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Article

Zooplankton of small shallow lakes after eco-rehabilitation activities

Olga Yu. Derevenskaya

Kazan Federal University, ul. Kremlyovskaya 18, Kazan, Republic of Tatarstan, 420008 Russia

oderevenskaya@mail.ru

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Abstract. The need for eco-rehabilitation of water bodies affected by strong anthropogenic influence increases greatly with an increase in the area of urbanized territories. The effectiveness of such measures may be evaluated by studying successions of hydrobiont communities in a rehabilitated water body. In 2017, actions were taken to rehabilitate the Lebyazhye Lakes system (Kazan), which included deepening the basins of Bolshoe Lebyazhye Lake and Svetloe Lebyazhye Lake to 4 m, isolating the bed of future basins with bentonite mats, supplying water from Izumrudnoye Lake through a pressure conduit, filling the lakes with water, and improvement of the shores. Then, in 2018–2021, zooplankton indicators of these lakes were studied and models of its food webs were proposed. After the work was completed, the lakes were successfully colonized by zooplankton: in 2018, the identified assemblage included 106 species, with 51 species of rotifers (46%), 36 species of cladocerans (34%) and 19 species of copepods (18%). However, in the absence of higher aquatic plants, a strong "bloom" of water was observed with the predominance of blue-green algae in the composition of phytoplankton and low water transparency. In 2020–2021, the zooplankton composition showed a decrease in the total number of species and the number of species in the sample, a decrease in the production in communities, a change in the composition of dominant species towards representatives of the genus *Brachionus*, and an increase in the variability of biomass dynamics. All these suggested instability and the gradual simplification of the community. In 2021, obligate predators disappeared from one of the lakes, which led to the shortening of food chains.

Keywords: restoration, aquatic ecosystem, community, eutrophication, water "bloom ", sustainability, food chains.

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Introduction

The impact of economic activity on ecosystems is most pronounced in urban areas. The transformation of landscapes due to the urban development leads to the appearance of new water bodies or, conversely, the disappearance of previously existing ones (Mingazova et al., 2014). Lakes in urban areas perform important ecosystem functions: they contribute to the conservation of biodiversity of aquatic organisms within heavily modified areas and increase local and regional biodiversity (Bolduc et al., 2016; Celewicz-Goødyn and Kuczyńska-Kippen, 2017; Kuczyńska-Kippen and Joniak, 2016; Stefanidis and Papastergiadou, 2010). Water bodies often have a recreational function, create a mosaic of habitats, and can be elements of the green zones of cities (Celewicz-Goødyn and Kuczyńska-Kippen, 2017; Cereghino et al., 2008a; Cereghino et al., 2008b; Pinel-Alloul and Mimouni, 2013). Therefore, the deterioration of the ecological state, the reduction of the water surface, or any other transformations of aquatic ecosystems that reduce their environmental, recreational value, limiting the possibility of their further use, necessitate eco-rehabilitation measures.

Despite the growing need for the restoration of polluted, heavily transformed water bodies, examples of such activities are rare. It is even more difficult to achieve the desired state of a basin with high water quality. Therefore, studies of successions in restored lakes are very relevant. In 2017, measures for eco-rehabilitation were undertaken in the Lebayzhye Lakes system. The basins are located in a locally protected natural site “Lebyazhye City Forest Park”; earlier the system consisted of four lakes (Maloe, Bolshoe, Svetloe and Sukhoe Lebyazhye). By origin, these lakes are interdune or karst-suffusion (Ocherki..., 1957; Taisin, 2006), shallow with an average depth of 1.1 m, located above the groundwater level and not recharged from groundwaters. The main sources of replenishment were surface runoff and atmospheric precipitation. By the 2000s, due to the development of the territory and the reduction in the catchment area, the lakes became shallower. The Sukhoe Lebyazhye, Svetloe Lebyazhye, and Bolshoe Lebyazhye lakes gradually dried up, leaving only Maloe Lebyazhye Lake, in which, from 2008 to 2017, the water level was artificially maintained by supplying groundwater pumped from wells (Derevenskaya, 2017).

The Lebyazhye park is a very important recreational park in importance, so a decision was made to restore the system of Lebyazhye lakes. In the former boundaries of lakes Bolshoe Lebyazhye and Svetloe Lebyazhye, dredging was carried out, as a result of which the depth increased to its original values (up to 4 m); the bottom was also waterproofed with bentonite mats. For the water supply of the lakes, a penstock with a length of 1.5 km was built. In October 2017, the lakes were filled with water from Izumrudnoe Lake. This lake, formed on the site of a former sand quarry, is also located on the territory of the park at a distance of 1 km from the lakes of the Lebyazhye system. No restoration work was conducted on Maloe Lebyazhye Lake, but it is connected to Bolshoe Lebyazhye Lake, so the changes that have occurred have also affected it. The change in the predominant source of nutrient led to a change in the type of water, the concentrations of predominant ions, and water salinity (Derevenskaya and Urazaeva, 2020). In 2019–2020 landscaping of the shore zone of Maloe Lebyazhye and Bolshoe Lebyazhye lakes was carried out: paths with a wooden surface were laid, a sports ground was reconstructed, a beach area was organized. Biotechnical measures aimed at restoring communities of hydrobionts were not conducted.

To analyze the effectiveness of the measures taken and the correct functioning of the main ecosystem processes, it is necessary to take into account several groups of organisms belonging to different trophic levels. In particular, the zooplankton community includes herbivorous, predatory, and detritivorous species, plays a key role in the transfer of matter and energy in aquatic ecosystems, and may reflect modifications that have occurred at lower or higher trophic levels (Anton-Pardo et al, 2013). The lakes of the Lebyazhye system already in the first year after the basins were filled with water began to be successfully populated by zooplankton. Of interest are subsequent changes in zooplankton communities and in the ecosystem of restored lakes in general, assessment of the long-term improvements and the possibility of achieving a stable state.

The purpose of the work is to assess the succession of zooplankton communities after the restoration of the Lebyazhye lake system.

Materials and methods

Zooplankton samples were taken during the growing seasons of 2018–2021 every 12–14 days. Sampling was carried out in the coastal zone of the lakes, from 1–2 stations at each of the lakes in the system. A 50 L volume of water was filtered through an Apstein net (mesh size 70 μm) and fixed with 4% formalin. Biomass was calculated using power equations relating the length of organisms to their mass (Metodicheskie..., 1982). Species diversity of zooplankton was assessed using the Shannon diversity index (H) calculated from abundance and biomass (Shannon and Weaver, 1949).

When constructing food web models, the food spectra of organisms were taken from publications (Gutelmacher et al., 1988; Ivanova, 1999; Krylov, 1989; Kutikova, 1970; Monakov, 1998). A particular species was considered as an element of the food chain if its biomass exceeded 2% of the total zooplankton biomass. Five possible links were identified:

herbivorous rotifers, predatory rotifers, herbivorous cladocerans and copepods, facultative predatory copepods, obligate predators. All rotifers were combined into one trophic group (except for the genus *Asplanchna*, half of which formed a separate group of predatory rotifers); cladocerans of the families Sididae, Daphniidae, Chydoridae, Bosminidae were also included in a special herbivorous group as well as copepods of all ages of the genus *Eudiaptomus* and naupliar and junior copepodite stages of Cyclopoida. Half of the *Asplanchna* of the river are classified as facultative predators along with adult members of the family Cyclopidae and their older copepodite stages. The group of obligate predators was represented by mature cladocerans *Leptodora kindtii* (Focke, 1844) and *Polyphemus pediculus* (Linnaeus, 1761) (Metodicheskie..., 1982).

The production of planktonic rotifers and crustaceans was calculated using the “physiological” method (Metodicheskie..., 1982). When calculating production and respiration, protozoan zooplankton was not taken into account. Zooplankton production was calculated using the next formula:

$$P = R \times k_2/(1-k_2),$$

where P – production, cal/(m^3×day); R – exchange expenditure, cal/(m^3×day); k_2 – coefficient of efficiency of the use of assimilated food energy for production. The rate of oxygen consumption was calculated using the formula

$$Q = a \times w^{a/b},$$

where Q – oxygen consumption rate at 20 °C, mlO_2/(ind.×hours); w – mean body mass in grams of wet weight, g; a and a/b – mean values of coefficients (Metodicheskie..., 1982).

The average body weight of the animal was calculated using the formula

$$w = B/N,$$

where w – mean body mass, g; B – population biomass, mg/m^3; N – abundance, ind./m^3.

To measure the rate of oxygen consumption per day, the Q value was multiplied by 24 hours. To switch from the amount of oxygen consumption to metabolic expenditure, the Q value was multiplied by an oxicaloric coefficient equal to 4.86 cal/mLO_2.

When the water temperature deviated by 2 or more degrees from 20 °C, the exchange costs were multiplied by the temperature correction q:

$$q = 2.3^{0.1(t-20)},$$

where t – actual water temperature, °C.

The production and exchange costs for the population were found by multiplying the corresponding values for one organism by the abundance of the species. The production and expenditure on the exchange of groups of organisms that make up the links of the trophic chain were calculated for the growing season using the trapezoid method.

The production of the entire community was calculated using the next formula:

$$P_z = P_n - R_p,$$

where P^z – zooplankton community production, cal/(m^3×day), P_n – herbivorous zooplankton production, cal/(m^3×day), R_p – cost of the exchange of predatory zooplankton, cal/(m^3×day).

Simultaneously with the sampling of zooplankton, water parameters were analyzed. Its temperature and oxygen content were measured with a Mark 302e oximeter, electrical conductivity with a DIST HI 98312 conductivity meter (Hanna, Romania), and water pH with a pHep+ HI 98108 portable pH meter (Hanna, Romania). The transparency of the water was determined using a white Secchi disk. The concentrations of ions of biogenic elements were found using generally accepted hydrochemical methods in the laboratory of the CSIAC of the Ministry of Ecology and Natural Resources of the Republic of Tatarstan.

Statistical processing of the data included the calculation of average values, the error of mean for each indicator of zooplankton communities, the coefficient of variation in the abundance and biomass of zooplankton over the years.

Results

At present, the water in the lakes of the Lebyazhye system belongs to the hydrocarbonate-calcium type. In 2018–2021, the electrical conductivity, which indirectly characterizes the magnitude of mineralization, was about 200 μS/cm. In May 2019, the average concentration of phosphates was 0.068 mg/dm^3, ammonium ions – 0.16 mg/dm^3, nitrites and nitrates were not detected. In 2018–2021 the oxygen content in the middle of the growing season in Bolshoe Lebyazhye and Svetloe Lebyazhye reached 250% of normal saturation and was associated with intense “blooming” of water. Outbreaks of “bloom” in Bolshoe Lebyazhye and Svetloe Lebyazhye lakes were noted already in the first year after the completion of activities during periods of maximum warming of the water, and since 2019 the lakes have been “blooming” throughout the growing season, with an increase in July. “Blooming” of water leads to a decrease in its transparency. For example, during the summer of 2021, the water transparency in Lake Bolshoe Lebyazhye varied from 10 to 50 cm, averaging 30 cm, and in Lake Svetloe Lebyazhye, from 30 to 45 cm, averaging 37 cm.

The pH values of the water during the period of maximum “blooming” increased to 10, while in normal times they were within a normal range (did not exceed 7.5). It is known that the decrease in the amount of carbon–bicarbonate and the subsequent increase in the level of acidity is a consequence of the photosynthetic activity of algae (Dorak and Temel, 2015).

From 2018 to 2021, 106 zooplankton species were identified in the lake system, including rotifers – 51 (48%), cladocerans – 36 (34%), copepods – 19 (18%). Already in the first year after the filling of the lakes, zooplankton communities formed in them with a relatively high species richness, comparable to what was observed earlier (Derevenskaya and Urazaeva, 2020). Zooplankton included quite abundant indicator species of both oligotrophic (*Kellicottia longispina* (Kellicott, 1879), *Bosmina (Eubosmina)* cf. *coregoni* Baird, 1851, *Daphnia (Daphnia) galeata* G.O. Sars, 1864) and eutrophic conditions (rotifers of the genera *Brachionus, Keratella, Trichocerca*). In subsequent years, indicators of oligotrophic waters were encountered progressively less frequently, and by 2021 they

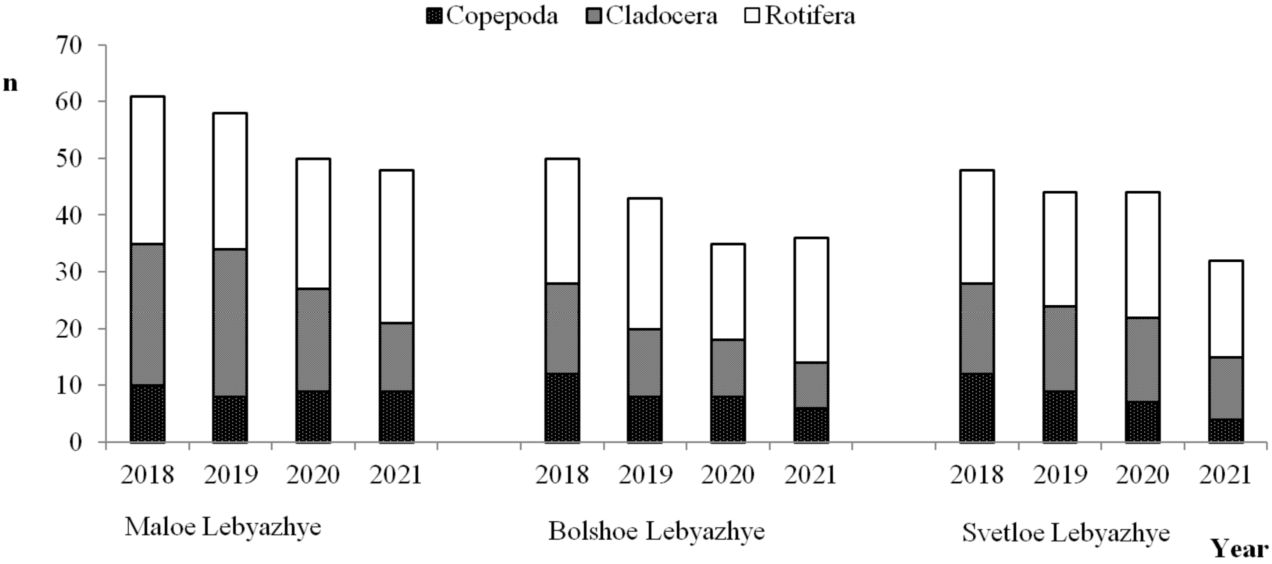

Fig. 1. Number of species (n) in the lakes of the Lebyazhye system.

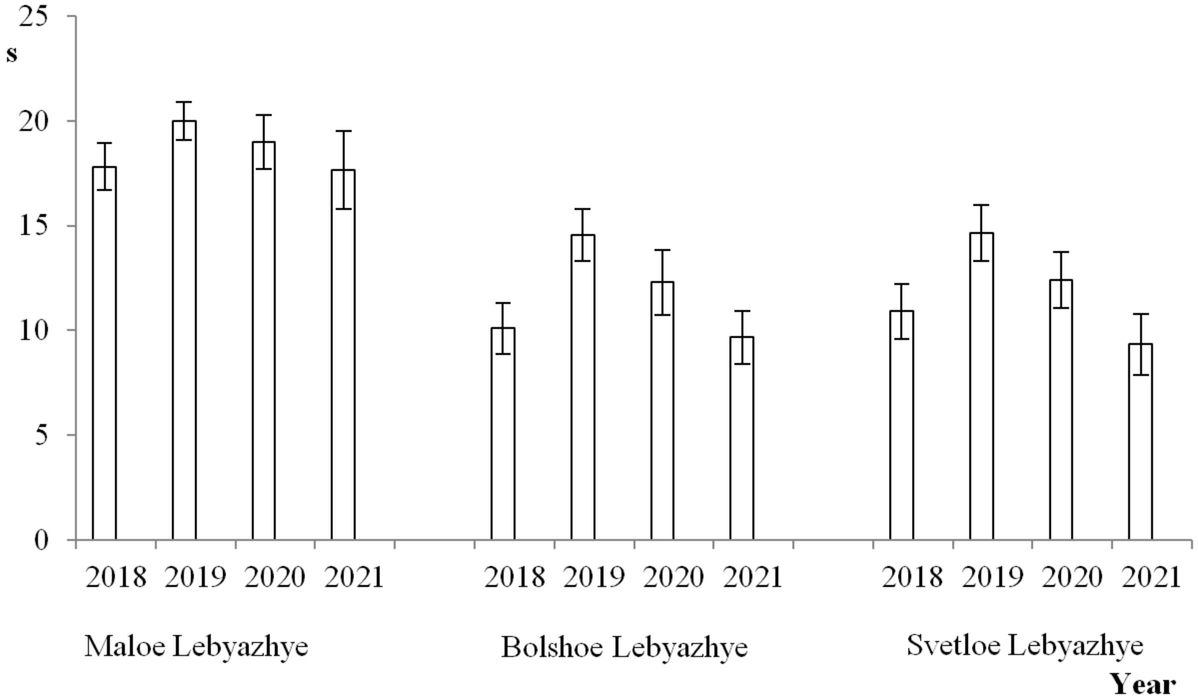

Fig. 2. Average number of species in a sample in lakes of the Lebyazhye system.

completely disappeared from the community. At the same time, the number of species of the genus *Brachionus* increased.

The total number of species found in zooplankton communities in lakes naturally decreased over the study period (Fig. 1). Similar dynamics are demonstrated by such a parameter as the number of species in the sample (Fig. 2): its highest values were noted in 2019, and in subsequent years, the indicators decreased.

Changes in the structure of communities during the study period are shown by the values of the Shannon index calculated by abundance (Hn) and biomass (Hb) (Fig. 3). The highest rates were noted a year after the completion of the activities (in 2019). In 2020–2021 there was a decrease in the index values, especially in the lakes Bolshoe Lebyazhye and Svetloe Lebyazhye, from which it can be concluded that the communities are simplified, and the species diversity is reduced.

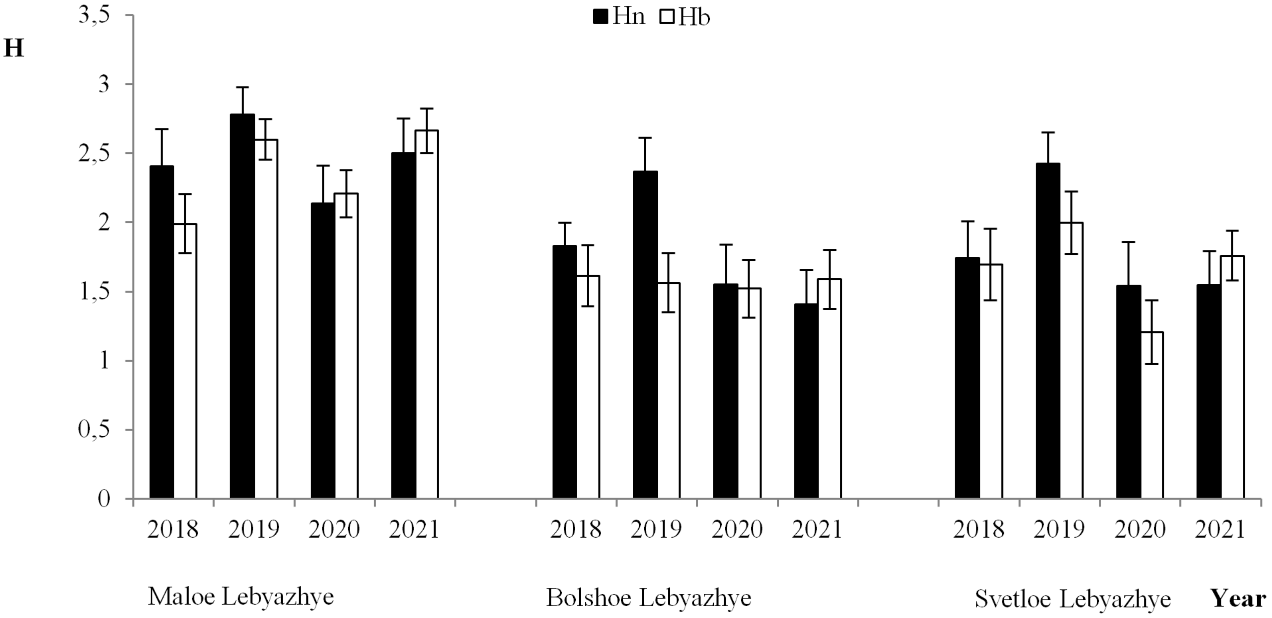

Fig. 3. Shannon diversity index by abundance (Hn) and biomass (Hb) of zooplankton in the lakes of the Lebyazhye system.

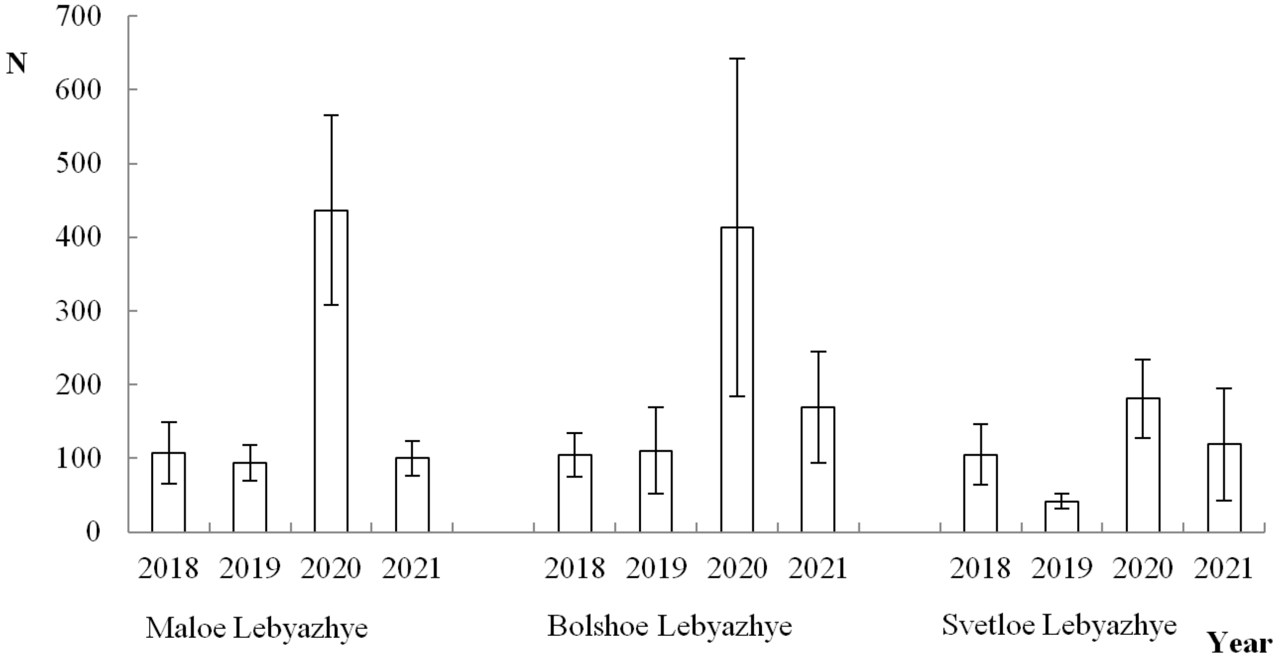

Fig. 4. Average abundance (N, thousand ind./m3) of zooplankton in lakes of the Lebyazhye system.

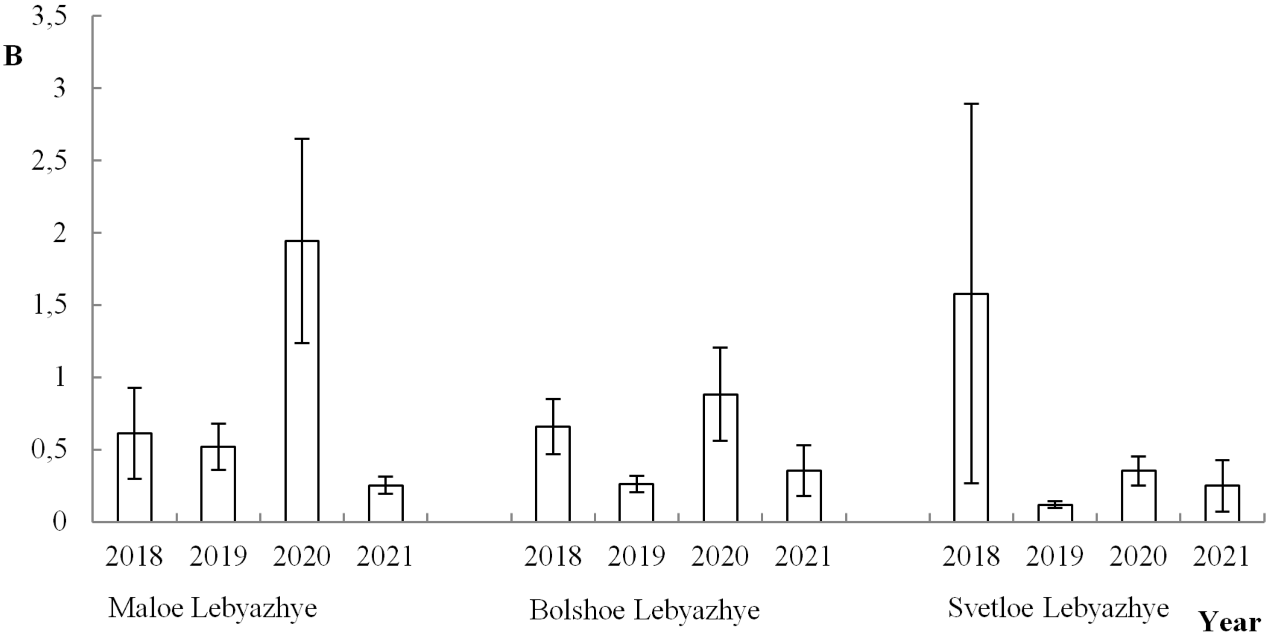

Fig. 5. Average biomass (B, g/m^3) of zooplankton in lakes of the Lebyazhye system.

The composition of the dominant species was not constant throughout the growing season, and also varied in different years. In Bolshoe Lebyazhye and Svetloe Lebyazhye lakes in 2018, there was a frequent change of dominant species with a predominance of 1–3 species. In 2019, *Filinia longiseta* (Ehrenberg, 1834), *K. longispina, Eudiaptomus gracilis* (Sars, 1863) dominated in Bolshoe Lebyazhe Lake, and *F. longiseta* and *Keratella cochlearis* (Gosse, 1851) dominated in Svetloe Lebyazhye Lake. In 2020 *Brachionus calyciflorus* Pallas, 1776, *F. longiseta* dominated in Bolshoe Lebyazhe Lake and *B. calyciflorus* and *Conochilus unicornis* Rousselet, 1892 dominated in Svetloe Lebyazhye Lake. In 2021, *B. calyciflorus* dominated in both lakes, accounting for up to 90% of the total zooplankton abundance. In Maloe Lebyzhye Lake, in 2018 *Asplanchna priodonta* Gosse, 1850*, B. longirostris, Thermocyclops oithonoides* Sars, 1863, juvenile stages of *Cyclops* dominated in 2018; *B. longirostris, Chydorus sphaericus* O.F. Muller, 1785, *T. oithonoides, Mesocyclops leukarti* (Claus, 1857), and juvenile stages of *Cyclops* dominated in 2019; and *A. priodonta, Brachionus diversicornis* (Daday, 1883), *B. calyciflorus,* and juvenile stages of *Cyclops* dominated in 2020–2021.

Quantitative indicators of zooplankton communities were low (Figs. 4, 5): the average abundance in different years ranged from 41.8 ± 9.56 to 436.67 ± 128.64 thousand ind./m^3, biomass – from 0.12 ± 0.02 to 1.58 ± 1.51 g/m^3. In the first years after the completion of restoration measures, short-term periodic increases in the abundance of one of the zooplankton species were observed, causing an increase in the number of peaks during the growing season. Thus, in 2021, in the Bolshoe Lebyazhye and Svetloe Lebyazhye lakes, the number of the rotifers *B. calyciflorus* during most of the growing season was 60–90% of the total number of zooplankton. Interannual variability of the abundance of zooplankton in Maloe Lebyazhye Lake for 2018–2020, estimated using coefficient of variation (CV), was 90%, biomass – 91%; for Bolshoe Lebyazhye Lake, these figures were 73% and 53%, and for Svetloe Lebyazhye Lake – 51% and 117%, respectively.

As a measure of community stability, A.F. Alimov et al. (2013) suggested using the variability of biomass dynamics (the ratio of the minimum and maximum biomass during the growing season). In Bolshoe Lebyazhye and Svetloe Lebyazhye lakes, the highest values of this indicator were observed in 2019, after which they decreased (Table 1). Thus, the variability of the community increased, which indicates its instability.

During the period of research in Bolshoe Lebyazhye and Svetloe Lebyazhye lakes, as well as in Maloe Lebyazhye Lake in 2021, there is an increase in the proportion of rotifers, and in some cases, larval stages of *Cyclops*, which leads to a decrease in the average individual mass of zooplankter (Table 2). According to the individual mass of zooplankter in 2021, the lakes can be classified as hypertrophic (Kryuchkova, 1987).

In zooplankton communities, complex trophic relationships are formed, the structure of which is determined not only by the food preferences of the species that form the community, but also by external

Table 1. Indicators of variability of biomass dynamics in lakes of the Lebyazhye System.

	Year			
Lake	2018	2019	2020	2021
Maloe Lebyazhye	0.010	0.015	0.045	0.058
Bolshoe Lebyazhye	0.030	0.080	0.004	0.011
Svetloe Lebyazhye	0.0004	0.083	0.035	0.004

Table 2. Average values of individual weight (w, mg) of zooplankton in lakes of the Lebyazhye system.

	Year			
Lake	2018	2019	2020	2021
Maloe Lebyazhye	0.0049 ± 0.0006	0.0049 ± 0.0005	0.0076 ± 0.0042	0.0028 ± 0.0004
Bolshoe Lebyazhye	0.0081 ± 0.0021	0.0056 ± 0.0012	0.0033 ± 0.0008	0.0021 ± 0.0003
Svetloe Lebyazhye	0.0062 ± 0.0025	0.0035 ± 0.0006	0.0047 ± 0.0027	0.0017 ± 0.0002

abiotic and anthropogenic factors. Zooplankton organisms belong to different systematic groups and differ in the type of food and food composition. Among them there are both herbivorous, feeding mainly on plant food and detritus, and predatory. Many zooplankton species have a mixed diet (Monakov, 1998). In accordance with the theoretical principles of ecology, a change in one of the links of the system affects the structure and functions of others or even the system as a whole (Reimers, 1994). Thus, a change in the species composition can lead to a change in the trophic structure of the community.

In 2018, in the lake Maloe Lebyazhye the main energy flow in the zooplankton community passed through the branch of crustaceans (herbivorous cladocerans and copepods → facultative predators → obligate predators) (Fig. 6**A**). In 2021, the energy flow through this branch decreased, but rotifers began to make a very significant contribution to energy transformation. The role of predatory rotifers of the genus *Asplanchna* increased (Fig. 7**B**).

In 2018, in Bolshoe Lebyazhye and Svetloe Lebyazhye lakes, as well as in Maloe Lebyazhye Lake, the main energy flow passed through the branch of crustaceans (herbivorous cladocerans and copepods → facultative predators → obligate predators) (Figs. 7**A**, 8**A**). In 2021, the "rotifer" branch became the main one. Products formed by herbivorous rotifers and predatory rotifers of the genus *Asplanchna*, several times exceeded this indicator in crustaceans (Figs. 7**B**, 8**B**). This year in the lake Svetloe Lebyazhye experienced a reduction in the length of food chains due to the absence of obligate predators (Fig. 8**B**).

During the study, a significant decrease in the production of the entire zooplankton community was observed. If during the growing season of 2018 the production in the lakes Maloe Lebyazhye, Bolshoe Lebyazhye and Svetloe Lebyazhye was 4.44, 6.17 and 15.58 kcal/m^3, then for the growing season of 2021 these figures were 2.56, 5.37 and 3.96 kcal/m^3, respectively.

Discussion

Anthropogenic impacts on ecosystems usually lead to a simplification of their structure. This effect is observed during pollution, acidification of water bodies, changes in the ionic composition and mineralization of waters. Pollution and eutrophication of water bodies leads to a decrease in the diversity and stability of ecosystems. Stability is understood as the ability of systems to maintain their structure and functional properties under the influence of external factors. The stability of ecosystems over time is maintained by intrapopulation relationships; complex and diversely organized systems are more stable (Alimov et al., 2013). There are few examples of anthropogenic influence increasing complexity of ecosystems. One of the types of such impact, leading to an increase in the number of ecosystem links and a complication of the structure of communities, is the eco-rehabilitation of water bodies.

According to Alimov et al. (2013), stability is associated with the ability of systems to withstand changes caused by outside influences and return to their original state, retaining their structure and functional features. The range of deviations from the average values of various components of the ecosystem (species composition, species diversity, abundance, biomass, production, exchange costs) reflects the stability of the system. The larger the

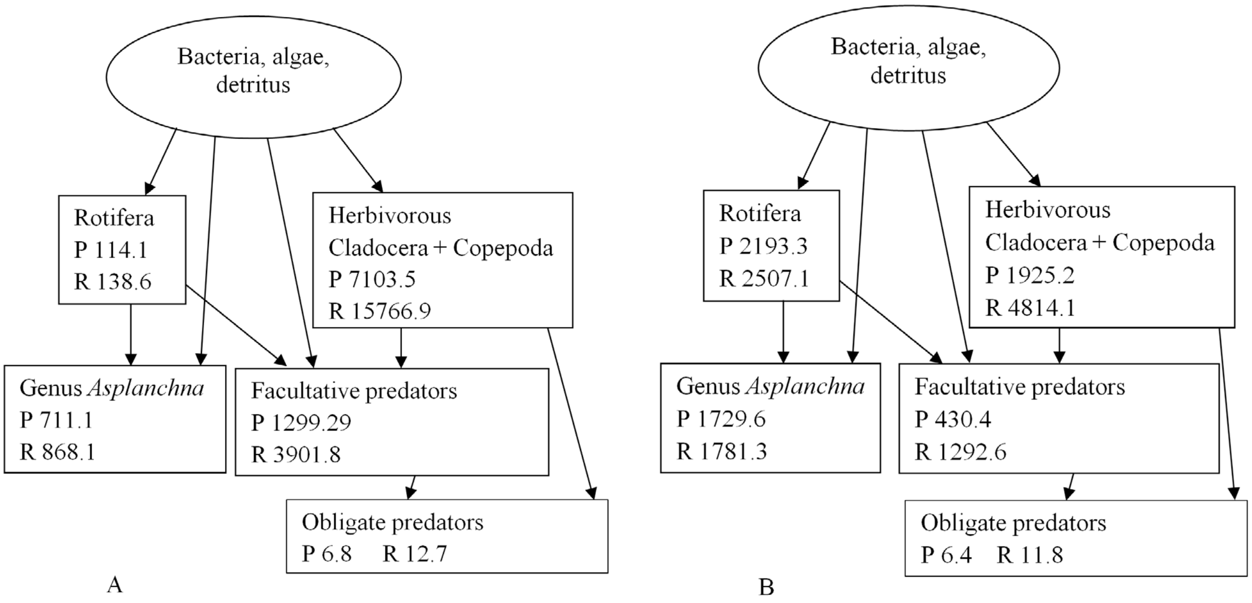

Fig. 6. Schemes of food webs in the zooplankton communities of Maloe Lebyazhye Lake: **A** – 2018, **B** – 2021. P – production, cal/m^3, R – expenditure on metabolic processes, cal/m^3.

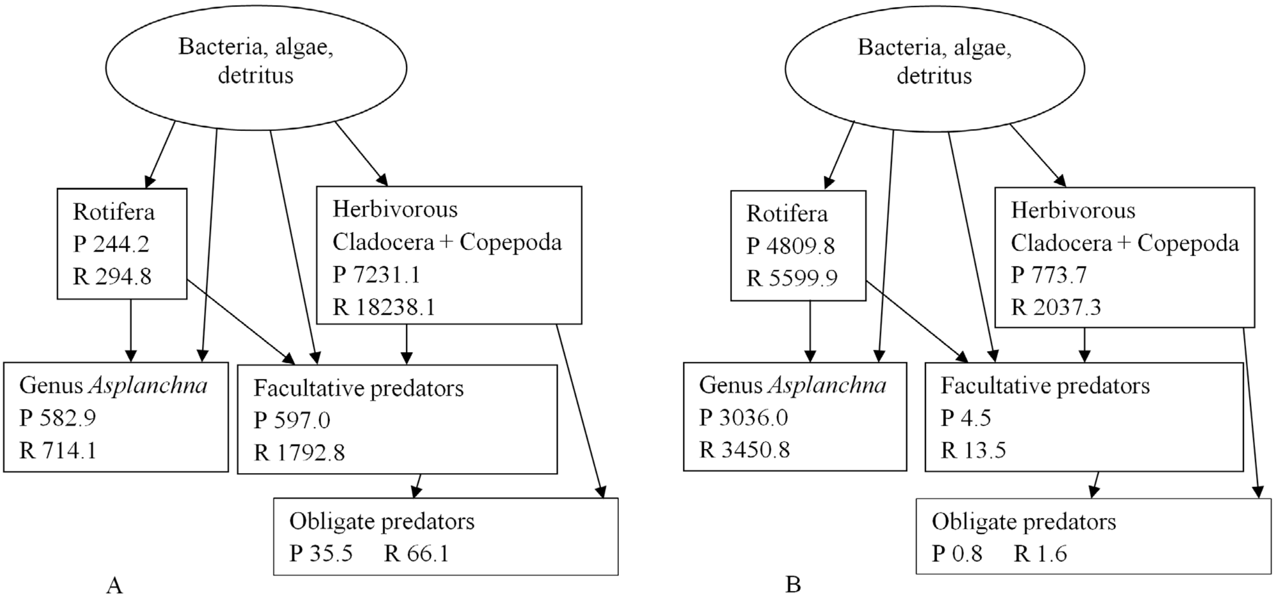

Fig. 7. Schemes of food webs in the zooplankton communities of Bolshoe Lebyazhye Lake: **A** – 2018, **B** – 2021. P – production, cal/m^3, R – expenditure on metabolic processes, cal/m^3.

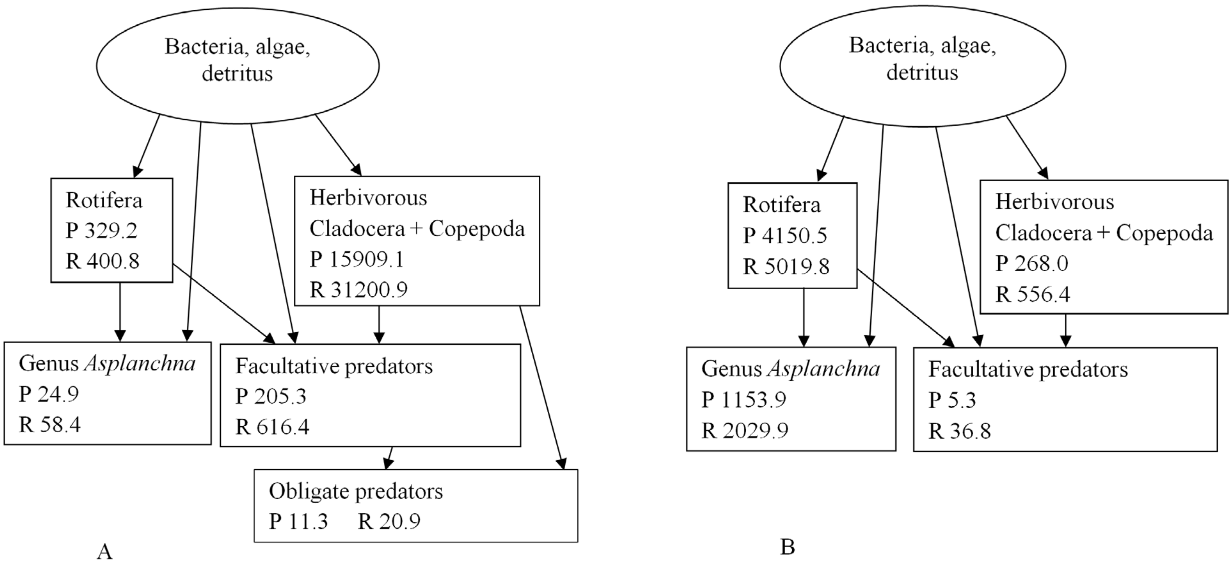

Fig. 8. Schemes of food webs in the zooplankton communities of Svetloe Lebyazhye Lake: **A** – 2018, **B** – 2021. P – production, cal/m^3, R – expenditure on metabolic processes, cal/m^3.

range of oscillations, the less stable the system, and, conversely, with a decrease in the range, stability increases. The persistence of the mean level reflects the stability of the system over time. With the simplification of the structure of communities and ecosystems, the amplitude of seasonal fluctuations in their functional characteristics increases, including quantitative expressions of the variability of biomass dynamics. With an increase in the productivity or degree of eutrophication of water bodies or streams, the stability of ecosystems and their components decreases. Under the influence of pollutants or other anthropogenic loads, the structural and functional characteristics of the system will change, and it will go into a different state, remaining stable as long as these factors continue to act (Alimov et al., 2013).

Actions aimed at the eco-rehabilitation of water bodies are factors influencing the course of successional processes or triggering them. In some cases, restoration measures allow the ecosystem to return to earlier stages of succession. It would be too optimistic to expect ecosystems to return to the state of the ancient geological past, since the composition of species has changed, and, consequently, the structural and functional characteristics of ecosystems. However, the reduction in the supply of biogenic elements due to eco-rehabilitation measures, i.e., changes in the conditions for the existence of species can cause the onset of successional changes in ecosystems. The process of ecosystem restoration follows the rule of evolutionary-ecological irreversibility (Reimers, 1994).

The hydrotechnical measures carried out on the Lebyazhye Lakes system were aimed at the physical restoration of the lakes Bolshoe Lebyazhye and Svetloe Lebyazhye. The hydrotechnical measures carried out on the Lebyazhye Lakes system were aimed at the physical restoration of Bolshoe Lebyazhye and Svetloe Lebyazhye lakes. As a result, the area of the system increased to 36.7 ha, i.e., 10.8 times (compared to 2015). However, the actions taken are not enough to restore the ecosystem. Restoring the flows of matter and energy inherent in natural ecosystems is a complex process that can take a long time and require additional biotechnical measures. Already in the first year after the hydrotechnical work was completed, the species richness of zooplankton was quite high, which indicated the successful colonization of the lakes; new species appeared, the quantitative indicators of zooplankton increased, trophic webs became more complex, and obligate predators appeared. At the same time, significant fluctuations in quantitative indicators during the growing season and in different years characterized the existing ecosystem as unstable.

A separate problem was the water “bloom” in the newly restored basins. It is known that with the same amount of biogenic substance available for autotrophs, both phytoplankton and phytobenthos (higher aquatic plants) can predominate in a lake. Phytoplankton, using the available biogenic elements, quickly increases in abundance, causing the water “blooms”. The transparency of the water decreases, as a result of which the so-called “muddy water” regime is formed in shallow water bodies; the resulting lack of light prevents the development of phytobenthos. On the contrary, the “clear water” regime, in which water transparency is high (throughout the depth of the basin), creates favorable conditions for the development of benthic autotrophs, which become the main producers (Alimov et al., 2013; Scheffer and van Nes, 2007). In Bolshoe Lebyazhye and Svetloe Lebyazhye lakes, even four years after the completion of hydrotechnical measures, the area overgrown with higher aquatic plants is only about 1% (Derevenskaya, 2021). The autotrophic component is mainly represented by phytoplankton; therefore, biogenic elements entering the lakes cause the water to "bloom". In Bolshoe Lebyazhye and Svetloe Lebyazhye lakes, even four years after the completion of hydrotechnical measures, the area overgrown with higher aquatic plants is only about 1% (Derevenskaya, 2021). The autotrophic component is mainly represented by phytoplankton; therefore, biogenic elements entering the lakes cause the water to "bloom". At the same time, in Maloe Lebyazhye lake, "blooming" of water in the first two years did not occur due to the large area of overgrowing with macrophytes and the preservation of high water transparency. Earlier (before 2000) in the lakes of the system, a rather strong overgrowth of higher aquatic vegetation was also observed, and "blooming" was not observed. Consequently, as an element of the biotechnical rehabilitation of lakes, contributing to the creation and maintenance of the "clear water" regime, it is necessary to create a bioplateau of higher plants in Bolshoe and Svetloe Lebyazhye lakes.

Thus, in the absence of higher aquatic plants, the ecosystems of the lakes of the Lebyazhye system develop along the phytoplankton path, which leads to a change in the physicochemical conditions for the existence of hydrobionts: water transparency and pH value; phytoplankton was dominated by cyanobacteria. This, in turn, leads to changes in zooplankton communities. Already in the third year of the existence of basins, the system is observed to transition to another stable state with a community more adapted to these conditions. It is characterized by low species diversity, low quantitative indicators, shortened trophic chains, and dominance of representatives of the genus *Brachionus*.

Conclusions

According to research in 2018–2021 into the zooplankton of the lakes of the Lebyazhye system, 106 species of zooplankton were identified, among which are 51 species of rotifers (48%), 36 species of cladocerans (34%) and 19 species of copepods (18%).

After the completion of eco-rehabilitation activities, there was a complication of the structure of zooplankton communities, the emergence of new species, including indicators of oligotrophic waters. The main energy flows in the trophic chains passed through the branch of crustaceans (herbivorous cladocerans and copepods → facultative predators → obligate predators). Significant fluctuations in quantitative indicators from year to year and during one growing season characterized the structure as unstable.

In the absence of higher aquatic plants, lake ecosystems developed along the phytoplankton path, and already in the third year of the existence of water bodies, a more resilient zooplankton community was formed with low species diversity, a predominance of rotifers, and massive development of *Brachionus calyciflorus*. The trophic chains of zooplankton communities began to be dominated by the "rotifer" branch. In Svetloe Lebyazhye Lake, there were no obligate predators, hence the trophic chains were simplified.

Based on the experience of carrying out restoration activities on the lakes of the Lebyazhye system in Kazan, it can be concluded that it is quite difficult to achieve a sustainable state of the aquatic ecosystem with favorable water quality for water users and high aesthetic properties of the water body. It is clear that the first stage of work should be followed by monitoring of the state of the water bodies. If the achieved state turns out to be unstable or the basin passes into another stable state with undesirable characteristics, it is necessary to carry out the second stage of restoration measures aimed at correcting the current situation.

ORCID

Olga Yu. Derevenskaya 0000-0001-9473-4352

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