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Zooplankton and trophic status of Peipsi-Pihkva Lake

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Long-term studies of the zooplankton of Chudsko-Pskovskoe (Peipsi-Pihkva) Lake have shown that the species composition and structure of the community correspond to those of eutrophic waters. Intensification of the eutrophication of the lake in the period from the beginning of the 1990s to the early 2000s has been revealed. The dynamics of zooplankton biomass in recent decades indicates a slowdown in the process of eutrophication. The main characteristics of zooplankton indicate a higher trophic level in Lake Pskov, which is smaller in area and shallower than Lake Peipsi.

Keywords: species composition, structure, long-term dynamics, dominant assemblage, trophic level, Chudskoe Lake, Pskov Lake.

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Introduction

Assessment of the ecological status of water bodies based on the structural and functional characteristics of communities of aquatic organisms remains one of the priority areas of hydrobiological research. The use of zooplankton as a system at the biocenotic level for the diagnosis of the trophic type of lake ecosystems is a uniformly accepted approach based on well-studied structure of aquatic communities, and is unquestioned today (Andronnikova, 1996; Lazareva, 2009).

Peipsi-Pihkva is a large lake complex located in the north-west of Russia on the border with Estonia. In its square area (3558 km^2) it is the fifth largest lake in Europe. The lake consists of three parts: the northern part, the largest (2611 km^2) and deepest (average depth 8.4 m) is Lake Chudskoe (Peipsi) the narrow middle part is Lake Teploe (Lämmijärv); the southern (708 km^2), shallowest (average depth 3.8 m) part is Lake Pskov (Pikhva).

Hydrobiological studies of the zooplankton of Lake Peipsi-Pihkva have a long history. The first systematic data on zooplankton were collected and processed by Rylov in 1934 and published by Sokolov (1941). This work presents a list of species of zooplankton (57 taxonomic units), containing brief information about biomass, vertical and horizontal distribution. Based on the analysis of the species composition and biomass of zooplankton, the author characterized Lake Peipsi-Pihkva as a water body of eutrophic type (cited from Yastremsky, 1972). Further studies conducted prior to the early 1960s were episodic. During this period, the species composition of planktonic animals was partially studied; seasonal taxonomic changes and distribution of zooplankton in the lake were described, and its fishery significance was noted.

In 1962, the State Scientific Institute of Lake and River Fisheries (GosNIORKh) and the Institute of Zoology and Botany of the Academy of Sciences of the Estonian SSR began to study the hydrobiology and fishery of the lake. Zooplankton research focused on quantitative collections, the identification of productivity, and the evaluation of the role of zooplankton in the lake ecosystem (Zaripova, 1983).

Colleagues from the Pskov Branch of GosNIORKh have since been systematically studying the hydrobiological characteristics of the lake. Material

was collected monthly during the growing period (May to October) at stationary stations. The main results concerning various aspects of the community study are presented in the publications of the 1980s.

In particular, the distribution of zooplankton in the water area of the basin in different seasons (Yakovleva and Ulyanov, 1980), its significance in the nutrition of fish of planktonic feeders (Ibneeva, 1980), and the dependence of seasonal and annual changes on environmental conditions (Zaripova, 1985, 1988) were noted. To date, the most complete data on the composition and structure of the Peipsi-Pihkva zooplankton are available in the works of Haberman (1996, 2000, 2001), which mainly present the results from the Estonian part of the lake.

The purpose of this work is to assess the long-term dynamics of the trophic state of Lake Peipsi-Pihkva including the composition and structure of the zooplankton, and compare the trophic level of its individual parts.

Material and methods

This article is based on material sampled by the present author in the pelagial of Lake Peipsi-Pihkva during the 2003–2017 growth periods. Literature data and materials from the collections of the Pskov branch of GosNIORKh were used to analyze a series of long-term observations. Zooplankton samples were collected at 10 stations of the longitudinal hydrological section (four stations in the Lake Pihkva and six in Lake Peipsi) (Fig. 1); the author collected and processed more than 1000 quantitative samples in total for this period.

Fig. 1. Location of sampling stations in Lake Pihkva and Lake Peipsi.

Sampling of zooplankton was carried out by vertical hauling of a standard Juday plankton net (mesh size 64 μm) from bottom to surface. The samples were fixed with a 4% formalin solution and processed by standard methods (Winberg, 1982). The number of zooplankton organisms was counted in a Bogorov chamber, the individual mass of organisms was determined by their average length (Balushkina and Vinberg, 1979; Ruttner-Kolisko, 1977).

Zooplankton was estimated by species composition (Kutikova and Starobogatov, 1977; Pugachev, 2010; Tsalolikhin, 1994, 1996), abundance (N), biomass (B), the share of taxonomic groups in total biomass, the Shannon index calculated from numbers (H_N) and biomass (H_B), the Mäemets trophic state index (E) (Mäemets, 1980), the mean individual mass of zooplankters (Wm), the Pantle and Buck saprobity index modified by Sladeček (1973).

Results and discussion

The complete list of species composition of zooplankton in Lake Peipsi-Pihkva is revealed from the results of many years of research covering various biotopes of the lake: an open pelagic zone, macrophyte thickets, estuaries of rivers flowing into the lake. As a result, 159 taxonomic units were identified in the lake zooplankton, including 73 rotifers, 57 cladocerans, 28 copepods, and 1 mollusk. Estonian specialists listed 290 taxa, owing to a more complete identification of Rotifera and inclusion of Protozoa (Haberman, 2001).

In 2003–2017, regular studies were carried out only on the pelagic region of the Lake Peipsi-Pihkva. About 50–60 species were recorded annually, some of which were represented by strictly pelagic taxa (mass species); the rest were eurybionts and littoral-thicket inhabitants, which are usually present in pelagic samples.

In general, zooplankton is represented by lacustrine species typical of northwestern Russia, and the species and quantity composition is similar in many ways to that of other large shallow eutrophic lakes of this geographical zone, the Vologda and Novgorod regions (Beloe, Kubenskoe, Vozhe, Lacha, Ilmen) and lakes of northwestern Belarus (Pidgayko, 1988).

The permanent inhabitants of the pelagial, encountered in almost all samples include, among the cladocerans – species of the genus *Daphnia* (in modern nomenclature, assigned to one group *Daphnia* gr. *longispina* and capable of interspecific hybridization), various taxa of the genus *Bosmina* subgenus *Eubosmina*, currently assigned to one species *Bosmina (Eubosmina) coregoni* (Baird, 1857) (Pugachev, 2010); among copepods – *Eu-*

Season	Lake Pihkva	Lake Peipsi
Spring	*Cyclopoida* juv. *Cyclops scutifer* *Mesocyclops leuckarti*	*Cyclopoida* juv. *Cyclops scutifer* *Termocyclops oithonoides* *Mesocyclops leuckarti*
Summer	*Daphnia cucullata* *Bosmina coregoni* cf. *coregoni* *Bosmina coregoni* cf. *gibbera* *Bosmina coregoni* cf. *tersites* *Eudiaptomus gracilis* *Thermocyclops crassus* *Chydorus sphaericus*	*Daphnia galeata* *Daphnia cristata* *Bosmina coregoni* cf. *coregoni* *Bosmina coregoni* cf. *berolinensis* *Eudiaptomus gracilis* *Diaphanosoma brachyurum*
Autumn	*Daphnia cucullata* *Bosmina coregoni* *Eudiaptomus gracilis*	*Bosmina coregoni* *Daphnia galeata* *Eudiaptomus gracilis*

Table 1. Dominant species of zooplankton in Lake Peipsi-Pihkva in different seasons.

diaptomus gracilis (Sars, 1863), *Cyclops vicinus* (Uljanin, 1875), *C. scutifer* (Sars, 1863), *Mesocyclops leuckarti* (Claus, 1857), *Thermocyclops oithonoides* (Sars, 1863), *T. crassus* (Fischer, 1853); among rotifers – *Kellicottia longispina* (Kellicot, 1879), *Keratella cochlearis* (Gross, 1851), *K. quadrata* (Müller, 1786), *Asplanchna priodonta* (Gross, 1850), *Polyarthra* spp., *Synchaeta* spp., *Filinia longiseta* (Ehrenberg, 1834).

Among the most common species, 27% are oligosaprobes – indicator species of pure waters; also 27% belong to o-β-mesosaprobes – indicators of slightly contaminated waters; 23% of the list is represented by β-mesosaprobes – indicator species of moderately polluted waters and 8% – β-α-mesosaprobes – indicators of increased contamination.

The magnitude of the Mäemets trophic state index (E), which is based on the number of indicator species of eutrophic and oligotrophic waters, taking into account the ratio of taxonomic groups of planktonic organisms, calculated for a list of species often found in pelagial, is about 1.5, which corresponds to eutrophic basins.

The dominant species assemblage indirectly, but quite adequately reflects the types of food chains and the trophic status of the lake. The composition of biomass-dominated species in the pelagial of the Lake Peipsi-Pihkva did not change during the whole period of the study. However, the dominant assemblage in the Pihkva and Peipsi is somewhat different.

In the former assemblage, major dominants are most often species characteristic of eutrophic basins: *Daphnia cucullata* (Sars, 1862), varieties *Bosmina coregoni* cf. *gibbera* (Schoedler, 1863) and *B. coregoni* cf. *tersites* (Poppe, 1887); the second also contain dominant species of oligo- mesotrophic waters: *B. coregoni* cf. *berolinensis* (Imhof, 1888), and *Daphnia galeata* (Sars, 1864), *D. cristata* (Sars, 1862). In addition, in the Lake Pihkva, the number of dominants is on average 2–3 species, and in Lake Peipsi 3–5 species (Table 1).

In general, there is a certain picture of the seasonal dynamics of dominants, whereas peaks in the development of a particular species are determined, primarily, by the hydrothermal conditions of the season. In the spring, the dominant position in the lake is occupied by adult and juvenile representatives of the genera *Cyclops* and *Mesocyclops* migrating from the hypolimnion into the water column. At the beginning of summer, as the water warms up, the structure of the zooplankton community changes, and thermophilic cladocerans of the genera *Bosmina* and *Daphnia* become dominant. The eurythermal species *Eudiaptomus gracilis* occupies a dominant position when the biomass of representatives of the genus *Daphnia* is at a low level; this can occur both in early summer and in autumn. In the mid-summer, in addition to these species, *Chydorus sphaericus* (Muller, 1785), *Diaphanosoma brachyurum* (Lievin, 1848) and predatory cladocerans *Leptodora kindtii* (Focke, 1844) and *Bythotrephes brevimanus* (Lilljeborg, 1901) also become dominant in some years.

In the long-term dynamics of the mean biomass of Lake Peipsi-Pihkva zooplankton during the growing season, there was a tendency to increase in the 1990s. (Fig. 2, Table 2), which indicates an increase in the trophic status of the basin. In the 2000s, a decrease in this value was observed, which is generally considered to be an indicator of the slowing down of the eutrophication process (Andronnikova, 1980). Quantitative indicators from the last decade show only fluctuations in the community of planktonic invertebrates, which are most likely related to the inter-annual features of the hydrological and hydrothermal regimes of the basin.

In 1980–2017, during the growing season, the biomass of the zooplankton of the Lake Pihkva and Lake Peipsi varied within wide limits (0.57–5.76 and 0.35–5.40 g/m^3), the numbers were 67.8–244.6 and 40.8–152.94 thousand individuals/m^3, respectively.

However, the biomass of zooplankton of

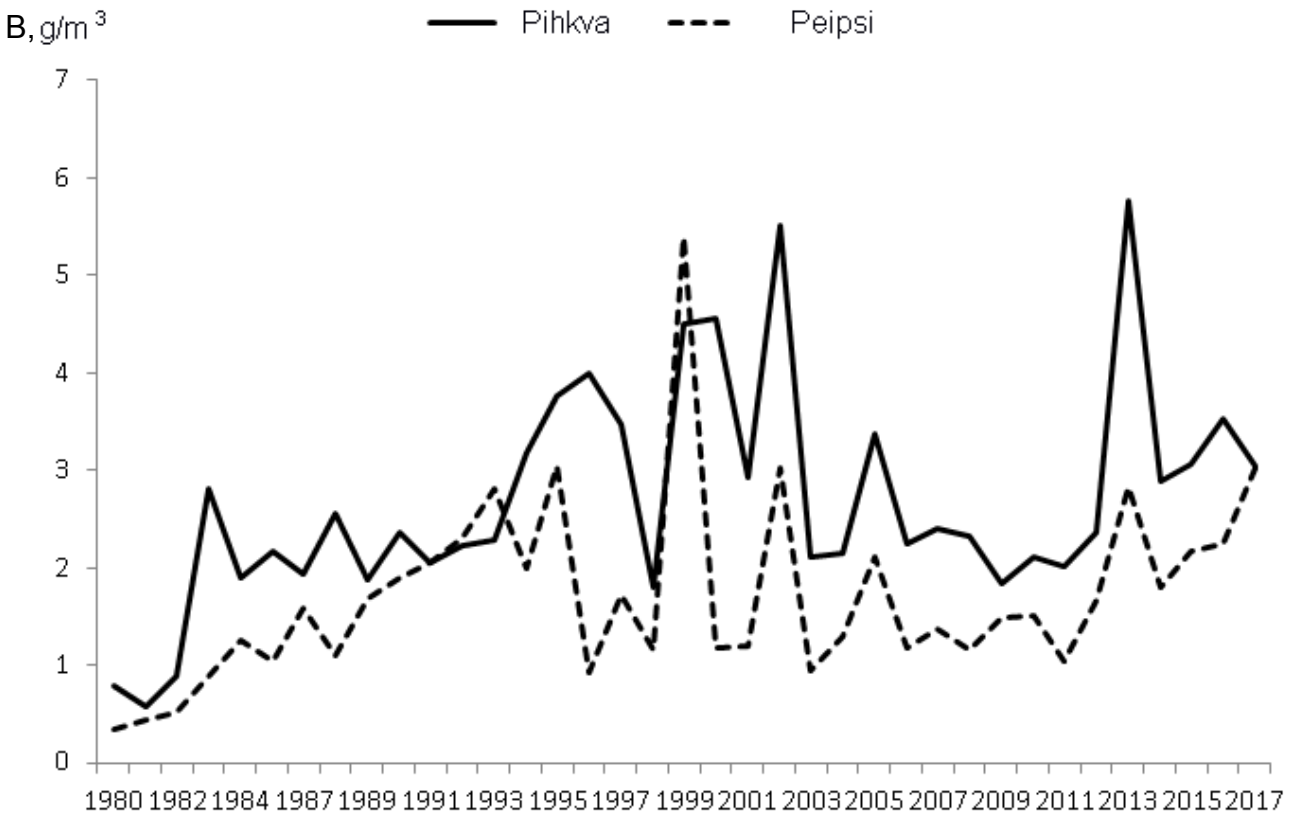

Fig. 2. Dynamics of the average biomass for the growing season of Lake Peipsi-Pikhva, 1980–2017.

the Lake Pihkva is usually higher than that of Lake Peipsi, which confirms a higher trophic status of this part of the lake (Fig. 2, Table 2). For a long period of research, this value in Lake Peipsi only twice rose to the level of Lake Pihkva, which happened in years with high heat accumulation (1993, 1999), when high quantitative indices of zooplankton in the autumn season were recorded in Lake Peipsi. In 2000–2017 the maximum numbers of zooplankton were recorded in 2002 and 2013, when the average biomass of zooplankton was more than 5.5 g/m³ in Lake Pihkva and close to 3.0 g/m³ in Peipsi, which is almost twice as high as the average for the entire period.

Seasonal dynamics of abundance and biomass of the zooplankton of the lake are characterized by two peaks: a summer maximum and an autumnal rise. The first occurs usually in June or July, and in the Lake Pihkva a little earlier than in Lake Peipsi. Autumn rise of biomass is not an annual, but quite a frequent phenomenon. Much more often it occurs in Lake Pihkva, and is associated with favorable conditions of the autumn season in some years, as well as with the decline of pressure from predators, especially juvenile fish changing their feeding preferences. More often in the autumn various varieties of *Bosmina coregoni* dominate, and in some years species of the genus *Daphnia*. Parthenogenetic reproduction of Cladocera lasts longer than usual, and the reproduction shifts to a later date. For the period 2000–2017, the autumnal rise was recorded 8 times in Lake Pihkva and 5 times in Lake Peipsi.

The ratio of the average biomass for the growing season of taxonomic groups of zooplankton in 2000–2017 shows that the Rotifera (0–5%) constitute the smallest proportion. The average ratio of the Cladocera and Copepoda biomass in Lake Peipsi-Pihkva is close to one.

Some variation of this parameter is noted,

Years	Lake Pihkva	Lake Peipsi
1980–1990	1.78	1.08
1991–2000	3.18	2.26
2001–2010	2.70	1.53
2011–2017	3.24	2.11

Table 2. Average long-terml biomass of zooplankton (g/m³) of the Lake Peipsi-Pihkva (1980–2017).

most pronounced in Lake Pihkva, which primarily results from hydrothermal seasonal conditions, which affect the life cycles of some species (Fig. 3, 4). A high proportion of cladocerans was recorded during the autumnal rise of biomass, when parthenogenetic reproduction of large crustaceans of the genera *Daphnia* and *Bosmina* continues in the autumn.

The proportion of Cladocera in the average biomass of zooplankton of Lake Pihkva fluctuated within a range of 43–76%; the minimum value was registered in 2000, the maximum in 2002 and 2003, while the proportion of Copepoda changed in the opposite direction (Fig. 3). In Lake Peipsi, the proportion of Cladocera in the mean zooplankton biomass during the growing season varied between 45–66%. The lowest values were recorded in 2002 and 2007, the maximum values in 2012 and 2016 (Fig. 4). No distinct trend towards increase of the proportion of individual taxonomic groups of zooplankton of Lake Peipsi-Pihkva was noted in 2000–2017.

There is no agreement in the literature on the average individual mass of zooplankters as an indicator of the trophic state of a basin. There are data indicating that with eutrophication of the basin, the individual mass increases in some species and decreases in others (Andronnikova, 1980). In Lake Peipsi-Pikhva, food conditions do not limit the development of large suspension feeders of the genera *Daphnia, Bosmina* and *Eudiaptomus*. Evidently, the average individual mass of crustaceans is mainly determined by predation pressure, represented here by young fish and plankton feeders, which eat the largest individuals (Zaripova, 1988). During the study period, the mean weight (Wm) of zooplankters of Lake Pihkva during the study period was 0.027 μg, and the maximum values (0.060 μg) were recorded in the years with the highest abundance of zooplankton.

In Lake Peipsi the average value of Wm was 0.024 μg, and the maximum values did not exceed 0.040 μg. A higher value of the average individual weight of the zooplankters of Lake Pihkva indicates a higher trophic level. However, higher pressure by plankton-feeding fish (European smelt and vendace), which live mainly in the deep-water part of Lake Peipsi, could also affect the population. Lack of oxygen in the water and siltation of spawning grounds, typical of the shallow Lake Pihkva, adversely affect the development of whitefish (Kontsevaya, 2000).

Shannon's indices, calculated for the number and biomass of zooplankton for individual stations of the lake, as a rule, exceeded 2 bits, which indicates relatively good leveling and quite favorable habitat conditions for various species and groups of zooplankton.

According to Andronnikova (1996), the value of the index within 1–2 bits corresponds to eutrophic waters, 2–3 bits to mesotrophic waters, and higher than that to oligotrophic. In the pelagic part of Lake Pihkva, the indices of species diversity were slightly higher than 2 bits, in Lake Peipsi this index often ex-

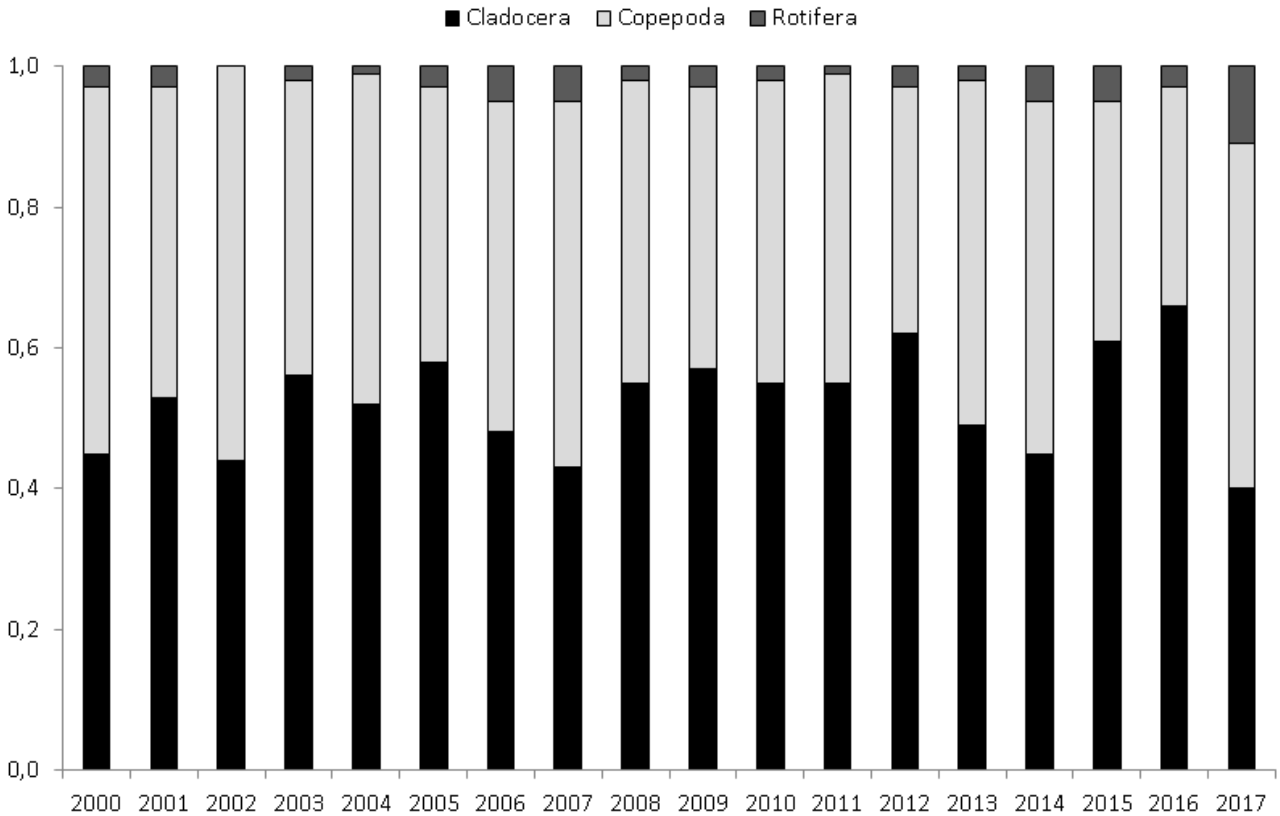

Fig. 3. Proportions of taxonomic groups of invertebrates in total biomass of zooplankton of Lake Peipsi in 2000–2017.

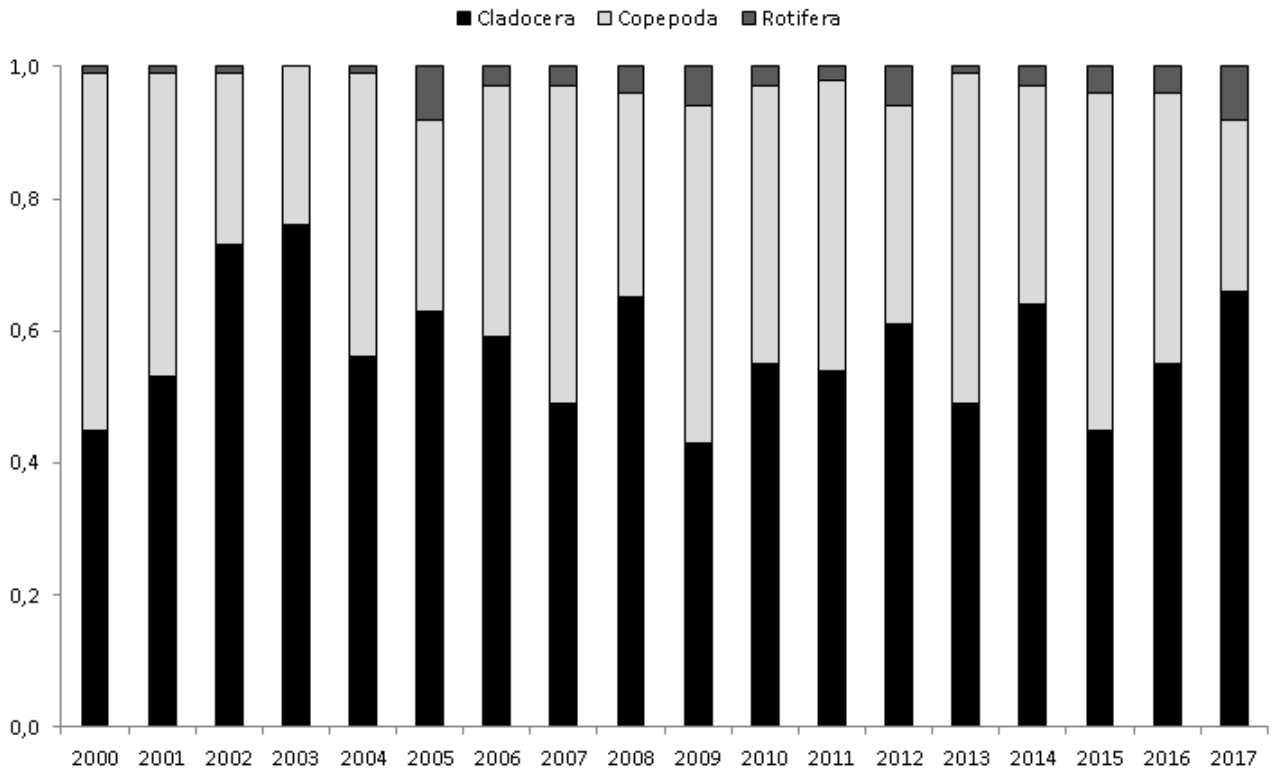

Fig. 4. Proportions of taxonomic groups of invertebrates in total biomass of zooplankton of Lake Pikhva n 2000–2017.

ceeded 3 bits, which also confirms the lower trophic level of the deep-water part of the lake.

The indices of saprobity were 1.49–1.75, which corresponds to the moderately polluted waters of the organic substance (β-mesosaprobic zone).

Conclusions

The species composition of the zooplankton of Lake Peipsi-Pihkva is characteristic of eutrophic basins. Lake Pihkva is dominated by only the indicator species of eutrophic waters; Lake Peipsi in addition shows abundance of species-indicators of oligo-mesotrophic waters, which indicates a higher trophic level of Lake Pihkva compared to Lake Peipsi.

The average quantitative indices (abundance and biomass) of zooplankton of Lake Peipsi-Pihkva during the last three decades during the growing period indicate a basin of the eutrophic type. The values of these indicators in Lake Pihkva are usually higher than those of Lake Peipsi, which confirms a higher trophic level.

In the dynamics of the biomass of the zooplankton of both Lake Pihkva and Lake Peipsi during the growing season, an increase in the 1990s was noted for the analyzed period of research (1980–2017), which may be due to the intensification of eutrophication processes in the basin. In recent years, there have been fluctuations in its magnitude, apparently related to the hydrothermal conditions of individual years.

The proportion of individual taxonomic groups, indices of species diversity, the average individual weight of zooplankters correspond to those for moderately-eutrophic water bodies. There is some variation in structural indicators, determined primarily by the hydrothermal conditions of the season, affecting the life cycles of individual species.

All described processes are most pronounced in the southern part of the basin, i.e., Lake Pihkva, where, due to the smaller area and shallow water, the impact on the ecosystem of various environmental factors more quickly affects the structure and function of the plankton community.

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