Zooplankton Communities of the Middle River Part of the Cheboksary Reservoir and Factors Influencing Their Species Structure

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Modern methodological approaches were applied to analyze the zooplankton community spatial distribution (with the example of the middle river part of the Cheboksary Reservoir). Zooplankton communities were sampled in the middle river part of the Cheboksary Reservoir (from the city of Nizhny Novgorod to Vasilsursk town) in the summer low-water period in 2018. The boundaries between the communities in the Cheboksary Reservoir were gradually changing during the history of the Cheboksary Reservoir from the time of its construction to present. In the middle river part of the Cheboksary Reservoir there are two distinct spatially stable zooplankton communities associated to the Oka and Volga streams. The distinction between these two zooplankton communities was demonstrated by hierarchical cluster analysis. Redundancy analysis has shown that chlorophyll-*a* and pH were the main factors influencing the specific zooplankton structure. Chlorophyll-*a* concentration reflects the meso-scale heterogeneity of the horizontal phytoplankton distribution and hence the distribution of the zooplankton's food sources. The relation of zooplankton to pH level reflects the high sensitivity of the species of the genus *Brachionus* Pallas, 1766 to high acidity. The influence of pH as an environmental factor was less evident. However, this variable is well known as one of the leading factors determining the structure of zooplankton communities. Its role in zooplankton community assembly of lowland reservoirs deserves further investigation.

Keywords: zooplankton community, species structure, spatial distribution, redundancy analysis, Cheboksary Reservoir, Nizhny Novgorod region.

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INTRODUCTION

There is a great interest in the problem of identification of spatial distribution of zooplankton communities and assembly of their species structure under the impact of various natural and anthropogenic factors (Leitao et al., 2006; Sokolova, 2012; Bolotov et al., 2013; Lazareva, Sokolova, 2015; Presnova, Khulapova, 2015; Joniak, Kuczynska-Kippen, 2016; Shurganova et al., 2018). The creation of reservoirs in the river beds transforms the original river ecosystem into a lentic ecosystem (Simões et al., 2015) and modifies the functioning of hydrobiocenoses. The dynamics of spatial distribution of zooplankton communities during long-term succession and changes of influence of various environmental factors is of particular interest in hydroecology (Shurganova, 2007). Species structure and abundance of zooplankton in reservoirs depends on a lot of environmental factors (Kiselev, 1969; Hayrapetyan et al., 2016) including food resources which are regarded by some authors as a leading ecological factors in water communities (Leibold et al., 1997; Dai et al., 2014).

Cheboksary Reservoir is the fifth stage in the cascade of reservoirs on river Volga. It was filled in 1981. Its area is 1080 km^2, maximal depth is 21 m (mean depth 5.8 m), water exchange coefficient is 19.8 per year (Shurganova, 2007), trophic status is stable eutrophic (Korneva, 2015). Cheboksary Reservoir is formed by two streams coming from the Gorky Reservoir and Oka River. These water masses differ from each other considerably in physical and chemical properties (Shurganova, 2007; Shurganova et al., 2018). Studies of the zooplankton of the Cheboksary Reservoir have been conducted since its construction (Kuznecova et al., 1991; Shurganova et al., 2003, 2014, 2018; Shurganova, 2007; Shurganova, Cherepennikov, 2010). However, the current spatial distribution and species structure of zooplankton communities in the middle river part of the Cheboksary Reservoir requires additional investigation because zooplankton communities change their structure and boundaries during succession (Shurganova, 2007). That's why the study of the dynamics of the spatial structure of hydrobiocenoses and evaluation of the impact of environmental factors on their assembly and functioning at the modern successional stage is an actual task.

The goal of the present work is to characterize the modern spatial distribution of zooplankton communities in the middle river part of Cheboksary Reservoir and to study the dependence of zooplankton communities on environmental factors.

MATERIAL AND METHODS

Zooplankton communities were sampled in the summer low-water period (July) in 2018 in the middle river part of the Cheboksary Reservoir (from the city of Nizhny Novgorod to Vasilsursk) (Fig. 1). Samples were taken with plankton net (70 µm nylon sieve) and fixed with 4% formalin solution. Sample processing was conducted with standard protocol (Metodicheskie rekomendacii…, 1982). Zooplankton species were identified with keys and handbooks (Kutikova, 1970; Korovchinsky, 2004, 2018; Key to Zooplankton…, 2010).

Water conductivity was measured at each sampling site with a YSI Pro30 (YSI Incorporated, USA) conductometer. pH value was measured with a YSI Pro10 pH meter (YSI Incorporated, USA). Water samples were taken at each site for the laboratory investigation. HCO_3 concentration was determined by titration with a solution of hydrochloric acid in the presence of indicators (as the difference between total and carbonate alkalinity) in accordance with GOST 31957-2012 (2014) concentration of SO_4 and sodium was determined by ion chromatography. The photosynthetic pigments content (chlorophyll-*a* and -*b*) was determined according to GOST 17.1.4.02-90 (1991) by spectrophotometry of the acetone extract from the precipitate obtained after filtering the sample through a membrane filter. Water turbidity was determined by an optical method with a HACH 2100 turbidimeter (Belozerova, Chalov, 2013) and was measured in nephelometric turbidity units (Hach Company, USA) (Grayson et al., 1996).

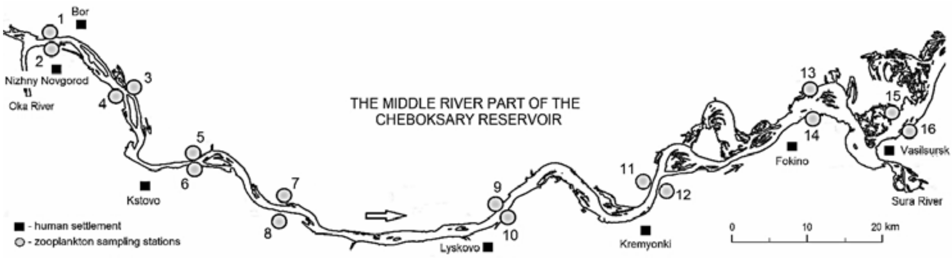

Fig. 1. The distribution of sampling sites in the middle river part of the Cheboksary Reservoir (two samples were taken near both banks at each position): *1*, *2* – Nizhny Novgorod, *3*, *4* – downstream the water refinement station, *5*, *6* – downstream the Kstovo town, *7*, *8* – downstream the mouth of the Kudma River, *9*, *10* – downstream the Lyskovo town, *11*, *12* – downstream the Kremyonki village, *13*, *14* – downstream the Fokino village, *15*, *16* – downstream the Vasilsursk village

Zooplankton species were considered as dominant according to Kownacki index (Bakanov, 1987). Multivariate vector analysis was applied to classification if zooplankton samples (Shurganova et al., 2003; Shurganova, 2007). It is a version of hierarchical cluster analysis based on angle (cosine) between samples in multivariate abundance space as a measure of their dissimilarity. Clustering was performed with the average linkage algorithm. Silhouette width analysis and Mantel correlation coefficient between distance matrix and binary matrix representing partitions were applied to determine the optimal number of clusters (Yakimov et al., 2016). Redundancy analysis (RDA) was applied to consider the association of zooplankton community structure and environmental factors (Shitikov, Rozenberg, 2013; Legendre P., Legendre L., 2012) and to display it with ordination diagram. All calculations were performed in R (R Core Team, 2015).

RESULTS

97 zooplankton species were identified in the middle river part of Cheboksary Reservoir: 46 Rotifera species (47%), 37 Cladocera species (38%) and 13 Copepoda species (15%). Rotifera were represented by 13 families; the most species-rich families were Brachionidae Ehrenberg, 1838 (19 species), Synchaetidae Hudson & Gosse, 1886 (6 species) and Trichocercidae Harring, 1913 (6 species). Water fleas were represented

by 10 families, mostly by Chydoridae Stebbing, 1902 (11 species) and Daphniidae Straus, 1820 (8 species). Copepoda were represented by families Cyclopidae Dana, 1846 (9 species), Temoridae Giesbrecht, 1893 (2 species) and Diaptomidae Baird, 1850 (2 species). Most species found in reservoir have a wide distribution. According to ecological classification most species were euplanktonic (63%), there were also phytophilic (19%), planktobentic (16%) and everytopic (2%) species.

Hierarchical clustering was performed to delineate zooplankton communities and to study their spatial arrangement. Corresponding dendrogram is shown in Fig. 2. All samples were divided into two clusters (it was optimal number according both to silhouette analysis and Mantel correlation analysis).

The first cluster consists of samples no. 1, 3, 5, 7, 9, 11, 13–16. It corresponds to zooplankton community of Volga stream. The second cluster consists of samples no 2, 4, 6, 8, 10, 12. It corresponds to zooplankton community of Oka stream. This community is characterized with much more similarity in comparison to Volga stream community. Species composition and dominant species abundances in the two communities differ considerably, as well as total abundance and biomass (Table 1).

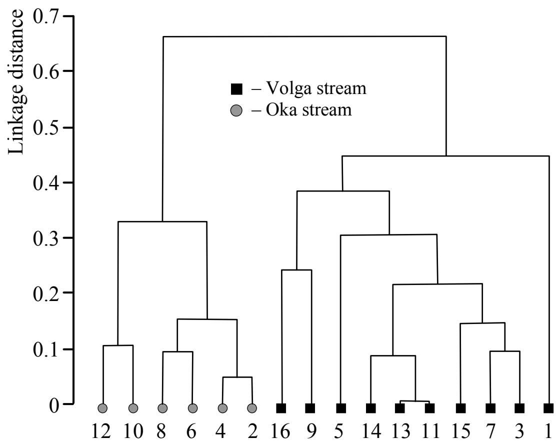

Fig. 2. Dendrogram of hierarchical clustering of zooplankton samples with average linkage algorithm. Sample numbers correspond to site numbers in Fig. 1

Table 1. Abundance, biomass and species richness of zooplankton communities of middle river part of the Cheboksary Reservoir

Indicator	Zooplankton community	
	Oka stream	Volga stream
Abundance, individuals / $m^3 \times 1000$	27.94±11.57	14.81±1.41
Biomass, g/m^3	0.30±0.09	1.16±0.27
Species richness	60	91
Rotifera : Cladocera : Copepoda, species number	28 : 25 : 7	43 : 35 : 13

Volga stream community was represented by 91 zooplankton species including 43 Rotifera, 35 Cladocera and 13 Copepoda species. The mean total abundance was two times lower in comparison to the Oka stream (14.81±1.41 ind./$m^3 \times 1000$). However, zooplankton biomass here was thrice more (1.16±0.27 g/m^3) because of the high abundance of large limnetic species. Volga stream community is characterized by the dominance of nauplial stages of Cyclopoida (33.42%) and of large euplanctonic filtering species *Daphnia galeata* (Sars, 1864) (29.99%) (Table 2).

Table 2. The most abundant species of zooplankton communities of the middle river part of the Cheboksary Reservoir

Oka stream		Volga stream	
species	D_i	species	D_i
Brachionus calyciflorus	**62.52**	**Nauplii Cyclopoida**	**33.42**
Brachionus angularis	**12.51**	***Daphnia galeata***	**29.99**
Nauplii Cyclopoida	7.36	Copepodit Cyclopoida	7.29
Daphnia galeata	5.35	*Ploesoma truncatum*	5.16
Brachionus budapestinensis	3.97	*Daphnia cucullata*	4.14
Ploesoma truncatum	1.23	*Mesocyclops leuckarti*	3.49
Diaphanosoma orghidani	0.99	*Diaphanosoma orghidani*	3.43
Mesocyclops leuckarti	0.57	*Euchlanis dilatata*	3.27
Asplanchna priodonta	0.53	*Moina micrura*	2.27
Daphnia cucullata	0.37	*Brachionus calyciflorus*	1.84

Note. Dominant species are marked with bold. D_i – Kownacki index.

60 zooplankton species were found in Oka stream community including 28 Rotifera species, 25 Cladocera and 7 Copepoda species (Table 1). The mean total abundance was 27.94±11.57 ind./m^3 × 1000. Biomas was as low as 0.30±0.09 g/m^3 due to the high abundance of Rotifera with low individual mass. Euplanctonic filter-feeding species *Brachionus calyciflorus* (Pallas, 1766) (62.52%) and *Brachionus angularis* (Gosse, 1851) (12.51%) were dominants in the Oka stream community (Table 2).

Redundancy analysis was performed to consider the relation of the structure of zooplankton communities to the following environmental factors: water conductivity, pH, turbidity, HCO_3^-, chlorophyll-*a* and -*b*, Na^+ and SO_4^{2-} concentrations (Table 3).

At the first step, separate models for each factor were considered. Statistical analysis has shown that all factors have a significant influence to zooplankton community structure ($p < 0.05$; Table 4). Next, full RDA model was constructed which included all factors as predictors. This model is characterized by exceedingly high correlation between predictors (variance inflation factors VIF > 20 for 5 out of 8 predictors). Therefore, our final analysis is based on parsimonious model which was constructed with a stepwise procedure of forward selection of explanatory variables. Parsimonious model included chlorophyll-*a* and pH as predictors. It significantly explained 35.84% of a total variation of zooplankton community structure ($p < 0.001$).

Table 3. Environmental factors for zooplankton communities of the middle river part of the Cheboksary Reservoir

Factor	Zooplankton community	
	Oka stream	Volga stream
Conductivity, µS	520.33±45.10	347.25±27.51
pH	7.98±0.08	7.73±0.07
HCO_3^-, mg/l	160.69±9.70	123.48±5.71
Chlorophyll-*a*, µg /l	21.86±5.47	10.89±1.70
Chlorophyll-*b*, µg /l	1.70±0.40	1.35±0.20
Na^+, mg/l	12.87±1.56	9.13±0.63
SO_4^{2-}, mg/l	48.38±7.96	27.65±3.14
Turbidity, NTU	5.72±0.80	1.41±0.06

Table 4. Redundancy analysis results for influence of each environmental factor on zooplankton community structure

Factor	Adjusted proportion of explained variance, %	Fisher's *F*	*p*
Chlorophyll-*a*, µg /l	26.93	6.53	< 0.001
Turbidity, NTU	24.98	5.99	< 0.001
HCO_3^-, mg/l	22.81	5.43	< 0.001
Conductivity, µS	21.94	5.22	< 0.001
pH	19.25	4.58	< 0.001
Na^+, mg/l	19.13	4.55	0.005*
SO_4^{2-}, mg/l	18.90	4.50	0.003*
Chlorophyll-*b*, µg /l	10.87	2.83	0.019*

Ordination diagram based on parsimonious RDA model is shown in Fig. 4. Two groups of sites may be distinguished along the first axis which explain 26.39 % ($p < 0.001$) of the total variance. These groups correspond to zooplankton communities delineated on the basis of cluster analysis (Fig. 3, Oka and Volga streams).

Analysis of ordination results shows that rheophilic rotifera of genus *Brachionus* Pallas, 1766 are associated with waters of Oka stream which have high pH and high concentration of chlorophyll-*a*. On the other hand, limnophilous species such as *D. galeata* and *P. truncatum* as well as naupliar and copepodit stages of Cyclopoida are associated with Volga stream (Fig. 3). Sites of the Oka stream close to confluence point are characterized by the highest values of the first ordination axis. The more the distance from the confluence (and the more the number of the site, Fig. 1) the less the value of the first ordination axis. Thus, zooplankton composition of the Oka stream continually approaches zooplankton composition of the Volga stream. This tendency can be explained by the gradual alignment of environmental variables.

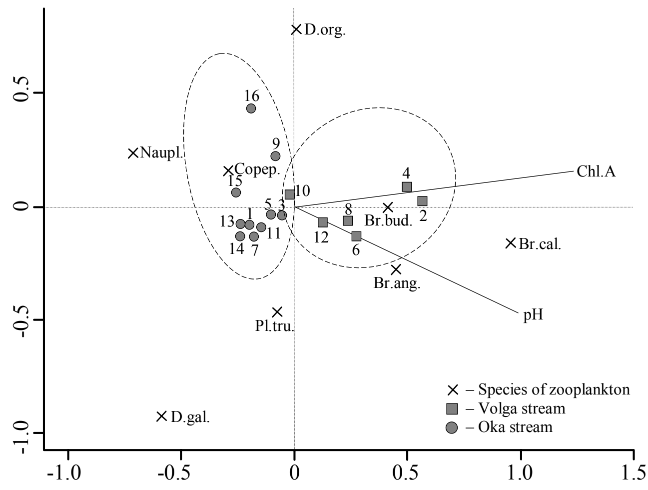

Fig. 3. Ordination of zooplankton sampling sites and the most abundant species in the middle river part of the Cheboksary Reservoir and their relation to environmental factors (Chl.A – chlorophyll-*a*, pH – acidity). Abbreviations for the most abundant species: D.org. – *Diaphanosoma orghidani*; Naupl. – Nauplii Cyclopoida; Copep. – Copepodit Cyclopoida; Pl.tru. – *Ploesoma truncatum*; D.gal. – *Daphnia galeata*; Br.bud. – *Brachionus budapestinensis*; Br.cal. – *Brachionus calyciflorus*; Br.ang. – *Brachionus angularis*

The two streams differed mostly in chlorophyll-*a* concentration. But the difference gradually decreased downstream the middle river part of the Cheboksary Reservoir (Fig. 4). This suggests the homogenization of water masses and, as a result, the disappearance of the difference between the species structure of the zooplankton communities of the Oka and Volga streams downstream the Kremenki village (site number 11–12).

Heterogeneity of other environmental variables (Table 3) also play a role in the formation of two separate zooplankton communities in the middle river part of the Cheboksary Reservoir (Oka and Volga streams). These communities differ in species composition until the point of water mass homogenization (close to Kremenki village).

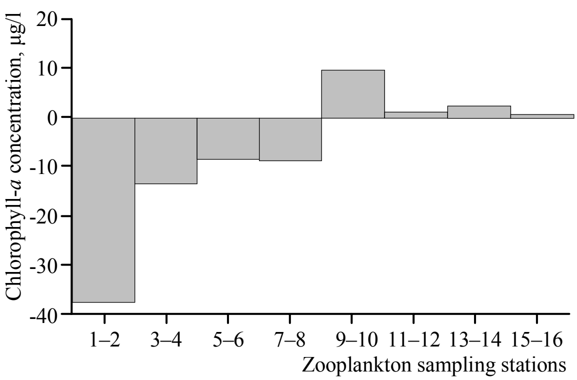

Fig. 4. The difference in the chlorophyll-*a* concentration between the left and right banks in the middle river part of the Cheboksary Reservoir. Site numbers are as in the Fig. 1

DISCUSSION

Chlorophyll-*a* and pH are the main environmental variables driving variability of zooplankton communities species structure in the middle river part of the Cheboksary Reservoir. Chlorophyll-*a* concentration characterizes production processes in water bodies. Maximal zooplankton abundance was found in the sites with maximal chlorophyll-*a* concentration (Oka stream, Tables 1 and 3). Zooplankton species structure of the Oka stream is dominated by rotifers of genus *Brachionus* Pallas, 1766. These rotifers are bacteriophages and herbivores and they cannot feed on particles more than 18 µm in size (Monakov, 1998). It is known that phytoplankton of the mouth part of the Oka River is represented mostly by small-cell cyanobacteria and diatoms (Pautova et al., 2013) which are the optimal food source for rotifers generally and for *Brachionus* Pallas, 1766 species specifically.

Minimal chlorophyll-*a* values were found in the sites of Volga stream where zooplankton abundance was also minimal (tables 1 and 3). Species structure is dominated by large cladoceran species *D. galeata* here which feeds on diatoms and cyanobacteria as well as on organic debris with particle size less than 60 µm. *D. galeata* abundance is negatively related to chlorophyll-*a* (Fig. 4). It can be explained by the fact that most chlorophyll-*a* is generated by cyanobacteria (Okhapkin et al., 2013) which can harm the filtering apparatus of *D. galeata* and cause their death. However, we shall note that cladoceran *D. orghidani* have a remote position on ordination diagram (Fig. 4) relatively to other species. This species is characterized by high resistance to clogging the filtering apparatus by large colonies of cyanobacteria which provides it with competitive advantage in the case of increasing intensity of water «blooming» (Lazareva, Bolotov, 2013). Relation of chlorophyll-*a* and zooplankton abundance is well-known in hydrobiology

(Orsi, Mecum, 1986). The difference in chlorophyll-*a* between Oka and Volga streams reflects mesoscale heterogeneity of the distribution of phytoplankton in the reservoir (Mineeva, Abramova, 2009) which is the main food source and one of the basic factors determining the species structure of zooplankton communities in the middle river part of the Cheboksary Reservoir.

The second significant environmental variable related to zooplankton species structure is pH. Its change is accompanied usually by a change in the structure and functioning of zooplankton communities. The sudden changes in pH can lead to changes in quantitative and qualitative development of species vulnerable to high acidity. These species can fall out of community. Cladoceran species are especially vulnerable to such effects (Sandoy, Nilssen, 1986; Korhola, 1992; Frolova et al., 2013). In our study species of genus *Brachionus* Pallas, 1766 react positively to increase in pH. On the other hand, some cladoceran species (particularly *D. galeata* and *D. orghidani*) are negatively related to pH. Similar effects were found in other studies (Kudrin, 2016; Fetter, Yermolaeva, 2018). We hypothesize that such a reaction of *Brachionus* Pallas, 1766 and some cladocerans to pH is a general regularity deserving further investigation.

CONCLUSION

We applied modern multivariate techniques and showed that in the middle river part of the Cheboksary Reservoir there are two distinct spatially stable zooplankton communities associated to Oka and Volga streams. Zooplankton species structure was influenced by chlorophyll-*a* and pH mostly. Oka stream community was dominated by euplanctonic filter-feeding species *B. calyciflorus* and *B. angularis*, whereas Volga stream community was dominated by naupliar stages of Cyclopoida and by large euplanctonic primary filtrator *D. galeata*.

Boundaries between communities of Oka and Volga streams has been changing during the history of Cheboksary Reservoir from the moment of its construction to present. These changes are studied thoroughly by Shurganova and colleagues (Shurganova, 2007). In the studies performed in the first decade of the XXI century it was shown that Oka stream community occupied the right-bank side of the middle river part of Cheboksary Reservoir reaching the sampling site downstream the Kstovo town (Fig. 1, site 6). At present (2018, this study) boundary between Oka and Volga stream communities moved downstream. Oka stream community reaches the site near Kremenki village (Fig. 1, site 12). Such changes in the boundaries between zooplankton communities may reflect changes in the hydrological regime of the reservoir.

Redundancy analysis of the influence of environmental variables on zooplankton community structure has shown that all variables were significant in single-variable analysis. However, only chlorophyll-*a* and pH were included in the parsimonious model due to high correlation among environmental variables. This model explained 35.84 % ($p < 0.001$) of variation in zooplankton species structure. The difference in chlorophyll-*a* concentration between Oka and Volga streams reflect mesoscale heterogeneity of phytoplankton distribution and, consequently, the basic difference in food sources for zooplankton communities associated to the streams. The influence of pH as environmental factor was less evident. However, this variable is well known as one of the leading factors determining the structure of zooplankton communities (Sandoy, Nilssen, 1986; Nilssen, Sandoy, 1990; Korhola, 1992; Frolova et al., 2013; Fetter, Yermolaeva, 2018). Its role in zooplankton community assembly of lowland reservoirs deserves further investigation.

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REFERENCES

Bakanov A. I. *Kolichestvennaya ocenka dominirovaniya v ekologicheskih soobshchestvah* [Quantitative assessment of dominance in ecological communities]. Borok, VINITI, 1987. 64 p. (in Russian).

Belozerova E. V., Chalov S. R. Opredelenie mutnosti rechnyh vod opticheskimi metodami [Assessment of river water turbidity using the optic methods]. *Moscow University Bulletin, Ser. 5, Geography*, 2013, iss. 6, pp. 39–45 (in Russian).

Bolotov S. E., Krylov A. V., Tsvetkov A. I., Sokolova E. A., Poddubnyi S. A. Water masses and zooplankton in a tributary of the Rybinsk Reservoir in its backwater zone. *Biology Bulletin*, 2013, vol. 40, iss. 10, pp. 809–814. DOI: 10.1134/S1062359013100026

Dai L., Gong Y., Li X., Feng W., Yu Y. Influence of environmental factors on zooplankton assemblages in Bosten Lake, a large oligosaline lake in arid northwestern China. *ScienceAsia*, 2014, vol. 40, pp. 1–10. DOI: 10.2306/scienceasia1513-1874.2014.40.001

Fetter G. V., Ermolaeva N. I. The influence of abiotic factors on zooplankton structure in small lakes in south of west Siberia. *Bulletin AB RGS*, 2018, vol. 49, iss. 2, pp. 95–103 (in Russian).

Frolova L. A., Nazarova L. B., Pestryakova L. A., Herzschuh U. Analysis of the effects of climate-dependent factors on the formation of zooplankton communities that inhabit arctic lakes in the Anabar River Basin. *Contemporary Problems of Ecology*, 2013, vol. 6, iss. 1, pp. 1–11. DOI: 10.1134/S199542551301006X

GOST 17.1.4.02-90. Voda. Metodika spektrofotometricheskogo opredeleniya hlorofilla-a [Water. Spectrophotometric determination of chlorophyll-*a*]. Moscow, 1991 (in Russian).

GOST 31957-2012. Metody opredeleniya shchelochnosti i massovoj koncentracii karbonatov i gidrokarbonatov [Water. Methods for determination of alkalinity and mass concentration of carbonates and hydrocarbonates]. Moscow, 2014 (in Russian).

Grayson R. B., Finlayson B. L., Gippel C. J., Hart B. T. The potential of field turbidity measurements for the computation of total phosphorus and suspended solids loads. *J. of Environmental Management*, 1996, vol. 47, iss. 3, pp. 257–267. DOI: 10.1006/jema.1996.0051

Hayrapetyan A. H., Bolotov S. E., Gevorgyan G. A., Gabrielyan B. K. Investigation of different environmental factors role in the formation of zooplankton community in the Arpa River (Armenia) and its main tributaries. *Proceedings of Yerevan State University*, 2016, iss. 3, pp. 53–59.

Joniak T., Kuczynska-Kippen N. Habitat features and zooplankton community structure of oxbows in the limnophase: reference to transitional phase between flooding and stabilization. *Limnetica*, 2016, vol. 35, iss. 1, pp. 37–48. DOI: 10.23818/limn.35.03

Key to Zooplankton and Zoobenthos in Freshwater in European Russia. Moscow, KMK Scientific Press Ltd., 2010. 495 p. (in Russian).

Kiselev I. A. *Plankton morej i kontinental'nyh vodoemov* [Plankton of the seas and continental waters]. Leningrad, Nauka Publ., 1969. 658 p. (in Russian).

Korhola A. The early holocene hydrosere in a small acid hill-top basin studied using crustacean sedimentary remains. *J. of Paleolimnology*, 1992, vol. 7, iss. 1, pp. 1–22. DOI: 10.1007/BF00197028

Korneva L. G. *Fitoplankton vodohranilishch bassejna Volgi* [Phytoplankton reservoirs of the Volga basin]. Kostroma, Kostroma Printing House, 2015. 284 p. (in Russian).

Korovchinsky N. M. Cladocera: Ctenopoda. Families Sididae, Hopopedidae & Pseudopenilidae (Brachiopoda: Cladocera). *Identification Guides to the plankton and benthos of Inland water*. Weikersheim, Margraf Publishers GmbH, 2018. 204 p.

Korovchinsky N. M. *Coniferous Crustaceans of the order Ctenopoda of the World Fauna* (*Morphology, Systematics, Ecology, Zoogeography*). Moscow, KMK Scientific Press Ltd., 2004. 410 p. (in Russian).

Kudrin I. A. *Vidovaya struktura i prostranstvennoe raspredelenie soobshchestv zooplanktona v usloviyah antropogennogo vozdejstviya* (*na primere Cheboksarskogo vodohranilishcha i ego pritokov*) [The species structure and spatial distribution of zooplankton communities in the conditions of anthropogenic impact (on the example of the Cheboksary reservoir and its tributaries)]: Thesis Diss. Cand. Sci. (Biol.). Nizhny Novgorod, 2016. 25 p. (in Russian).

Kutikova L. A. *Kolovratki fauny SSSR* [Rotifers of the USSR fauna]. Leningrad, Nauka Publ., 1970. 744 p. (in Russian).

Kuznetsova M. A., Shurganova G. V., Chernikov A. A. Analysis of the transformation process of zooplanktocenoses with flow regulation with the help of indicators of species diversity. *Ekologiia*, 1991, iss. 4, pp. 68–72 (in Russian).

Lazareva V. I., Bolotov S. E. Analysis of coexistence of the recent invader Diaphanosoma orghidani Negrea with the aboriginal species D. brachyurum (Lievin) (Crustacea, Cladocera) in the Rybinsk reservoir. *Russian J. of Biological Invasion*, 2013, vol. 4, iss. 3, pp. 161–173. DOI: 10.1134/S2075111713030077

Lazareva V. I., Sokolova E. A. Metazooplankton of the plain reservoir during climate warming: Biomass and production. *Inland Water Biology*, 2015, vol. 8, iss 3, pp. 30–38. DOI: 10.1134/S1995082915030098

Legendre P., Legendre L. *Numerical ecology*. Oxford, Elsevier, 2012. 990 p.

Leibold M. A., Chase J. M., Shurin J. B., Downing A. L. Species Turnover and the Regulation of Trophic Structure. *Annual Review of Ecology and Systematics*, 1997, vol. 28, pp. 467–494. DOI: 10.1146/annurev.ecolsys.28.1.467

Leitao A. C., Freire R. H. F., Rocha O., Santaella S. T. Zooplankton community composition and abundance of two Brazilian semiarid reservoirs. *Acta Limnologica Brasiliensia*, 2006, vol. 18, iss. 4, pp. 451–468.

Metodicheskie rekomendacii po sboru i obrabotke materialov pri gidrobiologicheskih issledovaniyah na presnovodnyh vodoemah. Zooplankton i ego produkciya [Methodical recommendations on the collection and processing of materials in hydrobiological studies on freshwater bodies of water. Zooplankton and its products]. Leningrad, GosNIORCH, 1982. 33 p. (in Russian).

Mineeva N. M., Abramova N. N. Phytoplankton pigments as ecological state indices of the Cheboksary Reservoir. *Water Resources*, 2009, vol. 36, iss. 5, pp. 560–567. DOI: 10.1134/S009780780905008X

Monakov A. V. *Pitanie presnovodnyh bespozvonochnyh* [Eating freshwater invertebrates]. Moscow, IPEE RAS, 1998. 322 p. (in Russian).

Nilssen J. P., Sandoy S. Recent lake acidification and cladoceran dynamics: surface sediment and core analyses from lake in Norway, Scotland and Sweden. *Philosophical Transactions of the Royal Society of London*, *Ser. B. Biological Sciences*, 1990, vol. 327, iss. 1240, pp. 299–309. DOI: 10.1098/rstb.1990.0066

Okhapkin A. G., Sharagina E. M., Bondarev O. O. Phytoplankton of the Cheboksary Reservoir at the present state of its existence. *Povolzhskiy J. of Ecology*, 2013, no. 2, pp. 190–199 (in Russian).

Orsi J. J., Mecum W. L. Zooplankton Distribution and Abundance in the Sacramento-San Joaquin Delta in Relation to Certain Environmental Factors. *Estuaries*, 1986, vol. 9, iss. 4, pp. 326–339. DOI: 10.2307/1351412

Pautova V. N., Okhapkin A. G., Gorokhova O. G., Genkal S. I., Nomokonova V. I. Composition and dynamics of the abundance of common phytoplankton species of the lower reaches of the Oka River at the end of the XX century. *Izvestia RAS SamSC*, 2013, vol. 15, iss. 3, pp. 177–184 (in Russian).

Presnova E. V., Khulapova A. V. Structure and distribution of zooplankton in the central discript of Votkinsk reservoir. *Bulletin of Perm University, Biology*, 2015, iss. 4, pp. 366–370 (in Russian).

R Core Team. R: A language and environment for statistical computing, 2015. Available at: http://www.R–project.org (accessed 12 December 2018).

Sandoy S., Nilssen J. P. A geographical survey of littoral crustacean in Norway and their use in paleolimnology. *Hydrobiologia*, 1986, vol. 143, iss. 1, pp. 277–286. DOI: 10.1007/BF00026671

Shitikov V. K., Rozenberg G. S. *Randomizaciya i butstrep: statisticheskij analiz v biologii i ekologii s ispol'zovaniem R* [Randomization and bootstrap: statistical analysis in biology and ecology using R]. Togliatti, Cassandra, 2013. 314 p. (in Russian).

Shurganova G. V. *Dinamika vidovoj struktury zooplanktocenozov v processe ih formirovaniya i razvitiya* (*na primere vodohranilishch Srednej Volgi: Gor'kovskogo i Cheboksarskogo*) [The dynamics of the species structure of zooplankton cenoses in the process of their formation and development (on the example of the Middle Volga reservoirs: Gorky and Cheboksary)]. Thesis Diss. Dr. Sci. (Biol.). Nizhny Novgorod, 2007. 49 p. (in Russian).

Shurganova G. V., Cherepennikov V. V. Dynamic of specific structure of the zooplankton-coenoses in the Middle Volga water reservoirs area while generation and development. *J. of Siberian Federal University*, *Biology*, 2010, vol. 3, iss. 3, pp. 267–277 (in Russian). DOI: 0.17516/1997-1389-0199

Shurganova G. V., Cherepennikov V. V., Kudrin I. A., Il'in M. Yu. Characteristics of the current state of the species structure and spatial distribution of the zooplankton communities of the Cheboksary Reservoir. *Povolzhskiy J. of Ecology*, 2014, no. 3, pp. 417–421 (in Russian).

Shurganova G. V., Cherpennikov V. V., Artelny E. V. Dynamics of the spatial distribution of the main zooplankton cenoses of the Cheboksary Reservoir. *Povolzhskiy J. of Ecology*, 2003, no. 3, pp. 297–304 (in Russian).

Shurganova G. V., Kudrin I. A., Yakimov V. N., Gavrilko D. E., Zhikharev V. S., Zolotareva T. V. Spatial distribution of zooplankton on the upper part of the Cheboksary Reservoir. *Inland Water Biology*, 2018, vol. 11, iss. 3, pp. 317–325. DOI: 10.1134/S1995082918030185

Simões N. R., Nunes A. H., Dias J. D., Lansac-Tôha F. A., Velho L. F. M., Bonecker C. C. Impact of reservoirs on zooplankton diversity and implications for the conservation of natural aquatic environments. *Hydrobiologia*, 2015, vol. 758, iss. 1, pp. 3–17. DOI: 10.1007/s10750-015-2260-y

Sokolova E. A. Modern state of zooplankton of the Rybinsk Reservoir. *Hydrobiological J.*, 2012, vol. 48, iss. 6, pp. 43–50. DOI: 10.1615/HydrobJ.v48.i6.40

Yakimov B. N., Shurganova G. V., Cherepennikov V. V., Kudrin I. A., Il'in Mu. Y. Methods for comparative assessment of the results of cluster analysis of hydrobiocenoses structure (by the example of zooplankton communities of the Linda River, Nizhny Novgorod region). *Inland Water Biology*, 2016, vol. 9, iss. 2, pp. 200–208. DOI: 10.1134/S1995082916020164

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СООБЩЕСТВА ЗООПЛАНКТОНА СРЕДНЕЙ РЕЧНОЙ ЧАСТИ ЧЕБОКСАРСКОГО ВОДОХРАНИЛИЩА И ФАКТОРЫ, ВЛИЯЮЩИЕ НА ФОРМИРОВАНИЕ ИХ ВИДОВОЙ СТРУКТУРЫ

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Shurganova G. V., Zhikharev V. S., Gavrilko D. E., Kudrin I. A., Zolotareva T. V., Yakimov B. N., Erina O. N., Tereshina M. A. Zooplankton Communities of the Middle River Part of the Cheboksary Reservoir and Factors Influencing Their Species Structure [*Шурганова Г. В., Жихарев В. С., Гаврилко Д. Е., Кудрин И. А., Золотарева Т. В., Якимов В. Н., Ерина О. Н., Терешина М. А.* Сообщества зоопланктона средней речной части Чебоксарского водохранилища и факторы, влияющие на формирование их видовой структуры] // Поволжский экологический журнал. 2019. № 3. С. 384 – 395. DOI: https: https://doi.org/10.35885/1684-7318-2019-3-384-395

В работе использованы современные методические подходы к анализу пространственного распределения сообществ зоопланктона (на примере средней речной части Чебоксарского водохранилища). Сообщества зоопланктона были исследованы в период летней межени 2018 г. в средней речной части Чебоксарского водохранилища (от г. Нижний Новгород до пос. Васильсурск). Границы сообществ зоопланктона Чебоксарского водохранилища закономерно менялись с момента его строительства и до наших дней. В средней речной части Чебоксарского водохранилища выявлено два четко выраженных пространственно устойчивых сообществ зоопланктона, связанных с окским и волжским потоками. Различие между этими зоопланктоценозами было продемонстрировано с помощью иерархического кластерного анализа. Анализ избыточности показал, что основными факторами, определяющими изменчивость видовой структуры зоопланктона, являются содержание хлорофилла-*a* и водородный показатель (pH). При этом концентрация хлорофилла-*a* отражает мезомасштабную неоднородность горизонтального распределения фитопланктона на исследованной акватории, а следовательно, и кормовой базы организмов зоопланктона. Отношение зоопланктона к уровню pH отражает высокую чувствительность видов рода *Brachionus* Pallas, 1766 к высокой кислотности. Влияние pH как фактора окружающей среды было менее очевидным. Однако эта переменная хорошо известна как один из ведущих факторов, определяющих структуру сообществ зоопланктона. Его роль в структурной организации сообществ зоопланктона равнинных водохранилищ заслуживает дальнейшего изучения.

Ключевые слова*:* сообщество зоопланктона, видовая структура, пространственное распределение, анализ избыточности, Чебоксарское водохранилище, Нижегородская область.

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