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*ZONING OF ZOOPLANKTON IN THE FRESHWATER LAKES OF WEST SIBERIA (THE CASE OF THE TYUMEN REGION)**

SUMMARY. This paper presents the data on the composition and taxonomic structure of zooplankton, its quantitative development (abundance, biomass) in the freshwater non-floodplain lakes in different geographical zones within the Tyumen region (the arctic tundra zone, the northern taiga zone, the middle taiga zone, the southern taiga zone, the middle forest-steppe zone). Distinctive and rare species are registered on the investigated territory. The indices of species diversity and fauna similarity of the communities are calculated. The structure-forming complexes of zooplankton in the lakes of different zones and the change of the dominant species in each taxonomic group along the climatic gradient are revealed. It is noticed that the average number of zooplankton tends to increase from north to south. To assess the main factors influencing the development and zoning of the plankton communities, a multifactor analysis is conducted. 12 biological indices, 15 hydrochemical indices and 11 indices of heavy metals are analysed. As a result of the factor analysis, main groups of the intercommunicated indices are identified when r≥0.7.

KEY WORDS. Zooplankton, taxon, abundance, biomass, multifactor analysis.

The allocations of geographical area of species, as well as the identification of conditions forming their community and environmental stability, are the central problems of modern ecology. The laws of geography play an important role in the zoning of freshwater fauna. Each zone is characterized by its own ground features, geologic basement, soil type, vegetation, wildlife, climate; they together form hydrobiological regimes of water bodies. Such regimes vary in the longitudinal and latitudinal directions [1], [2], [3], [4]. Moreover, scientific literature increasingly discusses the issue of future climate changes caused by the greenhouse effect. Change in temperature is slow, that makes the southern species migrate to higher latitudes and changes the structure of biocenoses [5], [6], [7].

Zooplankton is an important part of a lake ecosystem, as it plays a significant role in the maintenance of its homeostasis. The changes taking place in the community are directly reflected in all subsequent trophic links of aquatic ecosystems. The research conducted by M.B. Ivanova demonstrates that zooplankton is highly important for lakes, since about 80% of the energy assimilated by all aquatic animals accounts for it. [8] In addition, zooplankton being a biocenotic system is widely

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used to diagnose the state of lake ecosystems in the service of monitoring and ecological forecasting [9], [10].

The purpose of the research is to determine the zonal features of the zooplankton distribution in the lakes along the climatic gradient (from tundra to forest steppe). The following was analyzed: 1) the species composition and species occurrence; 2) the dominant species of zooplankton; 3) the abundance and biomass of zooplankton. To assess the zonal features of zooplankton distribution, a multifactor analysis was used; the way the structural indicators of the communities depend on the major ions of water and heavy metals was revealed.

A total of 9 freshwater lakes were studied. The samples of zooplankton were collected in July and August, 2011. Sampling and processing of the material was performed by standard methods of hydrobiology [11], [12]. A total of 48 plankton samples were collected and processed. The observed species were assessed in terms of modern taxonomy [13], [14], [15]. Along with the sampling of zooplankton, the water for hydrochemical and heavy metal content analysis was sampled.

As a part of the zooplankton community in the examined lakes, 59 species of invertebrates were registered. They belong to the three major taxonomic groups (Table 1). There were detected 19 species of rotifers *(Rotatoria)*, 26 species of cladocerans *(Cladocera)*, 14 species of copepoda *(Copepoda)*.

Table 1

The species composition and occurrence of zooplankton (P, %)

Zones	I		II		III			IV	V	P, %
Taxa	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Rotatoria										
Asplanchna priodonta Gosse	+			+	+	+	+	+	+	50.00
Brachionus angularis Gosse							+	+	+	18.75
Brachionus diversicornis (Daday)									+	3.13
Bipalpus hudsoni (Imhof)									+	3.13
Conochilus hippocrepis (Schrank)			+	+		+				6.25
Conochilus unicornis Rousselet			+		+	+	+			21.88
Euchlanis triquetra Ehrenberg			+						+	6.25
Keratella mixta (Oparina-Char)					+					9.38
Keratella quadrata (O.F.Muller)	+	+	+					+	+	37.50
Keratella cochlearis Gosse	+	+				+	+	+	+	50.00
Kellicottia longispina Kellicott	+	+	+		+	+	+	+	+	78.13
Lecane luna (O.F.Muller)			+						+	6.25
Polyarthra euryptera Wierzejski	+					+				9.38
Polyarthra major Burckhardt					+				+	12.50
Polyarthra vulgaris Carlin			+							3.13
Polyarthra dolichoptera Idelson	+									6.25
Trichocerca (D.)similis (Wierzejski)			+			+	+	+	+	14.35
Synchaeta stylata (Wierzejski)	+	+	+						+	18.75
Filinia terminalis (Plate)	+	+			+		+			18.75
Cladocera										
Alona rectangula Sars 1862									+	3.13

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Alona quadrangularis (O.F.Muller)				+						3.13
Alonella nana (Baird)			+	+						9.38
Alonopsis elongatus (Sars)			+	+						12.50
Acroperus harpae (Baird)			+							3.13
Anchistropus emarginatus Sars.								+		3.13
Bosmina (E) longispina Leydig			+	+	+			+	+	37.50
Bosmina longirostris (O.F.Muller)	+		+	+		+				31.25
Bythotrephes longimanus Leydig						+	+	+		21.88
Biapertura affinis (Leydig)			+	+				+		18.75
Chydorus gibbus Lilljeborg			+	+		+				12.50
Chydorus sphaericus (O.F.Muller)				+	+			+	+	53.13
Ceriodaphnia quadrangula (O.F.Muller)					+					9.38
Camptocercus rectirostris (Schedler)								+		3.13
D. (Daphnia) longiremis Sars	+		+							18.75
Daphnia longispina O.F.Muller			+		+	+	+		+	37.50
Diaphanosoma brachyurum (Lievin)					+				+	21.88
D.(Daphnia) cristata Sars					+	+		+		25.00
Daphnia galeata Sars				+				+		15.63
Eurycercus lamellatus (O.F.Muller)								+		6.25
Eurycercus glacialis (Lilljeborg)			+							3.13
Holopedium gibberum Laddach			+							15.63
Leptodora kindtii (Focke)					+	+		+	+	21.88
Lymnosida frontosa Sars						+				9.38
Pleuroxus trigonellus (O.F.Muller)							+			3.13
Rhynchotalona falcata (Sars)			+	+						0.93
Copepoda										
Acanthocyclops sp.								+		6.25
Cyclops scutifer Sars	+									12.50
Cyclops strenuus Fischer	+	+		+						6.25
Macrocyclops albidus (Jurine)								+		3.13
Mesocyclops leuckarti Claus					+	+	+	+	+	46.88
Microcyclops sp	+									3.13
Diacyclops limnobius Kiefer									+	9.38
Termocyclops crassus (Fischer)			+							3.13
Arctodiaptomus(Rh.) acutilobatus (Sars)							+			3.13
Eudiaptomus graciloides (Lilljeborg)	+		+							15.63
Eudiaptomus gracilis (Sars)		+	+	+	+	+		+		68.75
Eurytemora gracilis (Sars)	+									9.38
Heterocope appendiculata Sars			+							18.75
Heterocope borealis (Fischer)							+			3.13

Note: I — arctic tundra, II — northern taiga, III — middle taiga, IV — southern taiga, V — middle forest-steppe.

Lakes: 1 — Goltsovoye, 2 — Langatibeyto, 3 — Halyato, 4 — Pyagunto, 5 — Tomtalyahtur, 6 — Rangetur, 7 — Lohtotkurt, 8 — Dolgiy sor, 9 — Ugryumovo

The observed species are typical of the lakes in West Siberia; most of them are found in the basin of the middle and low Ob River [16], [17], [18]. These species also inhabit different zones of European Russia: tundra, taiga, mixed forests, and forest-steppe [1], [2]. The comparative analysis of the data shows that the greatest number of species inhabits the northern and middle taiga zones (30 and 26 species, respectively) and the lowest number of species (16) is registered in arctic tundra (Fig. 1). The basis of the species diversity of zooplankton in tundra is made up by *Rotatoria* and *Copepoda* with rotifers being dominant (50%). In the taiga zone, the major are *Rotatoria* and *Cladocera* with a dominance of cladocerans (56%), and in the middle forest-steppe zone, *Rotatoria* represent the largest group (60%).

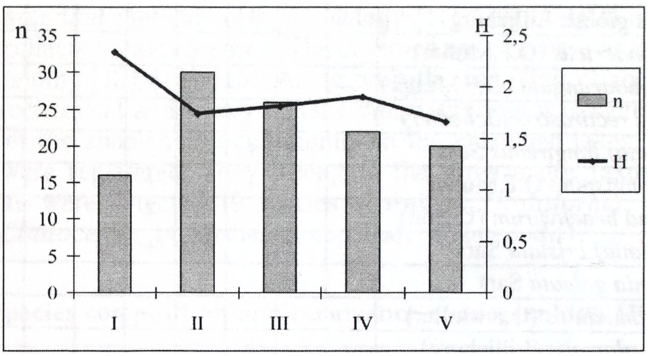

Fig. 1. The zonal change in the abundance of zooplankton species (n) and the Shannon index (H): I — arctic tundra, II — northern taiga III — middle taiga, IV — southern taiga, V — middle forest-steppe

To assess the diversity of the zooplankton communities and its changes along the climatic gradient, the Shannon information index (H) on abundance was used. This index includes two components — species richness and evenness among species. The zonal change in the index of species diversity is presented in Fig. 1. In general, the index decreases from north to south, but there is no clear linear tendency observed. Thus, despite the greater number of invertebrate species in northern taiga, the greatest Shannon indices are marked not in this zone, but in arctic tundra. This is explained by the fact that there is a strong dominance of certain zooplankton species, and this, in turn, leads to a low evenness between the species of the community. The zooplankton in tundra, on the contrary, is characterized by the lowest level of dominance and high evenness (Table 2).

Table 2

Assessment of zooplankton species diversity

Indices	I zone	II zone	III zone	IV zone	V zone
the Species Richness Index (R)	3.38	5.42	4.57	3.68	3.35
the Simpson Dominance Index (C)	0.12	0.30	0.25	0.19	0.26
the Pielou Evenness Index (E)	0.84	0.50	0.53	0.61	0.55

An important feature of a community is species occurrence (P, %), which points to the similarity or difference of habitat conditions, as well as a broad ecological valence of organisms. While processing the material, no species having a 100 per cent occurrence was registered (Table 1). However, in most of the surveyed lakes, eurybiontic species being cosmopolitan and abundant (P ≥ 50%) were found: *Asplanchna priodonta, Keratella cochlearis, Kellicottia longispina, Chydorus sphaericus,* as well as *Eudiaptomus gracilis,* typical of the northern zone and temperate latitudes, and *Mesocyclops leuckarti* typical of more southern latitudes. Slightly lower occurrence (P = 30-40%) was demonstrated by *Keratella quadrata, Bosmina (E.) longispina, Bosmina longirostris, Daphnia longispina.* The following species inhabiting the water bodies can be characterized as inconsiderable in number or single: *Eurycercus glacialis, Alonopsis elongatus, D.(Daphnia) cristata, Alonella nana, Chydorus gibbus.* Among the species growing in large numbers, but only appearing in one of the water bodies examined, *Lymnosida frontosa* and *Arctodiaptomus (Rh.) acutilobatus* should be noted. These species are more restrictedly adapted to the specific environmental conditions, although their geographic distribution is large, they are dominant only in the water bodies with a certain type of hydrobiological regime.

In the analysis of the material, we registered the species that were found in the lakes only of one zone. They are basically the species with limited geographical and biotope range. Thus, in arctic tundra the following species were registered: *Polyarthra dolichoptera, Eurytemora gracilis, Cyclops scutifer*; in northern taiga — *Euchlanis triquetra, Rhynchotalona falcata, Eurycercus glacialis, Holopedium gibberum, Heterocope appendiculata*; in middle taiga — *Keratella mixta, Lymnosida frontosa, Heterocope borealis*; in southern taiga — *Camptocercus rectirostris, Anchistropus emarginatus, Eurycercus lamellatus, Macrocyclops albidus*; in middle forest-steppe — *Brachionus diversicornis, Bipalpus hudsoni, Alona rectangula, Diacyclops limnobius.*

The structure-forming complex of zooplankton in the surveyed water bodies mainly consists of a small number of species (4-5), including the representatives of three taxonomic groups (Table 3). The dominant species of arctic tundra and northern taiga are included into the northern complex (to the north 60° N) and cold-water complex of zooplankton in temperate latitudes (50-60° N.); and they are typical of the water bodies of European Russia. The dominant species of middle and southern taiga are included into both the cold-water and warm-water zooplankton complexes of temperate latitudes. The dominants of middle forest-steppe refer to the warm-water complex of temperate latitudes. Analyzing the table, it can be noted that each zone is mainly inhabited by its own structure-forming species of *Cladocera.* In contrast, in groups of *Rotatoria* and *Copepoda,* the species typical not only of one zone, but also for the neighboring predominate. Thus, in the lakes of arctic tundra and northern taiga, a major role belongs to *Eudiaptomus gratsiloides* among *Copepoda,* but from north to south the importance of this species in the formation of the communities gradually decreases. It ceases to be dominant, although it is found within the zooplankton further to the south. It is replaced by *E. gracilis,* which, as a structure-forming species, plays the most important role in the lakes of middle taiga. In the lakes of the middle and southern taiga zones or middle forest-steppe, the dominant species is *Mesocyclops leuckarti.* It belongs to eurytopic species with a wide geographical range, but it is more thermophilic and can dominate in the water bodies with various types of hydrobiological regime. Among rotifers, contiguous species include *Kellicottia longispina* and *Keratella cochlearis.* In general, each geographical zone is characterised by its own structure-forming complex of zooplankton that displays the features of the aquatic organisms habitat.

Table 3

The change of the dominant species in taxonomic groups of zooplankton

Arctic zone	Northern taiga	Middle taiga	Southern taiga	Middle forest-steppe
		Rotatoria		
Asplanchna priodonta, Kellicottia longispina	*Kellicottia longispina*	*Keratella cochlearis*	*Keratella cochlearis*	*Keratella quadrata, Trichocerca (D.)similis*
		Cladocera		
D.(Daphnia) longiremis	*Bosmina longirostris, Holopedium gibberum*	*Diaphanosoma brachyurum, Daphnia longispina*	Daphnia galeata, Bosmina (E.) longispina	*Chydorus sphaericus*
		Copepoda		
Eudiaptomus graciloides, Eurytemora gracilis	*Eudiaptomus graciloides, Heterocope appendiculata*	Eudiaptomus gracilis, Mesocyclops leuckarti	Mesocyclops leuckarti	- *Mesocyclops leuckarti, Diacyclops limnobius*

The faunal similarity of the zooplankton in the lakes of different geographical zones is low, which is proved by the calculated Sørensen similarity index [12]. The obtained indices range from 0.21 to 0.52 with an average of 0.36. The lowest indices are registered for the communities of arctic tundra and southern taiga. The highest rates are found among the communities of the middle and southern taiga zones, and of middle taiga and middle forest-steppe. The greater similarity in the zooplankton of these zones is provided by the common dispersed species of *Rotatoria* and *Cladocera.*

It is known that the population density is regulated by a complex interaction of environmental factors, as well as endogenous mechanisms and population rhythms of species; therefore, it is an important indicator of a community. The spacing of the density along the climatic gradient, in its turn, reveals the redistribution of matter and energy contained in the biocenosis. Fig. 2 demonstrates the average amount of the zooplankton and certain taxonomic groups in each zone. The maximum indices are registered in the lakes of southern taiga and middle forest-steppe, the minimum ones — in arctic tundra. In general, there is a quite clear tendency for the zooplankton abundance to increase from north to south. A similar tendency was noted in the works of M.L. Pidgayko for the water bodies of different edaphic-climatic zones [1-2]. The part of the taxonomic groups in total number of the community is different in each region. The increase is mostly due to the representatives of *Rotatoria* and *Cladocera.*

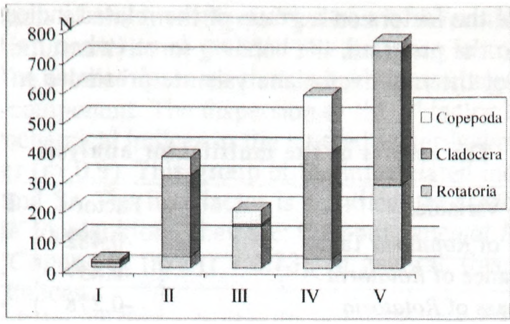

Fig. 2. The part of the taxonomic groups in total abundance of the zooplankton (N, thous. sp./m^3) in the lakes of different zones: I — arctic tundra, II — northern taiga, III — middle taiga, IV — southern taiga, V — middle forest-steppe

Fig. 3 presents the average of the zooplankton biomass and taxonomic groups comprising it. The maximum indices of the community are observed in the lakes of northern and southern taiga, which stand out against the background of other geographical zones. This occurs due to the fact that most of major zooplankton species with high individual mass are found in the lakes of these zones. These include the representatives of *Cladocera* and *Copepoda: D. (Daphnia) longiremis, D. longispina, D. galeata, Holopedium gibberum, Eudiaptomus graciloides, E. gracilis Heterocope appendiculata.* In this regard, a clear pattern in the distribution of the zooplankton biomass from north to south compared to the abundance is not revealed.

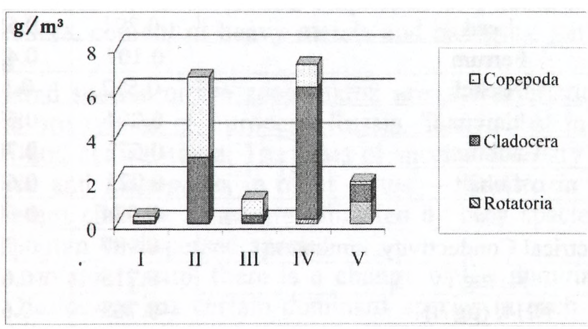

Fig. 3. The part of the taxonomic groups in the total biomass of the zooplankton (g/m^3) in the lakes of different zones: I — arctic tundra, II — northern taiga, III — middle taiga, IV — southern taiga, V — middle forest-steppe

To assess the major factors affecting the development and zonal distribution of the plankton communities in the lakes, we analyzed 12 biological parameters (the number of taxa and quantitative development of taxonomic groups, and the number of taxa, abundance and biomass of all zooplankton), 15 indices (pH, SEC, Ca^{2+}, Mg^{2+} Na^{+}, K^{+}, Si^{2+}, NH_4^{+} NO_3^{-} NO_2^{-} SO_4^{2-} CL^{-}, PO_4^{3-} P_{tot}, HCO_3^{-}) and 11 indices of heavy metals (Cu, Cr, Mn, Sr, Zn, Pb, Fe, Ni, Co, Al, Hg). Due to the study of a large number of the parameters, interrelations between them are extremely complicated. On the basis of these data, a multifactor analysis by the means of the STATISTICA software (Statsoft, USA) [19-20] was conducted. This allowed distinguishing the most important influence of the factors on a group of the related indices. When examining the data, according to the program, the bonding force (when r ≥ 0.7) was taken into account. The results of the multifactor analysis are presented in Table 4.

Table 4

The results of the multifactor analysis

Variables	Factor 1	Factor 2	Factor 3
Number of *Rotatoria* Taxa	-0.482	0.442	**0.700**
Abundance of *Rotatoria*	**-0.837**	-0.017	0.396
Biomass of *Rotatoria*	-0.278	**-0.934**	-0.174
Number of *Cladocera* Taxa	0.596	-0.426	0.700
Abundance of *Cladocera*	0.085	**-0.885**	0.186
Biomass of *Cladocera*	0.321	**-0.907**	-0.193
Number of *Copepoda* Taxa	**0.732**	0.455	-0.381
Abundance of *Copepoda*	0.335	**-0.929**	-0.153
Biomass of *Copepoda*	0.615	-0.071	0.658
Number of Zooplankton Taxa	0.575	0.029	**0.814**
Abundance of Zooplankton	-0.256	**-0.920**	0.278
Biomass of Zooplankton	0.467	**-0.832**	0.029
Cuprum	-0.482	**-0.700**	-0.356
Chrome	0.154	-0.181	-0.955
Manganese	0.265	**-0.911**	-0.275
Zinc	**-0.947**	-0.169	0.020
Strontium	**-0.964**	-0.072	0.251
Lead	-0.291	0.559	-0.638
Ferrum	0.107	0.422	-0.855
Nickel	-0.512	-0.147	**-0.844**
Aluminum	0.004	0.625	**-0.722**
Cadmium	0.572	**0.700**	0.016
Cobalt	0.023	0.625	**-0.715**
pH	**-0.934**	0.092	-0.110
Specific Electrical Conductivity, mmho/cm	**-0.987**	0.074	0.074
Si, mg/l	**-0.715**	-0.675	-0.173
NH4, (µg /l)	**-0.763**	-0.615	-0.218
Ca, (mg/l)	**-0.988**	-0.106	0.064
Mg, (mg/l)	**-0.980**	-0.032	0.181
Na, (mg/l)	**-0.982**	0.124	0.057
K, (mg/l)	**-0.981**	0.015	0.181
SO_4, (mg/l)	**-0.984**	0.131	0.020
NO_3, (µg /l)	-0.068	**-0.869**	-0.335
Cl, (mg/l)	**-0.970**	0.178	0.022
PO_4, (µg /l)	0.238	**-0.921**	-0.290
F, (µg /l)	**-0.869**	0.407	0.229
NO_2, (µg /l)	0.477	0.121	**0.714**
HCO_3, (µg /l)	**-0.983**	-0.004	0.163
Total Dispersion	17.62	11.36	7.62
% of Total Dispersion	45.18	29.43	19.53

The main variation of the investigated indices is determined by three factors that have the total informativity of 93.8%. The first two factors determine 74.3% of the variation in the studied features that indicates a stronger bond between the indices within each component. The dispersion of the 1st factor largely describes the amount of the hydrochemical indices in the studied water bodies that have a strong bond with each other ($r > 0.9$). This group of the interrelated indices includes heavy metals such as Zn and Sr. The first factor is significantly associated with only two characteristics of the zooplankton. They are: the abundance of *Rotatoria* ($r = -0.84$) and the number of *Copepoda* taxa ($r = 0.73$). In general, this factor influences 16 of the 38 common indices.

The dispersion of the 2nd factor is significantly associated with 6 indices of the zooplankton, which are mainly characterized by the quantitative development of taxonomic groups of the zooplankton in total, except for the number of *Rotatoria* and biomass of *Copepoda*. This group of the interrelated indices includes heavy metals, Cu, Cd and Mn. The strongest bond registered is that with manganese ($r = -0.91$). Among the hydrochemical indices, the strongest bonds are defined for NO_3 ($r = -0.87$) and PO_4 ($r = -0.92$). The present factor influences 11 indices.

The dispersion of the 3rd factor mostly describes the concentration of heavy metals in the water bodies studied. This group of the interrelated indices includes Cr ($r = -0.95$), Fe ($r = -0.85$), and Ni ($r = -0.84$), the bond with Al and Co is weaker ($r = -0.72$). Among the hydrochemical indices, the strong bond is found only with NO_2. The third factor is significantly associated with three indices of the zooplankton that mainly determine the species diversity of the community (number of taxa of *Rotatoria, Cladocera*, all zooplankton species). This factor affects only 9 indices.

In general, all three of these factors emphasize the connection between the hydrochemical indices, content of heavy metals and biological parameters.

Conclusions

1. The registered species of the zooplankton are characteristic of the lakes of West Siberia and are typical of European Russia. The richest in species are the lakes of northern and central taiga. The basis of species diversity in arctic tundra includes *Rotatoria* and *Copepoda*, in other zones — *Rotatoria* and *Cladocera*. The lakes of different climatic zones are inhabited by both species typical of this zone, and cosmopolitan or dispersed species.

2. In each taxonomic group, there is a change of the dominant species from north to south. *Cladocera* has certain dominant species in each zone. *Rotatoria* and *Copepoda* are represented by the species, dominant not only in one zone, but also in the neighboring.

3. There is a tendency for the zooplankton number to increase from north to south. In biomass, similar patterns are not found. The highest rates of the zooplankton biomass are observed in northern and southern taiga.

4. The greatest impact on species diversity of the zooplankton and some taxonomic groups (*Rotatoria, Cladocera*) have, among heavy metals, Cr, Ni, Fe, to a lesser extent — Al and Co. Among the hydrochemical indices, NO_2 has a significant impact. The number of *Copepoda* taxa depends on the majority of the hydrochemical indices and the contents of Zn and Sr.

5. The greatest impact on the quantitative development of the zooplankton and some taxonomic groups (*Cladocera, Copepoda*) has, among the heavy metals, Mn; to a lesser extent — Cu, Cd. Among the hydrochemical indices, the main

impact is that of NO_3 and PO_4. The number of *Rotatoria* depends on the majority of the hydrochemical indices and the contents of Zn and Sr.

6. In general, the development and distribution of the zooplankton in the zones is primarily impacted by, among heavy metals, Mn, Zn, Sr and Cr ($r > -0,9$); slightly weaker bond exists with Fe and Ni ($r = -0,85$), there is also a weak bond with Cu, Al, Cd, Co ($r = -0,72$).

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