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STUDY OF THE TROPHIC STATUS AND ECOLOGICAL STATE OF THE COASTAL ZONES OF THE NATURAL MONUMENTS OF THE CHELYABINSK REGION (RUSSIA) OF THE TURGOYAK AND UVILDY LAKES

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ABSTRACT: Human impact on the hydro-ecological state of water bodies affects every stage of water ecosystem formation. Such organisms as Phyto and zooplankton, which constitute the basis for trophic chains, are susceptible to the impact. The complex load has certain patterns of the spatial distribution of coastal geosystems with different stages of degression as a result of the direct recreational impact on natural hydrological monuments. Studying basic patterns of anthropogenic succession in lake agroecosystem, exploring Phyto and zooplankton communities, revealing natural and anthropogenic factors that determine their life cycles, and stating relationships between separate indices of a hydrological state of the lakes in South Ural and an anthropogenic load of geocomplexes near-by are of the utmost importance, especially for natural hydrological monuments. The purpose of this study is to carry out the zoning of the coastal landscape and recreational zones and the ecological state of the coastal territories of tectonic lakes at various spatial levels. For the study, complex water samples were taken in the summer of 2020 and 2021. To determine the trophic status, methods were used that included several criteria. They are the taxonomic structure and biomass of zooplankton, some hydroecological indices, and canonical correspondence analysis (CCA). It was determined that the natural basis for recreation is areas, mesogeosystems, and facies (on the example of tectonic lakes), with territorial formations where recreation facilities are formed playing the key role. The catchment areas of the studied lakes are more often represented by several landscapes and localities consisting of several dozen tracts.

Keywords: Lake, Trophic Status, Eutrophic, Degradation Level, Zooplankton

1. INTRODUCTION

Most of the research works are related to practical requests and the state of large aquatic ecosystems that have economic and recreational significance or belong to specially protected natural objects Chelyabinsk region [1-3]. There are many lakes in the Chelyabinsk region. Their numbers range from 1193 to 3170 [4], [5]. The lakes are located unevenly. The largest number of them is located in the northern and eastern parts of the region. They are located in different natural zones: mountain-forest, forest-steppe, and steppe.

At the end of the 20th century, the spontaneous recreational use of the water bodies of South Ural had led to the unauthorized development of the lake coasts. Spontaneously organized attempts at nature management has resulted in significant local contrast in environmental conditions. As a result, a rather complex hierarchical network of natural and anthropogenic coastal management occurs along the shores of the lakes. The degree of degradation of the environment varies through the region.

There are articles on the eutrophication of water bodies, which leads to restructuring the phytoplankton community, changing seasonal dynamics of biomass, and increasing the importance of individual species [6]. At that time, there were many articles related to the identification of indicators of the ecological state of water bodies under anthropogenic impact [7].

Thus, phytoplankton communities of lakes were studied to identify indicator species of phytoplankton suitable for determining the water quality in the water body and its trophic capacity [8]. It was found that with an increase in the eutrophication rate, phytoplankton is one of the first to react to changes in habitat conditions [9-11]. The nature of the long-term dynamics of the taxonomic diversity of algae generally reflects the course of succession due to the processes of eutrophication.

It has been shown that when the trophic status of waterbodies changes from oligotrophic to eutrophic, the number of species, varieties and forms increases. This condition gradually decreases after the ecosystem reaches a certain critical level, with a minimum reached in highly polluted hypertrophic waters [11, 12].

The lakes of the Uvildy zone are actively used as sources of drinking water and industrial water supply, for drainage and recreation, and fishing purposes. The authors of this article have repeatedly studied the relationship between the trophic level of aquatic ecosystems of the forest zone of the Chelyabinsk region using quantitative and qualitative methods for assessing the phytoplankton community [13-16].

The lakes under study are located in the Eastern foothills and mountains of the Southern Urals. Their location within the above-mentioned territories contributed to the wide development of tourism, recreation, and healthcare services [4, 5]. The birch-pine forests prevailing in the catchments, as well as the lime and spruce forests, increase the attractiveness of the territory. On a ten-point scale, most of the parameters of the natural and recreational potential of water bodies are within 6-9 points [5, 6]. Most recreation facilities near the water bodies are concentrated within the area of twenty-minute walking distance from bus stops and railway stations, which determines the prospect of further development of recreation infrastructure in the study area.

Due to the increasing anthropogenic load on water bodies and the contrasting recreation, there was a problem in organizing a high-quality landscape and recreational structure of lake ecosystems. An important task was to study the trophic state of Lake Turgoyak, Uvildy (Russia), and the degree of degradation of coastal zones. The purpose of this study is to carry out the zoning of the coastal landscape and recreational zones and the ecological state of coastal territories of tectonic lakes at various spatial levels.

2. RESEARCH SIGNIFICANCE

Lake Uvildy and Lake Turgoyak, located in the South Urals (Russia), on the one hand, are natural monuments, and on the other, they are intensively used as tourist sites. Direct recreational impacts alter coastal geosystems depending on the intensity of this load. As a result, special conditions in the aquatic and semi-aquatic environment are created, which affect the species composition, diversity, and dominance of planktonic communities. Therefore, it is of great importance to assess the relationship between the degree of degradation of the coastal area and changes in the species structure of aquatic organisms. It is important to note that, in our case, the chemical indicators of water quality do not exceed the standards, and the revealed ratios of the species composition of aquatic organisms indicate a change in the conditions of the ecosystems of the studied lakes.

3. METHODOLOGY

3.1 Study Area

Lake Uvildy is located in the north of the Chelyabinsk region (Fig. 1), 80 km northwest of Chelyabinsk. The lake is a natural monument, and since the 1970s, it has been included in the international list of the most valuable lakes in the world. The main morphometric parameters of Lake Uvildy are: the height above sea level is 272 m, the water surface area is 68.1 km2, and the maximum and average depths are 38 and 13 m [4]. The lake is a typical tectonic water body located in a deep front fault. The shores of Lake Uvildy are strongly indented by peninsulas and bays. The western and southwestern parts are characterized by a significant rise in depth [4]. Lake Uvildy belongs to the group of low-water basin lakes. The water is completely renewed in 17 years. Most of the winding coastline is covered with pine and mixed forests. The water in the lake is fresh. According to its chemical composition, it belongs to the bicarbonate-calcium and according to the ratio of ions - to the sulfate-sodium [4]. In the catchment area of the lake, there are sources of sapropel mud and radon, which contributed to the development of national resorts [4, 5]. The total volume of water in the lake is about 1000 million cubic meters. The bottom of the lake is sandy, with pebbles and silt. The water in the lake warms up very slowly due to the great depth. Currently, it has a transitional status between oligo - and mesotrophic. In the coastal zone, over 90% of the forest stand is pine forests. The rest is birch and alder. As a result of a decreasing water level in the lake in the 1985-1990-s, the coastal part of the shallow waters was exposed to an area of about 200 hectares, and woody vegetation appeared on 10-15 % of this area [13]. Since the mid-twentieth century, Lake Uvildy has been used for recreational purposes. There are about seventy recreation centers, several sanatoriums, children's health camps, and private cottages on its shores. Almost the entire coastline is built up (except for small areas in the south and northwest of the lake).

Lake Turgoyak belongs to the Eastern Foothill Limnological Region [4]. The main morphometric parameters of Lake Turgoyak are the following: the area of the lake is 26.4 km^2, the length is 6.9 km, the maximum width is 6.3 km, and the length of the coastline is 27 km. The lake is located in a deep intermountain basin between the Ural-Tau and Ilmensky ridges at an altitude of 320 m above sea level. This is the deepest lake in South Ural. The maximum depth reaches 34 m, and the average is 19.2 m [4]. Stony soils (granites) are the most widespread in the catchment area. Their outcrops are often found on the surface in the form of entire massifs and rock outcrops (the northern and eastern shores of the lake) and in the form of clots and bolder stones on the mountain slopes. The soil layer covering granite massifs is low-power (0.3-0.5 m), unevenly podzolic in composition, and in river valleys, it is with an admixture of serozem. The hydrographic network of the catchment area is poorly developed - only six rivers and streams with a total length of 17 km.

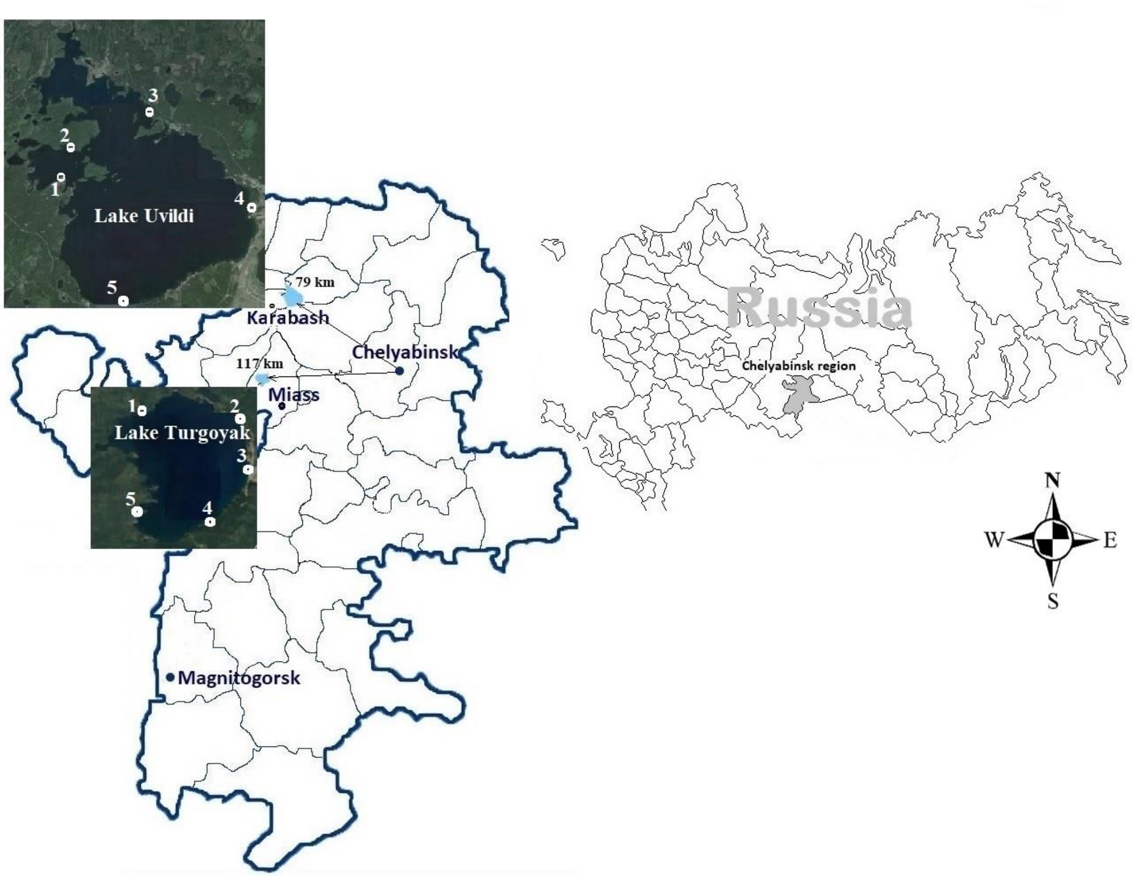

Fig. 1. Studied Lakes Uvildy and Turgoyak. 1 – 5 – sampling sites.

There are no marshes on its territory, and a third of the area is occupied by the lake. A lake basin is of tectonic origin. It does not have a definite geometric shape; it is relatively rounded. At a distance of about 200 m from the shore, the depth of the lake reaches 15-18 m. The role of surface runoff in the water supply of the lake is small due to the small size of the catchment area. The total length of flows within the catchment area does not exceed 20 km. Groundwater plays a significant role in the nutrition of the lake. The nutrition of all aquifers occurs through the infiltration of atmospheric precipitation.

The catchment area of the lake is located in a zone of a distinctly continental climate. The annual amplitude of the air temperature in the studied area is 33.6 °C. Winter is cold and long, and summer is warm but relatively short. A characteristic feature of the area is the late termination of spring and early resumption of autumn frosts in the air and on the soil surface. The Siberian anticyclone plays an important role in the formation of the climate in the Urals in winter, as well as cyclonic activity on the Arctic front. Intrusions of Arctic air masses lead to sudden weather changes. It is often influenced by southern cyclones moving from the Black, Caspian, and Aral Seas, as well as cyclones from the Barents Sea [4]. The average annual precipitation is 496 mm. Most of the precipitation falls during the warm period of the year, with a maximum in July.

Field expedition studies were conducted from 2017 to 2021 on the lakes Uvildy and Turgoyak. Five sites were selected for the study on Lake Uvildy and Lake Turgoyak (Fig. 1). The coordinates of the sites of Lake Uvildy: site 1 - 55 ° 32'9.13 "N, 60 ° 25'34.05" E, site 2 - 55°32'37.8"N 60°26'14.5"E, site 3 - 55°33'11.0"N 60°30'07.7"E, Site 4 - 55°31'12.1"N 60°34'26.5"E, site 5 - 55°28'45.4"N 60°29'36.0"E. Coordinates of Lake Turgoyak's sites: Site 1 - 55°10 '42.9"N 60°01'56.2" E, site 2 - 55°10'41.1"N 60°05 '43.9" E, Pad 3-55°09 '19.2"N 60°06 '35.3" E, Pad 4 - 55°07'44.6"N 60°04 '12.6" E, Pad 5 - 55°07'56.9"N 60°01'54.5" E. The selected sites are located in areas with different degrees of recreational load on the coast (various sanatoriums, recreation centers, and settlements).

To prepare for measurements and measure recreational load, the methods of trial areas, transect, mathematical-statistical and registration-measuring methods were used, according to OST 56-100-95 [17]. The degression stages (from 1 to 5) were determined by the ratio of the ground cover surface trampled to the mineral horizon to the total surface of the studied area (from 1.0 to 25.0 %, respectively) [17].

Table 1. There are 5 degression stages

degression stages	characteristics of the stages of digression	the ratio of the area of trampling to the total area of the surveyed land (%)
1	absence of the noticeable change in the biocenosis as a human activity result	≤ 1.0
2	is a minor change	1.1 – 5.0
3	is moderate change	5.1 – 10.0
4	is a strong degree of change	10.1 – 25.0
5	is almost completely degraded biocenosis	more than 25.0

To assess the degression of recreational forest areas, the method of test sites in recreation areas with a size of at least 100 x 100 m. The level of degression at the test site was determined by a generalized integral assessment of fifteen characteristic criteria for the anthropogenic transformation of geosystems on a five-point scale. The estimated number of one-time visitors to the territory of parks, forest parks, forests, and green zones was determined according to SP 42.13330.2016 (SNiP 2.07.01-89) [18].

3.2 Sampling of Zooplankton

Zooplankton was caught in the littoral part of the lakes. An automatic bathometer with a capacity of 5 liters was used for catching. The method of weighted average samples was applied. The volume of the selected water was, depending on the density of plankton, from 20 to 50 liters. The sample was concentrated immediately using a sieve from gas No. 64 to a volume of 35 ml. The work started in May and is planned to finish in November. 25 samples have been worked out. The samples were examined on the day of collection. The material was fixed with 70° alcohol. To determine the species, classical determinants were used [19-20].

3.3 Water Quality Analysis

The following instream parameters, including pH, dissolved oxygen (DO), and water temperature (TW), were measured in situ by a Portable Meter (Multitest IPL-513, Semico Ltd, Russia, Novosibirsk). Salinity (SALIN) was measured in situ by a Portable Meter (Multitest KSL-111, Semico Ltd, Russia, Novosibirsk). The air temperature was determined with a mercury thermometer.

At each site, water samples were also collected for further laboratory analysis, including nitrate-nitrogen (NO_3^-), nitrite–nitrogen (NO_2^-), ammonium–nitrogen (NH_4^+), chlorides (Cl^-), sodium (Na^+), potassium (K^+), total hardness (H), calcium hardness (Ca^{2+}), bicarbonates (HCO_3^-), permanganate oxidability ([O]), total iron (Fe). All these parameters were measured in the lab of the Department of Chemistry of South Ural State University according to the standard methods. For spectrophotometric analysis, the Spectrophotometer KFK-3 was used.

3.4 Data Analysis

The calculation of animal biomass was carried out according to the equations of proportional growth. Saprobity is determined by Pantle Buccu. All mathematical calculations and diagrams were performed in Excel 7.0.

To assess the similarity of plankton in different lakes and to analyze the influence of abiotic factors on the formation of a zooplankton community, the Chekanovsky-Sorensen coefficient was used, which was determined using GRAFS [21].

4. RESULTS AND DISCUSSION

The field studies revealed the landscape differentiation of the catchment areas. 3 landscapes and 15 localities were revealed within the watershed of Lake Uvildy [5]; 2 landscaping es and 5 localities were revealed for Lake Turgoyak (Fig. 2).

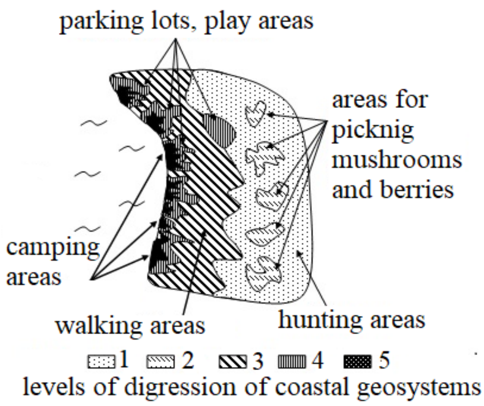

Fig. 2. Digression scheme of landscape-recreational zones of the third-order (camping sites) of the coastal territory of Lake Uvildy

More detailed landscape differentiation is revealed for the coastal 300-meter zone, which is intensively used in recreation. 101mesogeosystems are distinguished for Lake Uvildy; more than 40 – for Lake Turgoyak (Fig. 3).

The area of recreation facilities near the studied lakes varies from 0.5 to 20.0 hectares, and the number of vacationers is from 20 to 1500 people. The maximum one-time recreational load on the coastal territories of lakes ranges from 5 to 120 people/ha. The prevailing load is 25-50 people/ha since most facilities are represented by small recreation centers, where the maximum occupancy of vacationers is observed at this load.

Tables 2 and 3 show the results of the physicochemical analysis of water in the sampling sites Lake Uvildy and Lake Turgoyak. Figure 3 shows that anthropogenic activity has severely destroyed the state of coastal areas and the degree of digression is very high. However, the values of water quality indicators do not exceed environmental standards. Even the highest recreational load does not degrade water quality at present. Likely, these reservoirs are not yet devoid of the ability to self-purify.

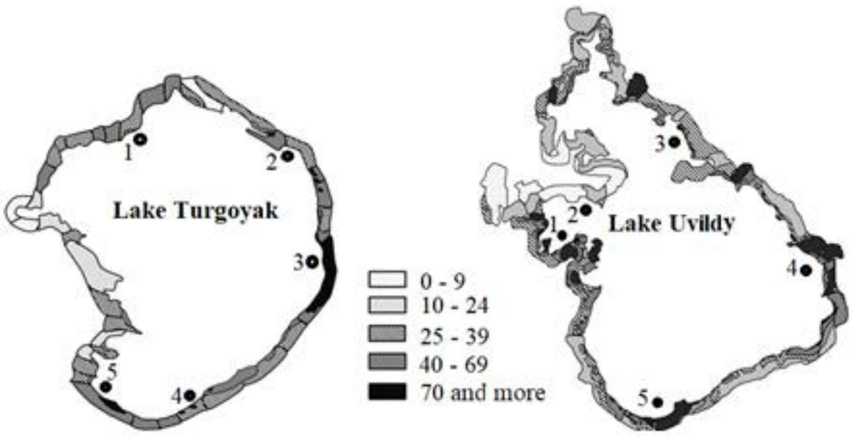

Fig. 3. Maximum one-time recreation density of the coastal territories of Lake Turgoyak and Uvildy 2021 (person per hectare))

The territorial pattern of the recreational infrastructure and especially its density have left a significant " imprint "on the formation of the spatial “pattern” of the degression of coastal geosystems of lakes. The assessment of the stages of degression of geosystems was based on 5 criteria according to the matrix method of introducing weight parameters of degression according to Volkova [22].

Table 2. Physicochemical parameters Lake Uvildy

Chemical parameters	Site				
	1	2	3	4	5
TW, °C	24	24	22	22	21
DO, mg/l	9.06	8.92	8.90	3.56	4.54
pH	8.45	8.47	8.86	8.89	8.95
SALIN, mg/l	305.0	308.3	195.5	209.4	215.1
NH_4^+, mg/l	0.49	0.40	0.75	0.85	0.76
NO_3^-, mg/l	0.668	0.475	1.51	2.51	2.34
NO_2^-, mg/l	0.0005	0.002	0.004	0.006	0.008
Cl^-, mg/l	9.23	10.66	11.85	12.56	16.65
Na^+, mg/l	2.63	2.55	2.80	3.98	4.08
K^+, mg/l	1.59	1.79	1.80	1.96	2.80
Ca^{2+}, mg/l	35.10	33.76	29.8	30.2	28.6
HCO_3^-, mmol/l	3.0	3.0	3.3	3.5	3.3
H, mmol/l	3.85	3.70	3.65	4.81	4.92
[O], mgO/l	1.6	2.0	2.9	2.4	3.95
COND, mS/m	32.79	38.43	38.77	36.82	37.23

Table 3. Physicochemical parameters Lake Turgoyak

Chemical parameters	Site				
	1	2	3	4	5
TW, °C	21	21	21	18	21
DO, mg/l	8.16	7.37	4.27	6.97	7.37
pH	7.54	7.43	7.58	6.93	7.41
SALIN, mg/l	120.6	121.2	149.2	160.1	162.6
NH_4^+, mg/l	0.085	0.060	0.135	0.150	0.135
NO_3^-, mg/l	0.46	2.46	2.79	2.05	1.51
NO_2^-, mg/l	0.003	0.002	0.004	0.006	0.007
Cl^-, mg/l	3.54	4.00	5.31	13.74	7.53
Na^+, mg/l	1.17	1.03	1.14	3.02	2.05
K^+, mg/l	0.56	0.66	1.36	3.49	5.31
Ca^{2+}, mg/l	38.66	37.97	36.31	33.49	29.27
HCO_3^- mmol/l	1.20	1.15	1.2	1.4	1.35
H, mmol/l	1.40	1.75	1.50	1.90	1.65
[O], mgO/l	1.6	0.8	5.6	1.6	1.6
COND, mS/m	114.7	110.0	90.63	177.0	135.9

According to the results of our research in 2017 in the three-hundred-meter coastal zone of the lake about 8 % of the territory is represented by geosystems with the 5th stage of degression, 27 % of the territory – with the 4th stage, about 65 % of the territory is with stage 2-3 [5]. In a similar zone of Lake Turgoyak, 9 % of the territory is represented with stage 5, 26 % – with stage 4, and 65 % – with stages 2-3. By 2021, there have been changes for the worse.

We calculated the ratio of taxa Rotifera (R): Copepoda (C): Cladocera (Cl), at which we took Cladocera as a unit (Table 4).

Table 4. The ratio of the main zooplankton taxa in the lakes Uvildy and Turgoyak, depending on the degree of degression of the territory

Lake	Site	Degression degree		Relation of zooplankton groups R: C: Cl
		2017	2021	
Turgoyak	1	1	1	0.3:1.15:1
	2	4	4	1:1.5:1
	3	5	5	2.5:1.8:1
	4	2	5	2.2:1.6:1
	5	3	4	1.2:1.5:1
Uvildy	1	2	2	0.9:1.5:1
	2	1	1	0.2:0.19:1
	3	3	4	1.3:1.6:1
	4	4	4	1.5:1.8:1
	5	5	5	2.5:1.8:1

The deterioration is associated with an increasing degree of degression as a result of an increasing number of vacationers. The increase in the load on the lakes is associated with quarantine measures for the coronavirus, which did not allow the population to leave the region.

The 4-th and 5-th s degrees of degression prevail on the camping sites (Fig. 4) located not far than 50 m from the lake. The 3-d degree is at a distance of 50-200 m from the lake. The 2-nd degree dominates at a distance of 200-500 m.

Figure 4 shows that the decrease in the degree of degression on the territory of camping sites is almost directly proportional to the square of the distance from the lake. A significant improvement in the ecological state is observed here already at a distance of more than 200 m from the edge of large tectonic lakes.

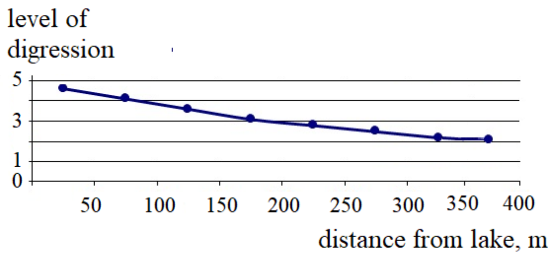

Fig. 4 Dependence of the remoteness of the territory from the lake's edge and the stage of its degression on the territory of camping sites.

When moving away from the lake's edge within large recreation centers, the degree of degression of the territory does not practically change, slightly decreasing from a distance of more than 200 m. On average, the 4th degree of degression dominates (Fig. 5).

When moving away from the lake's edge within small recreation centers, the degree of degression of the territory decreases in proportion to the distance from the water bodies. At a distance of up to 150-200 m from the edge of water bodies, the 4-5 degrees of digression dominates.

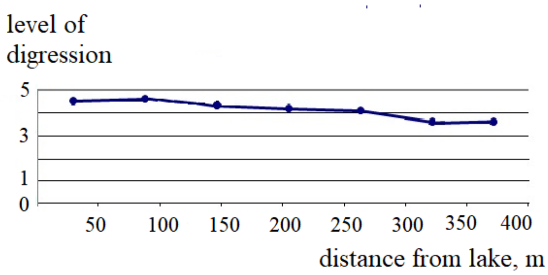

Fig. 5 The dependence of the remoteness of the territory from the lake's edge and the degree of its degression on the territory of large recreation centers.

Degree 3 prevails, and areas with the 2nd one appear (Fig. 6). A close relationship between the maximum recreational density and the degree of degression of the coastal territory of lakes is revealed (Fig. 6).

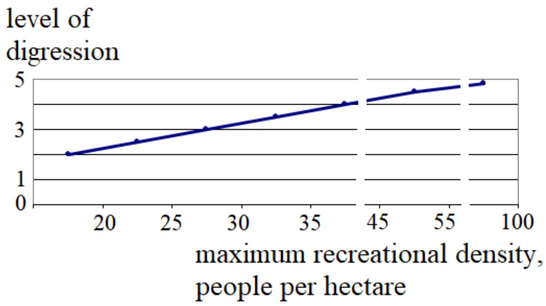

Fig. 6 The dependence of the degression of the territory on the recreational density.

In the plan, the areas with the 4-5 stage of degression at any of the considered spatial levels in the coastal territories have a radial linear-nodal or linear-block pattern. Nodes correspond to recreation facilities. Lines are trails, roads, and communications. In most recreation centers, geosystems with degrees 4-5 are distributed at a greater distance from lakes than similar geosystems of camping sites.

For coastal geosystems with the 3rd "threshold" degree of degression, the recreational density most often corresponds to from 20-25 (in spruce forests) to 40 people/ha (in birch and birch-lime forests).

Given a brief characteristic of the distribution of zooplankton in lakes, it should be noted that Rotifera is distributed fairly evenly across all sites, with a total average number from 1176 animals/m^3 (Lake Turgoyak) to 2517 animals/m^3 (Lake Uvildy). Concerning crustaceans, the differences between the sites are very large. Cladocera is the leading group of zooplankton, prevailing in taxonomic diversity, occurrence, and zoonotic significance. The density and biomass of zooplankton of Lake Turgoyak at sites 1 (5912 animals/m^3, 0.5323 g/m^3, respectively) and 2 (5731 animals/m^3, 0.4134 g/m^3) have the highest values for the lake, at site 3 - the lowest (401 animals/m^3, 0.0211 g/m^3), sites 4 (1452 animals/m^3, 0.0842 g/m^3) and 5 (1853 animals/m^3, 0.1322 g/m^3) occupy an intermediate position according to these indicators. The density and biomass of zooplankton of Lake Uvildy at sites 1 (15918 animals/m^3, 1.5453 g/m^3, respectively) and 2 (15731 animals/m^3, 1.2154 g/m^3) have the highest values for the lake, at site 5 - the lowest (1251 animals/m^3, 0.0617 g/m^3), sites 3 (8531 animals/m^3, 0.5842 g/m^3) and 4 (7867 animals/m^3, 0.4928 g/m^3). Table 1 shows that the ratio of the main groups of zooplankton varies depending on the state of the environment. The higher the degression of the territory, the greater the impact on the ecosystem, and the more Rotifera are in the water, some of which are very stable.

5. CONCLUSION

It was found that moving from the peripheral areas of recreational zones to the coasts and in the direction of territories with transport accessibility, the degree of degression increases from the 2nd to the 4th stage, and the recreational load increases from 5-10 to 100 people/ha or more. On 18-45 % of the coastal territories, the allocated maximum recreational density exceeds the permissible values according to OST 56-100-95 and ranges from 0.3 to 3-4 maximum permissible recreational loads. Most often, the contours of coastal geosystems with one degree of degression coincide with the contours of the landscape and recreational zones of the 3rd order. It is established that the larger the recreation facility is, the smaller the spatial differences in the ecological state of its geosystems. In general, littoral zooplankton is more abundant in those parts of the lake water area where there are optimal conditions for its development, the lowest recreational load, and the lowest degree of degression.

6. ACKNOWLEDGMENTS

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