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Specific Features of the Species Composition of Zooplankton in Mineralized Waterbodies of Specially Protected Natural Territories in the Ulug-Khem Depression (Republic of Tuva)

N. A. Kirova*

Tuvinian Institute for Exploration of Natural Resources, Siberian Branch, Russian Academy of Sciences, Kyzyl, 667007 Russia
**e-mail: chink@list.ru*

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Abstract—The species composition of zooplankton in mineralized waterbodies located in the Ulug-Khem depression (Republic of Tuva) was studied. These lakes have the status of natural monuments of regional significance. In total 53 species of microscopic crustaceans and rotifers from 32 genera, 13 families, and eight orders were recorded. Cladocerans comprise 53% of the species. The dependence of the species diversity on the level of mineralization was revealed; 89% of the species were found in brackish water bodies. The zooplankton composition of the hyperhaline Dus-Khol (Svatikovo) and Cheder lakes has remained constant for many decades. The zooplankton includes some species known only from the Republic of Tuva in Russia: *Microcyclops afganicus* and *Macrotrix tabrizensis*. The species *Metadiaptomus asiaticus* and *Alona irinae*, rare for the fauna of Russia, live in Haak-Khol Lake. A decrease in the total numbers of zooplankton is observed in the lakes: in Dus-Khol Lake, it has decreased by a factor of four; in Khadyn Lake, by 10–19 times as compared to the middle of the last century. Despite the lack of intermediate information, this could be regarded as a consequence of the anthropogenic impact. The emergence of a species indicator of pollution (*Brachionus nilsoni*) in Khadyn Lake confirms this version. At the same time, the stable finding of species rare for the fauna of Russia indicates the presence of favorable conditions for their development and life, which increases the value of the waterbodies themselves, which are already unique natural objects.

Keywords: zooplankton, saline lakes, specially protected areas, rare Crustacean species, pollution indicator
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INTRODUCTION

In organizing specially protected natural areas (SPNA), an inventory of the species composition of biota is carried out, but, often, not all groups of organisms are covered by such studies. This applies to the zooplankton of the majority of waterbodies in the SPNA of Tuva, which has turned out to be practically unexplored. The salt–mud lakes of balneological importance, known for their healing properties far beyond the borders of the republic are situated in the central part of the republic (Pinneker, 1968). Since 2007, these lakes have received the status of natural monuments of regional significance (*Postanovlenie* ..., 2007). One of them, Khadyn Lake, is included in the Perspective List of Wetlands Protected by the Ramsar Convention of International Importance and is a Key Bird Area of Russia (IBA), included in the Catalog of Important Birds Areas in Asia (2004) (*Vodno-bolotnye* ..., 2000). The data on the zooplankton of the lakes are rather scarce, and the published papers on this issue are separated by a significant time interval (Gundrizer and Ivanova, 1966; Popkov and Popkova, 1983; Popkova, 2004; Litvinenko et al., 2009). Studies carried out at Dus-Khol Lake in recent years were associated with an attempt to describe the state of the brine shrimp population (Kirova et al., 2018). In recent years, some information has appeared on the species composition of zooplankton in Khaak-Khol and Khadyn lakes (Kirova et al., 2012; Kirova, 2018). At the same time, numerous adjacent small water bodies have remained completely unexamined by hydrobiologists, although, as practice shows, it is these small water bodies that make a significant contribution to the overall biodiversity of the territories (Kotov, 2013).

The goal of the present paper is (a) to reveal the taxonomic composition of zooplankton of the salt lakes and adjacent water objects situated within the borders of SPNA of the Ulug-Khem depression, (b) to reveal the dependence of zooplankton species diversity on water salinity, and, (c) based on the comparison with published data on previous years, to reveal the long-term tendencies in the changes of the zooplankton species composition.

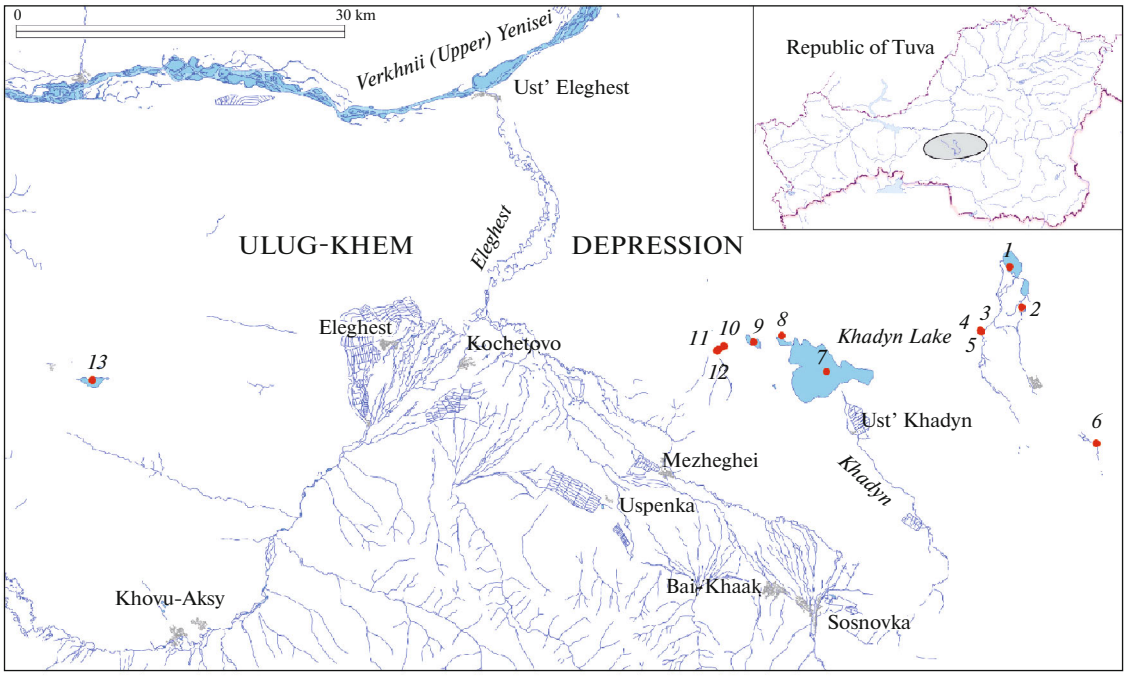

Fig. 1. Locations of the waterbodies surveyed in the Ulug-Khem depression: catchment area of Cheder Lake (*1–6*): *1,* Cheder Lake; *2,* a hollow near Cheder Lake; *3,* Kozhur-Sudak spring (dam); *4,* pond no. 1; *5,* pond no. 2; *6,* Kozhur-Sudak spring (middle of the length); catchment area of Khadyn Lake (*7–8*): *7,* Khadyn Lake; *8,* a hollow near Khadyn Lake; *9,* Dus-Khol Lake (Svatykovo); catchment area of Kaak-Khol Lake (*10–12*): *10,* a small lake in the Kuluzun tract; *11,* adjacent water near Kaak-Khol Lake; *12,* Kaak-Khol Lake; *13,* Haak-Khol Lake (the map was made based on the database Resource Potential of the Republic of Tuva (Tuvinian Institute for Exploration of Natural Resources, Siberian Branch, Russian Academy of Sciences).

MATERIALS AND METHODS

The study area is located in the central part of Tuva, in the Ulug-Khem depression, and includes Khadyn, Cheder, Dus-Khol (Svatikovo), and Kaak-Khol lakes located compactly; Khaak-Khol Lake is situated in the northern spurs of the Tannu-ool mountain ridge, bordering the depression from the south (Fig. 1). The lakes studied are landlocked, muddy, well-warmed, and small in area, except for Khadyn Lake, which is the largest salt waterbody in the republic (Pinneker, 1968); its depths reach 10 m (Vysotina, 2009).

Inflowing watercourses maintain the water level: Cheder and Kozhur-Sudak creeks feed Cheder Lake; Kara-Sug Creek, Kaak-Khol Lake; Khadyn Creek, Khadyn Lake (see Fig. 1). The atmospheric precipitation and groundwater contribute to the lake's water supply. Within the depression the groundwaters are fresh and mineralized (1.1–1.8 g/L); these waters discharge mainly into lake basins, forming adjacent waterbodies, for example, in the Kuluzun land tract (Fomicheva et al., 1966) (see Fig. 1). In the steppes, widespread saline soils are tamed to areas wedging out of brackish groundwater, contributing to the salinization of shallow steppe waterbodies (Fomicheva et al., 1966). This phenomenon resulted in salinization of the floodplain waterbodies of Kozhur Sudak Creek and its channel was dammed where the road crossed. As a result, a water area about 60 m^2 was formed filled with, as it was revealed by the chemical analysis, brackish water (Table 1). The creek itself was initially freshwater and is used for watering cattle. Aquatic vegetation is developed in all waterbodies except for Dus-Khol and Kaak-Khol lakes.

At present, the lakes are actively used for recreation and health care (on Cheder Lake, from 1932 to 2015, a resort functioned; Dus-Khol Lake (Svatikovo) is mostly used for unorganized recreation).

The zooplankton sampled in the Khadyn, Cheder, Dus-Khol, Kaak-Khol, Khaak-Khol salt lakes and adjacent small waterbodies and brooks served as the material for the present study. Samples were collected during the open water period (May to September) in the years 2009–2012, 2014, and 2017. The sampling of the materials was carried out according to standard methods, using a hydrobiological net with a gauze mesh size of 100 μm; the samples were preserved with 4% formalin. The materials were processed according to the generally accepted routine (Abakumov, 1992). The animals were identified, if possible, down to the species (*Opredelitel'*..., 1995, 2010).

The fauna types of microscopic crustaceans and rotifers are given according to the identification key books (*Opredelitel'*..., 1995, 2010). The biotopic con-

Table 1. Characteristics of the lakes studied

No.	Catchment area	Waterbody	Coordinates	Absolute height, m	Area, km^2	Depth, m	T, °C	TDS, g/L	pH	Type
1	Catchment area, Cheder Lake	Cheder Lake	51.422055° 94.773963°	706	5.0	2.0	26	24.82–67.17*	9.1–10.95*	4
2		Wet hollow, Cheder	51.388958° 94.789439°	721	–	0.35	23.3	slightly salty to taste	–	2
3		Kozhur-Sudak Creek-1	51.276568° 94.884687°	805	–	0.5	18	0.43	–	1
4		Floodplain waterbody no. 1	51.369487° 94.735314°	726	0.009	0.3	21	4.26	9.64	2
5		Floodplain waterbody no. 2	51.369819° 94.734954°	728	0.009	0.2	21	4.32	9.95	2
6		Kozhur-Sudak Creek-2	51.369175° 94.735969°	736	–	0.6	18.3	1.22	–	2
7	Catchment area, Khadyn Lake	Khadyn Lake	51.337617° 94.533055°	707	23.6	10.0	23.0	13.0–16.0	8.4–9.4	3
8		Wet hollow, Khadyn	51.367068° 94.475021°	720	–	0.3	24.1	slightly salty to taste	–	2
9	–	Dus-Khol (Svatikovo)	51.362253° 94.438132°	707	0.55	3.4	27	127.5	7.9	4
10	Catchment area, Kaak-Khol Lake	Kuluzun land tract	51.358820° 94.398796°	704	0.01	0.3	24	4.24	9.26	2
11		Adjacent waterbody no. 1 (Kaak-Khol)	51.356531° 94.392774°	702	0.01	0.1	23	2.6	–	2
12		Kaak-Khol Lake	51.355380° 94.390341°	699	2.2	0.6	28	173.9	8.6	4
13	–	Khaak-Khol Lake	51.331152° 93.573276°	1100	4.0	2.0	19	7.4	–	2

* Data courtesy of Ch.K. Oydup (Tuvan Institute for Integrated Development of Natural Resources, Siberian Branch, Russian Academy of Sciences). The types of water bodies are given according to O.A. Alekin (1970): 1, fresh (0.2–1 g/L); 2, brackish (1–7 g/L); 3, saline (7–45 g/L); 4, brines (>45 g/L).

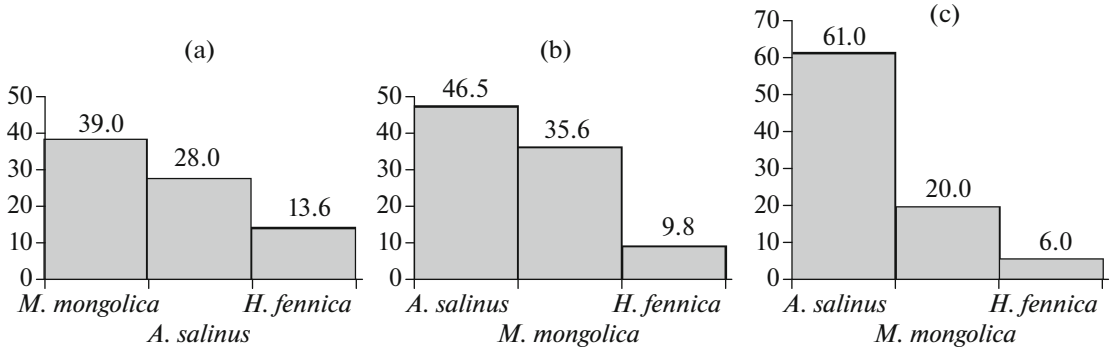

Fig. 2. Rank distribution (Ni, %) of the dominant species of zooplankton in Khadyn Lake: (a) 2011; (b) 2012; (c) 2017.

finement of species in the waterbodies studied is given according to I.K. Rivier et al. (2001).

The dominant and structure-forming species were assessed using the rank distribution function of the relative abundance of species (Andronikova, 1996). Species with an abundance of at least 5% were considered dominant. To assess the species diversity, the Shannon information index (H_{bit}) by abundance was used (Magarann, 1992). The dependence of the number of species on water salinity was analyzed using the approximation of a nonlinear power function, the quality of which was assessed using the coefficient of determination (R^2). For statistical data processing, the Excel 10.0 software package was used.

RESULTS

Totally 53 species of microscopic crustaceans and rotifers from 32 genera, 13 families, and eight orders were found. Of these, 28 species of five families are cladocerans (this is 53% of the total), 13 species of two families are copepods, and one species belongs to the fairy shrimps (*Artemia* sp., Anostraca) (Table 2). Among cladocerans, the greatest species richness is noted in the families Daphniidae and Chydoridae: ten and seven species, respectively. Among the copepods of the fam. Cyclopidae ten species are registered; in the fam. Diaptomidae, three species. Rotifers are represented by 12 species, of which six taxa below the genus rank belong to the fam. Brachionidae (see Table 2). In terms of zoogeographic distribution among the taxa identified, Palearctic species comprise 52%; cosmopolitan species, 32%; Holarctic species, 14%; and one species has a Central Asian range, i.e., the identified fauna is typical for the Palaearctic. Most of the Palearctic species are recorded among cladocerans, while most cosmopolitans are recorded among rotifers. According to the biotopic confinement in the waterbodies studied, eurytopic and littoral forms comprise 28% each; phytophilic forms, 19%; planktonic, 17%; and benthic, 8% (see Table 2).

Dus-Khol Lake (Svatikovo) is inhabited exclusively by a halobiont brine shrimp *Artemia* cf. *sinica* Yaneng 1989 (Litvinenko et al., 2009). The density of this species in 2017 was 7 ind./L; in 2018, 18 ind./L (Kirova et al., 2018). In Cheder Lake, in addition to brine shrimp (88%), the zooplankton community consists of *Brachionus plicatilis* (11.9%) and harpacticoids (0.1%). May samples (24.82 g/L) contain *B. urseus* (see Table 2). In 2017 and 2018 the abundance of *Artemia* sp. in Cheder Lake was 86 and 98 ind./L; in Kaak-Khol Lake the density in 2010 was 16 ind./L; in 2017, 9 ind./L.

The species composition of the zooplankton of the salt Khadyn Lake includes 16 taxa with a rank below the genus (see Table 2). The majority of the population is determined by the halophiles *A.* (*R.*) *salinus* (28–61%), *M. mongolica* (20–39%), and *H. fennica* (6–13.6%). The proportion of taxa in terms of dominance differs somewhat over the years, but in general, the dominant assemblage remains unchanged (Fig. 2). In terms of biomass, only crustaceans *A. salinus* (to 71%) and *M. mongolica* (to 28%) dominate.

It is noteworthy that *B. plicatilis* is present in all samples but does not reach the 5% threshold. In 2017, *B. nilsoni*, an indicator of pollution, was noted here (Kutikova, 1970; Kirova et al., 2018). The interannual values of abundance are 33830–65280 ind./m^3, and those of biomass, 1.85–3.75 g/m^3.

The zooplankton of the brackish water Haak-Khol Lake includes 27 species (see Table 2). The structure-forming nucleus consists of halophiles *D. magna*, *M. asiaticus*, *H. fennica*, and euryhaline *E. arcanus* and *A. basilifer* (Fig. 3). In all years, the core includes *D. magna*, *H. fennica*, and *E. arcanus.* Of the diaptomuses, *M. asiaticus* dominated in 2010; and *A. basilifer,* in 2016 (see Fig. 3). The interannual values of the number are 215500 and 116500 ind./m^3; and those of biomass, 64.3 and 41.6 g/m^3. The biomass is dominated by *D. magna* (87–92%). *Wlassiscia pannonica* is present in all years studied, but solitary; anostracan nauplii were found.

Table 2. Taxonomic composition of zooplankton in mineralized water bodies of specially protected natural areas of the Ulug-Khem depression

Taxon	Zoogeographic characteristics	Ecological characteristics	Cheder Lake	Wet hollow Cheder	Ko-Su Creek (levee)	Floodplain waterbody 1	Floodplain waterbody 2	Kozh-Sul Creek 2	Khadyn Lake	Wet hollow Khadyn	Dus-Khol Lake	Kuluzun land tract	Adjacent waterbody Kaak-Khol	Kaak-Khol Lake	Khaak-Khol Lake
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Type Rotifera															
Class Eurotatoria Markevich, 1990															
Order Protoramida Markewich, 1990															
Family Hexarthridae Bartos, 1958															
Hexarthra fennica (Levander, 1892)	C	Pl	–	–	–	–	–	–	+	–	–	–	–	–	+
Order Transversiramida Markevich, 1990															
Family Brachionidae Ehrenberg, 1838															
Brachionus plicatilis Müller, 1786	C	Pl	+	–	–	+	–	–	+	–	–	+	+	–	–
Brachionus nilsoni Ahlstrom, 1940	P	Eut	–	–	–	–	–	–	+	–	–	–	–	–	–
B. urseus (Linnaeus, 1758)	C	Eut	+	–	–	–	–	–	–	–	–	–	+	–	–
B. variabilis Hempel, 1896	C	Eut	–	–	–	–	+	–	–	+	–	–	–	–	–
Brachionus sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Family Brachionidae Ehrenberg, 1838															
Keratella quadrata Müller, 1786	C	Eut	–	–	–	–	–	–	+	–	–	–	–	–	+
Notholca acuminata (Ehrenberg, 1832)	C	Pl	–	–	–	–	–	–	+	–	–	–	–	–	+
Family Euchlanidae Bartoš, 1959															
Euchlanis dilatata Ehrenberg, 1832	C	Eut	–	+	+	–	+	+	+	–	–	–	+	–	–
E. piriformis Gosse, 1851	P	Ph	–	–	+	–	–	–	–	+	–	–	–	–	–
Family Mytilinidae Bartoš, 1959															
Mitilina mucronata (Müller, 1773)	H	Ph	–	–	–	+	–	–	–	–	–	–	–	–	–
Order Transversiramida Markewich, 1990															
Family Lecanidae Bartoš, 1959															
Lecane luna (Müller, 1776)	C	Eut	–	–	–	–	–	–	–	–	–	–	+	–	–
Order Saltiramida Markevich, 1989															
Family Asplanchnidae Harring et Myers, 1926															
Asplnchna brighrwelli Gosse, 1850	C	L	–	–	–	–	–	–	–	+	–	–	+	–	–

Table 2. (Contd.)

Taxon	Zoogeographic characteristics	Ecological characteristics	Cheder Lake	Wet hollow Cheder	Ko-Su Creek (levee)	Floodplain waterbody 1	Floodplain waterbody 2	Kozh-Sul Creek 2	Khadyn Lake	Wet hollow Khadyn	Dus-Khol Lake	Kuluzun land tract	Adjacent waterbody Kaak-Khol	Kaak-Khol Lake	Khaak-Khol Lake
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Order Saeptiramida Markevich, 1990 Family Notommatidae															
Cepalodella sp.			–	–	–	–	–	–	–	–	–	–	–	–	+
Class Archiorotatoria, Markevich, 1990 Order Bdelloida Hudson, 1884															
Bdelloida		–	+	–	+	–	+	+	+	–	–	–	–	–	+
Type Arthropoda Superclass Crustacea Class Branchiopoda Latreille, 1816 Order Anomopoda Sars, 1865 Family Moinidae Goulden, 1968															
Moina mongolica Daday, 1901	P	Pl	–	–	–	–	–	–	+	–	–	–	–	–	–
M. brachiata Jurine, 1820	P	Pl, L	–	–	–	+	+	–	–	+	–	–	–	–	+
Family Macrothricidae Norman et Brady, 1876															
Wlassicia pannonica Daday, 1904	P	L	–	–	–	–	–	–	–	–	–	–	–	–	+
Macrothrix rosea (Lievin, 1848)	H	L,Ph	–	–	–	+	–	–	–	–	–	–	+	–	+
M. hirsuticornis Norman et Brady, 1876	H	Ph,Bt	–	–	–	+	–	–	–	–	–	+	+	–	–
Macrothris tabrizensis Dumont et al., 2002	P	Ph	–	–	–	+	+	–	–	–	–	–	–	–	–
Family Daphniidae Straus, 1820															
Dahnia magna Straus, 1820	H	L	–	–	+	+	+	–	–	–	–	–	+	–	+
D. longispina O.F. Müller, 1875	P	Pl	–	–	+	–	–	+	–	–	–	–	–	–	+
D. pulex Leydig, 1860	P	Eut	–	+	+	+	+	–	–	+	–	–	+	–	+
D.curvirostris Eylmann, 1887	H	L	–	+	+	–	–	–	–	–	–	–	–	–	–
Ceriodaphnia reticulata (Jurine, 1820)	P	L	–	+	+	+	–	–	–	–	–	–	+	–	+
Scapholeberis rammneri Dumont et Pensaert, 1983	P	Ph	–	–	–	–	–	–	–	+	–	–	+	–	+
S. mucronata (Sars, 1890)	P	Bt, Ph	–	–	+	+	–	–	–	–	–	–	+	–	–

Table 2. (Contd.)

Taxon	Zoogeographic characteristics	Ecological characteristics	Cheder Lake	Wet hollow Cheder	Ko-Su Creek (levee)	Floodplain waterbody 1	Floodplain waterbody 2	Kozh-Sul Creek 2	Khadyn Lake	Wet hollow Khadyn	Dus-Khol Lake	Kuluzun land tract	Adjacent waterbody Kaak-Khol	Kaak-Khol Lake	Khaak-Khol Lake
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Meganefenestra aurita (Fisher, 1849)*	P	Ph	–	–	+	+	–	–	–	–	–	–	+	–	+
Simocephalus vetulus (Müller, 1776)	P	L, Ph	–	+	–	+	–	–	–	–	–	–	+	–	–
S.expinosus (de Geer, 1778)	P	Ph	–	+	+	–	–	–	–	–	–	–	+	–	–
S. mixtus Sars, 1903	H	Ph	–	–	–	–	–	–	–	–	–	–	+	–	–
Family Bosminidae Sars, 1865															
Bosmina longirostris (Müller, 1785)	C	Eut	–	–	–	–	–	–	–	–	–	+	–	–	–
Family Chydoridae Dubowski et Grochowski, 1894															
Chydorus sphaericus Müller, 1785	C	Eut	–	+	+	+	+	+	–	–	–	–	+	–	+
Alona affinis (Leydig, 1860)	P	Ph	–	–	–	+	+	–	+	–	–	–	–	–	+
Alona guttata Sars, 1862	P	L, Ph	–	–	–	+	+	–	–	–	–	–	–	–	–
Coronatella rectangular (Sars, 1862)	P	Eut	–	–	+	+	+	–	+	–	–	+	–	–	+
Alona flossneri Sinev, Alonso, Sheveleva, 2009	P	L	–	–	–	+	+	–	+	–	–	–	+	–	+
A. costata Sars, 1862	H	L, Bt	–	–	–	–	–	–	+	–	–	–	–	–	–
A. irinae Sinev, Alonso et Sheveleva, 2009	CA	Ph	–	–	–	–	–	–	–	–	–	–	–	–	+
Alonella excisa (Fisher, 1854)	C	L,Ph	–	–	–	+	+	–	–	–	–	–	+	–	–
Family Chydoridae Dubowski et Grochowski, 1894															
Oxyurella tenuicaudis Sars, 1862	P	Bt,Ph	–	–	–	+	+	–	–	–	–	–	+	–	+
Disparalona rostrata (Koch, 1841)	P	L, Bt	–	–	–	–	–	+	–	–	–	–	–	–	–
Class Maxillopoda Edwards, 1840 Subclass Copepoda Edwards, 1840 Order Cyclopoida Burmeister, 1834 Family Cyclopidae Dana, 1853															
Eucyclops serrulatus Fischer, 1851	C	Eut	–	–	+	+	+	+	+	–	–	–	+	–	+
E. arcanus Alekseev, 1990	P	Bt, L	–	–	–	+	+	–	–	–	–	–	–	–	+

Table 2. (Contd.)

Taxon	Zoogeographic characteristics	Ecological characteristics	Cheder Lake	Wet hollow Cheder	Ko-Su Creek (levee)	Floodplain waterbody 1	Floodplain waterbody 2	Kozh-Sul Creek 2	Khadyn Lake	Wet hollow Khadyn	Dus-Khol Lake	Kuluzun land tract	Adjacent waterbody Kaak-Khol	Kaak-Khol Lake	Khaak-Khol Lake
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
E. dumonti Alekseev, 2000	P	Bt	–	–	–	+	–	–	–	–	–	–	+	–	–
Thermocyclops dybowski (Lande, 1890)	P	L	–	–	–	–	–	–	–	–	–	–	–	–	+
T. crassus (Fisher, 1853)	C	Eut	–	–	–	+	–	–	–	–	–	–	–	–	+
Megacyclops viridis (Jurine, 1820)	C	Eut	–	+	+	+	+	–	+	–	–	+	+	–	+
Cryptocyclops bicolor (Sars,1863)	H	L	–	–	+	–	–	+	–	–	–	–	–	–	+
Mesocyclops leukarti (Claus, 1857)	P	Eut	–	–	–	+	–	–	+	–	–	–	+	–	+
Microcyclops afganicus Lindberg, 1959	C	L	–	–	–	–	–	–	+	–	–	–	–	–	–
Cyclops scutifer Sars, 1863		Eut	–	–	–	+	–	–	–	–	–	–	–	–	–
Order Calanoida Sars, 1903 Family Diaptomidae Sars, 1903															
Arctodiaptomus (*Rh.*) *salinus* Daday, 1885	P	Pl	–	–	–	+	+	–	+	+	–	+	+	–	–
Arctodiaptomus bacillifer (Koelber, 1885)	P	Pl	–	–	+	+	–	+	–	–	–	–	+	–	+
Metadiaptomus asiaticus (Uljanin, 1875)	P	Pl	–	–	–	–	–	–	–	–	–	–		–	+
Order Harpactiformes															
Harpactidae sp.	–	–	+	–	+	+	+	–	+	–	–	–	–	–	+
Class Phyllopoda Order Anostraca Sars, 1867 Family Artemiidae Grochowski, 1896															
Artemia sp.	–	–	+		–	–		–	+	–	+	–			+
Amphypoda	–	–												+	
Total number of species: 53			3	8	16	28	17	7	16	7	1	6	26	1	27

P, palearctic; H, Holarctic; C, cosmopolitan; CA, Central Asian; Eut, eurytopic; Ph, phytophilic; L, littoral; Bt, benthic, Pl, planktonic.

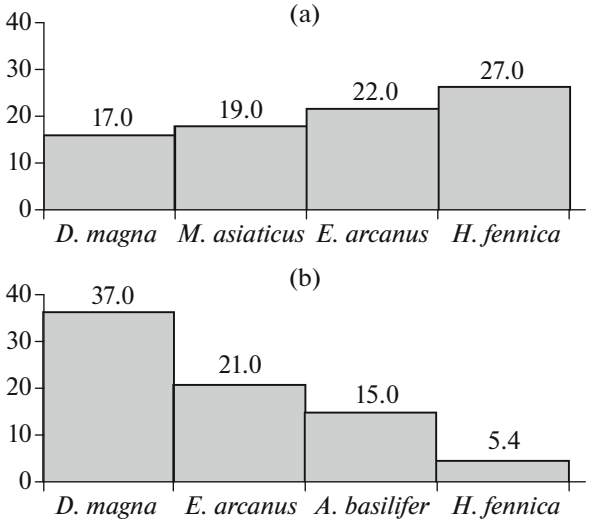

Fig. 3. Rank distribution (Ni, %) of the dominant species of zooplankton in Khaak-Khol Lake in (a) 2011 and (b) 2012.

On the dammed section of Kozhur-Sudak Creek, the species diversity increases in comparison with the upstream section of the brook from seven to 16 species (see Table 2). In the floodplain waterbodies of the brook, among 30 taxa of a rank below the genus, the halobionts *B. plicatilis* and *A. salinus* occur (see Table 1). Noteworthy are the findings of *M. tabrizensis* throughout the entire sampling period and in all months, including May and September. The planktic fauna of a small brackish waterbody adjacent to Kaak-Khol Lake is rich in the species composition: 29 species, including *M. hirsuticornis* and *M. rosea*. In wet hollows near Cheder and Khadyn lakes, there are seven and eight species, respectively; these species are representatives of the brackish and freshwater complexes (see Table 2).

In general, the diversity of zooplankton in waterbodies ranges widely from one to 28 and depends on the level of water mineralization (Fig. 4). The value of the significance of the approximation R^2 is maximal for the power regression line ($R^2 = 0.7839$). The regression line reflects a regular decrease in the number of species with an increase in water mineralization. The largest number of species was recorded in brackish water bodies; the smallest, in hyperhaline ones (see Table 2). The diversity index values in Khadyn and Haak-Khol lakes are 1.51–1.83 and 2.21–2.9, respectively; in hyperhaline lakes, the brine shrimp is monodominant. Between waterbodies of the depression (excluding Dus-Khol and Kaak-Khol lakes), a wide range of values of species similarity indices is observed: from 0.06 to 0.68. The highest values (0.68) were noted between the floodplain waterbodies of Kozhur-Sudak Creek, between its dammed area, and the waterbody adjacent to Kaak-Khol Lake (0.55) (Table 3).

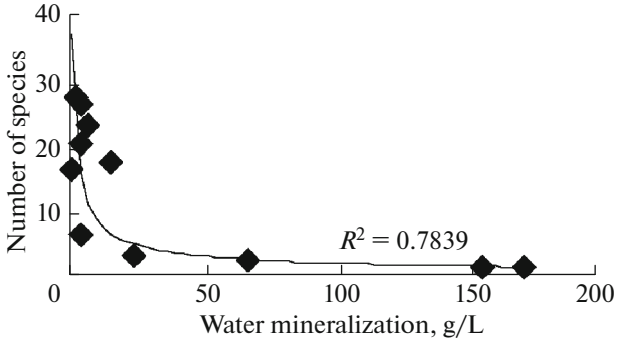

Fig. 4. Species diversity of zooplankton in mineral water bodies of specially protected natural areas of the Ulug-Khem depression, depending on their mineralization.

DISCUSSION

Earlier, rotifers and crustaceans of salt waterbodies of the depression were studied only in Cheder, Dus-Khol, and Khadyn lakes. The present list of Khadyn Lake zooplankton species has been supplemented by 11 taxa below the genus rank, in addition to the previously indicated *H. fennica*, *B. plicatilis*, *D. salinas*, *E. serrulatus*, and *M. brachiata* (Gundrizer and Ivanova, 1966; Popkova, 2004). However, the new findings do not indicate a change in the fauna of the lakes, since recently the taxonomy of many groups of planktonic animals has changed greatly and it is rather difficult to compare taxonomic lists of different years.

Interannual fluctuations in numbers are characteristic of zooplankton, which is a consequence of the interaction of natural (environmental) factors. The lack of intermediate numerical parameters of the zooplankton of lakes from the moment of their first survey to the present time is vulnerable to an objective assessment of what is happening. However, given the popularity of the lakes, we believe that the anthropogenic factor is decisive in the decrease in the number of brine shrimp in Dus-Khol Lake from 65 thousand ind./m^3 to the modern 18 thousand ind./m^3, as well as in the reduction of the total number of zooplankton in Lake Khadyn from 664.0 thousand ind./m^3 to modern 33.83–65.28 thousand ind./m^3 (Gundrizer and Ivanova, 1966; Kirova et al., 2018).

It seems obvious that the taxonomic composition of zooplankton in the hyperhaline Cheder and Dus-Khol lakes (Svatikovo) has remained unchanged since at least the 1960s (Gundrizer and Ivanova, 1966; Litvinenko et al., 2009; Kirova et al., 2015).

Species new for planktic fauna of the Republic of Tuva were discovered: rotifers *A. brightwelli*, *B. urseus*, and *E. piriformis* and cladocerans *W. pannonica* and *A. irinae*. Taxon *A. irinae* was described relatively recently; it is known from the Zeya and Amur basins, waterbodies of Irkutsk oblast (Sinev et al., 2009; Kotov et al., 2011). *W. pannonica* is a typical inhabitant of

Table 3. Values of similarity indices of the species composition (according to Chekanovsky–Sørensen) of mineralized water bodies of specially protected natural areas of the Ulug-Khem depression

Waterbody	Cheder Lake	Wet hollow Cheder	Ko-Su Creek	Floodplain waterbody no. 1	Floodplain waterbody no. 2	Khadyn Lake	Wet hollow Khadyn	Kuluzun land tract	Adjacent waterbody Kaak-Khol	Khaak-Khol Lake
Cheder Lake	1									
Wet hollow Cheder	0	1								
Ko-Su Creek 1	0	0.37	1							
Floodplain waterbody no. 1	0.06	0.27	0.41	1						
Floodplain waterbody no. 2	0	0.33	0.37	0.68	1					
Khadyn Lake	0.1	0.08	0.19	0.36	0.5	1				
Wet hollow Khadyn	0	0.13	0.17	0.17	0.34	0.08	1			
Kuluzun land tract	0.22	0.14	0.11	0.29	0.18	0.36	0.15	1		
Adjacent waterbody Kaak-Khol	0.07	0.43	0.55	0.31	0.48	0.35	0.25	0.27	1	
Khaak-Khol Lake	0.07	0.23	0.45	0.29	0.51	0.45	0.17	0.12	0.47	1

Cases of high similarity between water bodies are highlighted in color.

steppe waterbodies (Kotov, 2013). In Russia *M. tabrizensis* and *M. afganicus* are registered only in Tuva (*Opredelitel'...*, 1995). Rare for the fauna of Russia *M. asiaticus* in Tuva was found only in Khaak-Khol Lake; it is more widely known in Transbaikalia and Mongolia (Itigilova, 2009; Shaburova and Sheveleva, 2009; Sheveleva et al., 2009a, 2009b; Alonso, 2010; Afonina and Itigilova, 2014). The scarcity of findings in Tuva of one or another species of zooplankton may be related to the poor knowledge of the region.

The level of water mineralization is one of the leading factors determining the specific features of the species composition and the number of zooplankton species (Alimov, 2008). The greatest species richness is noted in brackish waterbodies at 47 species, which is 89% of the total number; the lowest is in hyperhaline lakes. The observed decrease in the species diversity indices with an increase in water mineralization in lakes (from brackish to hyperhaline) is a natural phenomenon (Alimov, 2008). In our opinion, the wide range of water mineralization parameters (1.22–173.9 g/L) particularly determines the spread in the values of the species similarity indices. In general, zooplankton is represented by brackish water and freshwater complexes; in the lakes as mass species are euryhaline (*E. arcanus*, *A. basilifer*) and halophile species (*D. magna*, *M. mongolica*, *A. salinas*, *M. asiaticus*, and *H. fennica*); in hyperhaline waters, there are halobiont brine shrimp. In the mineralized lakes of Transbaikalia, Mongolia, Khakassia, and Altai *D. magna*, *M. mongolica*, and *A. salinas* are also mass species (Vesnina, 1997; Anufrieva, 2006; Penkova et al., 2007; Makarkina and Sheveleva, 2008; Itigilova and Afonina, 2009; Sheveleva et al., 2009a, 2009b; Flossner et al., 2005; Alonso, 2010; Paul, 2012; Afonina and Itigilova, 2014). For the development of *D. magna*, the salinity optimum is at the level of over 6 g/L (Wieser, 2014). *M. mongolica*, *A. salinas*, and *H. fennica* form the basis of the zooplankton of the salt lakes of the Ubsunur Basin (South Tuva); these are Shara-Nur, Bai-Khol, and Ubsu-Nur lakes (Kirova et al., 2015). Findings of *T. dybowski* in the brackish waterbodies of Tuva are not rare; the possibility of its dwelling in waters of this type is confirmed by published papers (Monchenko, 1974; Kirova et al., 2012). The pollution indicator *B. nilsoni* (Kutikova, 1970) was previously noted in the salt Shara-Nur Lake (Ubsunur Basin); it entered the lake from Bulak Creek (0.45 g/L), polluted by machine water extraction (Kirova et al., 2015).

CONCLUSIONS

The diversity depending on the level of water mineralization is a characteristic of the zooplankton species composition in mineralized waterbodies of the Ulug-Khem depression. The discovery over a long period of species rare for the fauna of Russia increases the importance of waterbodies and indicates the presence of favorable conditions for the continuation of the life of these taxa, which increases the value of the

waterbodies themselves, which are already unique natural objects.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The author declares no conflict of interest.

Statement on the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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