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Seasonal and interannual dynamics of Artemia crustacean population from hypersaline Lake Kuchukskoye (Western Siberia)

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Abstract. The paper presents the findings of studying the influence of main natural environmental factors on interannual (2017–2018, 2020–2021) and seasonal (from April to October) dynamics of Artemia population from large hypersaline lake Kuchukskoye located in the Kulunda steppe (Altai Krai, Russia). We studied the relationship of 7 key indicators of the population structure (abundance, biomass and age structure) with hydrophysical and hydrochemical indixes (temperature, transparency, pH and total salinity). In different years, hydrophysical and hydrochemical regime of lake Kuchukskoye may vary significantly thus affecting brine shrimp population indicators. The revealed changes in the structure of zooplankton are mainly due to the inhibitory effect of increased salinity on the Artemia population and other taxa.

1 Introduction

Lake Kuchukskoye (Kuchuk) is located on the southern edge of the West Siberian Plain in the closed Ob-Irtysh interfluve. Its water area is 166 km^2, the average depth - 2.3 m (maximum of 3.3 m), and the lake basin area - 3240 km^2. The lake is drainless with inflowing Rivers Kuchuk and Solonovka. The water is bitterly salty; its salinity is within 216–320 g/L. At the bottom there are deposits of mirabilite (Glauber's salt) of about 3.5 m thick. Note that Roshydromet does not implement any hydrological, hydrochemical and hydrobiological observations of the lake [1, 2].

Similar to some other hypergaline water bodies in this region, lake Kuchukskoye is of economic significance due to intensive extraction of aquatic biological resources, i.e. Artemia gill-footed crustacean cysts used as a starter feedstuff in aquaculture and valuable raw material for cosmetic and pharmaceutical production [3, 4]. However, Artemia productivity and biological resources extraction in the region under study are changeable and hardly predictable [2, 5].

According to S.V. Gerd biolimnological zoning of Russia [6], the Kulunda Plain belongs to the Barabinsk-Kulunda lake district. A distinctive feature of lakes of this region is shallow basin depth and increased water salinity. Their ecosystems are subject to cyclic successions

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because climate in the south of Western Siberia is characterized by alternating dry and wet periods with significant fluctuations in water levels and the area of drainless lakes. Strong fluctuations in water levels lead to the pronounced changes in hydrochemical and hydrobiological regime of lakes [7–9].

Aquatic communities promptly respond to the changes in environmental factors affecting lakes; their response time depends on the duration of life cycle of the species. For planktonic invertebrates from the south of the West Siberian Plain, life cycles usually last from a few days to several months. Despite rather long investigations of zooplankton from lake Kuchukskoye, the dependences of its dynamics on environmental factors were previously studied mainly in the phenomenological aspect. Our goal was to study the composition, structure and dynamics of zooplankton of lake Kuchukskoye influenced by natural factors using the up-to-date computer-based statistics programs [2, 10].

2 Materials and methods

The paper deals with analyzing field data obtained during the complex limnological and hydrobiological investigations of lake Kuchukskoye in 2017–2018, 2020–2021 data. During this period, samples were collected monthly at the same 22 sampling stations (Fig. 1).

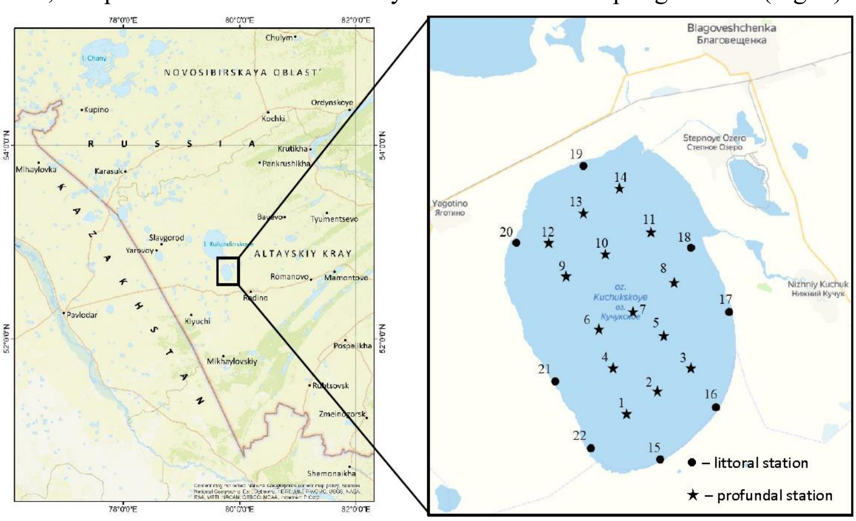

Fig. 1. The schematic map of location of lake Kuchukskoye and sampling stations (No. 1–22)

The selection and processing of zooplankton samples were implemented by means of standard limnological methods [11]. Samples were taken monthly in the period from April (or May) to October using a small Apstein plankton net (with a mesh size of 64 microns), fixed with formalin (up to 4%) and processed using the Bogorov camera and an MBS-10 stereomicroscope. The chemical analysis of water samples was made by an accredited laboratory of JSC "Kuchuksulfat".

For statistical processing of the obtained data, we used MS Excel-2017 and Statistica 10 software packages. Since the data generally had a normal distribution, the Pearson linear correlation coefficient matrices were constructed to identify the impact of natural factors on Artemia population.

3 Results and discussion

3.1 Key parameters of hydrochemical regime

Water temperature in the surface layer of lake Kuchukskoye in April was rather high – 11.5–15.0 ºС. In summer (July), it reached 24.8–33.1 ºС and by October fell to 6.8–8.4 ºС. The coldest was the year 2017, while the hottest - 2020 (Table 1). Water transparency varied from 0.1 m (August and September 2021) to 0.7 m (October 2018).

Table 1. The main abiotic factors of lake Kuchukskoye (2017–2018, 2020–2021), M±m

Month	Temperature of the surface layer of water, ºС	Water transparency, m	Salinity of water, g/L	pH
2017				
IV	12.5±0.9	0.1±0.02	257.4±32.2	7.9±0.52
V	8.3±1.3	0.1±0.02	102.7±3.75	8.2±0.46
VI	23.2±0.8	0.1±0.02	256.7±2.86	7.7±0.90
VII	24.0±1.3	0.2±0.04	259.3±1.96	7.9±0.53
VII	19.5±0.8	0.2±0.04	284.3±2.62	7.9±0.48
IX	12.2±1.2	0.1±0.02	288.2±3.53	7.9±0.46
X	6.8±0.9	0.1±0.02	252.7±2.09	7.5±0.51
2018				
IV	11.1±0.6	0.2±0.03	240.0±2.54	8.6±0.32
V	10.0±0.4	0.3±0.01	242.2±0.94	8.2±0.39
VI	24.8±1.2	0.3±0.02	249.7±1.42	8.2±0.44
VII	23.2±1,4	0.4±0.22	235.4±1.99	7.8±0.50
VIII	18.6±0,9	0.5±0.82	247.8±2.05	7.7±0.31
IX	15.0±0.6	0.6±0.74	276.9±1.16	7.7±0.32
X	8.4±0.7	0.7±0.68	280.0±1.12	7.7±0.34
2020				
V	15.0±1.2	0.3±0.01	316.0±1.16	7.5±0.78
VI	26.0±0.8	0.3±0.02	324.1±1.20	7.5±0.64
VII	33.1±0.9	0.2±0.04	329.9±0.74	6.8±0.80
VIII	31.3±0.8	0.2±0.09	319.7±1.06	7.6±0.36
IX	15.4±1.3	0.2±0.04	327.0±1.18	7.5±0.42
X	8.3±0.7	0.4±0.52	327.0±0.21	7.3±0.30
2021				
IV	12.5±0.9	0.3±0.02	138.7±0.72	7.7±0.28
V	30.0±1.2	0.2±0.01	141.3±1.80	8.1±0.44
VI	25.0±1.4	0.2±0.04	322.2±2.04	7.5±0.64
VII	28.0±0.8	0.2±0.02	339.8±3.46	7.6±0.62
VIII	23.4±1.3	0.1±0.06	344.3±3.68	7.6±0.34
IX	18.2±0.8	0.1±0.04	329.7±3.74	7.7±0.29
X	7.0±0.7	0.5±0.05	156.0±2.80	7.9±0.32

According to salinity classification, Kuchukskoye refers to a hypersaline lakes [12]. From long-term observations (2017–2018, 2020–2021), water salinity was noted within 102.7–344.3 g/L. An increase in salt concentrations in brine was marked by the midsummer. As for the main ion composition, the lake water was chloride-sulfate of the sodium group, by pH as neutral – slightly alkaline (6.8 to 8.6).

The chemical composition of water from the 1st station was studied in more detail (Table 2). The concentration of nitrites (0.005–0.19 mg/L), nitrates (0.9–147 mg/L), ammonium ions (0.18–11.8 mg/L) and phosphates (0.05–0.64 mg/L) usually was high and significantly exceeded the Russian MPC standard for fishery reservoirs. The permanganate oxidizability of water ranged from 35.6 (in April 2017) to 247 mgO_2/L (July 2020) showing the increased content of organic substances in the water. Concentration of iron in water varied from 0.38 (June 2020) to 1.2 mg/L (in June 2017).

Table 2. The main hydrochemical indicators of lake Kuchukskoye (1st station)

Month	Cl^-, g/L	SO_4^{2-}, g/L	NH_4^+, mg/L	NO_3^-, mg/L	NO_2^-, mg/L	PO_4^{3-}, mg/L	Fe, mg/L	Permanganate oxidizability, mgO_2/L
2017								
IV	133	26.7	0.18	34	0.14	0.05	0.9	35.6
V	85.9	19.8	0.81	25	0.10	0.12	1,0	98.2
VI	130	39.6	30.0	6.0	0.07	0.34	1.2	133
VII	127	39.8	0.60	0.9	0.03	0.40	1,0	122
VIII	134	44.2	27.6	51	0.01	0.51	0.4	140
IX	136	47.5	14.8	59	0.013	0.31	1.4	120
X	133	20.4	18.7	62	0.005	0.50	1,0	128
2020								
VI	143	38.4	11.8	34	0.083	0.36	0.38	219
VII	145	46.5	4.55	32	0.093	0.52	0.60	247
VIII	139	48.6	4.41	63	0.058	0.35	1.1	130
IX	147	50.8	80.4	21	0.05	0.28	0.49	155
X	160	27.6	5.40	33	0.037	0.23	0.54	113
2021								
IV	135	22.0	5.80	67	0.103	0.25	0.48	129
V	142	33.4	6.62	147	0.190	0.33	0.42	114
VII	149	45.4	3.20	52	0.178	0.48	0.86	126
X	58.5	38.1	3.19	32	0.095	0.64	0.49	103

3.2 Key parameters of zooplankton

Zooplankton of lake Kuchukskoye was represented by only 1 species – halobionts brine shrimp *Artemia* sp. We cannot but touch upon the problem of taxonomic identification of *Artemia* crustacean. According to modern taxonomy, *Artemia* from the lakes of Western Siberia belongs to the order Anostraca, the family Artemiidae and the genus *Artemia* Leach, 1819. The specific name of the crustacean (*Artemia salina* Linnaeus, 1758) is recognized as taxonomically invalid. Six species have been described for bisexual races (consisting of males and females), and the populations consisting of only females are conventionally designated as *Artemia parthenogenetica* [3]. The identification of these species is still incomplete. In this paper, we designate it as *Artemia* sp.

In lake Kuchukskoye, brine salinity of >100 g/L is, probably, a barrier to the development of all accompanying *Artemia* species. Brine shrimp can tolerate any levels of salinity from 10–340 g/L, with an optimal range of 60–100 g/L [13, 14], and occupy the ecological niche that can protect them from predators. In 2017–2021, an increase in water salinity led to reduction in the Artemia population. In the last years, the economic significance of the lake decreased because of the lack of bio-raw materials, i.e. commercial accumulations of *Artemia* cysts (Table 3, 4).

Table 3. Seasonal and interannual dynamics of Artemia population in lake Kuchukskoye (2017–2018, 2020–2021)

Month	Abundance, thousands ind./m^3	Biomass, g/m^3
2017		
IV	16.9±2.98	2.88±0.51
V	35.4±2.95	212±17.7
VI	17.9±1.80	107±10.8
VII	109±6.81	654±40.8
VII	690±61.8	4135±370
IX	111±15.6	663±93.2
X	0.99±0.17	4.77±0.82
2018		
IV	214±89.4	36.4±15.2
V	52.2±4.58	38.1±3.29
VI	103±21.9	74.2±15.7
VII	179±24.0	1072±144
VIII	32.2±2.88	193±17.3
IX	8.40±0.69	50.3±4.13
X	0.39±0.07	1.28±0.23
2020		
V	56.3±3.05	137±7.41
VI	334±20.6	2003±123
VII	192±23.4	1151±140
VIII	47,0±13.9	286±83.1
IX	13.3±0.74	79.8±4.43
X	0.26±0.07	0.85±0.23
2021		
V	48.4±2.72	118±6.61
VI	197±9.95	1177±59.6
VII	0.00	0.00
VIII	0.00	0.00
IX	0.00	0.00
X	0.00	0.00

Table 4. Seasonal and inter-annual dynamics of Artemia larval stages (abundance, thousands ind./m3) in lake Kuchukskoye (2017–2018, 2020–2021)

Month	Nauplia	Juvenile	Subadults	Adults	Cysts
2017					
IV	16.9±2.60	0.00	0.00	0.00	71.5±3.50
V	28.9±7.92	1.45±0.96	4.01±2.34	0.99±0.57	357±101

VI	16.6±6.82	0.11±0.06	0.08±0.02	1.05±0.28	363±142
VII	93.2±23.4	12.9±3.35	0.51±0.28	2.65±0.15	1786±95.0
VII	673±242	3.46±1.13	1.85±0.47	12.2±3.25	7994±4128
IX	56.1±37.5	17.6±9.32	0.56±0.18	36.4±15.3	1203±189
X	0,00	0.10±0.03	0.10±0.04	0.79±0.43	9.85±1.53
2018					
IV	214±89.4	0.00	0.00	0.00	2276±1130
V	52.2±9.13	0.04±0.03	0.00	0.00	662±185
VI	271±80.6	31.3±6.42	0.02±0.01	1.28±0.37	1168±601
VII	174±94.5	0.60±0.23	2.02±0.60	2.62±0.77	519±338
VIII	28,0±9.61	0.19±0.04	0.01±0.01	4.04±1.86	315±122
IX	7.01±2.42	0.006±0.004	0.04±0.02	1.34±0.31	155±30.1
X	0.02±0.01	0.006±0.0006	0.00	0.36±0.18	36,0±16.3
2020					
V	56.2±0.12	0.05±0.03	0.03±0.01	0,00	754±183
VI	291±9.12	41.26±6.46	0.06±0.01	2.64±0.32	18254±700
VII	185±92.2	0.86±0.24	3.08±0.40	3.42±0.65	621±336
VIII	38.6±8.41	0.25±0.04	0.06±0.01	8.06±1.42	421±131
IX	8.03±2.62	0.009±0.004	0.04±0.02	5.24±0.31	257±30.1
X	0.02±0.01	0.004±0.0006	0.00	0.24±0.18	42.4±14.2
2021					
V	48.3±8.14	0.07±0.02	0.03±0.01	0,00	620±164
VI	160±34.2	34.2±5.34	0.04±0.01	1.98±0.26	985±326
VII	0.00	0.00	0.00	0.00	7.42±3.28
VIII	0.00	0.00	0.00	0.00	2.60±1.22
IX	0.00	0.00	0.00	0.00	1.80±0.35
X	0.00	0.00	0.00	0.00	0.00

3.3 Assessment of natural factors effect on Artemia population

We studied the relationship of 7 key indicators of *Artemia* population structure (abundance, biomass and age structure) with hydrophysical and hydrochemical indicators (temperature, transparency, pH and total salinity).

The correlation analysis of monthly values of hydrochemical and hydrobiological indicators (2017–2018, 2020–2021) was found to be informative. A total of 11 pairs of reliable (significance level $p<0.05$) low, medium and strong correlations (Pearson correlation coefficient $r=0.39–0.97$) between the analyzed indicators were revealed (Table 5). However, in these pairs, only hydrochemical variables reliably correlated with hydrochemical and hydrobiological ones. Reliable correlation coefficients for hydrochemical and hydrobiological indicators were not established, probably, because of the low range of the studied environmental factors.

Table 5. Correlations of Artemia and environmental variable in lake Kuchukskoye based on monthly data (marked correlations are significant at $p < 0.05$, N=26)

Vari-able	**T**	**Tr**	**S**	**pH**	**AA**	**AB**	**NA**	**JA**	**SA**	**Ad**	**CA**
T	–	-0.24	0.31	-0.31	0.24	0.28	0.27	0.29	0.08	-0.02	0.21

Tr	-0.24	–	-0.08	-0.06	-0.11	-0.09	-0.08	-0.07	-0.19	-0.21	-0.01
S	0.31	-0.08	–	**-0.63**	0.10	0.15	0.07	0.17	-0.33	0.13	0.16
pH	-0.31	-0.06	**-0.63**	–	0.07	-0.12	0.14	0.00	-0.07	0.02	-0.03
AA	0.24	-0.11	0.10	0.07	–	**0.96**	**0.97**	0.36	0.34	0.29	**0.67**
AB	0.28	-0.09	0.15	-0.12	**0.96**	–	**0.90**	0.35	**0.39**	0.33	**0.67**
NA	0.27	-0.08	0.07	0.14	**0.97**	**0.90**	–	**0.40**	0.32	0.21	**0.62**
JA	0.29	-0.07	0.17	0.00	0.36	0.35	**0.40**	–	-0.10	0.21	**0.61**
SA	0.08	-0.19	-0.33	-0.07	0.34	**0.39**	0.32	-0.10	–	0.13	0.03
Ad	-0.02	-0.21	0.13	0.02	0.29	0.33	0.21	0.21	0.13	–	0.12
CA	0.21	-0.01	0.16	-0.03	**0.67**	**0.67**	**0.62**	**0.61**	0.03	0.12	–

Note: T – temperature, Tr – transparency, S – salinity, pH, AA – Artemia abundance (total), AB – Artemia biomass (total), NA – Nauplia abundance, JA – juvenile abundance, SA – subadults abundance, Ad – adults abundance, CA – cysts abundance

Artemia abundance increased with salinity of 40–240 g/L and decreased at >240 g/L [14]. Artemia effectively colonize extreme (hypersaline) habitats, being able to tolerate physiologically large changes in salinity, ionic composition, temperature and oxygen tension [15]. However, they also have limits of endurance and with a salinity of more than 300 g/L their populations are on the verge of extinction. That was the reason for extinction of the brine shrimp population in lake Kuchukskoye in 2021.

4 Conclusions

Lake Kuchukskoye is a hypersalinic reservoir with the absolute dominance of gill-footed crustacean *Artemia* in zooplankton. In different years, hydrophysical, hydrochemical and hydrobiological regime of the lake undergoes changes that affects its economic use, i.e. the extraction of crustacean cysts. The observed variations in zooplankton structure are mainly caused by a depressing effect of increased salinity on the brine shrimp population and other taxa. The revealed changes in the structure of *Artemia* population are mainly due to the inhibitory effect of high-level (>300 g/L) salinity.

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