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*ZONING OF MACROZOOBENTHOS IN THE FRESHWATER LAKES OF THE TYUMEN REGION**

SUMMARY. This paper provides the data on fauna composition, taxonomic and quantitative (abundance, biomass) structure of macrozoobenthos in the freshwater non-floodplain lakes in different geographical zones in the Tyumen Region (the Arctic tundra zone, the northern taiga zone, the middle taiga zone, the southern taiga zone, the middle forest-steppe zone). Typical and rare species and groups of benthic invertebrates are registered on the investigated territory. The most bio-diverse zones are marked. The faunal similarity of the communities in the lakes of different zones is shown. The structural complexes of macrozoobenthos and changing of dominant species along the climatic gradient are revealed. It is determined that the leading role in the communities (according to the number and biomass) belongs to Chironomidae. With the help of a multifactor analysis, the dependence of the components of water chemistry and the heavy metal content on the structural indicators of macrozoobenthos is shown. 6 biological indices, 15 hydrochemical indices and 11 indices of heavy metals are analysed. As a result of the factor analysis, main groups of the interrelated indices are revealed ($r \geq 0.7$).

KEY WORDS. Macrozoobenthos, species, abundance, biomass, multifactor analysis.

The study of lake ecosystems variability under the influence of climatic factors is one of the relevant topics in hydrobiology. This area of research is closely related to the problem of the dynamics of natural biosystems under growing anthropogenic load. The increasing interest in it manifests in ambiguous interpretation of planetary climate change and related phenomena. The allocations of geographical areas 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, and climate; they together form hydrobiological regime of water bodies, which vary in the longitudinal and latitudinal directions [1], [2], [3]. In addition, scientific literature increasingly discusses the issue of future climatic changes caused by the greenhouse effect. Change in temperature is slow, that causes the penetration of the southern species to higher latitudes and changes the structure of biocenoses [4], [5], [6].

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Macrozoobenthos is a good indicator of long-term changes in the environment. [7] This is an ecological group that unites animals living most of their lives on the surface or in the ground, leading a sedentary lifestyle and having a long life cycle. At present, the changes in the qualitative and quantitative characteristics of zoobenthos in the Tyumen Region are underexplored. A lot remains unclear in the way we should estimate the regularities of quantitative zoobenthos zoning in the water bodies of the Tyumen Region due to the lack of evidence and statistical calculations.

The purpose of the research is to identify the structural features of the zoobenthos organization and zoning in the lakes of different natural and climatic zones on the basis of the data obtained. These features were analyzed according to the following: 1) the species composition and occurrence of species; 2) the dominant species of macrozoobenthos; 3) the abundance and biomass of macrozoobenthos. To assess the characteristics of macrozoobenthos zoning, the dependence of structural indicators of the communities on the major ions of water and the contents of heavy metals was revealed using a multifactor analysis.

Macrozoobenthos samples were collected in July and August, 2011 from 10 fresh non-floodplain lakes located in different natural and climatic zones: Arctic tundra, northern taiga, middle taiga, southern taiga, subtaiga, and middle steppe. Macrozoobenthos samples were collected with the help of the methods standard for hydrobiology [8], [9]. A total of 44 benthic samples were collected and processed. The observed species were assessed in terms of modern taxonomy [10], [11], [12], and [13]. Along with macrozoobenthos, the water samples were taken to conduct hydrochemical analysis and to define the contents of heavy metals.

It was found that the macrozoobenthos communities of ten lakes included 75 species and taxa of higher level. They belong to 13 taxonomic groups (Table 1). The most numerous in species were: chironomids, oligochaetes, mollusks. There were registered 36 species of chironomids *(Chironomidae)*, 8 species of oligochaetes *(Oligochaeta)*, and 9 species of molluscs. *(Mollusca)*.

Table 1

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

Taxa	Zones										P,%
	I		II		III			IV	V	VI	
	1	2	3	4	5	6	7	8	9	10	
Acariformes											
Limnesia koenikei (Piersig)							+				2.27
Limnesia undulate (Müller)			+								2.27
Piona stjordalensis (Thor)			+								4.54
Chironomidae											
Cryptochironomus obrebtans (Walker)			+	+			+	+		+	34.00
Cryptochironomus agilis (Linevitsh)			+			+		+		+	34.00
Cryptochironomus redekei (Kruseman)			+				+				13.63

Table 1 continued

Procladius gr. choreus (Meigen)			+			+	+	+	+	+	45.50
Procladius ferrugineus (Kiffer)	+			+					+		16.00
Einfeldia dissedens (Walker)							+	+		+	9.00
Psektrocladius gr. dilatatus (v.d. Wulp,)	+		+	+							18.18
Psektrocladius limbatellus (Holmgred)			+	+			+				18.18
Polypedilum nubeculosum (Meigen)			+					+	+		13.63
Polypedilum scalenum (Schrank,)				+		+	+				16.00
Paratanytarsus siderophila (Zwerewa)				+							6.81
Microtendipes pedellus (De Greer)			+	+	+	+					20.50
Chironomus acutiventris (Wulker et al)			+	+							20.50
Chironomus plumosus (Linne)							+		+		13.63
Limnochironomus lobiger (Kieffer)			+	+		+	+		+		34.00
Stictochironomus gr. histrio (Fabricius)	+	+	+	+			+				55.00
Stictochironomus crassiforceps (Kieffer)				+							13.63
Cricotopus cylindracaus (Kieffer)			+								2.27
Cricotopus silvestris (Fabricius)			+								2.27
Orthocladius consobrinus (Holmgren)		+	+								4.54
Anatopynia plumipes (Fries)			+								4.54
Glyptotendipes paripes (Edwards)	+		+								9.00
Pseudochironomus prasinatus (Staeger)			+				+				6.81
Endochironomus donatoris (Shilova)			+						+		4.54
Endochironomus specius (Meigen)						+					2.27
Cladotanytarsus gr. mancus (Walker)			+			+	+				9.00
Tanytarsus gregarius (Kieffer)	+		+		+		+	+	+		34.00
Tanytarsus pallidicornis (Walker)	+										2.27
Tanytarsus exkawatus (Edwardas)				+							2.27
Corynocera ambigua (Zetterstedt)									+		11.36

Table 1 continued

Ablabesmyia phatta (Eggert)						+					4.54
Monodiamesa bathyphila (Kiffer)	+										2.27
Prodiamesa bothyphila (Kiffer)	+										2.27
Abiskomyia sp.(Vizga)	+										2.27
Zalutschia zalutschicola (Skuze)						+					2.27
Oligochaeta											
Tubifex tubifex (O.F. Müller)	+		+		+		+				22.72
Limnodrilus hoffmeisteri (Claparede)	+				+						4.54
Limnodrilus hilveticus (Claparede)											2.27
Lumbriculus variegates (O.F. Müller)				+							11.36
Peloscolex ferox (Eisen)							+				4.54
Potomothrix hammoniensis (Michaelsn)									+		9.00
Speros sperma (Walker)							+				2.27
Ilyodrilus bedoti (Pigyet)								+			2.27
Nematoda											
Idiodorylaimus robustus (Scheider)	+		+								11.36
Digenea											
Digenea sp.	+										2.27
Ceratopogonidae											
Sphaeromius pictus (Meigen)			+		+					+	18.18
Polpomyia lineate (Meigen)			+		+			+	+		20.45
Culicoides sp.					+						4.54
Culicoides nebuculosus (Walker)				+							4.54
Hirudinea											
Helobdella stagnalis (Linne)			+	+	+						11.36
Glossiphoria comlanata (Linne)			+								2.27
Erpobdella nigricollis (Linne)			+								2.27
Erpobdella octoculata (Linne)				+							4.54
Trichoptera											
Rhyacophila sp.				+					+		6.81
Dicosmoecus sp.				+							2.27
Limnephilus sp.			+	+							4.54
Molanna sp.			+	+							4.54
Oligotricha sp.			+								4.54
Megaloptera											
Sialis sp.				+							2.27
Chaoboridae											
Chaoborus flavicans (Meigen)								+	+		9.00

The end of Table 1

Chaoborus sp. puppo							+	+			6.81
Amphipoda											
Gammarus lacustris (Sars)	+										9.00
Mollusca											
Valvata sibirica (Middendorf)			+								2.27
Valvate depressa (C. Pfeifer)									+		2.27
Valvata sp.					+						2.27
Choanomphalus rossmaessleri (Auerswald)			+	+							4.54
Limnea auricularia (Müller)									+	+	6.81
Pisidium amnicum (Müller)			+								2.27
Musculium sp.				+							2.27
Euglesa sp.	+		+	+			+			+	18.18
Sphaerium nitidium (Clessin)			+	+						+	9.00

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

Lakes: 1 — Goltsovoye, 2 — Longatibeyto, 3 — Pyagunto, 4 — Halyato, 5 — Lohtotkurt, 6 — Tomtalyahtur, 7 — RangeTur, 8 — Dolgyi Sor, 9 — Kuchak, 10 — Ugryumovo.

Comparative analysis of the data showed that the greatest number of species inhabits on the territories of northern and middle taiga (49 and 29 species, respectively) and the lowest number of species (7) is found in the middle forest-steppe (Fig. 1). The basis of the species diversity of macrozoobenthos in all natural and climatic zones consists of the *Chironomidae* representatives ($\geq 50\%$).

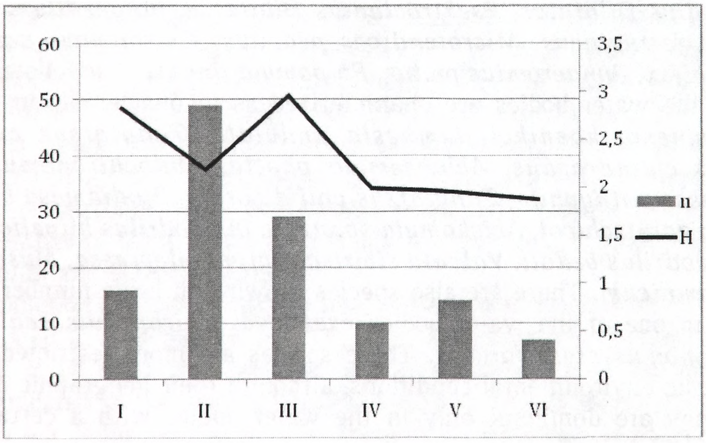

Fig. 1. The zonal changes in the abundance of macrozoobenthos species (n) and the Shannon index (H): I — arctic tundra, II — northern taiga, III — middle taiga, IV — southern taiga, V — middle forest-steppe

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. Zonal change in the index of species diversity is represented 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 middle taiga. This is explained by the fact that there is a strong dominance of certain macrozoobenthos species, and this, in turn, leads to a low evenness between the species of the community (Table 2).

Table 2

Assessment of macrozoobenthos species diversity

Indices	I zone	II zone	III zone	IV zone	V zone	I zone
Species Richness Index (R)	5.56	13.10	10.54	3.82	4.31	2.77
Simpson Dominance Index (C)	0.19	0.20	0.93	0.16	0.25	0.17
Pielou Evenness Index (E)	0.77	0.56	0.88	0.86	0.66	0.9

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 ($P \geq 50\%$) were found: *Stictochironomus histrio* (P=55%) and *Procladius choreus* (P=45%). Slightly lower occurrence (P=34%) was demonstrated by *Cryptochironomus obrebtans, Cryptochironomus agilis, Limnochironomus lobiger, Tanytarsus gregarious*. Lower occurrence (P=16-20%) was shown by *Psektrocladius Dilatatus, Psektrocladius Dilatatus, Polypedilum scalenum, Procladius ferrugineus, Microtendipes pedellus, Chironomus acutiventris, Tubifex tubifex, Sphaeromius pictus, Polpomyia lineate*. The following species inhabiting the water bodies are characterized as inconsiderable in number or single: *Limnesia koenikei, Limnesia undulate, Tanytarsus exkawatus, Cricotopus cylindracaus, Ablabesmyia phatta, Endochironomus specius, Monodiamesa bathyphila, Tanytarsus pallidicornis, Prodiamesa bothyphila, Zalutschia zalutschicol, Abiskomyia sp.vizga, Limnodrilus hilveticus, Speros sperma, Ilyodrilus bedoti, Valvata sibirica, Valvate depressa, Musculium sp., Pisidium amnicum*. There are also species growing in large numbers, but only appearing in one of the water bodies examined: *Chironomus acutiventris и Stictochironomus crassiforceps*. 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: *Monodiamesa bathyphila, Tanytarsus pallidicornis, Prodiamesa bothyphila, Abiskomyia sp. Vizga, Gammarus lacustris*; in northern taiga — *Tanytarsus exkawatus, Paratanytarsus siderophila Chironomus acutiventris, Stictochironomus* *crassiforceps, Cricotopus cylindracaus, Anatopynia plumipes, Lumbriculus variegates, Culicoides nebuculosus, Valvata sibirica, Chaanompholus rossmaaessleri, Musculium sp., Pisidium amnicum*; in middle taiga — *Ablabesmyia phatta, Endochironomus specius, Zalutschia zalutschicola, Peloscolex ferox, Speros sperma*; in southern taiga — *Ilyodrilus bedoti*; in subtaiga — *Potomothrix hammoniensis, Valvate depressa.*

The structure-forming complex of macrozoobenthos in the surveyed water bodies was calculated on the basis of the Simpson index. It mainly consists of a small number of species (4-5), including the representatives of four taxonomic groups (Table 3). Analyzing the table, it becomes apparent that in groups of *Ceratopoganidae* and *Chironomidae*, dominant arc the species typical not only of one zone, but also of the neighboring one. Thus, among *Ceratopogonidae*, the dominant group in all the zones includes *Polpomyia lineate*. In the surveyed lakes of arctic tundra, this species and other members of this family were not registered. Of *Chironomidae,* the dominant group in most of the zones includes *Cryptochironomus agilis* and *Procladius choreus,* but they do not occur in arctic tundra. This zone has its own dominant species, typical of the cold-water complex (*Tanytarsus pallidicornis* and *Glyptotendipes paripes*). Among *Oligochaeta, Tubifex tubifex* is a structure-forming community for the northern zones. In the more southern zones, this position is occupied by other species of oligochaetes. In our studies, it is difficult to detect the change of the dominant species among *Mollusca*, as the representatives of *Euglesa* are found only in the juvenile stage. However, other species identified as dominant in some zones, never occur in neighboring. In general, each geographical zone is characterised by its own structure-forming complex of macrozoobenthos that displays the features of the aquatic organisms habitat.

To calculate the faunal similarity index of the macrozoobenthos communities in the lakes of different geographical zones, the Sørensen formula was used [9]. The obtained indices are quite low. They range from 0.08 to 0.44 with an average of 0.24. The lowest indices are registered for the communities of arctic tundra and middle forest-steppe. The highest rates are found among the communities of the southern taiga and middle forest-steppe zones, and of southern taiga and subtaiga, as well as of northern taiga and middle taiga. The greater similarity in the macrozoobenthos of these zones is provided by the common dispersed species of *Chironomidae* and *Ceratopogonidae.*

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. Fig. 2 demonstrates the average abundance of the macrozoobenthos in each zone. It varies from 0.3 thous. sp./sq.m to 4.5 thous. sp./sq.m. The maximum abundance is registered in the northern taiga zone. *Chironomidae* species comprise the basis of the benthic community abundance in all the zones. The part of other taxonomic groups is different in each region and less significant. According to the results available, it is difficult to identify a clear pattern of the macrozoobenthos zoning along the climatic gradient.

Table 3

The change of the dominant species in taxonomic groups of macrozoobenthos

I	II	III	IV	V	VI
Ceratopogonidae					
-	*Polpomyia lineate*	*Culicoides sp.*	*Polpomyia lineate*	Polpomyia lineate	Sphaeromius pictus
Chironomidae					
Tanytarsus pallidicornis, Glyptotendipes paripes	Polypedilum nubeculosum, Stictochironomus crassiforceps, Cryptochironomus agilis	Cryptochironomus agilis, Procladius choreus	Tanytarsus gregarious, Cryptochironomus agilis	Procladius Choreus, Chironomus plumosus	Cryptochironomus agilis, Procladius choreus
Oligochaeta					
Tubifex tubifex	*Lumbriculus variegates, Tubifex tubifex*	*Tubifex tubifex, Lumbriculus hoffmeisteri*	*Ilyodrilus bedoti*	Potomothrix hammoniensis	-
Mollusca					
Euglesa juv.	*Chaanompholus rossmaaessleri*	*Euglesa juv.*	-	*Valvate depressa*	Euglesa juv. Limnea auricularia Sphaerium nitidium

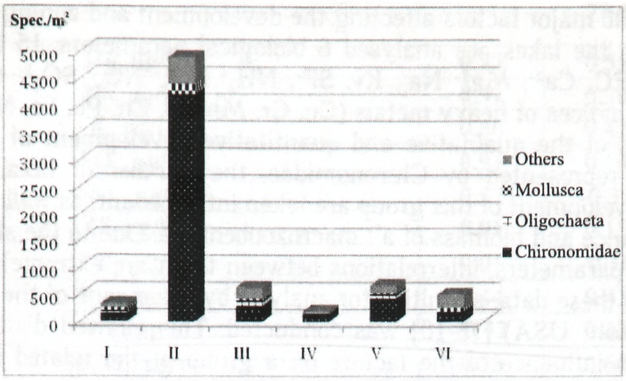

Fig. 2. The part of the taxonomic groups in total abundance of the macrozoobenthos (N, sp./m^2) in the lakes of different zones: I — arctic tundra, II — northern taiga, III — middle taiga, IV — southern taiga, V — subtaiga, VI — middle forest-steppe

Fig. 3 presents the average of the macrozoobenthos biomass and main taxonomic groups comprising it. The maximum indices of the community are observed in the lakes of the northern taiga zone, which stand out against the background of other geographical zones. This occurs due to the fact that most of major macrozoobenthos species with high individual mass are found in the lakes of the mentioned zone. They are the bigger representatives of *Trichoptera* and *Chironomidae*: *Stictochironomus crassiforceps, Polypedilum nubeculosum, Cryptochironomus agilis, Chironomus acutiventris*. In general, the largest part of the biomass in the zones comprises chironomids, with the exception of arctic tundra, where *Gammarus (Gammarus lacustris)* predominate in the samples, and subtaiga, where caddis flies, *Rhyacophila sp.* play a significant role. It is difficult to reveal a clear pattern in the distribution of the macrozoobenthos from north to south, whether the abundance is taken into account, or when we consider the biomass. Concerning the group of *Chironomidae,* the tendency of increasing biomass is noted, even though the direction is nonlinear.

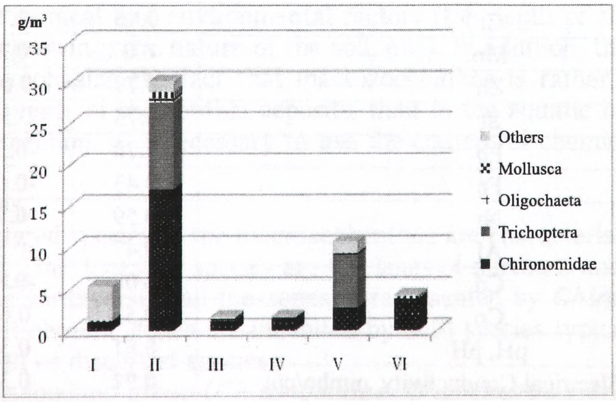

Fig. 3. The part of the taxonomic groups in total biomass of the macrozoobenthos (g/m^2) in the lakes of different zones: I — arctic tundra, II — northern taiga, III — middle taiga, IV — southern taiga, V — subtaiga, VI — middle forest-steppe

To assess the major factors affecting the development and zoning of the benthic communities in the lakes, we analysed 6 biological parameters, 15 hydrochemical 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, Cd). Since the basis of the qualitative and quantitative development of the ecological community is represented by Chironomidae, the number of taxa, biomass and quantitative development of this group are taken into account, as well as the number of taxa, abundance and biomass of all macrozoobenthos. 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) [15-16] 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 $r \geq 0.7$) was taken into account. The results of the multifactor analysis are presented in Table 4.

The main variation of the investigated indices is determined by three factors that have the total informativity of 75.0%. The first two factors determine 61.0% of the variation in the studied features that indicates a stronger bond between the indices within each component (Table 3).

Table 3

The results of the multifactor analysis

Variables	Factor 1	Factor 2	Factor 3
Number of Macrozoobenthos Taxa	**-0.72**	0.52	0.19
Abundance of Macrozoobenthos	**-0.60**	0.45	0.48
Biomass of Macrozoobenthos	0.20	-0.32	**0.62**
Number of *Chironomidae* Taxa	**-0.72**	0.43	0.10
Abundance of *Chironomidae*	-0.60	0.42	0.46
Biomass of *Chironomidae*	-0.49	0.51	0.44
Cu	0.55	-0.54	-0.40
Cr	0.46	**-0.71**	0.28
Mn	-0.07	-0.32	**-0.60**
Zn	0.79	0.06	0.16
Sr	**0.75**	0.50	-0.06
Pb	**0.70**	-0.52	0.47
Fe	0.43	-0.61	0.50
Ni	0.59	**-0.70**	0.22
Al	0.47	-0.50	**0.60**
Cd	0.08	**-0.81**	-0.30
Co	0.53	0.62	-0.46
pH, pH	**0.81**	0.38	0.09
Specific Electrical Conductivity, mmho/cm	**0.92**	0.31	0.16
Si, mg/l	0.41	0.39	-0.42
NH_4, μg /l	**0.65**	-0.23	-0.13
Ca, μg /l	**0.65**	0.57	-0.24

The end of Table 3

Mg, μg/l	**0.82**	0.55	-0.08
Na, μg/l	**0.91**	0.20	0.26
K, μg/l	0.86	0.41	0.06
SO_4, μg/l	**0.91**	0.14	0.28
NO_3, μg/l	0.22	-0.31	**-0.78**
Cl, μg/l	**0.91**	0.15	0.33
PO_4, μg/l	0.01	-0.16	-0.50
P_{total}, μg/l	0.44	0.43	-0.07
NO_2, μg/l	-0.42	0.32	0.35
HCO_3, μg/l	**0.73**	0.64	-0.12
Total Dispersion	12.59	7.02	4.50
% of Total Dispersion	39.0	22.0	14.1

The dispersion of the 1st factor largely describes most of the hydrochemical indices content. The strongest bonds ($r>0.9$) are registered for the ions of Cl, SO_4, Na, and K ($r=0.86$). This group of interrelated indices includes heavy metals such as Zn, Sr and Pb ($r\geq0.7$). The first factor is significantly associated with the taxonomic structure of *Chironomidae* ($r=-0.72$) and macrozoobenthos in general ($r=-0.72$). The less significant bond exists with the number of these biological indices ($r=-0.60$). The dispersion of the 2nd factor is slightly associated with the characteristics of the benthic communities. The group of the most interrelated indices includes only heavy metals: Cd ($r=-0.81$), Cr ($r=-0.71$), and Ni ($r=-0.70$). The dispersion of the third factor mostly connects the concentration of NO_3 ($r=-0.78$) and macrozoobenthos biomass ($r=0.62$). The dependence is positive, it emphasizes the way biogenes influence the productivity of the water bodies. This group of interrelated components includes Al and Mn with the bonding force $r=-0.60$, that, in their turn, have a negative impact on the biomass of the benthic community.

The obtained dependences of the quantitative indices of the macrozoobenthos for which $r<7$ may indicate that these characteristics can be influenced by some other physical-chemical and environmental factors (the depth of the water body, the area of overgrowing, the nature of the soil, etc.). In addition, the dependences obtained may emphasize the fact that macrozoobenthos is rather related to the chemical constituents of the benthal deposits, than to the aquatic habitat. And, to identify the connection, it is necessary to use the content of chemical elements in the soil [17-18].

Conclusions.

1. The registered species of the macrozoobenthos are characteristic of the lakes of West Siberia. The richest in species are the lakes of northern and central taiga. The basis of species diversity all the zones is represented by *Chironomidae*. 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 (*Chironomidae, Oligochaeta, Ceratopogonidae, Mollusca*), there is a change of the dominant species along the climatic gradient. The structure-forming complex includes the species, dominant both only in one zone, and also in the neighboring.

3. The maximum quantitative indices of the macrozoobenthos are registered in the northern taiga zone. The basis of the abundance and biomass in all the zones accounts for *Chironomidae*. No regular changes in the quantitative characteristics of the macrozoobenthos along the climatic gradient are registered.

4. The greatest impact ($r>0.8$) on species diversity of the macrozoobenthos and *Chironomidae* in particular have, among hydrochemical indices, pH, specific electrical conductivity, Mg, K, Na, K, SO_4, Cl; and, among heavy metals, Zn, Sr, Pb. The biomass of all the macrozoobenthos is significantly influenced by NO_3. And among heavy metals, the greatest influence is that of Al and Mn.

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