Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Zooplankton indices in the evaluation of the ecological state of the eutrophic lake (Case study: Karasikha Lake, Russia)

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ABSTRACT

Long-term (1998-2018) studies have been carried out on the small lake, Karasikha, located in the territory of the Volga-Kama State Nature Biosphere Reserve. Physicochemical characteristics of the lake water classify it as eutrophic, polluted, with a low oxygen content, but a high content of organic matter and phosphates. In parallel, some studies were carried out on its zooplankton community. Karasikha Lake is the habitat of 70 species of planktonic rotifers and crustaceans identified. Based on the number of species, rotifers predominated and their largest number belonged to *Brachionidae* family. On average 3-4 species were dominant, as indicators of eutrophic and polluted waters. However, with a relatively high species richness of zooplankton, the community has low quantitative indicators. The low oxygen content in the water column makes zooplankton concentrate mainly in the epilimnion layer (up to 2-3 m in depth). The lowest quantitative indicators of zooplankton are characteristic of the under-ice period, which is also associated with a lack of oxygen in the water. The community is dominated by indicators of dirty waters. The structure of zooplankton communities is typical of highly polluted lakes. Indices based on the taxonomic structure of zooplankton classify the reservoir as highly eutrophic and even hypertrophic.

Keywords: Zooplankton, Lake, Bio-indicator, Nature reserve, Eutrophication, Water quality.

Article type: Research Article.

INTRODUCTION

Various types of anthropogenic impact cause a series of changes in the ecosystems of water bodies and its individual components. They lead to eutrophication and pollution of water bodies. An increase in the trophic status of water bodies is also observed in natural conditions, due to the supply of biogenic elements from the catchment area and the accumulation of organic matter in the lake. Anthropogenic impact accelerates this process a hundred-fold (Andronikova 1996). The zooplankton community is an integral part of aquatic ecosystems and is a direct participant in various interactions with other communities. The features of the structure of zooplankton communities make it possible to assess and predict the development of other components and the ecosystem as a whole (Shumilov *et al.* 2005; Ershad Langeroudi *et al.* 2010; Andronikova 1996; Alimov *et al.* 2013; Jafari *et al.* 2015; Derevenskaya *et al.* 2017). The species, spatial structure, the structure of trophic relationships, and biotic indices based on these indicators make it possible to assess the trophic status, to analyze the pollution of the reservoir and to assess the quality of water (Derevenskaya *et al.* 2017). Karasikha Lake is located on the territory of the Volga-Kama State Natural Biosphere Reserve, on its border. The village of Sadovy adjoins the northeastern and eastern shores of the lake. The village discharges polluted surface runoff to the lake. The lake is suffusion-karst, flow-through water body. The average depth of the lake, maximum depth, its volume and water surface area are 2.3 m, 10.8 m, 17.16 thousand m^3 and 4.1 ha respectively. The objective of the study was to assess the ecological state of Karasikha Lake and its water quality, and also identifying the factors that have the greatest impact on the zooplankton community.

Caspian Journal of Environmental Sciences, Vol. 19 No. 4 pp. 701-708
DOI:
Received: June 07, 2021 Accepted: Aug. 28, 2021

Publisher: University of Guilan, Iran

MATERIALS AND METHODS

Karasikha Lake was explored in 1998-2018. In 2003-2005, sampling of zooplankton was carried out in all seasons of the year (winter, spring, summer, and autumn), once a season. In other years (1998-2002 and 2012-2018), samples were taken in the middle of the growing season, since in summer the development of zooplankton is maximal and is determined mainly by trophic conditions (Ejsmont-Karabin & Karabin 2013; Ochocka & Pasztaleniec 2016). Zooplankton samples were taken using a Juday net (mesh size - 100 μm), by seining the epilimnion, metalimnion, and hypolimnion layers. Cameral processing included the determination of the species composition, abundance and biomass of zooplankton, in accordance with generally accepted hydrobiological methods.

To assess the species diversity of zooplankton, the Shannon-Weaver index (Shannon & Weaver 1949) was calculated based on the abundance (H_N) and biomass (H_B) of zooplankton. The indices based on the structure of zooplankton communities were also calculated: average weight of zooplankton (w); the Cyclopoida-to-Calanoida biomass ratio (B_{Cycl}/B_{Cal}); the crustaceans-to-rotifers biomass ratio (B_{Cr}/B_{Rot}); the crustaceans-to-rotifers number ratio (N_{Cr}/N_{Rot}); the eutrophic-to-oligotrophic species number ratio (E/O). To assess the level of pollution of the reservoir with organic substances, the Sladechek (S) saprobity index was used (Sladečhek 1973).

In parallel, abiotic parameters were analyzed, including the Secchi disc transparency, temperature, electrical conductivity, pH, dissolved oxygen, carbon dioxide, PO_4^{3-}, NH_4^+, NO_3^-, NO_2^-, organic matter. The Secchi disc transparency was used to calculate the Carlson Trophic State Index (TSI) (Carlson 1977). Samples for hydrochemical analyses were taken separately from the surface and bottom layers of water using a Molchanov GR-18 bathometer, and analyzed using the methods generally accepted in environmental analysis (Alkein *et al.* 1973; Yu 1973). The influence of environmental factors on zooplankton communities was assessed using the Spearman's correlation coefficient and the principal component analysis. Statistical analysis was performed using Statistica 6.0.

RESULTS AND DISCUSSION

Water in Karasikha Lake is low transparent. In summer it was 0.60 ± 0.03 m. Carlson index (TSI), calculated from the transparency value, corresponded to a eutrophic reservoir (67.7 ± 0.8). In summer, the lake is characterized by stratification of water layers based on temperature, typical for deep-water lakes in the region. The water in the lake is neutral or slightly acidic. The content of dissolved oxygen in water is low, averaging 3.6 ± 0.6 in the surface layers. The bottom layers of water often lacked oxygen. Hydrogen sulfide was present in concentrations exceeding the permissible values. The water contained a high content of organic matter.

The values for biological oxygen consumption (BOC_5) in the surface and bottom water layers were 2.77 ± 0.30 and 4.22 ± 0.92 mg O L^{-1} respectively, which is over 2 times higher than the permissible values. Chemical oxygen demand (COD) showed even higher values: 65.69 ± 2.46 and 61.75 ± 2.39 mg O L^{-1} in the surface and bottom layers respectively. Among the compounds of biogenic elements, a high content of phosphates was noted. In the surface and bottom layers of water, their content were 0.58 ± 0.11 and 2.17 ± 0.48 mg L^{-1}, which was almost 2 times and 11 times higher than the permissible standards, respectively. According to the hydrochemical classification of Alekin *et al.* (1973), water refers to the hydrocarbonate class of the low-mineralized calcium group.

Thus, Karasikha Lake is characterized by a high content of organic substances, which, as decompose, lead to a decrease in the oxygen content in the water, the formation of hydrogen sulfide, and elevated content of phosphorus compounds.

Organic and biogenic substances enter the lake with inflow, as well as in the composition of surface runoff. The high content of nutrients in the water promotes the growth of macrophytes and duckweed. Now it is necessary to identify the zooplankton features of this type of lakes. Over the entire period, we identified 70 species of zooplankton in the zooplankton community of Karasikha Lake, of which rotifers were 38 (54%), cladocerans 20 (29%) and copepods 12 (17%). In terms of species, rotifers predominated, the largest number of them belonged to *Brachionidae* family. The average number of species in the sample was 14.2 ± 1.5. The number of dominant species was small, usually 3-4 species. In terms of numbers, *Polyarthra vulgaris* Carlin, 1943, *Filinia longiseta* (Ehrenberg, 1834), *Keratella cochlearis* (Gosse, 1851), *Bosmina (B.) longirostris* (OF Muller 1785) and *Thermocyclops oithonoides* (Sars, 1863) dominated. In terms of biomass, *T. oithonoides*, *Asplanchna priodonta* Gosse, 1850, *M. leuckarti* (Claus, 1857), *B. longirostris* dominated. These species are typical of eutrophic and polluted lakes of the Middle Volga region.

Seasonally, the lowest quantitative indicators of zooplankton are characteristic of the under-ice period, which is associated with a lack of oxygen in the water. The highest numbers were observed at the end of May (Fig. 1), due to the massive development of rotifers.

Table 1. Mean values ± standard error of abiotic parameters of water in the lake.

Index	Surface layer (n = 20)	The bottom layer (n = 20)
Secchi disc visibility (m)	0.60 ± 0.03	
TSI_{SD}	67.66 ± 0.76	
T (ºC)	22.30 ± 0.65	7.00 ± 0.55
pH	7.01 ± 0.09	6.79 ± 0.08
Dissolved oxygen (mg L^{-1})	3.60 ± 0.57	1.26 ± 0.26
H_2S (mg L^{-1})	0.00 ± 0.00	0.10 ± 0.03
BOC_5 mg O L^{-1}	2.77 ± 0.30	4.23 ± 0.92
NH_4^+ (mg L^{-1})	0.55 ± 0.09	1.85 ± 0.38
NO_2^- (mg L^{-1})	0.03 ± 0.01	0.04 ± 0.01
NO_3^- (mg L^{-1})	0.50 ± 0.23	0.52 ± 0.23
PO_4^{3-} (mg L^{-1})	0.58 ± 0.12	2.17 ± 0.48
COD (mg L^{-1})	65.69 ± 2.47	61.76 ± 2.40
Ca_{2+} (mg L^{-1})	13.46 ± 0.86	12.56 ± 0.47
Mg^{2+} (mg L^{-1})	4.18 ± 0.44	5.32 ± 0.64
HCO_3^- (mg L^{-1})	49.67 ± 4.89	57.19 ± 6.49
SO_4^{2-} (mg L^{-1})	3.46 ± 074	3.41 ± 0.67
Cl^- (mg L^{-1})	2.69 ± 0.60	2.77 ± 0.59

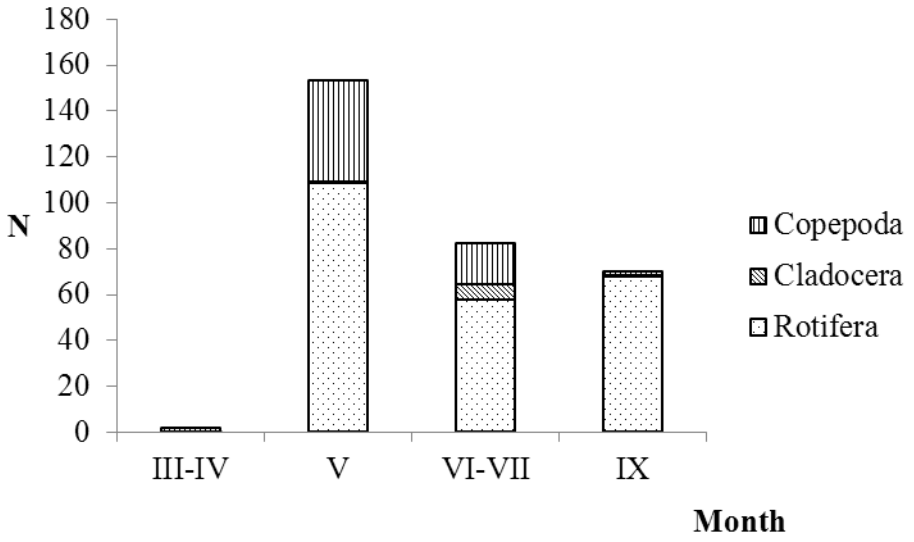

Fig. 1. Distribution of the number of zooplankton (N, thousand ind. m^{-3}) by seasons.

The largest zooplankton biomass was recorded in summer (Fig. 2). *Cladocera* predominated in terms of biomass. The average summer abundance of zooplankton varied over the years from 0.47 to 434.12 thousand ind. m^{-3} (Fig. 1), averaging 53.85 ± 22.25. Biomass varied from 0.01 to 1.22 g m^{-3}, averaging 0.25 ± 0.08 g m^{-3}. The quantitative indicators of zooplankton are distinguished by extremely low values, which is probably due to the low quality of water. Calculation of Spearman's correlation coefficient revealed a statistically significant ($p < 0.05$) correlation of oxygen content in water with the total abundance of zooplankton and the abundance of individual taxonomic groups. Karasikha Lake has uneven zooplankton distribution over the water column. The concentration of organisms was observed in the epilimnion layer; few of them were found in the hypolimnion (Figs. 4-5). Rotifers predominated in number. The factor analysis, carried out with the method of principal

components, revealed the influence of the physicochemical parameters of water on the zooplankton communities (Fig. 6). As a result of the analysis, factors were identified to explain 51% of the total variance of traits. A positive correlation was found between the oxygen content in water (O_2) and the quantitative parameters of zooplankton. A negative correlation of these indicators was found with the content of organic matter (BOD_5) and nitrite ions (NO_2^-). Abiotic, biotic, and anthropogenic factors affect zooplankton communities, cause a change in the structure of communities such as alterations in the composition of dominant species, the ratio of different groups of zooplankton, and quantitative indicators. Once polluted, the species composition of zooplankton is depleted. One or two species dominate in heavily polluted water bodies. There is a massive development of rotifers of the genus *Brachionus*. Given the resence of colorates of the genus *Brachionus* and high abundance of the genus *Keratella*, genus *Thermocyclops* is typical of reservoirs with a high level of trophicity (Andronikova 1996; Dembowska *et al.* 2015). Representatives of these genera are part of the dominant species in Karasikha Lake.

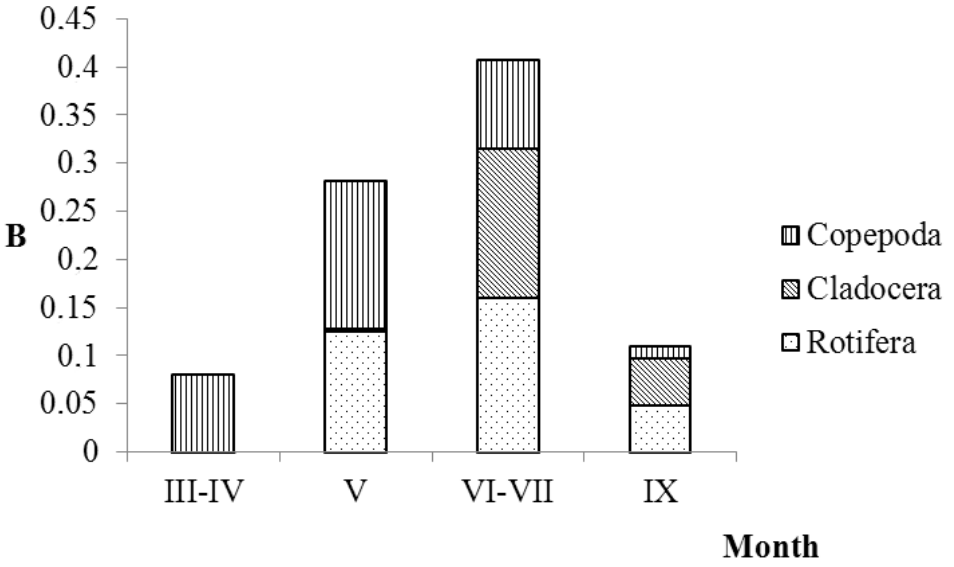

Fig. 2. Distribution of the zooplankton biomass (B, g m^{-3}) by seasons in Karasikha Lake.

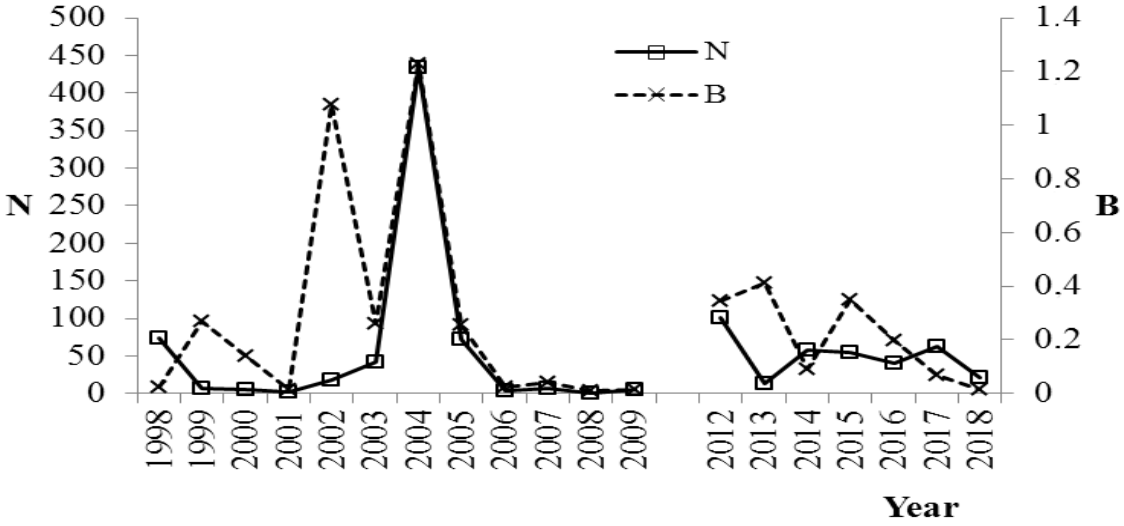

Fig. 3. Alterations in the summer values of abundance (N, thousand ind. m^{-3}) and biomass (B, g m^{-3}) of zooplankton in Karasikha Lake over the years.

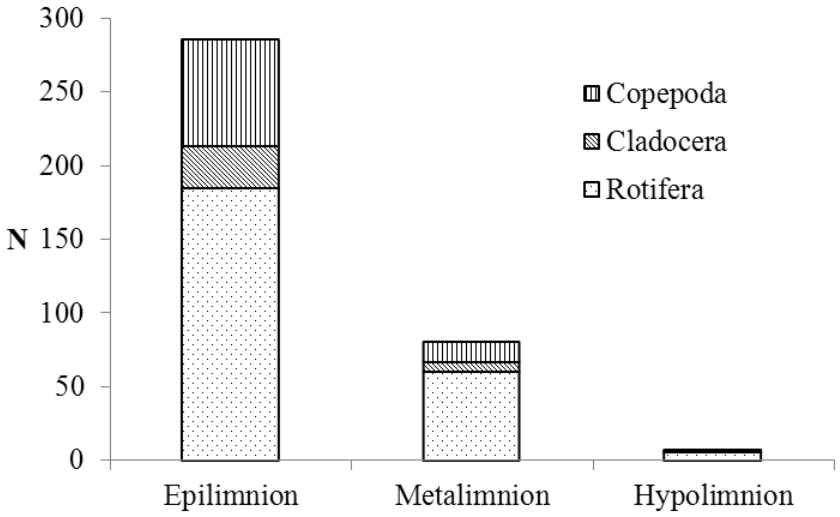

Fig. 4. Abundance (N, thousand ind. m^{-3}) of zooplankton in Karasikha Lake in different horizons.

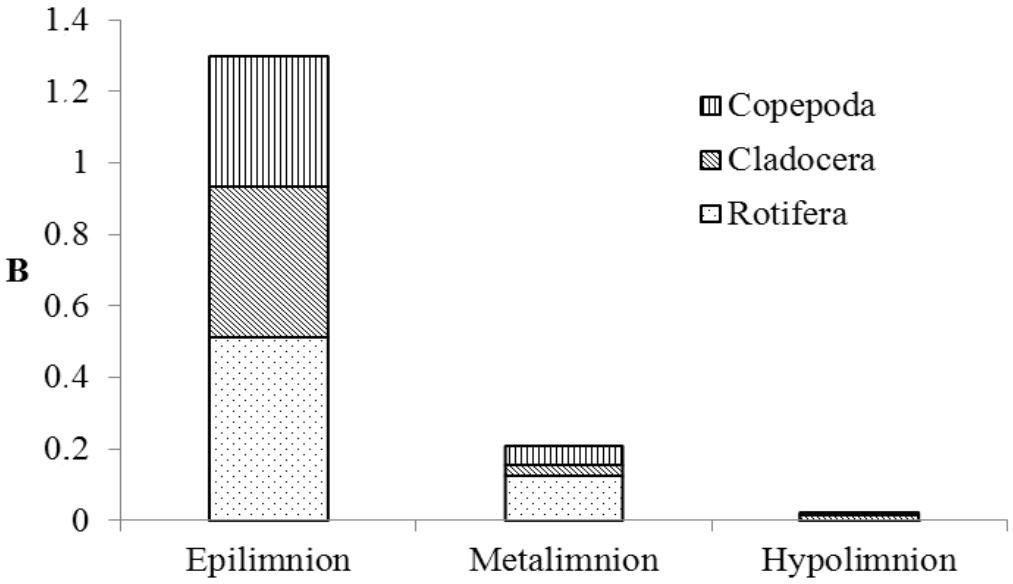

Fig. 5. Biomass (B, g m^{-3}) of zooplankton in Karasikha Lake in different horizons.

As reported inliterature, during eutrophication the number of rotifers increases and they prevail in communities (Ejsmont-Karabin & Karabin 2013). Accordingly, the *Rotifera-Cladocera-Copepoda* ratio alters towards an elevation in the proportion of rotifers, while a decreased proportion of crustaceans (Haberman & Haldna 2014; Adamczuk *et al.* 2015; Ochocka & Pasztaleniec 2016). Among the taxonomic groups of zooplankton in Karasikha Lake, rotifers predominated in terms of numbers, while cladocerans in terms of biomass (Table 2). According to the literature data, during the eutrophication of lakes, the biomass of *Cyclopoida* decreases in comparison with *Calanoida*, hence the values of the B_{Cycl}/B_{Cal} index decrease (Ejsmont-Karabin & Karabin 2013). In Karasikha Lake, the *Cyclopoida*-to-*Calaboida* biomass ratio (B_{Cycl}/B_{Cal}) in most cases could not be calculated due to the absence of the latter. In the process of eutrophication, due to an increased number of small rotifers, a drop in the biomass of this group was often observed, which leads to a decrease in the values of the B_{Cr} / B_{Rot} index. However, in Lake Karasikha there were significant fluctuations in the values of this indicator (CV = 353%), and the average values of the index are quite high. The NCl / NCop index values are relatively high and correspond to eutrophic water bodies. The ratio of the number of eutrophic to oligotrophic species (E / O) can also be used to characterize the trophic status of a water body (Andronikova 1996; Hakkari 1972). The

values of this index were 4.95 ± 0.72. The water body according to the value of this index belongs to eutrophic - hypertrophic. The value of the average individual mass of a zooplankter (w) characterizes the reservoir as highly eutrophic. The average values of the Shannon index, calculated from the biomass (HN), characterize the reservoir as eutrophic. In addition, the values of the saprobic index (S) refer the reservoir to the β-mesosaprobic zone with moderately polluted water.

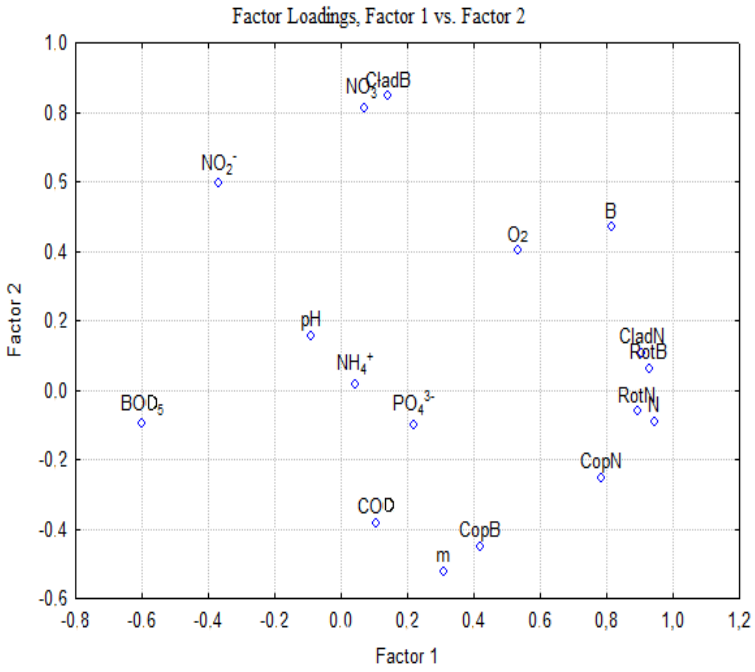

Fig. 6. Location coordinates of the centroids of habitat factors and quantitative indicators of zooplankton in Karasikha Lake (m is the number of species in the sample; RotN: The abundance of *Rotifera*; RotB: The biomass of *Rotifera*; CladN: The abundance of *Cladocera*; CladB: The biomass of *Cladocera*; CopN: The abundance of *Copepoda*; CopB: The biomass of *Copepoda*, N: Zooplankton abundance, B: Zooplankton biomass).

Table 2. Mean values ± std. error of biotic indexes of zooplankton in Karasiha Lake.

Index	Karasiha (n = 22)
R:Cl:Cop (N, %)	64:8:28
R:Cl:Cop (B, %)	30:39:30
B_{Cycl}/B_{Cal}	10.9 ± 2.8
B_{Cr}/B_{Rot}	267 ± 201
w, mg	0.0106 ± 0.0033
N_{Cl}/N_{Cop}	1.45 ± 0.72
E/O	4.95 ± 0.72
S	1.69 ± 0.05
H_N	2.39 ± 0.11
H_B	2.00 ± 0.15

SUMMARY

Our studies have shown that Karasikha Lake is a low-transparent one. According to this indicator, the water body corresponds to the eutrophic type. In summer, there is a stratification of water layers by temperature. The content of dissolved oxygen in water is relatively low, in the bottom layers of water it drops to zero, hydrogen sulfide is present. The water in the lake is neutral or slightly acidic. The water contains a high organic matter content, which is twice the permissible value.

We identified 70 species of planktonic rotifers and crustaceans in Karasikha Lake. By the number of species, rotifers predominated, the largest number of them belonged to family *Brachionidae*. On average, 3-4 species

were dominant, as indicators of eutrophic and polluted waters. The quantitative indicators of zooplankton were low, which is associated with unfavorable abiotic conditions and low oxygen content in the water. The smallest values of quantitative indicators of zooplankton were characteristic of the under-ice period, which is associated with a lack of oxygen in the water. Indices based on the taxonomic structure of zooplankton classify the reservoir as highly eutrophic and even hypertrophic. Thus, the assessment of the trophic state of the lake in terms of zooplankton indicators in most cases corresponded to the assessment given by the results of physicochemical studies of water and the TSI_{SD} value.

CONCLUSIONS

Long-term studies of Karasikha Lake, according to the physicochemical parameters of the water, make it possible to classify it as eutrophic, polluted, with a low oxygen content in the water, a high content of organic substances and phosphates. In parallel, studies of zooplankton communities were carried out, which showed that with a relatively high species richness of zooplankton, the community is characterized by low quantitative indicators. The low oxygen content in the water column makes zooplankton concentrate mainly in the epilimnion layer (up to 2-3 m depth). The structure of zooplankton communities is typical of highly polluted lakes. The community is dominated by indicators of dirty waters. Rotifers predominate in number. The lowest quantitative indicators of zooplankton are characteristic of the under-ice period, which is also associated with a lack of oxygen in the water. Indices based on the taxonomic structure of zooplankton classify the reservoir as highly eutrophic and even hypertrophic.

ACKNOWLEDGMENTS

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

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Bibliographic information of this paper for citing:

Derevenskaia, O,I, Borisova, N,I, Unkovskaia, E,N 2021, Zooplankton indices in the evaluation of the ecological state of the eutrophic lake (Case study: Karasikha Lake, Russia). Caspian Journal of Environmental Sciences, 19: 701-708