Influence of trophic status on zooplankton structure in Chelyabinsk region lakes (Russia)

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Abstract. Eutrophication of water-bodies, as well as lakes, is currently one of the crucial problems of both theoretical and applied ecology. Zooplankton is sensitive to changes in the ecological state of different types of reservoirs. The article analyses differences and similarities of zooplankton communities in 10 lakes of Kisegach - Miassovo hydrological system of Chelyabinsk region (Russia). The current research aims at identifying taxonomic structure of zooplankton communities of the lakes in Chelyabinsk region (Russia) and stating the influence of some abiotic factors on its formation. Integrated samples were gathered in summer 2015 - 2019. The given paper studied the correlation of the main taxonomic groups of zooplankton, marked a regular decrease in the number of zooplankton species under adverse environment. When the trophic level of water in natural fresh lakes changes in the direction of oligotrophic-mesotrophic-eutrophic, the total number of zooplankton decreases from 400.90 individuals per L⁻¹ to 106.06 individuals per L⁻¹. In the same direction, the number of Cladocera representatives decreases (from 362.03 individuals per L⁻¹ to 66.34 individuals per L⁻¹) and the number of Copepoda representatives decreases (from 34.01 individuals per L. 12.67 individuals per L⁻¹), and the number of Rotifera representatives increases (from 6.97 individuals per L⁻¹ to 26.60 individuals per L⁻¹).

1. Introduction

Much evidence suggests that uncontrolled human activity has an adverse impact on the environment associated with degrading ecosystem stability [1]. Trophic status is one of the most important characteristics of water ecosystems. Zooplankton being an object of biomonitoring in ecological studies of water-bodies is potentially effective in assessing trophic status [2] as zooplankton community could be changed completely or partly due to the trophic status change [3]. Zooplankton is often used to determine a variety of environmental characteristics due to its high susceptibility to environmental changes [4].

In order to give a comprehensive analysis of water ecosystems the complexity of interrelations between hydrobionts against the background of different adaptation to extreme weather conditions, temperature, salinity, pH, water clarity, is considered. In spite of bioindication being the subject of a
lot of controversy [5-7], most scholars admit the possibility of using zooplankton to study ecology [8, 9]. The use of indicator species of zooplankton to assess water quality has been thoroughly investigated [1, 10].

The relation of trophic status with qualitative and quantitative characteristics of water organisms in natural water-bodies in different regions of Russia has been the object of much research [11, 12]. But very few studies have explored the ecology of zooplankton species in the lakes of Chelyabinsk region. There is sporadic research of spacious distribution, seasonal abundance and biomass changes [13-16]. Moreover, the ecology of zooplankton in cold temperate lakes is studied very little, so our research can be a good contribution [15]. The current research aims at identifying taxonomic structure of zooplankton communities of the lakes in Chelyabinsk region (Russia) and stating the influence of trophic status on its formation.

2. Materials and methods

2.1. Study area

10 lakes in Chelyabinsk region (Russia) were studied. They belong to Kisegach-Miassovo hydrological system, which is almost a closed chain comprising 10 large and medium-sized lakes linked by small rivers and flowing streams. The studied lakes are under a human-made impact of various degrees, and they are characterized by different trophic status. Table 1 presents the main data about the water-bodies.

Bolshoye Miassovo, Ishkul, Bolshoy Tatkul, Argayash, Savelkul, Baraus are located on the territory of the Ilmen State Reserve and could be considered as conventionally undisturbed, while Maloye Miassovo, Bolshoy Kisegach, Maly Kisegach and Ilmenskoe are affected by human activity, which presents an extra eutrophic factor connected with the presence of residential and recreational areas near the shores. These lakes are partly outside the territory of the State Reserve.

Table 1. Information about water-bodies.

| Lake                | Shortened names | Max. depth, m | Surface, km² | Geographic coordinates | Clarity Secchi disc, m | TSI   | Trophicity    |
|---------------------|-----------------|---------------|--------------|------------------------|------------------------|-------|--------------|
| Argayash            | Arg             | 3.2           | 1.44         | 54°59'27"             | 60°13'23"              | 1.6   | 53           | eutrophic   |
| Bolshoy Tatkul      | B.T.            | 3.4           | 2.48         | 55°11'50"             | 60°17'02"              | 2.5   | 47           | mesotrophic |
| Ilmenskoe           | Im              | 6.1           | 4.76         | 55°00'27"             | 60°08'50"              | 2.3   | 48           | mesotrophic |
| Maloye Miassovo     | M.M.            | 7.8           | 12           | 55°10'04"             | 60°21'08"              | 3.7   | 41           | mesotrophic |
| Savelkul            | Sav             | 8.4           | 6.64         | 55°08'07"             | 60°18'19"              | 4.2   | 39           | oligotrophic|
| Baraus              | Bar             | 10.0          | 1.08         | 55°08'43"             | 60°19'44"              | 4.5   | 38           | oligotrophic|
| Ishkul              | Ishk            | 15.0          | 2.7          | 55°08'67"             | 60°16'32"              | 1.6   | 53           | eutrophic   |
| Maly Kisegach       | M.K.            | 16.3          | 2.04         | 55°05'43"             | 61°17'13"              | 1.5   | 54           | eutrophic   |
| Bolshoye Miassovo   | B.M.            | 22.5          | 11.4         | 55°08'67"             | 60°16'32"              | 3.7   | 41           | mesotrophic |
| Bolshoy Kisegach    | B.K.            | 35.2          | 14.2         | 55°02'36"             | 60°18'26"              | 4.0   | 40           | mesotrophic |

The Ilmen group lakes are situated within the limits of low-mountain and piedmont zones at the height of 270-375 m above sea level along meridional mountain ridge (table 1). According to the classification [17], Ishkul, Maly Kisegach, Bolshoye Miassovo, Bolshoy Kisegach are deep lakes if maximum depth is taken as a criterion (table 1), they could be characterised by pronounced basins.

The coastal areas of the lakes are poorly developed with irregular shores broken by many bays and creeks. Ilmenskoe, Maloye Miassovo, Savelkul, Baraus belong to the lakes of medium depth (table 1). Their shores are clearly defined. The bottoms and shores of the lakes are rocky as there is sometimes a submerged outcrop. Argayash and Bolshoy Tatkul are shallow lakes (table 1).

They have significant silt deposits that sometimes reach 6 m, which has caused the lakes to decrease in depth. These lakes are bays once separated of the largest lakes.
According to the chemical composition, the lake waters are classified as hydrocarbonate, calcium and magnesium waters of various types [18]. The lakes are characterised by low water salinity 115.0-417.0 mg· L⁻¹.

2.2. Sample collection
The authors present data of their own that was collected in 2015-2019 [10-13] and analyse the data of other researchers [14, 15]. Rechkalov V.V. and Golubok O.V., who studied vertical distribution of zooplankton in some lakes of South Ural, found that the main mass of hydrobionts is concentrated in the epilimnion, while the peculiarities of their distribution are related to the depth of the metalimnion and the temperature gradient within it [14]. Therefore, to study the number of zooplankton, we identified key areas in each lake where geobotanical descriptions, physical and chemical studies, and zooplankton sampling were performed, in order to reflect the diversity of biotopes (soil, depth, water trophic capacity, anthropogenic impact). Since the number of zooplankton is highly dependent on the water temperature, we took samples of zooplankton at separate points when the water of the epilimnion warmed up to a temperature of 20-23 °C. The basic material was gathered as follows: in June-July 2015 the samples from Ilm and Arg were collected; in June-July 2016 - Sav, Bar and B.M.; in 2017 - M.M., B.K. and M.K.; in 2018 - 2019 - B.T. and Itk. Alongside, species were counted and taxonomically identified [19-21].

A conical plankton net with the upper ring diameter of 18 cm, lower 24 cm and a net cell of 25 mkm was used to catch zooplankton in the upper layers of the lakes. When sampling the water column of lakes, levels were determined: large with an interval of 3 m, medium - with an interval of 2 m, small with an interval of 1 m. Samples from these horizons were taken using a bathometer. Then water samples with zooplankton from each horizon at the research site were filtered through a grid with a standard cell diameter [22]. All samples of a column of water from one point were mixed with each other and with a sample of surface water. Thus, an average sample (integrated sample) of a column of water at each point was obtained; such average samples were delivered to the laboratory for further studies. The samples were fixed with 5 % formalin, then reduced to 100 ml, three consecutive samples of 1 ml were studied with the binocular microscope and analysed by the standard methods in the laboratory [22]. To identify most of the species and genera, a 100-400 magnification microscope was used. To study crustaceans under a microscope, they were transferred on a slide in a drop of glycerol and placed sideward with the antennae set aside from the body, if possible. Dissection was not required. For the analysis, average-weighted samples were prepared for each site. The results for the number of species were expressed as the number of animals per liter. The standard counting method was used to assess the number of zooplankton species [22]. Rare species were counted in the third, half and whole sample depending on the size. The dominant species were identified according to the abundance in taxonomic groups of crustaceans and rotifers separately.

The lake clarity value was determined by a white Secchi disk (SD) with a diameter of 30 cm. We used Non-metric Multidimensional Scaling (NMDS) to examine zooplankton community [23]. To assess the similarity of plankton in different lakes and analyse the influence of trophicity on the formation of zooplankton community, the Czekanowski-Sorensen coefficient was used, which was determined with the GRAPHS [23].

3. Results and discussion
We analyzed 33 integrated samples from 10 lakes of the unified hydrological system to find out the influence of various levels of trophicity on the formation of the zooplankton community. Our hypothesis was that the biological diversity of zooplankton in the studied lakes may be mostly similar, but the number of species and core-species complexes of the zooplankton communities of these lakes may change under the influence of environmental factors. We considered the trophic status of these lakes in terms of clarity, biodiversity and density. In our research it does not always coincide with the ranging of lakes according to the zooplankton species diversity index. According to the Trophic State Index of Carlson (TSI) calculated on water clarity values, the studied lakes could be classified as
follows: Sav and Bar are oligotrophic lakes; B.M., M.M., Ilm, B.K. and B.T. are mesotrophic; M.K., Ishk and Arg are eutrophic (table 1).

The range of lakes with the help of non-metric multidimensional scaling (nMDS) on biodiversity and density does not always coincide with a trophic status of the studied lakes on clarity value. The analysis of the graph (figure 1), drawn in accordance with biodiversity and density, made the following range possible: the first group consists of Sav and Bar, which are oligotrophic according to the TSI; the second group comprises B.M., M.M., B.T., which are mesotrophic according to the TSI; B.K., Ilm, M.K., Ishk belong to the third group (eutrophic lakes), although B.K., Ilm are mesotrophic lakes according to the TSI.

A total of 44 species of zooplankton were registered in the studied lakes ranging from 33 in M.K. to 43 in B.M. (table 2). The registered species belong to the three main taxa: Cladocera, Copepoda and Rotifera. Most of them are widely distributed in the temperate natural zone. Based on table 2, the core-species complexes of lakes different in trophicity differed. Thus, B. longirostris, C. pulchella, T. oithonooides were the center of community formation in oligotrophic lakes, in mesotrophic lakes it was D. magna, and B. coregoni, B. calyciflorus are in eutrophic lakes. It is of interest to note that S. vetulus was part of the core formation of lake communities of all types. And the species C. sphaericus and F. longisetia were part of the core formation of meso- and are eutrophic lake communities.

### Table 2. Zooplankton species composition and abundance, ind-L$^{-1}$.

| Species                        | Arg | Sav | Bar | B.M. | M.M. | B.T. | Ishk | Ilm | B.K. | M.K. |
|--------------------------------|-----|-----|-----|------|------|------|------|-----|------|------|
| Bosmina longirostris (O. F. Müller, 1776) | 0.27 | 207.45 | 156.11 | 1.20 | 0.19 | 0.32 | 0.23 | 0.09 | 0    | 0    |
| Bosmina coregoni (Muller, 1785) | 0.68 | 0.05 | 0.15 | 3.94 | 2.04 | 3.72 | 2.12 | 10.04 | 12.72 | 15.62 |
| Bythotrephes longimanus (Leydig, 1860) | 0.05 | 0.95 | 0.77 | 0.47 | 0.18 | 0.13 | 0.53 | 0.09 | 0    | 0    |
| Ceriodaphnia affinis (Lilljeborg, 1862) | 0.08 | 30.46 | 25.30 | 3.12 | 0.12 | 2.02 | 0.93 | 0.09 | 0.03 | 0.56 |
| Ceriodaphnia pulchella (Sars, 1862) | 0.18 | 41.65 | 53.15 | 2.38 | 0.21 | 0.32 | 1.14 | 0.14 | 0.01 | 0.01 |
| Ceriodaphnia reticulata (Jurine, 1820) | 3.72 | 6.83 | 7.69 | 5.31 | 3.34 | 3.47 | 6.14 | 2.36 | 2.67 | 2.16 |
| Ceriodaphnia quadranranga (O. F. Müller, 1785) | 0 | 0 | 0 | 0.01 | 0.03 | 0.01 | 0.01 | 0 | 0.01 | 0.01 |
| Chydorus sphaericus (Muller, 1785) | 0.36 | 0.11 | 0.10 | 58.36 | 25.24 | 49.47 | 11.86 | 0.52 | 23.72 | 23.72 |
| Daphnia cucullata (Sars, 1862) | 43.02 | 43.55 | 35.43 | 0.02 | 21.64 | 0.02 | 6.02 | 26.47 | 4.68 | 5.26 |
| Daphnia magna (Straus, 1820) | 34.06 | 0.02 | 0.02 | 0.05 | 31.11 | 2.46 | 0.03 | 13.96 | 0.02 | 0.04 |
| Daphnia longispina (O. F. Muller, 1776) | 0.09 | 0.01 | 0.01 | 0.11 | 3.17 | 0.13 | 0.65 | 2.82 | 4.13 | 7.13 |
| Daphnia pulex (Leydig, 1860) | 0.36 | 0 | 0 | 0.61 | 1.52 | 2.37 | 1.19 | 4.52 | 4.07 | 6.77 |
| Daphnia cristata (Sars, 1862) | 0.34 | 0.49 | 0.57 | 0.16 | 0.10 | 0.11 | 0.18 | 0.12 | 0.11 | 0.10 |
| Diaphanosoma brachirium (Levin, 1848) | 0.12 | 0.29 | 0.29 | 8.27 | 7.89 | 4.67 | 0.96 | 3.89 | 4.67 | 4.08 |
| Leptodora kindtii (Focke, 1844) | 0.25 | 0.32 | 0.35 | 0.16 | 0.18 | 0.15 | 0.24 | 0.17 | 0.15 | 0.13 |
| Sinocephalus vetulus O.F. Muller 1776 | 12.79 | 29.84 | 15.48 | 13.46 | 11.63 | 9.85 | 10.84 | 3.21 | 8.77 | 5.89 |
| Scapholeberis mucronata (O. F. Müller, 1785) | 0.01 | 0 | 0 | 0.02 | 0.23 | 0.19 | 0.26 | 0.76 | 0.33 | 0.43 |
| Polyphemus pediculus (Limnaeus, 1761) | 0.09 | 0.02 | 0.01 | 0.45 | 0.38 | 0 | 0 | 0.68 | 0.34 | 0.27 |
| Eucyclops macrurus (Sars, 1863) | 1.46 | 3.50 | 3.44 | 1.52 | 1.35 | 1.76 | 0.94 | 0.10 | 0.12 | 0.24 |
| Eucyclops serrulatus (Fischer, 1851) | 0.14 | 0.01 | 0.01 | 0.20 | 0.29 | 0.22 | 0.10 | 0.66 | 0.48 | 0.49 |
| Eudiaptomus graciloides (Lilljeborg, 1888) | 2.73 | 3.44 | 4.45 | 1.32 | 1.35 | 1.03 | 0.64 | 0.38 | 0.39 | 0.23 |
| Eudiaptomus vulgaris (Schmeil, 1896) | 0.04 | 0.12 | 0.13 | 0.05 | 0.03 | 0.03 | 0.05 | 0 | 0 | 0 |
| Cyclops vicinus (Ulianin, 1875) | 1.46 | 1.10 | 1.30 | 0.65 | 0.33 | 0.59 | 0.74 | 0.33 | 0.29 | 0.19 |
| Cyclops strenuus (Fischer, 1851) | 0.03 | 0.01 | 0.01 | 0.17 | 0.12 | 0.13 | 0.01 | 0.82 | 0.40 | 0.33 |
| Mesocyclops leuckarti (Claus, 1857) | 0.14 | 0.20 | 0.29 | 0.02 | 0 | 0 | 0.03 | 0 | 0 | 0 |
| Macrocyclops albidus (Jurine, 1820) | 1.53 | 0.34 | 0.43 | 1.42 | 1.41 | 2.33 | 1.24 | 3.48 | 2.39 | 3.80 |
| Thermocyclops oithonoides (Sars,1863) | 1.80 | 21.82 | 22.16 | 17.41 | 16.54 | 5.43 | 0.07 | 0.54 | 0.43 | 0.10 |
| Nauplii | 16.71 | 1.33 | 1.64 | 11.26 | 7.37 | 13.26 | 1.08 | 6.37 | 9.13 | 8.26 |
| Type Rotifera | | | | | | | | | | |
| Asplanchna priodonta (Gosse, 1850) | 0.05 | 0.03 | 0.02 | 0.01 | 0.02 | 0.02 | 0 | 0 | 0.01 | 0 |
| Bipalpus hudsoni (Imhof, 1891) | 0.03 | 0.09 | 0.08 | 0 | 0.01 | 0.01 | 0.08 | 0 | 0 | 0 |
| Brachionus diversicornis (Daday, 1883) | 4.98 | 0.70 | 0.74 | 3.55 | 4.33 | 6.94 | 0.53 | 6.53 | 7.14 | 6.77 |
Zooplankton communities turn out to be very similar in taxonomic composition in all the lakes (table 2). This is due to the fact that the lakes form the unified hydrological system. However, Cladocera was distinguished by the richest species diversity (figure 2) ranging from 15 in oligotrophic lakes to 18 in mesotrophic (from 38 % to 50 % from the total number of zooplankton species). Slightly fewer species have been registered in type Rotifera - from 9 species in are eutrophic lakes to 17 species in oligo and mesotrophic lakes (from 28 % to 40 %). In terms of species diversity, Order Copepoda is represented almost equally in all the studied water-bodies - 9 species (20 % of the total number of species) (table 2). The communities differ mainly in the structure of dominance not in species composition.

As it has been proved by the previous studies [2, 3, 8, 9], zooplankton structure is sensitive to the trophic status of lakes and reflects separate stages of eutrophication. The proportion of zooplankton community density of the studied groups Cladocera - Rotifera - Copepoda in lakes different in trophicity appeared to be different. In oligotrophic lakes this proportion is 89:2:9 (%). The proportion of Cladocera decreases in mesotrophic lakes with the proportion of Rotifera and Copepoda increasing 70:10:20 (%). In eutrophic lakes, the proportion of Rotifera increases and the proportion of Copepoda and Cladocera decreases 66:22:10 (%) (figure 3). Besides, in oligotrophic lakes, Cladocera dominates in all water layers and the average weighted zooplankton community density is high and accounts for
368.59± 32.31 individuals per L\(^{-1}\) (figure 4). Unlike in oligotrophic, in mesotrophic lakes, the part of Copepoda is increasing (figure 4), the average weighted zooplankton community density is 132.17 ± 8.50 individuals per L\(^{-1}\). In eutrophic lakes, the community density of Rotifera is growing (figure 4), and the average weighted zooplankton community density is 92.60 ± 2.88 individuals per L\(^{-1}\).

4. Conclusions
The obtained results show that the only parameter is not enough to determine the lake trophic status. But ranging lakes according to biodiversity and density mostly coincides with the lakes trophicity according to SD value. Physical factors of shallow lakes might reflect trophic changes more quickly than biological ones. And for large lakes the situation is opposite. So, such lakes as Argayash, Ilmenskoe, Bolshoy Kisegach could be referred to transitive, i.e. mesoeutrophic.

It was noted that when trophic status of fresh lakes changes towards oligotrophic-mesotrophic-eutrophic, the total zooplankton community density decreases from 400.90 individuals per L\(^{-1}\) (Sav) to 106.06 individuals per L\(^{-1}\) (Ilm). If trophic status is considered in separate groups, then, Cladocera is changing from 362.03 individuals per L\(^{-1}\) (Sav) to 66.34 individuals per L\(^{-1}\) (BK), Copepoda is decreasing from 34.01 individuals per L\(^{-1}\) (Bar) to 12.67 individuals per L\(^{-1}\) (Ilm), and Rotifera is increasing from 6.97 individuals per L\(^{-1}\) (Bar) to 26.60 individuals per L\(^{-1}\) (MK).

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Figure 3. Proportion (%) of zooplankton main groups in lakes different in trophicity A - oligotrophic lakes; B - mesotrophic lakes; C - eutrophic lakes.

Figure 4. Average weighted density (ind·L\(^{-1}\)) of zooplankton main groups in lakes: 1 - Sav; 2 - Bar; 3 - Arg; 4 - B.M.; 5 - B.T.; 6 - M.M.; 7 - Ishk; 8 - Ilm; 9 - B.K.; 10 - M.K.
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