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BIOMONITORING LAKE CHEBARKUL WATER ON MACROPHYTE COMMUNITY, RUSSIA

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ABSTRACT: The article studies macrophyte biodiversity in Lake Chebarkul (Russia) and the influence of water chemistry on it. The macrophyte community composition is sensitive to any environmental changes. Higher or lower trophic status is the most important factor responsible for changing taxons of high environmental value (sensitive taxon) into potentially ruderal species. This is typical for the areas with an increased anthropogenic impact on the lake. This paper identifies species diversity, the taxonomic structure of aquatic flora for each section of the lake. Macrophytes were studied along the lake shore both with the help of qualitative and quantitative analysis. The lake flora was listed for each lake profile, and then the general list of differences and similarities for all the studied sites was compiled. The final flora list includes about 90 spices plants. According to the study results, the macrophyte species composition of the studied sites is different. 59 % of the total number of taxa was present at all sites, while 9 % of them, mostly sensitive taxa, were found only in a group of points with relatively clean water. However, the overgrowth was highest in the fourth group (102 %), slightly lower at the points of the third group (92 %) and significantly lower in the second (58 %) and first (44 %) groups. The article considers the possibility of bioindication quality with the biomass of common macrophytes- *Potamogéton lucens L., P. obtusifolius, P. pusillus, P. crispus* and *Phragmites australis L.* of Lake Chebarkul (Russia).

Keywords: Aquatic Macrophytes, Macrophyte Biodiversity, Trophic Status, Biomonitoring

1. INTRODUCTION

Water quality in water-bodies has been of increased interest recently, with changing water chemistry is one of the crucial environmental issues [1]. Chemicals get into water systems in various ways including industrial, municipal and agricultural effluents [2-4]. Being resistant, they tend to accumulate in soil, water, sediment and pass through trophic chains.

Particularly toxic chemicals can bind to proteins and prevent DNA replication [5]. But some elements such as Cu, Fe, Zn, Mn, Ni are necessary for plants to grow. And some macrophytes can accumulate metals and metalloids [6-8]. Macrophytes are very important for the community as they take part in oxygen production, nutrient cycle, stabilizing sediments and providing habitat for water life [9, 10]. Macrophytes can actively absorb calcium, magnesium, sodium salts, calcium sulphates, chlorides, hydrocarbonates from water and sediments so that they become accessible for epiphytic phytoplankton and other herbivores and detrivores [11]. So, assessing the formation of macrophyte communities is of special interest as they are important for ecology [12]. Macrophytes' attached mode of life makes them especially effective in bioindication pollution of particular zones of water-bodies. Besides, there is research showing significant differences in chemical accumulation by different macrophyte species [13-14]. Macrophytes take a priority part in the methods of treatment and detoxification of water-bodies. Submergent vegetation accumulates chemicals more than coastal. Macrophytes are one of the most sensitive biocommunities to assess the anthropogenic impact. Community composition is very responsive to environmental changes by changing its biodiversity [15]. Higher or lower trophic status (i.e. concentration of nutrients, suspended particulate matters, chlorophyll) and temperature changes are the most important factors responsible for changing taxons of high environmental value (sensitive taxon) into potentially pathogenic species.

Few studies have investigated macrophyte biodiversity in South Ural. Such discussions and research have become timely. Taking into account the fact that the problem has been little investigated in the South Ural region [16], we continued to study the formation peculiarities of macrophyte communities. The current paper aims to identify the macrophyte biodiversity of Lake Chebarkul (Russia) and to study water chemistry's influence on them.

2. MATERIALS AND METHODS

2.1 Study Area

Lake Chebarkul is on the eastern slope of the Urals range of mountains. Its altitude is 320 m above sea level. It is a low-land lake with firm shores overgrown with reeds. The creeks are full of water vegetation. Lake Chebarkul is of tectonic origin. Its eastern part is very deep, the northern and western shores are steep and rocky, eastern and southern are flat, flooded in spring. There are rocky promontories. Western coasts are forested. The bottom is covered with silt, sand, pebble, and shells. It is the lake where the meteorite fell in 2013 (Chelyabinsk, point 6, Fig. 1). Several small, dry in summer, rivers fall into the lake. The lake area is 19.8 km^2, its volume is 0.154 km^2, the deepest part is 12 m, the average depth is 2.3 m. the water level varies between 1.5 m, the highest water is in June. The lake is frozen early in November, and is opened in May. There are many health resorts and recreation facilities on the lake coasts. It is also of much fishery importance. Lake Chebarkul has extensive resources of quality fresh drinking water of 154 million m^3. It is a source of drinking water supply for the city of Chebarkul and its neighboring villages. The water level has dropped almost by 3 m for the last 70 years. As a result, the natural hydrological regime was disturbed. The lake has become shallow, its southern and eastern coasts got swamped, weeds have grown not only on the coasts but also away from them.

Water is accumulated by spring snowmelt runoff and by surface rainfall runoff that contributes less than snowmelt. Depending on weather conditions and a number of other reasons, mainly due to evaporation in summer there is a change in the mineralization class and pH level. Fluctuations of mineralization during a season could be up to 50‰. There is a complete or partial change of the macrophyte community, determined primarily by changing the physical and chemical factors of the environment [17]. The mineralization level and its connection with different quantitative and qualitative characteristics of the macrophyte community formation have been researched repeatedly in different regions [10, 12, 14, 16, 17]. But the impact of mineralization factors and pH on the number of individual species has not been quantified.

To give a comprehensive analysis of water ecosystems it is necessary to consider the complex nature of hydrobionts' interaction against the background of different degrees of adaptation to extreme environmental conditions (temperature, mineralization level, pH, etc.). The mineralization of the lakes of the Eastern slope of the South Urals directly depends on the geochemical composition of the underlying gneissose granite rock formations. However, anthropogenic processes are also important. The current paper considers the probable conditions of the organization of the taxonomic structure of macrophyte communities in Lake Chebarkul.

2.2 Sample Collection

12 sampling points were chosen to study macrophyte species diversity in Lake Chebarkul (Fig. 1).

Water and macrophytes were randomly sampled at the points. To determine species diversity all the existing macrophyte species were collected at each sampling point with their further taxonomic identification.

The five-grade scale was used to give a quantitative characteristic of species occurrence: 1 – rarely or isolatedly occurred species; 2 – rarely or sporadically occurred; 3 – occurred frequently enough but without dominating; 4 – occurred frequently, able to form communities; 5 – widely occurred species that make coenosis. The total area of macrophyte species overgrowth in communities was determined on average at the point of observation at each point by the visual census.

Climatically identical days were chosen for sampling to eliminate weather impact on the research results. The days were sunny and not windy. Sampling was made in June – September 2017-2018. The period from June to September was chosen deliberately, as this is the vegetation time for macrophytes in the studied area. It is in this period that bioaccumulation tends to reach a high concentration in macrophytes. Each sampling point was surveyed twice over the period**.**

2.3 Defining Water Chemistry

Hydrochemical samples were taken by the sampling system PE-1110 (RF patent No. 2090856) in accordance with GOST 24902-81 [18] and GOST 17.1.5.04-81 [19]. At the sampling site, the temperature was measured with an oximeter HANNA "HI-9143" (state register No. 14302-99). Chemical analysis was carried out in stationary conditions according to the uniform methods in the accredited laboratory in the accredited laboratory of the South Ural core facility center, accreditation no.0001.514536 till 07.06.2015 G.

2.4 Data Processing

Relations between macrophytic communities of each sampling point and environmental parameters were obtained using canonical correspondence analysis. The data was analyzed using graphs that were made by calculating similarity based on the Sorensen coefficient as the affinity index, taking into account the positive matches for the cluster analysis. The graphs were calculated using a special software module "Graphs" [20].

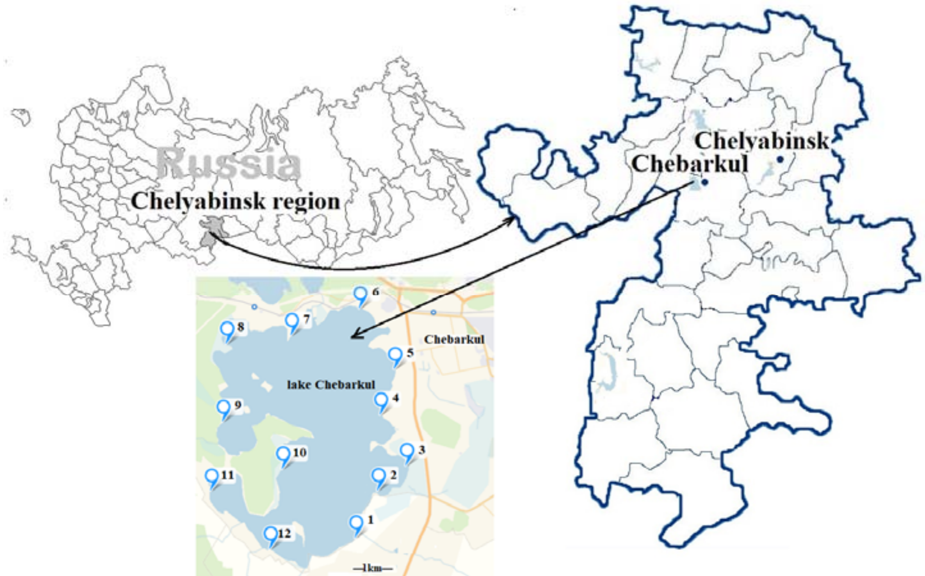

Fig.1 Sampling points of Lake Chebarkul

3. RESULTS AND DISCUSSION

The lake vegetation is diverse enough and well-developed. In shallow waters macrophytes are distributed evenly with the zones covering relatively large areas towards the basin (covering up to 100 % locally). The formed communities cover the bottom up to the depth of 3.0–4.0 m on average. Some species such as *Fontinalis antipyretica* and representatives of *Charophytes* are met at the depth of 5 m.

About 90 species of macrophytes of 35 families were identified, 53 (59 %) of them are water plants and 33 (41 %) are coastal.

We think that some species were not covered, as we did not take tree species into account. Besides, the given research aimed to study the lake ecosystem, so the small rivers and streams entering the lake were not considered

Analyzing water chemistry and sampling results four groups were determined according to the common vegetation associations and the man-made impact that was described in grades (Fig. 2).

The first group (0 grade) comprises the sampling points that are not under a man-made impact (sampling points 6, 10-12). The second group (1 grade) presents a recreation territory that is under a significant tourist-made impact (sampling points 7-9). The third (2 grades) is located in the zone that is affected by the households of small villages on the coasts (sampling points 1-3). The fourth point (3 grades) is the area under an adverse impact of both domestic and commercial character, it is situated within the limits of the city of Chebarkul (sampling points 4 and 5).

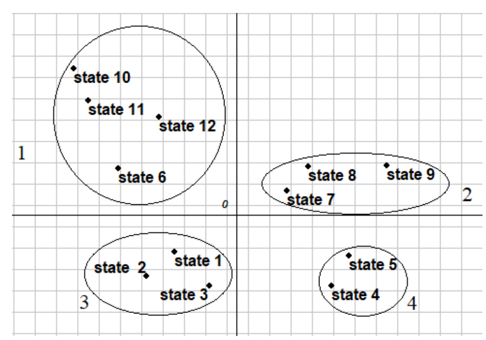

Fig.2 Associations of groups of points according to the generality of plant associations and the degree of anthropogenic impact: 1 - the first group (0 grade), 2 - the second group (1 grade), 3 - the third group (2 grade), 4 - the fourth group (3 grade).

There is a recent tendency to change the ionic water composition of the lake to the increase of sulphates from 30.0 mg·l^{-1} to 45.3 mg·l^{-1} and calcium and magnesium water depletion from 40.0 mg·l^{-1} to 32.3 mg·l^{-1} and 31.0 mg·l^{-1} – 29 mg·l^{-1} respectively. Mineralization is gradually increasing from 311.0 mg·l^{-1} to 421.30 mg·l^{-1}. General water analysis for the studied sampling points is mostly similar with slight differences (Table 1). Thus, for instance, Na, Fe, ammonium, nitrites, nitrates concentrations in water are spatially-heterogeneous dependent on how far a pollutant is. The values are higher in points 3 and 4 (Table 1).

Table 1 Chemical composition of Lake Chebarkul

Показатель ±Δ(p=0,95)	Presence in lakes			
	1	2	3	4
HCO_3^- ± Δ, мг/дм^3	190,0±10,0	196,0±11,0	200,8±6,0	202,9±9,0
Общая щелочность ±Δ, ммоль/дм3	3,80±0,31	3,57±0,18	3,62±0,11	3,80±0,22
Cl^- ± Δ, мг/дм^3	49,52±0,8	50,99±0,6	51,03±0, 9	51,08±0, 7
SO_4^{2-} ± Δ, мг/дм^3	43,25	43,10	45,09	45,09
Na ± Δ, мг/дм^3	47,48	45,12	48,36	50,06
K ± Δ, мг/дм^3	11,25±0,58	11,13±0,40	11,28±0,34	11,34±0,44
Ca ± Δ, мг/дм^3	32,1±4,9	30,1±3,2	32,3±1,3	32,8±1,2
Mg ± Δ, мг/дм^3	29,42±2,0	30,3±3,6	29,48±1,36	30,3±2,3
Жесткость± Δ, ммоль/дм3	3,99±0,45	4,30±0,35	4,05±0,12	4,30±0,22
Аммоний ± Δ, мг/дм^3	0,190±0,06	0,19±0,04	0,45±0,04	0,44±0,05
Нитриты ± Δ, мг/дм^3	0,004±0,001	0,005±0,001	0,007±0,002	0,008±0,002
Нитраты ± Δ, мг/дм^3	0,25±0,05	0,25±0,05	0,44±0,09	0,46±0,08
Ортофосфаты ± Δ, мг/дм^3	0,010±0,008	0,010±0,005	0,012±0,008	0,013±0,008
Фосфор общий (на фосфаты) ± Δ, мг/дм^3	0,085±0,005	0,076±0,008	0,085±0,008	0,085±0,008
Fe ± Δ, мг/дм^3	0,013±0,005	0,028±0,006	0,250±0,006	0,230±0,006
Zn± Δ, мг/дм^3	0,003±0,001	0,003±0,001	0,004±0,001	0,004±0,001
Cu ± Δ, мг/дм^3	0,0023±0,0006	0,0020±0,0008	0,0020±0,0008	0,0020±0,0008
Mn ± Δ, мг/дм^3	0,021±0,006	0,021±0,002	0,023±0,002	0,025±0,002
Pb ± Δ, мкг/дм^3	<0,001	<0,001	<0,001	<0,001
Sr ± Δ, мг/дм^3	0,41±0,03	0,45±0,04	0,49±0,06	0,49±0,06
Cd ± Δ, мг/дм^3	<0,0001	<0,0001	<0,0001	<0,0001
Ni ± Δ, мг/дм^3	<0,001	<0,001	<0,001	<0,001
Co ± Δ, мг/дм^3	<0,001	<0,001	<0,001	<0,001

The macrophyte species composition of Lake Chebarkul is shown in Table 2.

Figure 3 shows the frequency distribution of different macrophyte species in Lake Chebarkul. It also shows the differentiation of plant associations for the four groups based on human-made impact. Species in Square 1 are equally found in all the sampling points. Square 2 combines species that do not occur in the fourth group but are equal in number in the other 3 groups. Species common for both groups 1 and 2 are identified in Square 3. Square 4 contains species that are dominant in the 1-st sampling point and occur in the second.

Species diversity of some families differs with the groups of sampling points, e.g., *Potamogeton*, *Hydrocharitaceae*, *Polygonaceae*, *Nymphaeaceae*, *Characeae,* and *Ranunculaceae*. Unlike groups 3 and 4, groups 1 and 2 have a richer diversity of these species (Table 2).

The qualitative analysis shows that the studied areas do not significantly differ in taxonomic diversity of water flora. According to the collected data macrophyte species composition of group 1 includes 90 species of 35 families. Many species are met here including *Characeae*, water moss (*Fontinalis*), some species of *Potamogeton*, some species of hygrophytes growing in swamps. The list of macrophytes of this group includes all the registered in Lake Chebarkul species belonging to the general list. Groups 2 (82 species of 34 families) and 1 are 91 % close in species composition. Species composition of group 3 is even lower (71 species of 32 families). Group 4 is characterized by a much poor species diversity 65 % of the general list (59 species of 25 families, namely). Rare species of some families such as *Alismataceae*, *Araceae*, *Ranunculaceae*, *Primulaceae*, *Lamiaceae*, *Scrophulariaceae*, *Lentibulariaceae*, *Potamogetonaceae*, *Characeae* are met in groups 1 and 2. That can be associated with natural eutrophication of these sampling points. Overgrowing of the sampling points of group 3 and 4 is accelerated due to the man-made impact of the territory: the flora of sensitive species becomes poor, but weeds do richer, on the contrary.

The analysis shows that the studied lake parts significantly differ in the frequency of occurrence of general species. Overgrowing, which is higher in groups 4 and 5, contributes to it.

For groups 3 and 4, unlike groups 1 and 2, slightly bigger concentrations of Cu, Fe, Zn, and Mn were revealed (Table 2). But, as it was shown above, they did not pollute the water. Our previous study considered the possibility of heavy metal accumulation in different water plant organs [12, 18]. There is evidence that macrophytes have a positive influence on water treatment from heavy metals [21].

Table 2 The species composition of the macrophyte community and the frequency of macrophytes in Lake Chebarkul

№	Plant species	Presence in lake				№	Plant species	Presence in lake			
		1	2	3	4			1	2	3	4
	Family Thelypteridaceae						Family Nymphaeaceae				
1	*Thelypteris palustris (Th. P)*	3	3	2	0	50	*Nuphar lutea (N. L)*	3	2	1	0
	Family Equisetaceae					51	*N. pumila (N. P)*	2	2	0	0
2	*Equisetum fluviatile (Eq. F)*	3	3	2	0	52	*Nymphaea candida (Ny. C)*	2	0	0	0
	Family Typhaceae					53	*N. tetragona (Ny. T)*	1	0	0	0
3	*Typha angustifolia (T. A)*	2	3	3	0		Family Ceratophyllaceae				
4	*T. lantifolia (T. L)*	2	2	1	1	54	*Ceratophyllum demersum (Cer. D)*	3	3	4	4
	Family Sparganiaceae						Family Ranunculaceae				
5	*Sparganium simplex (Sp. S)*	2	2	2	1	55	*Batrachium circinatum (B. C)*	2	0	0	0
	Family Potamogetonaceae					56	*Caltha palustris (Cal. P)*	3	3	2	1
6	*Potamogeton compressus (P. C)*	3	2	1	1	57	*Ranunculus sceleratus (R. S)*	2	2	4	3
7	*P. lusens (P. L)*	2	2	3	3	58	*R. lingua (R. L)*	1	0	0	0
8	*P. perfoliatus (P. P)*	1	1	2	2	59	*R. repens (R. R)*	1	1	5	5
9	*P. natans (P. N)*	3	2	2	1		Family Brassiaceae				
10	*P. obtusifolius (P. O)*	2	2	3	3	60	*Roripa palustris (Ro. P)*	2	2	5	5
11	*P. pusillus (P. Pu)*	2	2	2	2		Family Rosaceae				
12	*P. filiformis (P. F)*	1	1	0	0	61	*Comarum palustre (Com. P)*	2	2	4	5
13	*P. pectinatus (P. Pe)*	2	2	1	1	62	*Filipéndula ulmária (F. U)*	3	3	3	2
14	*P. crispus (P. Cr)*	2	2	5	5		Family Callitrichaceae				
15	*P. praelongus (P. Pr)*	1	2	0	0	63	*Callitriche palustris (Call. P)*	3	2	1	1
16	*P. friesii (P. Fr)*	1	1	5	5		Family Lythraceae				
17	*P. alpinus (P. A)*	2	1	0	0	64	*Lythrum salicaria (Ly. S)*	2	2	2	1
18	*P. gramineus (P. G)*	2	2	2	1		Family Halorhagaceae				
19	*P. rutilus (P. R)*	3	3	2	3	65	*Myriophyllum sibiricum (M. S)*	2	3	3	1
20	*Zannichellia repens (Z. R)*	2	2	2	1	66	*M. spicatum (M. Sp)*	2	3	3	5
	Family Alismataceae						Family Hippuridaceae				
21	*Alisma plantago–qatica (A. P)*	2	2	2	1	67	*Hippuris vulgaris (Hi. V)*	2	2	3	5
22	*A. gramineum (A. G)*	1	0	0	0		Family Apiaceae				
23	*Sagittaria sagittifolia (S. S)*	2	2	2	1	68	*Cicuta virosa (Cic. V)*	2	3	3	1
	Family Butomaceae						Family Primulaceae				
24	*Butomus umbellatus (B. U)*	3	3	4	5	69	*Lysimachia vulgaris (Lys. V)*	2	3	3	1
	Family Hydrocharitaceae					70	*Naumburgia thyrsiflora (Na. T)*	2	1	0	0
25	*Stratiotes aloides (St. A)*	3	3	5	5		Family Elatinaceae				
26	*Hydrocharis morsus–ranae (H. M)*	5	4	3	1	71	*Elatine hydropiper (Ela. H)*	2	2	3	3
27	*Caulinia flexilis (C. F)*	4	3	2	2		Family Menyanthaceae				
28	*Elodea canadiensis (E. C)*	2	3	4	5	72	*Menyanthes trifoliata (Me. T)*	3	3	4	1
	Family Poaceae						Family Lamiaceae				
29	*Phragmites australis (Ph. A)*	3	3	5	5	73	*Lycopus exaltatus (Lyc. E)*	2	2	2	0
30	*P. arundinaceae (Ph. Ar)*	3	3	4	5	74	*Scutellaria galericulata (Sc. G)*	1	1	3	2
31	*Calamagrostis langsdorffii (Cal. L)*	2	3	4	5		Family Scrophulariaceae				
32	*Scolochloa festucacea (Sc. F)*	2	2	4	5	75	*Pedicularis palustris (Ped. P)*	2	2	2	1
33	*Glyceria maxima (G. M)*	3	3	4	5		Family Lentibulariaceae				
	Family Cyperaceae					76	*Utricullaria vulgaris (U. V)*	1	0	0	0
34	*Scirpus lacustris (Scir. L)*	3	2	2	1		Family Rubiaceae				
35	*Carex vesicaria (C. V)*	3	3	4	4	77	*Galium uliginosum (Ga. U)*	1	1	1	0
36	*C. rostrata (C. R)*	3	3	4	4		Family Asteraceae				
37	*C. ripapia (C. Ri)*	3	3	4	4	78	*Petasites radiatu (Pet. R)*	1	1	0	0
38	*C. pseudocyperus (C. P)*	3	3	4	4	79	*Bidens tripartita (Bi. T)*	2	3	3	3
39	*C. canescens (C. C)*	3	3	4	4	80	*Tussilago farfara (T. F)*	2	3	3	3
40	*C. atheroides (C. A)*	3	3	4	4		Family Fontinaliaceae				
41	*C. acuta (C. Ac)*	3	3	4	4	81	*Fontinalis antipyretica (Fo. A)*	1	1	0	0
42	*Eleocharis acicularis (El. A)*	3	3	4	4	82	*F. hypnoides (Fo. H)*	1	1	0	0
43	*E. palustris (El. P)*	3	3	3	1		Family Nitellopsidaceae				
44	*E. mamillata (El. M)*	4	2	2	1	83	*Nitellopsis obtusa (Ni. O)*	1	1	0	0

	Family Araceae						Family Characeae				
45	*Calla palustris (C. P)*	3	4	2	0	84	*Chara aspera (Ch. A)*	1	1	1	0
	Family Lemnacae					85	*C. fragifera (Ch. F)*	2	2	2	2
46	*Lemna trisulca (L. T)*	2	3	4	4	86	*C. strigosa (Ch. S)*	1	0	0	0
47	*L. minor (L. M)*	2	2	3	3	87	*C. tomentosa (Ch. T)*	1	0	0	0
48	*Spirodela polyrhiza (Sp. P)*	1	3	4	4		Family Polygonaceae				
	Family Juncaceae					88	*Polygonum amphibium (Pol. A)*	2	1	2	0
49	*Juncus buffonius (J. B)*	1	2	2	1	89	*P. hydropier (Pol. H)*	2	2	5	0
						90	*P. bistorta (Pol. B)*	2	1	0	0
	Species total	90	82	71	59						
	Families total	35	34	32	25						

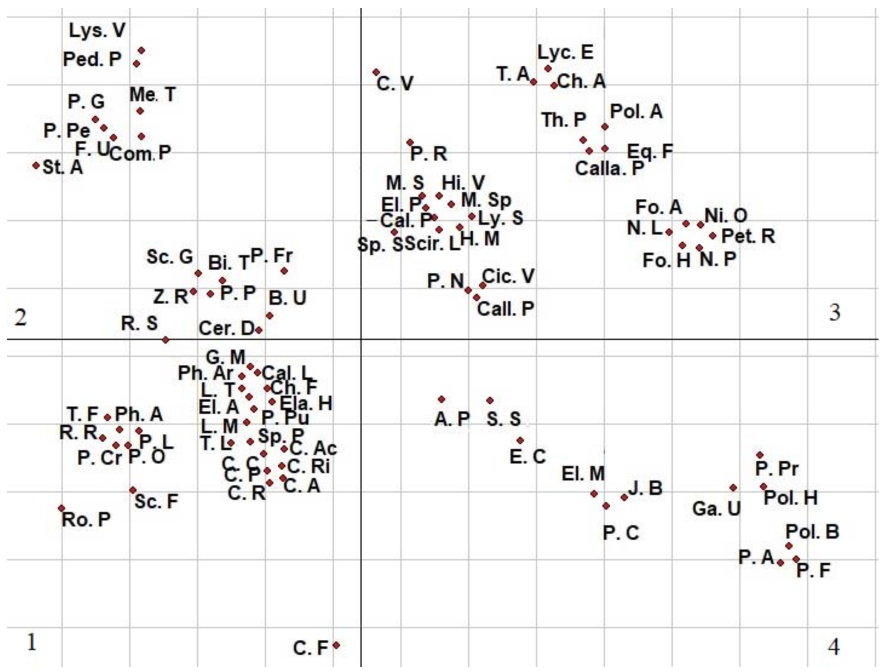

Fig.3 Frequency distribution of different macrophyte species in Lake Chebarkul
Note: Full species names are shown in Table 2 in brackets corresponding to each species

So, it gives ground to test the accumulation of these elements with the macrophytes of Lake Chebarkul. To give a complete answer to the question a comprehensive study of the accumulation by water plants of the mentioned above elements is necessary.

The research reveals the abundant growth of *Potamogéton lucens L.*, *P. obtusifolius*, *P. pusillus*, *P. crispus* and *Phragmites australis L.* in all the studied parts of the lake. These species were chosen as bioindicators.

4. CONCLUSION

Thus, the composition of ecological groups of macrophytes in relation to the water factor is one of the most important characteristics of water biotopes. The local flora of a separate water-body has some differences. The first group has a higher level of taxonomic diversity and the diversity of ecological forms of plants. This is due to the large variety of microbiotopes and the lack of man-made impact.

Macrophyte structure in Lake Chebarkul responds to the water-body environment. Approximately 59 % of the total taxon number is identified in all the sites. Only 9 % of them are sensitive taxons mainly and revealed in the first group. Taxons registered only in two groups (1 and 2) comprise 11 %, while the similarity of species of groups 1, 2 and 3 is 13%. As regards the macrophyte cover area, the highest level of the cover is for group 4 (102 %), a bit lower is for group 3 (92 %) and it is significantly low in groups 2 and 1 (58 % and 44 % respectively). There is an urgent need for such studies to identify more species capable of greater bioaccumulation.

5. REFERENCES

[1] Bastian R.K. and Hammer D., The Use of Constructed Wetlands for Wastewater

Treatment and Recycling, In Moshiri, G.A. (ed.). Constructed Wetlands for Water Quality Improvement, Lewis Publishers, CRC Press: Boca Raton, Fl, 1993, p. 59.

[2] Guzma H.M. and Jimenez C.E., Contamination of coral reefs by heavy metals along the Caribbean coast of Central America (Costa Rica and Panama), Marine Pollution Bulletin, Vol. 24, 1992, pp. 554–561.

[3] Gonzalez H., Pomares M., Ramirez M. and Torres I., Heavy metals in organism and sediments from the discharge zone of the submarine sewage outfall of Havanna city, Cuba, Marine Pollution Bulletin, Vol. 38, 1999, pp. 1048–1051.

[4] Echols K.R., Meadows J.C., and Orazio C.E., Pollution of aquatic ecosystems II: hydrocarbons, synthetic organics, radionuclides, heavy metals, acids, and thermal pollution. In G. E. Likens (Ed.), Encyclopedia of inland waters, Cambridge: Elsevier/Academic Press, 2009, pp. 120– 128.

[5] Kar R.N., Sahoo B.N. and Sukla L.B., Removal of heavy metal from mine water using sulphate reducing Bacteria, Pollution Research, Vol. 11, 1992, pp. 1–13.

[6] Mejare M. and Bulow L., Metal-binding proteins and peptides in bioremediation and phytoremediation of heavy metals. Trends Biotechnology, Vol. 19, 2001, pp. 67–73.

[7] Prasad M.N.V., Freitas H. and Pratas J., Metal tolerant plants and biodiversity prospecting to promote phytotechnologies for cleanup of metals in the environment, Chap. 25 In: Trace elements in the environment: Biogeochemistry, Biotechnology and Bioremediation, M.N.V. Prasad, K.S.Sajwan, and Ravi Naidu (Eds). (eds) CRC Press, USA, 2005, pp. 483-506.

[8] Vardanyan L.G. and Ingole B., Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems, Environment International, Elsevier, Vol. 32, 2006, pp. 208-218.

[9] Malec P, Mysliwa-Kurdziel B, Prasad MNV, Waloszek A. and Strzałka K., Role of aquatic macrophytes in biogeochemical cycling of heavy metals—relevance to soil: sediment continuum detoxification and ecosystem health, In: I. Sherameti and A. Varma (eds.). *Detoxification of Heavy Metals*. Soil Biology, Springer-Verlag Berlin Heidelberg, Vol. 30, 2011, pp. 345–368.

[10] Kostryukova A.M., Mashkova I.V., Trofimenko V.V. and Vasilieva E.I., Taxonomic structure of phytoplankton in Shershnevskoe Reservoir (Chelyabinsk, Russia), an artificial lake, IOP Conference Series: Earth and Environmental Science (EES), Vol. 351, 2019, 012001.

[11] Cardwell A.J., Hawker D.W. and Greenway M., Metal accumulation in aquatic macrophytes from southeast Queensland, Australia, Chemosphere, Vol. 48, 2002, pp. 653-663.

[12] Mashkova I.V., Krupnova T.G. and Kostryukova A.M., Water quality and aquatic macrophytes interrelationships for selected reserved lakes of south ural International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, Vol. 1, Issue 3, 2015, pp. 763-770.

[13] Prasad M.N.V. and Freitas H., Metal hyperaccumulation in plants - Biodiversity prospecting for phytoremediation technology. (Review article). Electronic Journal of Biotechnology, Vol.6, 2003, pp. 275–321.

[14] Mashkova I.V., Kostriykova A.M., Trofimenko V.V. and Slavnaya A.I. Study of the zooplankton community as an indicator of the trophic status of reservoirs of the Chelyabinsk Region, Russia, IOP Conference Series: Earth and Environmental Science, Vol. 344, Issue 1, 2019.

[15] Buosi A. and Sfriso A., Macrophyte assemblage composition as a simple tool to assess global change in coastal areas. Freshwater impacts and climatic changes, Science of the Total Environment, Vol. 605-606, 2017, pp. 559-568.

[16] Krupnova T.G., Mashkova I.V., Kostryukova A.M., Egorov N.O. and Gavrilkina S.V., Bioconcentration of heavy metals in aquatic macrophytes of South Urals region lakes, Biodiversitas, Vol. 19, Issue 1, 2018, pp. 296-302.

[17] Rogozin A.G. and Gavrilkina S.V., Causes for high concentration of copper and zinc in the water of some lakes in the Southern Urals, Water Resources Vol. 35, Issue 6, 2008, pp 701-707 (in Russian).

[18] GOST (Interstate standard) 24902-81, 1981. Housekeeping and potable water. General requirements for field methods of analysis (in Russian).

[19] GOST (Interstate standard) 17.1.5.04 – 81, 1981. Nature protection. Hydrosphere. Apparatus and mechanisms for selection, initial treatment and stering samples of natural waters. General technical conditions (in Russian).

[20] Nowakowski A.B., Possibilities and principles of operation of the software module "Graphs". Automation of scientific research, Issue 27, 2004, 31 p (in Russian).

[21] Parzych A, Cymer A and Macheta K., Leaves and roots of *Typha latifolia L.* and *Iris pseudacorus L.* as bioindicators of contamination of bottom sediments by heavy metals, Limnol. Rev. Vol. 16, Issue 2, 2016, pp. 77–83.