Distribution of zooplankton in Lake Aslikul (South Urals, Russian Federation)

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Abstract. Fauna of aquatic invertebrates from various biotopes of the mineralized Lake Aslikul of the Asly-Kul natural park was studied. Lake Aslikul is the largest body of water in the Republic of Bashkortostan, one of the largest lakes in the Middle Volga region. Crustaceans dominated (67%) in the zooplankton in terms of the number of species. Typical eurythermal species such as Keratella quadrata (Müller, 1786), Eudiaptomus gracilis (Sars, 1863), and E. graciloides (Lilljeborg, 1888) were recorded in the zooplankton, that thrived throughout the summer and autumn. Typical brackish-water species were encountered, for example, Hemidiaptomus ignatovi Sars, 1903. A specific community of zooplankters was formed in different biotopes of the lake: Daphnia galeata and Bosmina (E.) cf. longispina (Leydig, 1860) were found in the pelagial; Pleuroxus aduncus (Jurne, 1820) and Eucyclops macruroides (Lilljorg, 1901) in macrophyte beds. The species inhabiting the deep-water part of the water body may be considered as indicators of oligo- and mesotrophic waters (Diaphanasoma brachyurum (Lievin, 1848), Bosmina (Eubosmina) cf. longispina Leydig, 1860, and Bilpalpus hudsoni (Imhof, 1891)). Two rotifer species Rotaria rotatoria (Pallas, 1766) and Lecane (s. Str.) luna (Müller, 1776) were found only in macrophyte beds indicating mesotrophic conditions. In June and September 2010, the abundance of zooplankton throughout the entire lake varied from 1200 to 196 (on average, 484.3±166.4) thousand individuals/m³, and the biomass from 13.6 to 0.9 (on average, 8.5±2.5) g/m³. Crustaceans (78%) have also made the main contribution to the formation of quantitative indicators of zooplankton in various biotopes of the lake.

1. Introduction
Zooplankton organisms are ecologically important, as the integral components of the food chain in any body of water, and representing the planktonic, neustonic, benthic, and complex phytophilic cenoses [1, 2]. According to the type of nutrition, zooplankters may be primary and secondary filter feeders, gatherers, predators and necrophages. Some serve as an important factor in the formation of water quality, as well as being the objects of bioindication and monitoring of the environmental conditions [1, 3]. However, one of the important conditions that favorably affect the development of aquatic organisms is the low water mineralization, preferably less than 2 g/l. High salinity adversely affects...
organisms. Nevertheless, crustaceans live mainly in continental waters, both fresh and brackish as well as saline, inhabiting various types of waterbodies from temporary puddles and accumulations of water in tree hollows and leaf axils to large lakes [3]. It is believed that most of the Cladocera of Northern Eurasia live exclusively in fresh waters, and only relatively few of them, mainly the representatives of the genera *Diaphanosoma*, *Moina*, *Daphnia*, *Scaphaleberis*, *Ceriodaphnia*, *Bosmina*, and some Chyddidae are also found in brackish and saline habitats, including soda lakes [4, 5]. Our study aimed at determining the species composition and assessing the quantitative indices of zooplankton in the brackish waters of Lake Aslikul of the Asly-Kul natural park of the Republic of Bashkortostan. This serves as the basis for the successful study of the biology of planktonic animals and the ecology of the communities of the lake, as well as bioindication and monitoring, the areas related to environmental research, protection and restoration.

2. Materials and Methods

Lake Aslikul is a natural monument of regional significance, the largest lake in Bashkortostan located on the territory of the Asly-Kul natural park. It is located on the Bugulma-Belebey Upland between the low mountains Tubulak, Ul-Karagach, Ulutau and Belekey-Karagach. In the southwestern part, the lake is propped up by the spurs of the Tashlytau ridge, composed of sandstones of the Ufa stage, underlain by layers of pebble conglomerate. The lake has the following dimensions: area is 23.5 km², length - 7.1 km, average width - 3.3 km, average depth - 5.1 m (maximum - 8.1 m), volume ~ 119x10⁶ m³, coastline length ~ 20-21 km. The lake is of karst origin, the water in it is brackish, with high content of sulphate-hydrocarbonate calcium-magnesium and total mineralization of 1.94 g/l [6, 7].

The study of Lake Aslikul was carried out in June and September 2010.

The study has shown that there was no thermal stratification in the lake, there were insignificant changes in the parameters in the water column: in June - 21.5°C at the surface and 19°C at the bottom; in September - 19.5°C at the surface and 19°C at the bottom.

In the pelagic part of the lake, zooplankton samples were taken with a Ruttner bathometer (4 l) and 10 l of water was concentrated through a nylon sieve with a mesh of 99 µm.

Areas of the littoral zone overgrown with macrophytes are situated in the lake’s northeastern part. Samples were taken in separate associations of macrophytes: with submerged leaves - *Potamogeton tenuifolius* Raf., coastal (aerial) - *Typha angustifolia* L., *Phragmites australis* (Cav.) Trin. ex Steud., open littoral and separately pelagic using a graduated cylinder, while concentrating 5 L of water through a nylon sieve with a mesh of 99 µm. To compare the development of zooplankton in different biotopes of Lake Aslikul, we used the samples taken from the surface (0m), in the pelagic zone, littoral and macrophyte beds.

Data collection and analysis were carried out by standard methods [2, 8]. The material was fixated with a 4% formaldehyde solution. To determine the species of zooplankton, a specialized key and articles for each group of species were used [2,9–13].

The abundance (N, thousand ind./m³), biomass (B, g/m³) of zooplankton and Sørensen's coefficient were calculated. We used the individual masses of zooplanktoners, which were calculated according to special tables [9], as well as the Pantle-Buck index modified by Sladecek. The dominant species included the number and biomass of 10% or more of the total. To determine the trophic type of the lake according to the biomass (B) of zooplankton, we used the classification by SP Kitaev [14]. To determine the zone and saprobity index of zooplankton, unified methods for studying water quality were used [15]. Sometimes we used the mean values of the indicator ± standard deviation. We used the Spearman rank correlation coefficient, a measure of the linear relationship between random variables. Spearman's correlation is rank-based, that is, to assess the strength of the relationship between the parameters, not numerical values were used, but the corresponding ranks. To assess the biodiversity of aquatic organisms, the indices of species diversity (Shannon, H) and evenness (Pielu, E) in abundance (N) were used. The primary descriptive statistics of the data were carried out using
the Statistica 8.0 and Excel 2003 software packages.

3. Results and Discussion

Studies of the zooplankton of Lake Aslikul began in the 1940s, but initially the data were of a special nature, associated with the food supply of fish in the waterbody. Of all aquatic organisms, only cladocerans were taken into account. Five species were observed by M G Khanislamov (1949), and ten by M G Bayanov and T N Starukhina (1970) [15, 16]. In 2010 the lake was found to be inhabited by 42 species of zooplankton. Rotiferans are represented by 17 species (40.1% of the total number of aquatic species), Crustacea - 25 (59.5%), of which Cladocera - 16 (38.1%) and Copepoda - 9 (21.4%), respectively. Thus, having analyzed previous findings and our own data, it turned out that 52 species of zooplankton were found in the lake. Of these, 17 rotifer species (33% of the total number of invertebrate species) Crustacea - 35 (67%); Cladocera - 26 (50%) and Copepoda - 9 (17%), respectively. The complete list of invertebrates of the lake was described earlier in [18]. The species Hemidiaptomus ignatovi Sars, 1903 that prefers brackish waters was found in the lake for the first time. The conditions of existence in the lake are well suited to these calanids, since it is sufficiently mineralized and fed by numerous cold-water streams flowing down from rocky hills [7, 16, 18].

From an ecological point of view, the composition of the zooplankton of a mineralized water body consisted of typically eurythermal, year-round (continuing to function both in summer and in autumn) species were found (Keratella quadrata, Eudiaptomus gracilis, E. graciloides). Typical brackish-water species were also encountered (for example, Alonopsis elongata, Hemidiaptomus ignatovi). Specific communities of zooplankters are formed in different ecotopes of the lake: organisms that prefer open water (Daphnia galeata, Bosmina longispina) are expected to develop in the pelagic part of the lake, while phytophilic species (Pleuroxus aduncus, Eucyclops macrouroideus) inhabit macrophyte beds.

Similar to other lotic and lentic aquatic systems, the largest number of invertebrate species was recorded in communities formed in the higher aquatic vegetation [19, 20, 21]. The communities formed in the thickets of submerged macrophytes such as Phragmites australis, Typha angustifolia – a coastal aquatic plant, were distinguished by the highest species richness of invertebrates. The minimum was seen in the thickets of Phragmites australis. A high number of zooplankton species in communities formed by submerged macrophytes is also typical for other water bodies [19, 20]. This is probably due to the use of thickets by aquatic organisms as a shelter, with a large amount of organic matter in them, more suitable hydrodynamic conditions, and a better food base. In each group of vegetation (submerged and coastal), species associated with each of the identified parts were encountered. Thus, such species as Cephalodella gibba (Ehrenberg, 1832), Bipalpus hudsoni (Imhof, 1891), Euchlanis lyra Hudson, 1880, Pleuroxus trigonellus (O F Müller, 1785), P. aduncus (Jerne, 1820), Alonella nana (Baird, 1850), Alona quadrangularis (O F Müller, 1875), Alonopsis elongata (Sars 1862), Simocephalus vetulus (O F Muller, 1776) were found only in the associations of plants with submerged leaves. At the same time, Lecane (s. str.) luna (Müller, 1776), L. (s. Str.) unguata (Gosse, 1898), S. hesperus (De Geer, 1778) were only recorded in the coastal (air-water) macrophyte beds.

The invertebrates that we found have different indicator significance; o- and o-β-mesosaprobic species were more common than others (on average, 1.5 ± 0.9 calculated saprobity according to Pantle-Buck index modified by Sladecek), and the lake corresponds to the o- and o-β-mesosaprobic type.

According to A Kh Mäemets, indicators of oligo- and mesotrophic status within this group, were Diaphanosoma brachyurum, Bosmina longispina, Bilpalpus hudsoni, etc. These species were found in the pelagic zone and were recorded only in the deep-water part of the lake (on average, 1.1±0.6 calculated saprobity according to Pantle-Buck index)

Indicators of meso- and eutrophic waters (Bosmina longirostris, Chytorus sphaericus,
*Thermocyclops crassus*, all species from the genus *Brachionus*, *Keratella quadrata*, *Trichocerca capucina*, *Filinia longiseta*) were recorded in macrophyte beds (on average, 2.0±0.7 Pantle-Buck index). *Euchlaniis dilatata* Ehrenberg, 1832 and *E. lyra* Hudson, 1880 were found only in higher aquatic vegetation.

The species composition of the zooplankton of Lake Aslikul, taking into account the vertical distribution, and the biotope preferences, was distinguished by a low degree of similarity - the Sorensen coefficient was ~49%. The maximum rates of similarity (48%) were noted between the zooplankton communities that formed in the thickets of *Potamogeton tentifolius* and *Typha angustifolia*, the minimum (17%) - between the pelagial and *Phragmites australis* beds.

The vertical distribution of zooplankton had its own peculiarities. In the summer, the abundance of zooplankton varied heterogeneous from 1200 to 195 (394.1±112.3, on average) thousand ind./m³, the maximum was noted from 0 to 1 m, the minimum - at 7 m. The main role in the formation of the abundance was played by nauplii (15.1%) and copepodite stages (I – V) of copepods (16.3%). The biomass of aquatic organisms varied from 31.22 to 0.3 (on average, 15.1 ± 3.4) g/m³. Its greatest indicators were recorded at a depth of 2 (30.7 g/m³) - 3 (31.2 g/m³) m, the minimum - at 7 m. The maximum biomass indicators were formed due to the development *Eudiaptomus graciloides* (7.2%) and *E. gracilis* (5.2%).

In the autumn, the quantitative indicators of zooplankton in the water column are presented more evenly. In September, the abundance of zooplankton varied from 441 to 209 (318.5±103.7, on average) thousand ind./m³, the maximum was recorded at - 0 m, the minimum - at 5 m. The main role in the formation of the number was again played by nauplii (10.2%) and copepodite stages (I – V) of Cyclopoidea (9.1%). The amplitude of biomass fluctuations in autumn was from 3.6 to 1.6 (2.1±1.1, on average) g/m³, the highest value was recorded at 2 m, the lowest at 0 m. The maximum biomass indicators are formed due to the development *Diaphanosoma brachyurum* (Lievin, 1848) (6.3%), *Bosmina (Bosmina) longirostris* (O F Müller, 1785) (5.5%) and *Metacyclops gracilis* Lilljeborg, 1853 (3.2%).

When comparing the development of zooplankton in different biotopes of Lake Aslikul, we used the data obtained surface (0m) samples, as well as those taken in the pelagial, littoral and macrophyte beds. In June and September, the abundance of zooplankton throughout the entire lake varied from 1200 to 196 (on average, 484.3±166.4) thousand ind./m³, and the biomass from 13.6 to 0.9 (on average, 8.5±2.5) g/m³. Crustaceans (78%) made the main contribution to the formation of quantitative indices of zooplankton in various biotopes (table). It can be noted that, in contrast to the zooplankton communities of the waterbodies we studied earlier [21, 22, 23], higher values of the abundance (442 thousand ind./m³) and biomass (11.5%) are observed in the open littoral of the lake in the summer, compared to those in the macrophytes beds (on average, 248 ± 38.2 thousand ind./m³ and 1.3 ± 0.5 g/m³). In the autumn, on the contrary, higher quantitative indices of hydrobiions’ development were seen in the communities formed in thickets of higher aquatic vegetation (718±218.1 thousand ind./m³ and 10.8±7.5 g/m³), compared with the open littoral (331 thousand ind./m³ and 8.1 g/m³). During the autumn sampling, the weather was windy, and it is possible that aquatic organisms used macrophyte thickers for cover. In addition, this may also be associated with the accumulation of organic matter from the decomposing parts of macrophytes from summer to autumn in the zone of macrophyte beds [24, 25]. Thus, epilimnetic zooplankton is concentrated on the leeward side of water bodies [25], in the shallow lake Neusiedlersee (Austria) strong wind turbidity of water caused a significant increase in the mortality of *Diaphanosoma*, especially young individuals [26], other data demonstrate that in deep water bodies daphnids migrate to greater depths with strong winds [24].
Table. Abundance \((N\), thousand ind./m\(^3\)), biomass \((B, \text{ g / m}^3\)) and number of species \((S)\) of zooplankton, the ratio of cladocerans’ abundance to such of copepods \((N_{cl}/N_{cop})\), ratio of crustaceans’ abundance to such of rotifers \((N_{cr}/N_{rot})\), the ratio of copepods’ biomass to that of cladocerans \((B_{cyc}/B_{cl})\) from the pelagial, littoral, and macrophyte beds of Lake Aslikul

| Biotope                      | June                               | September                          |
|------------------------------|------------------------------------|-------------------------------------|
|                              | \(N\)  | \(B\)  | \(S\)  | \(N_{cl}/N_{cop}\) | \(N_{cr}/N_{rot}\) | \(B_{cyc}/B_{cl}\) | \(N\)  | \(B\)  | \(S\)  | \(N_{cl}/N_{cop}\) | \(N_{cr}/N_{rot}\) | \(B_{cyc}/B_{cl}\) |
| Pelagial                     | 120    | 0      | 5.8    | 4          | 0.04            | 13.7            | 0.08 | 209    | 3.8    | 5          | 0.04            | 11.4            | 0.09 |
| Littoral                     | 442    | 11.5   | 4      | 0.4        | 3.2             | 1.9             | 8.1  | 331    | 8.1    | 5          | 0.4             | 4.2             | 0.4  |
| Potamogeton tenuifolius      | 196    | 1.1    | 4      | 0.2        | 6               | 15.9            | 1456 | 7.9    | 21     | 1.1        | 1.1             | 2.2             |      |
| Typha angustifolia           | 328    | 1.5    | 5      | 0.6        | 7.2             | 3.2             | 468  | 23.8   | 13     | 0.6        | 3.3             | 0.2             |      |
| Phragmites australis         | 220    | 0.8    | 2      | –          | 4               | –               | 232  | 0.9    | 5      | 0.3        | 3.2             | 7.2             |      |

In summer and autumn, the littoral zone of the lake was marked by high indices of the total abundance (on average, 453.7 ± 101.9 thousand ind./m\(^3\)) and biomass (on average, 13.9±6.2 g/m\(^3\)) of zooplankton (table). The main contribution to the formation of quantitative values was made by five cladoceran species - *Diaphanosoma brachyurum* (12.6%), *Ceriodaphnia pulchella* (9.5%), *Pleuroxus truncatus* (3.1%), and *Mesocyclops leuckarti* (3.0%). The changes in September compared to June were small rearrangements in the composition of dominating species, where *Diaphanosoma brachyurum* also played a significant role in the formation of quantitative indicators (13.5%), while nauplii stations of Cyclops and Calanids were noted as subdominants (6.4%).

In the thickets of *Potamogeton tenuifolius*, the abundance (on average, 899.8±826 thousand individuals/m\(^3\)) and biomass (on average, 4.8±4.5 g/m\(^3\)) of species inhabiting the water column is high. The difference was that the zooplankton abundance was highest in the beds of submerged plants with floating leaves (*P. tenuifolius*) (September, 1456 thousand ind./m\(^3\)) among the three species of macrophytes. In the summer, copepodite stages I – II (6.3%) and nauplii (5.2%) of Cyclopoida dominated in abundance, and *Eucyclops serrulatus* (8.9%) in biomass. In September, *Pleuroxus aduncus* (4.1%), *Scapholeberis mucronate* (3.2%) and Cyclopoida nauplii (3.1%) dominated in terms of abundance, while *Eucyclops macruroides* (7.3%) and *E. macrurus* (5.6%) (table) formed the highest share in biomass.

Among plants that are only partially submerged in water, such as *Typha angustifolia*, the abundance (on average, 398 ± 98.9 thousand ind./m\(^3\)) and biomass (on average, 12.6 ± 15.7 g/m\(^3\)) of zooplankton are quite high compared to *Potamogeton tenuifolius*, however, comparing these three macrophyte species, it turned out that only in the coastal thickets of *Typha angustifolia* a high biomass (23.8 g/m\(^3\)) was recorded over the entire study period in 2010 (table). In summer, copepodite stages I – II Cyclopoida (6.1%) and *Keratella quadrata* (6.0%) prevailed in abundance; *Eucyclops serrulatus* (36.7%) dominated in biomass among crustaceans. In September, only nauplii (15.5%) were ranked as dominants in abundance, and *Simocphalus espinulos* (body length ~ 2.3 mm) in biomass (41%).

Compared with other macrophytes (*Potamogeton tenuifolius* and *Typha angustifolia*), the thickets of *Phragmites australis* had the lowest quantitative parameters (on average, 226 ± 8.9 thousand ind./m\(^3\)) and biomass (on average, 0.9±0.07 g/m\(^3\)) of aquatic organisms. In summer and autumn, copepodite stages of Cyclopoida (34.8%) dominated in abundance, while *Eucyclops serrulatus* (6.9%), *Eucyclops macruroides* (5.7%), and *E. macrurus* (5.1%) predominated in biomass (table).

The correlation coefficient between the abundance (thousand ind./m\(^3\)) of zooplankton and water mineralization (g/l) is –0.33 (P < 0.05), and with biomass (g/m\(^3\)) and water mineralization - 0.49 (P
The data obtained demonstrate the relationship between one of the environmental factors (mineralization) and selectivity. According to Ivanova M B [27, 25], when comparing the correlation coefficients of the considered environmental factors with the number of species in lakes of different areas, it has shown that the active reaction (pH) and total salinity (salinity) of water affect the biological diversity of zooplankton in small lakes most strongly.

The ratio of the biomasses of copepods and cladocerans (Bcyc/Bcl) in macrophyte thickets is quite high, indicating the eutrophication process taking place here. Perhaps this is because constant nesting of local and migratory birds is observed in the higher aquatic vegetation [6, 7]. And A V Krylov et al. [28] indicate that the value of Bcyc/Bcl increases slightly in these areas. I N Andronikova [29] also discusses a similar response of copepods to anthropogenic impact. An increase in the abundance of zooplankton, which develops under conditions of weak waves, upon the intake of additional amounts of organic and mineral substances with the waste products of birds is a quite expected reaction, described as a natural change at the initial stages of anthropogenic eutrophication [27, 28]. At the same time, an increase in the number and biomass of zooplankton under the influence of birds is observed not due to cladocerans and/or rotifers, as is during anthropogenic eutrophication, but due to copepods [22]. This is also evidenced by the low value of the ratio of the abundance of cladocerans and copepods (Ncl/Ncop) in Lake Aslikul. The ratio of the abundance of crustaceans and rotifers (Ncr/Nrot) also indicates the predominance of crustaceans (Crustacea) in Lake Aslikul [27, 28].

The zooplankton community in the pelagic zone is less leveled than in the littoral zone (Pielu index is 0.43 in the pelagic zone, 0.87 and 0.72 in macrophytes and the open littoral zone, respectively). The species diversity in general for the pelagic community (HN = 2.09) is lower than in the macrophytes and littoral communities (HN = 2.44 and HN = 2.89). Therefore, the lake can be considered as a waterbody of transitional type – from oligotrophic to mesotrophic.

Using another scale for assessing water quality [14], based on the biomass of zooplankton, the lake can be also classified as transitional from oligotrophic to mesotrophic type. However, the values reached the level characteristic of eutrophic waters in macrophyte communities, according to this scale.

4. Conclusion
As of today, 52 species have been registered in the zooplankton of Lake Aslikul, of which only ten were recorded earlier. The highest species richness of zooplankton is observed in the thickets of Potamogeton tenuifolius, the lowest is Phragmites australis. The species composition of zooplankton in different biotopes of Lake Aslikul was distinguished by a low degree of similarity. The maximum quantitative indicators of the development of aquatic organisms were recorded in the communities of Potamogeton tenuifolius and Typha angustifolia.

Lake Aslikul is one of the favorite places for recreation, therefore the lake experiences a huge recreational load, especially strong in the summer. According to the degree of organic pollution, calculated using zooplankton indices, the lake can be considered as transitional from oligo- to mesosaprobic type.

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Compliance with ethical standards
Conflict of interests. The authors declare that they have no conflict of interest.

Statement on the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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