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ZOOPLANKTON, ZOOBENTHOS, AND ZOOPERIPHYTON

Species Composition and Community Structure of Zooplankton in Small Rivers of the Forest-Steppe Zone

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Abstract—The zooplankton communities have been studied in nine small rivers of Penza oblast. In total, 157 taxa are identified; 24 taxa are observed for first time for Penza oblast and one species is found for the first time for the Volga Region. Rotifers dominate in all studied communities. Spring zooplankton communities differ from those in summer by a high relative abundance of eurythermal species *Synchaeta oblonga*. Summer communities are more diverse because of the greater heterogeneity of the environment.

Keywords: zooplankton, small rivers, the Volga Upland, Penza oblast
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INTRODUCTION

Small rivers are the most numerous type of continental water bodies [10]. Due to their small size, the communities developing there are more sensitive to the changes in the environmental conditions than the communities of large watercourses that react more slowly to natural changes and human interference because they are full-flowing. Studying the small rivers, the ecological situation in their catchment areas may be inferred [28].

The hydrobionts of small rivers respond to a different extent to the changes in environmental conditions. Thus, macrozoobenthos has no sharp fluctuations and reflects long-lasting effects [6], unlike zooplankton, whose structure reacts more quickly even to the most insignificant changes in the environmental factors. Therefore, the zooplankton of small rivers is an informative object for monitoring.

In the studies of the zooplankton of small rivers of Penza oblast, most attention is paid to the analysis of the taxonomic composition [2, 26], the assessment of structural parameters in the autumn period [3], and the state of communities in the tributaries of the Sura River [18, 19]. At the same time, system researches of the zooplankton community structure, which varies significantly in time and space and under the influence of various environmental factors, including anthropogenic factors, were carried out only 20 years ago [18].

This research aims to study the species composition and structure of zooplankton communities of small rivers in the basin of the Sura River on the territory of Penza oblast and to assess their temporal dynamics in the period of the greatest succession.

MATERIALS AND METHODS

The study region is located in the forest-steppe zone and is characterized by a temperate continental climate. The average temperature of the coldest month in the year (January) is –12 to –13°C; the warmest (July) is 19–20°C. The territory is characterized by moderate humidity (average annual precipitation of 560 mm) [12]. River alimentation is mixed, supported mainly by snow (60%) and partly by ground waters (23%) and rainfalls (<20%) [22]. The river-level regime is characterized by a pronounced high spring flood, a summer drought period interrupted by rainfalls, and a sustained long winter drought period. In autumn, the regime of the rivers is unstable and depends on the amount of precipitation. The spring flood begins at the end of March–beginning of April, and ice formation usually occurs in the second half of November [12].

In May, July, and August 2015, nine small rivers (four rivers of the first order and five rivers of the second order) belonging to the basin of the Sura River were investigated (Table 1). All the studied rivers are located on the western slope of the Volga Upland within Penza oblast; only the source of the Kadada River is located in Ulyanovsk oblast. The soils in river valleys belong to meadow–black humus earth and alluvial types [12]. The vegetation of the valleys is rather monotonous. Broadleaf cattail, common reed, acute sedge, greater pond sedge, wood club–rush, lakeshore bulrush, and arrowhead are common at

Table 1. General characteristics of small rivers and sampling sites

River	Tributary order	Geographical coordinates of the sampling site, N, E	Total length, km	Length from source to sampling site, km	Total catchment area, km^2	Number of tributaries upstream the sampling site	Number of regulated sections of the river
Kadada	1	53.0721°, 46.0509°	150	136	3620	12	2
Kryazhim	2	53.0945°, 46.0613°	24	23	205	2	No
Elyuzan'	1	53.0903°, 46.0026°	20	18	88.6	No	2
Vyadya	1	53.2844°, 45.2817°	41	23	496	2	No
Otvel'	2	53.2761°, 45.2921°	17	17	138	1	1
Inra	2	53.2687°, 45.2548°	24	15	133	1	2
Shuksha	1	53.5762°, 45.1977°	84	72	946	6	No
Elshanka	2	53.5599°, 45.1385°	8	7	30	No	2
Ivanyrs	1	53.5451°, 45.3109°	35	30	413	5	No

shallows and along the coasts; yellow water-lily, European white water-lily, *Nymphaea candida* water lily, floating pondweed, sago pondweed, frogbit, common duckweed, star duckweed, and hornwort are found some distance from the shoreline.

Zooplankton samples were taken in ripal at three stations located along a 100- to 150-m transect (Table 1). In the Elyuzan', Inra, Shuksha, and Elshanka rivers, the state of development of higher aquatic vegetation was noted at the sampling sites. In total, 81 samples were collected by a bucket from the surface, 100 L of water was filtered through the Apstein plankton net (mesh size 64 μm) and fixed with 4% formalin. The river width, depth, current velocity, and water temperature were measured at each station. In July and August, a hydrochemical analysis of water was carried out according to the guidelines [14, 27].

Laboratory treatment of samples was carried out by standard methods [17, 23]; the identification of species was performed under the species keys [13, 21]. The state of zooplankton was estimated according to species richness (S), abundance (N, 10^3 ind./m^3), biomass (B, μg/m^3), dominant species, and to the ratio of taxonomic groups [1, 17]. The biomass of zooplankters was calculated using the tables of the dependence of the individual weight on the body length. All calculations and statistical analyzes were performed using the programming language R (https://www.R-project.org) and vegan: Community Ecology Package (https://CRAN.R-project.org/package=vegan). An analysis of the species structure of the communities was carried out by the principal component analysis, PCA (only the species found in three and more samples with a relative abundance ≥3% were included into the analysis). The data of the relative species abundance underwent the Hellinger transformation, which made it possible to use the Hellinger distances as a measure of community dissimilarity instead of Euclidean distances, since the latter are sensitive to the double absence of species [29]. The results of the analysis are presented in the form of diagrams in which the distance between the points (samples) is proportional to the Hellinger distance; the angle between the species vectors is correlation.

RESULTS

Ivanyrs, Kadada, Kryazhim, and Otvel' rivers were the torrential rivers; in other rivers, the flow velocity during particular periods was less than 0.23 m/s (Table 2). The flow velocity naturally decreases from May through August, with the exception of the Kryazhim River, where this parameter increases, and of the Elyuzan' and Otvel' rivers, where the minimum flow velocity has been recorded in July. The unusual water regime in the Kryazhm River may be associated with the location of the sampling station: it was in the area of its confluence with the Kadada River; as a result, during the spring flood, there was a river backwater, which led to a lower flow velocity in May. In all rivers, the water temperature was the highest in July. The highest temperature of water during the whole study period was recorded in the Kadada and Shuksha rivers.

All studied rivers were characterized by a high content of total iron (average 0.35 mg/dm^3, range of 0.17–0.5 mg/dm^3) and manganese (average 0.14 mg/dm^3, range of 0.06–0.24 mg/dm^3). In the Elshanka, Ivanyrs, Kryazhim, and Kadada rivers, a high content of suspended particulate matter was observed (an average of 18.3 mg/dm^3), while in other rivers it was much lower (6.6 mg/dm^3). Relatively high alkalinity was registered in the Vyadya, Otvel', Elshanka, and Shuksha rivers (average 5.7 mmol/dm^3 and range of 5.2–6.4 mmol/dm^3) compared to the average of 2.9 mmol/dm^3 in the other rivers. In the Shuksha River, a high content of sulfate ions SO_4^{2-} has been registered (69 mg/dm^3; in the other rivers, there was an average of 20.4 mg/dm^3). A high

Table 2. Summary of sampling sites during the study period

River	Month	Depth, m	Width, m	Velocity of current, m/s	Water temperature, °C
Inra	V	0.4	1.5	0.6	12
	VII	0.5	1.5	0.19	19.3
	VIII	0.5	1.5	0.03	14.3
Otvel'	V	0.4	5	0.43	12
	VII	0.7	5	0.31	16.8
	VIII	0.7	5	0.37	16
Vyadya	V	0.8	7.7	0.53	10
	VII	0.8	7.7	0.3	16.8
	VIII	1.2	7.7	0.1	15
Elyuzan'	V	0.6	4.7	0.4	10.3
	VII	0.4	4.7	0.35	17.5
	VIII	0.4	4.7	0.23	14.7
Kryazhim	V	0.5	8.7	0.37	12
	VII	0.4	8.7	0.53	17.2
	VIII	0.3	8.7	0.7	13.5
Kadada	V	0.4	32	0.6	15
	VII	0.6	32	0.52	22
	VIII	0.3	32	0.5	18.2
Elshanka	V	0.4	1.5	0.63	11
	VII	0.3	1.5	0.43	18
	VIII	0.1	1.5	0.17	11.5
Shuksha	V	1.7	15	0.67	15
	VII	1.5	15	0.37	22
	VIII	1	15	0.2	17
Ivanyrs	V	0.8	10.7	0.97	14
	VII	0.3	10.7	0.7	20
	VIII	0.3	10.7	0.57	13

content of chlorides (Cl^-) was observed in the Otvel', Vyadya, and Inra rivers (38 mg/dm^3 versus 10.1 mg/dm^3 in the other rivers). These rivers were characterized also by high concentrations of ammonium ions NH_4^+ and nitrites NO_2^- (average 0.59 and 0.08 mg/dm^3, respectively). The increased content of chlorides and sulfates is not a characteristic of natural watercourses and indicates contamination with household waste. The presence of excess ammonium ions in the water may be associated with the processes of decay and contamination with effluents with a high content of organic substances. The deterioration of water quality of these rivers may be due to their location in the area of high anthropogenic load (proximity to the city of Penza, large agricultural sites, and landfills for the disposal of solid waste).

A total of 157 taxa were found in the zooplankton composition of the studied rivers (rotifers 114, cladocerans 24, and copepods 19). The most abundant were the nauplia of Cyclopidae (18.2%), *Synchaeta oblonga* Ehrenberg (15%), *Rotaria* sp. 1 (9.1%), *Euchlanis lucksiana* Hauer (4.5%), *Keratella cochlearis* (Gosse) (3.1%), *Bosmina longirostris* (O.F. Müller) (3%); in biomass, *Rotaria* sp. 1 dominated (16.5%), followed by *Synchaeta oblonga* (11.2%), nauplia of Cyclopidae (8.9%), *Bosmina longirostris* (5.4%), copepodites of cyclopids (4.5%), *Simocephalus vetulus* (O.F. Müller) (3.8%), *Disparalona rostrata* (Koch) (3.6%), and *Euchlanis lucksiana* (3.3%). All these species, except for *Eu. lucksiana* and *Simocephalus vetulus*, as well as rotifers *Brachionus angularis* Gosse, *Euchlanis dilatata* Ehrenberg, *Filinia longiseta* (Ehrenberg), *Keratella cochlearis tecta* (Gosse), *K. valga* (Ehrenberg), *Polyarthra dolichoptera* Idelson, and *Synchaeta pectinata* Ehrenberg, were characterized by high occurrence and were found in more than 30% of samples. Twenty-four species of zooplankters were recorded for the first time in Penza oblast: *Ascomorpha saltans* Bartsch, *Aspelta angusta* Harr. et. Myers, *Cephalodella stenroosi* Wul-

Table 3. Total number of zooplankton species in small rivers

River	Rotifera	Cladocera	Copepoda	Total number of species
Kadada	65	10	3	78
Kryazhim	32	3	5	40
Elyuzan'	36	4	4	44
Vyadya	53	11	8	72
Otvel'	57	10	6	73
Inra	51	9	6	66
Shuksha	18	9	5	32
Elshanka	18	3	4	25
Ivanyrs	27	5	3	35
Total	114	24	19	157

fert, *Dicranophorus caudatus* (Ehrenberg), *D. forcipatus* (Müller), *D. hercules hercules* Wiszniewski, *Drilophaga bucephalus* Vejdovsky, *Encentrum putorius* Wulfert, *E. saundersiae saundersiae* (Hudson), *Itura viridis* (Stenroos), *Keratella tropica reducta* Fadeev, *K. valga*, *Lecane elachis* (Harring et Myers), *Lindia torulosa* Dujardin, *Metadiascha trigona* (Rousselet), *Notholca caudata* Carlin, *Notommata cerberus* (Gosse), *Paradicranophorus aculeatus* (Neiswestnova-Shadino), *Proales sigmoidea* (Skorikov), *P. theodora* (Gosse), *Resticula melandocus* (Gosse), *Testudinella truncata* (Gosse), *Trichocerca tigris* (Müller), and *Picripleuroxus striatus* (Schoedler)).

The number of species in the samples varied from 1 to 36. The richest zooplankton communities were found in the Kadada, Vyadya, Otvel', and Inra rivers (66–78 species); the poorest were in the Kryazhim, Elyuzan', Shuksha, Elshanka, and Ivanyrs rivers (25–44 species) (Table 3). Rotifers dominated in all streams (56–83% of the total number of species). The zooplankton abundance varied as 0.01–571.11 10^3 ind./m^3; biomass varied from 0.002 to 1104.27 μg/m^3.

According to the number of species, abundance, and biomass of zooplankton, two groups of rivers have been defined (Fig. 1). The Kadada, Vyadya, Otvel', and Inra rivers were characterized by high average values of these parameters, while in the Kryazhim, Elyuzan', Shuksha, Elshanka, and Ivanyrs rivers they were low. The high values of the parameters of zooplankton in the Vyadya, Otvel', and Inra rivers may be associated with the significant anthropogenic load, as was indicated by the high content of chlorides, ammonia nitrogen, and nitrites in the water. In the Kadada River, rich species composition and high abundance and biomass of zooplankton may be a consequence of the large size of the watercourse and the number of tributaries (length of 150 km in comparison with the length of 8–84 km of other rivers). Low species richness, abundance, and biomass of zooplankton cenoses in the Elshanka, Ivanyrs, and Kryazhim rivers may be associated with a high content of suspended particulate matter and, in the Shuksha River, with a significant concentration of sulfates and decay processes in the over-developed communities of macrophytes, which create an unfavorable temperature and gas regime for the life of organisms [20, 24].

During the study period, the maximum zooplankton abundance and biomass were recorded in spring, and the subsequent decline was during the summer period. The highest abundance ($(79.7 \pm 28.32) \times 10^3$ ind./m^3, hereafter the arithmetic mean ± error of mean) and biomass (149.5 ± 52.9 μg/m^3) of the zooplankton in the studied rivers were recorded in May; in July and August, these parameters were 3.0–3.6 and 1.2–1.4 times lower, respectively. The high zooplankton abundance in the spring was caused by the dominance of the eurythermal rotifer *Synchaeta oblonga*, which outbreak at a relatively low water temperature with no competition from warm-water species. The average number of species in the samples increased by the end of the summer: in May it was 12.5 ± 1.26, in July it was 15.3 ± 2.16, and in August it was 17.3 ± 1.56.

An analysis of the temporal dynamics of the species structure by abundance (Figs. 2a, 3) showed that the spring communities (May) differed from the summer ones (in July and August), while the communities observed in July and August were actually similar. In summer, the dominant complexes of the zooplankton species in the rivers were quite specific, while in the spring they were most similar. Typical species for the zooplankton communities in May were rotifers *Synchaeta oblonga* (38% of total abundance), *Keratella cochlearis* (7%), *K. valga* (6%), *Polyarthra dolichoptera* (6%), *Notholca squamula* (Müller) (4%), *Synchaeta pectinata* (4%), and *Keratella quadrata* (Müller) (3%). Among the small species typical in May were *Rotaria rotatoria* (Pallas) (1%) and *Thermocyclops oithonoides* (Sars) (0.9%). Most of the rotifers found are vertical feeders; they consume bacteria, protozoa, phytoplankton, and suspended fine detritus. In summer, *Rotaria* sp. 1 rotifers dominated in zooplankton (12% of the total abundance) and *Euchlanis lucksiana* (7%), which swam and crawled, gathering food (bacterio- and phytoplankton and suspended fine detritus) from the substrate. The increase in the proportion of crustaceans, in particular *Bosmina longirostris* (5%), *Disparalona rostrata* (4%), copepodites of cyclops (4%), *Paracyclops fimbriatus* (Fischer) (2%), and *Alona rectangula* Sars (1%) was a specific feature of summer zooplankton communities. In addition, rotifers *Brachionus bidentata* Anderson (3%), *Keratella cochlearis tecta* (3%), *Aspelta angusta* (2%), *Hexarthra mira* (Hudson) (2%), and *Pompholyx complanata* Gosse (2%) were typical in the summer communities. The increase in the percentage of rotifers and crustaceans feeding close to the bottom in zooplankton cenoses was caused by a decrease in the water level and the flow velocity in the rivers (Table 2).

Among the summer communities, the most specific species composition was observed in the Inra River in July (Figs. 2b, 3), when a high proportion of rotifers was noted, which were few and rare in other rivers: *Lecane bulla* (Gosse) (7.8% total), *Keratella tropica reducta* (6.5%), *Trichocerca similis* (Wierzejski) (4.4%), and *Lecane stenroosi* (Meissner) (1.2%). The rivers Vyadya; Otvel'; and, to a lesser extent, Shuksha had a similar species composition of zooplankton community. The species common for the rivers were two-thirds eurybiont species and one-third phytophilic zooplankers. The zooplankton of the Ivanyrs and Kryazhim rivers was characterized by high similarity; in addition, these communities were close to those of the Elyuzan' and Elshanka rivers. The species common for these rivers were mainly eurybionts. The Kadada River was characterized by the greatest differences in the species structure of the zooplankton community during the study period (the maximum scatter of the points at Fig. 2b).

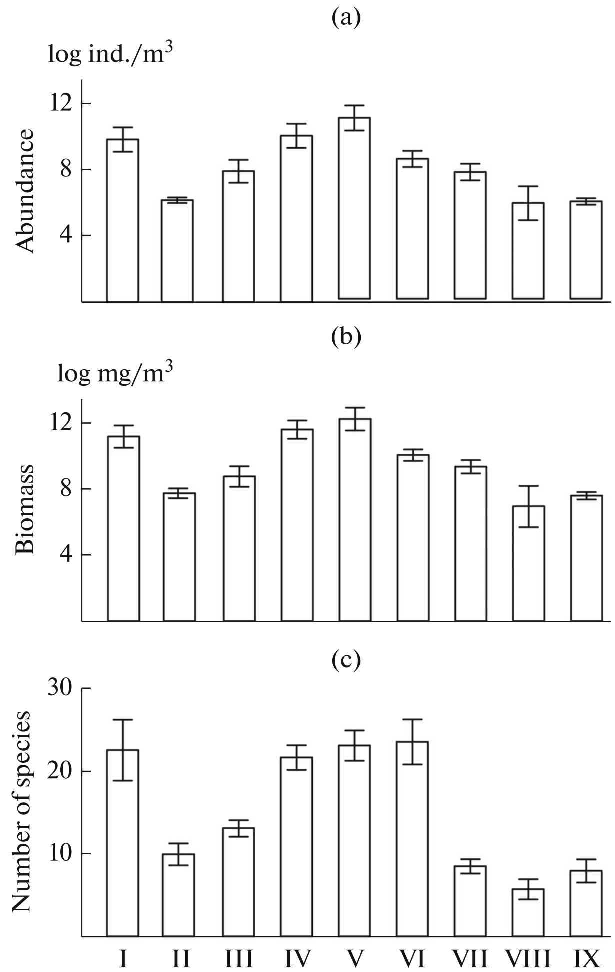

Fig. 1. Dynamics of abundance (a), biomass (b), and number of species in the sample (c) zooplankton in small rivers: (I) Kadada, (II) Kryazhim, (III) Elyuzan', (IV) Vyadya, (V) Otvel', (VI) Inra, (VII) Shuksha, (VIII) Elshanka, and (IX) Ivanyrs. Error bars are the standard error of mean.

DISCUSSION

In the studied small rivers, the content of iron and manganese is high, which is typical for many water bodies in Penza oblast; this is due to the high content of these elements in the soils. A similar situation is noted for other regions. Thus, in the rivers of Chita oblast, the concentration of metal ions (iron, manganese, zinc, copper, molybdenum, etc.) is high; this is explained by the influence of the corresponding deposits [7]. According to some authors [5], the chemical composition of the water of small rivers directly depends on the level of anthropogenic load, in particular, on the composition, quantity, and quality of the household and industrial waters entering them, and it is determined by the lithology of the rocks of their catchment area and by the composition of groundwater. High anthropogenic load is typical for many water bodies of Penza oblast. For example, the high content of nitrites, ammonium nitrogen, phenols, petroleum products, iron, manganese, and copper has been registered in the waters of the Sura River and the Penza (Sura) Reservoir [18]. The high content of sulfates and chlorides indicates a high anthropogenic load [28]. Thus, the hydrochemical indicators of water in the studied rivers are determined by the features of the chemical composition of the catchment area and by the degree of the anthropogenic load.

Rotifers formed the basis of zooplankton communities in the studied rivers by the number of species and by abundance; this was noted for other small rivers of Penza oblast [2, 3, 18, 19, 26] and of the regions of Russia [28], although in some cases cladocerans [15] or copepods prevailed or the abundances of Rotifera and Cladocera were equal [8, 10]. However, the prevalence of cladocerans is characteristic mainly for the coastal areas and the river sites overgrown with macrophytes, while in the most lotic waters and open areas rotifers are the leading group. Consequently, a greater number of rotifers in the zooplankton of the studied

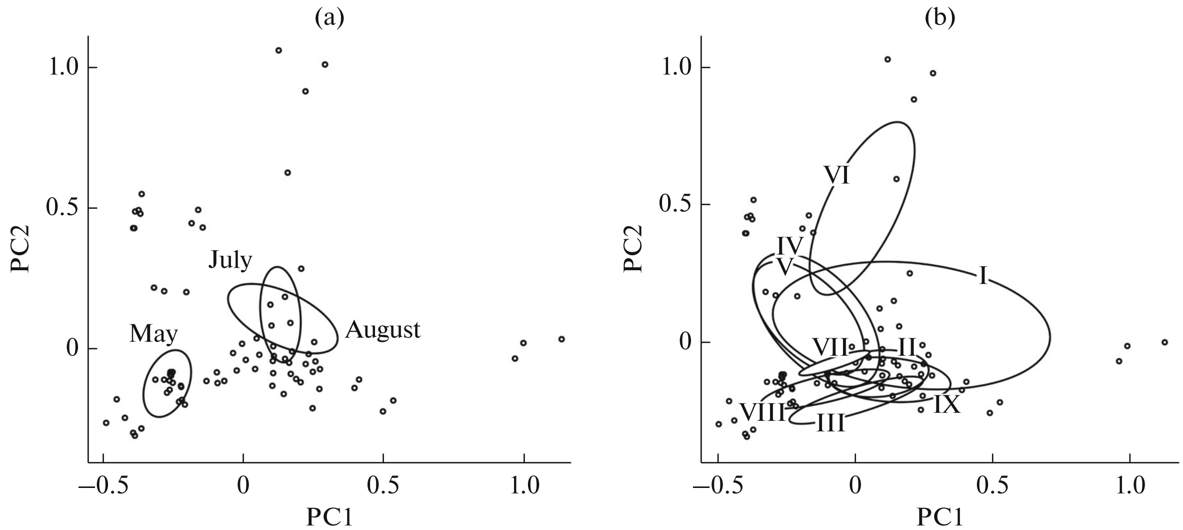

Fig. 2. Results of ordination of zooplankton communities (by abundance) during the study period (a) and in the studied rivers (b). Ellipses are the confidence intervals of the variability of the species structure in communities. The designation of rivers is given in Fig. 1; the results of ordination of species is in Fig. 3.

small rivers is associated with a rapid water flow and a low degree of the overgrowth by macrophytes.

Species that have the highest occurrence in the studied rivers (*Euchlanis dilatata*, *Filinia longiseta*, *Keratella cochlearis*, *Polyarthra dolichoptera*, *Bosmina longirostris*, and *Disparalona rostrata*) are eurybiont species [9, 10, 16, 18, 19]. The rotifer *Aspelta angusta*, which is first noted for Penza oblast within this study, is also a new species for the Volga Region [25]. Earlier, this species was found in the rivers on the southwestern coast of the Onega Lake basin during the cold season [11]. Four species of rotifers (*Dicranophorus caudatus*, *Notommata cerberus*, *Proales sigmoidea*, and *Testudinella truncata*) have only recently been identified for the first time in Samara oblast. [4]. The findings of a significant number of new species of zooplankton in Penza oblast may be due to insufficient knowledge on the water bodies in this area.

The number of species and zooplankton abundance and biomass is higher in rivers with an increased content of chlorides, ammonia nitrogen, and nitrites and decreases with increasing suspended particulate matter. High concentrations of chlorides, ammonia nitrogen, and nitrites indicate contamination with household waste and various effluents; as a result, the content of dissolved organic matter in water increases, which can favorably affect zooplankton due to the increase in the number and variety of the food objects. The reverse situation can develop at a high content of suspended particulate matter in water, which probably complicates the filtration activity of crustaceans. Therefore, the increased content of suspended particulate matter in water has a negative effect on zooplankton in comparison with the positive effect of a moderate increase in the content of dissolved organic matter.

It was found that the abundance and biomass of zooplankton in rivers decrease and the number of species increases during the spring–summer period. Such dynamics is not very typical for small rivers, and most often these parameters increase during the vegetative period [9, 10]; in some cases, the peak of the community development occurs in the middle of summer and coincides with the period of maximum water temperature and the decrease in flow velocities [15]. In the studied rivers, the high abundance and biomass of zooplankton communities in May was affected by the predominance of the eurythermal rotifer *Synchaeta oblonga*, which reached a high abundance in the absence of competition with the warm-water species. As a result of the dominance of *S. oblonga*, the riverine communities in the spring were more similar to each other than in the summer. The prevalence of eurythermal species in spring zooplankton communities in small rivers has also been noted in previous studies.

Despite the rise in the water temperature during the summer, the watercourses generally remain colder than the reservoirs due to the continued overflow and/or groundwater alimentation. As a result, coldwater and warm-water species are jointly present in the zooplankton communities; this leads to an increase in species richness in summer. In addition, the zooplankton species richness and the heterogeneity of its composition in different rivers increase due to the combination of stagnant zones and the zones overgrown with macrophytes in the areas with rapid water flow [9].

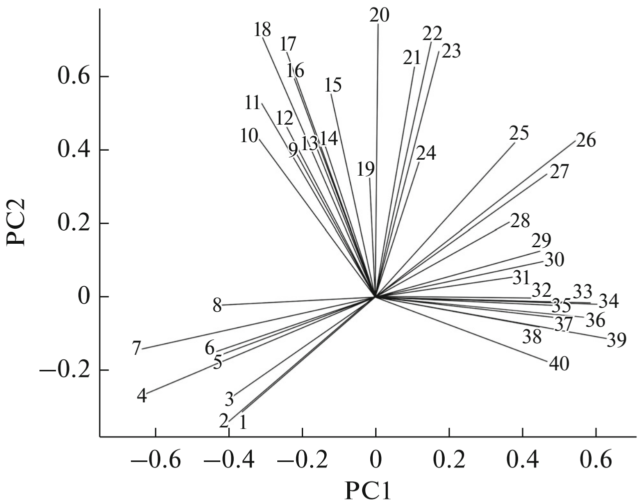

Fig. 3. Results of ordination of the species structure of zooplankton communities by abundance (species found in three or more samples with a relative abundance of ≥3% are shown). (1) *Keratella quadrata*, (2) *Synchaeta oblonga*, (3) *Keratella valga*, (4) *Synchaeta pectinata*, (5) *Notholca squamula*, (6) *Polyarthra dolichoptera*, (7) *Keratella cochlearis*, (8) *Thermocyclops oithonoides*, (9) *Polyarthra major*, (10) *Thermocyclops crassus*, (11) *Ceriodaphnia pulchella*, (12) *Hexarthra mira*, (13) *Pompholyx complanata*, (14) *Brachionus diversicornis*, (15) *Brachionus calyciflorus*, (16) *Bosmina longirostris*, (17) *Brachionus angularis*, (18) *Filinia longiseta*, (19) *Keratella cochlearis tecta*, (20) *Trichocerca similis*, (21) *Lecane stenroosi*, (22) *Keratella tropica*, (23) *Lecane bulla*, (24) *Brachionus calyciflorus spinosus*, (25) *Rotaria* sp. 3, (26) *Brachionus guadridentatus*, (27) *Conochiloides coenobasis*, (28) *Testudinella patina*, (29) *Lecane lunaris*, (30) *Lecane closterocerca*, (31) *Brachionus bennini*, (32) *Rotaria* sp. 1, (33) *Trichocerca tenuior*, (34) *Brachionus nilsoni*, (35) *Alona rectangula*, (36) *Disparalona rostrata*, (37) *Taphrocampa selenura*, (38) *Paradicranophorus aculeatus*, (39) *Macrothrix hirsuticornis*, and (40) *Cephalodella gibba*.

CONCLUSIONS

In the spring–summer period, 157 species and subspecies of planktonic invertebrates have been registered in the small rivers of the basin of the Sura River, of which 24 taxa has been found in Penza oblast for the first time; one species was new for the Volga Region. The significant number of newly discovered species indicates insufficient knowledge on the zooplankton fauna of the region. Thus, in the Kadada River, there were 65 species of rotifers identified, while 16 years ago the species list comprised only 22 species [18]. Rotifers dominated in the number of species and abundance. Spring communities were characterized by the lowest number of species and the highest abundance and biomass due to the predominance of eurythermal species *Synchaeta oblonga*. Summer communities differed due to an increase in the number of species due to high spatial inhomogeneity of environmental conditions, as well as due to an increase in the proportion of organisms feeding in the surface of the substrate caused by a decrease in flow velocity. The main differences in the species structure of communities between rivers were associated with the hydrological and hydrochemical characteristics of the rivers.

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