ratio of biomass of Cyclopoida to Calanoida (B_{Cycl}/B_{Cal}) decreases with the eutrophication, due to a decrease in the number of Calanoida. It is argued, that calanoida copepods adapt better to oligotrophy conditions, and cyclopoida copepods are more abundant in eutrophic waters [2]. In our studies, this index could not always be calculated, since Calanoida copepods were represented by a few *Eudiaptomus graciloides* (Lilljeborg, 1888) and they were not always present in the samples. An increase in the B_{Cr}/B_{Rot} index, in the process of eutrophication, is also connected with the increase in the number of rotifers, having a low individual weight. The values of B_{Cr}/B_{Rot} index were 7.74 ± 2.81 . An increase in the number of small branchy crustaceans is also observed, that causes an increase in the N_{Cl}/N_{Cop} index. Its

values were 0.48 ± 0.07 . The last two indicators showed a tendency to increase, during the period of the study (Table 2).

Table 2. Mean values \pm standard deviation ($n = 17$) of biotic indexes in Lake Ilinskoe.

Indexes	Mean \pm st.dev.
R:Cl:Cop (N, %)	55:14:31
R:Cl:Cop (B, %)	55:24:21
B_{Cycl}/B_{Cal}	2291,90 \pm 1663,16
B_{Cr}/B_{Rot}	7,74 \pm 2,81
N_{Cl}/N_{Cop}	0,48 \pm 0,07
w, mg	0,0073 \pm 0,0024
E/O	8,97 \pm 0,42
H_N	3,15 \pm 0,08
H_B	2,63 \pm 0,10

The ratio of eutrophic and oligotrophic species (E/O) can be used to characterize the level of trophicity [1, 17]. According to the value of E/O, Lake Ilinskoe is hypertrophic.

The individual average mass of zooplankton (w), according to many researchers, is a good indicator of eutrophication, as the increase in the number of species with a small individual mass (rotifers, juvenile cyclops) and a reduction in the number of large crustaceans occur in the process of eutrophication [18]. In Lake Ilinskoe, the average mass of zooplankton is 0.0073 ± 0.0024 mg, that corresponds to high-trophic waters.

The mean values of Shannon index, calculated using the abundance (H_N) and biomass (H_B), were 3.15 ± 0.08 and 2.63 ± 0.10 , respectively (Table 2). According to the classification of I.N. Andronikova (1996), the considered reservoir is oligotrophic [1].

SUMMARY

As a result of the conducted studies, the tendency of increasing the content of biogenic elements in the lake water, low concentrations of oxygen in the bottom layers of water, the presence of hydrogen sulphide, and blooming of water, caused by phytoplankton in summer, were revealed. Lake Ilinskoe is characterized as eutrophic, according to the physicochemical parameters of water, the value of TSI_{SD} .

In the composition of zooplankton, 61 species were identified, including Rotifera - 36 species (59%), Cladocera - 18 (30%), Copepoda - 7 (11%). Rotifers significantly prevailed in species diversity over other groups of zooplankton.

The following species were the most frequently dominated in number: *D. (D.) cucullata*, *B. diversicornis*, *B. angularis*, *Th. oithonoides*, *K. cochlearis*, *F. Longiseta*, - species typical for eutrophic water bodies.

The number of zooplankton varied from 41.15 thousand specimens/m³ to 980.12 thousand specimens/m³, the average value was 347.38 ± 69.13 thousand specimens/m³ (according to summer data). The biomass varied from 0.12 to 17.1 g/m³, averaging 2.82 ± 1.07 g/m³.

Such indicators as the ratio of the main taxonomic groups of zooplankton, B_{Cycl}/B_{Cal} , B_{Cr}/B_{Rot} , N_{Cl}/N_{Cop} showed a tendency to increase during the study period. The values of the E/O index, the average individual weight of the zooplankton corresponded to eutrophic water bodies. The values of Shannon-Weaver biodiversity index were unrepresentative; they corresponded to the water bodies of the lower trophic level.

The assessment of trophic state of the lake in terms of indicators of zooplankton in most cases corresponded to the assessment, given to the results of physico-chemical studies of water and the value of TSI_{SD}.

CONCLUSION

According to the results of physical and chemical studies of water, it was established that Lake Ilinskie corresponded to the eutrophic type. Among the zooplankton, rotifers were predominant in the number of species; the composition of the dominant species is characteristic of eutrophic water bodies. The tendency to decrease in the share of Copepoda in the community, and the increase in the share of Rotifera has been revealed.

The community of zooplankton has proved to be a good indicator of the trophic state of the lake. Changes in the values of indices, based on the ratio of number or biomass of zooplankton groups (B_{Cycl}/B_{Cal} ; B_{Cr}/B_{Rot} ; N_{Cl}/N_{Cop}) can be used to identify the trend of trophic status over the long term. The ratio of shares of the main taxonomic groups of zooplankton, the average individual weight of the zooplankton, and the value of E/O make it possible to characterize the trophic status of the reservoir. All these indicators are recommended for use in monitoring the state of the lakes of Volzhsko-Kamsky State Natural Biosphere Reserve.

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