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Article

Tolerance limits and ecological optima of mass zooplankton species of lakes in the south of Western Siberia*

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Abstract. In the study, the optima and tolerance limits of various zooplankton species in the diverse geochemical conditions of the south of Western Siberia have been calculated. It is shown that in various climatic conditions zooplankton organisms form different limits of halotolerance and adaptability to pH range. In the drainless lakes under study, the optimal values of pH for most mass zooplankton species are within 7.5–8.5. The majority of Rotifera, Cladocera and Cyclopoida do not tolerate salinity above 5 g/l, except for typical halophiles. The halotolerance level of the representatives of the order Calanoida is much higher; for some species, this indicator exceeds 90 g/l.

Keywords: ecological valence, abiotic factors, tolerance range, pH, salinity

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Научная статья

Границы толерантности и экологические оптимумы массовых видов зоопланктона озер юга Западной Сибири*

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Аннотация. Проведен расчет оптимумов и пределов экологической толерантности различных видов зоопланктона по отношению к солености и к уровню pH в сложных геохимических условиях юга Западной Сибири. Показано, что в разнообразных климатических условиях у зоопланктонных организмов формируются различные пределы галотолерантности и приспособленности к диапазону значений pH. В условиях озер замкнутого стока на юге Западной Сибири оптимальные значения pH для большинства массовых видов зоопланктона составляют 7.5–8.5. Большинство Rotifera, Cladocera и Cyclopoida (за исключением типичных галофилов) не выдерживают уровень солености выше 5 г/л. У представителей отр. Calanoida уровень галотолерантности значительно выше и у некоторых видов превышает 90 г/л.

Ключевые слова: экологическая валентность, абиотические факторы, диапазон толерантности, pH, соленость

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Introduction

It is a common knowledge that the formation of the species composition and quantitative characteristics of zooplankton are governed by the combination of physical and chemical processes in the catchment area and in the reservoir itself depending on climatic, geological and other parameters. Each species of the community has its own ecological valency or tolerance to external factors. Each organism has a certain maximum, minimum and optimum environmental factor or a combination of factors that determine its success. In 1913, V. Shelford formulated the law of tolerance, which states that the success or absence of a given organism in a given place can be controlled by the deficiency or the excess of different factors within the tolerance limits of said individual for these factors. Both, the deficiency or the excess can be harmful to a biological object (organism, population), and the range between the ecological minimum/ecological maximum is the limit of sustainability, i.e. the organism tolerance (Shelford, 1913). According to V.V. Zdanovich and E.A. Kriksunov (2004), "a tolerance range is the interval of values of a certain (usually abiotic) factor ensuring the existence of a given organism (species)." It is possible to identify the optimum range (a zone of normal vital activity) and the threshold of organism tolerance to each factor.

It is hard to determine tolerance limits of living organisms to one or another factor in the natural ecosystems. As a rule, organisms try to avoid the zones of extreme values and, accordingly, gravitate towards the optimal conditions of existence. Hence, the actual limits of tolerance observed in nature are lower than the potential adaptability of organisms to the given factor. We emphasize that studying the organism response to external factors in most natural ecosystems is very complicated because of the difficulties in obtaining the experimental data, especially those on tolerance limits.

Limnetic zooplankton communities have a number of features, which make them effective biological indicators of environmental conditions and objects for studying tolerance limits. The zooplankton composition includes species that are extremely sensitive to changes in abiotic factors (pH, temperature, salinity, dissolved oxygen, etc.) due to different physiological processes (Brett, 1989; Ermolaeva et al., 2019; Havens and Hanazato, 1993; Marmorek and Korman, 1993; Sterner et al., 2002). In addition, most zooplankton taxa have a fairly short generational cycle. Therefore, varying environmental conditions are promptly reflected on the community structure.

Western Siberia is a biogeochemically complex region distinguished by vast territories with low and high natural concentrations of macro- and microelements in the natural environment objects (Ermolaeva, 2021; Zapadnaya Sibir', 1963). Here, the chemical composition of the lake water changes greatly. For example, salinity varies widely from ultrafresh to hypersaline. Besides, drainless small lakes in the arid and subarid areas are characterized by extreme habitat conditions of aquatic animals. This is due to a small size of water bodies and thereby sharp daily and seasonal fluctuations in their physicochemical characteristics (Ermolaeva, 2021; Vesnina, 2003). It is worth noting that significant variability of zonal and local factors has contributed to the formation of geochemically different types of lakes with largely fluctuated concentrations of various ions that makes this territory a perfect natural test area for studying tolerance limits of planktonic organisms to external factors. In extreme conditions of the territory in the south of Western Siberia, one would expect better adaptability of zooplankton organisms to changing environmental factors than in other regions.

The purpose of the study is to determine the tolerance ranges and to identify the zones of optimal existence of mass zooplankton species widespread in Western Siberia as well as to assess the regional features of formation of their ecological valency.

Materials and methods

The work is based on the generalized results of a comprehensive study of hydrobiological and hydrochemical characteristics of small lakes in the south of the West Siberian Plain implemented along the transect from the southern border of Altai Krai (N 51°) to the southern border of the Vasyugan Mires (N 60°) (Fig. 1). The investigations were carried out in 2000–2019 using the unified method. Samples were taken once (single examination) in the period from July 15 to August 15. During the collection of zooplankton, 50–100 l of water (depending on the trophic level of the reservoir) was filtered through the Apshtein net with a mesh size of 64 μm. The collected samples were fixed with 40% formalin to a final

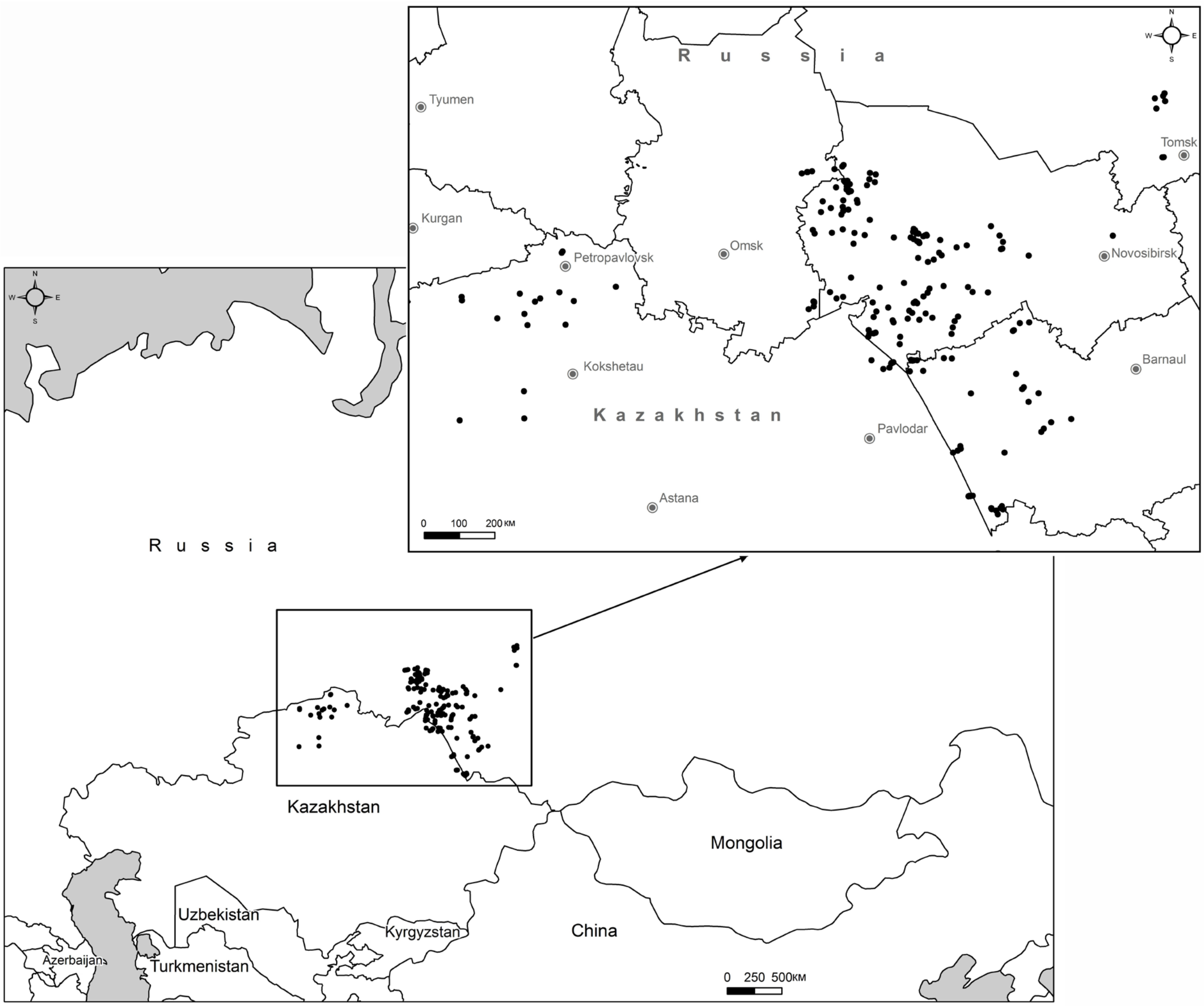

Fig. 1. Schematic map of the location of the study lakes.

concentration of 4% Rukovodstvo..., 1992). To determine the taxonomic composition and to count the number of zooplankton, the samples were analyzed in the Bogorov chamber (Rukovodstvo..., 1992). We studied 237 lakes, collected and processed 1775 samples.

Along with zooplankton, we took water for a chemical analysis at the same sampling sites. Salinity and pH were measured using an ANION 4120 portable ion-selective conductometer (Russia). Temperature was measured simultaneously with the dissolved oxygen content by a MARK-302 analyzer (Russia).

The chemical analysis of water samples was performed with the use of the unified methods in the accredited laboratories of the Chemical Analytical Center of IWEP SB RAS, Federal State Institution VerkhneOb'regionvodkhoz, Institute of Geology and Mineralogy SB RAS, and Institute of Catalysis SB RAS.

In this study, the method for determination of the optima and tolerance limits proposed by C. ter-Braak (1985) was employed. For calculations of the environmental factor optimum, we used the following formula:

$$W_{opt} = \sum_i^n (A_i \times S_i) / \sum_i^n A_i$$

where W_{opt} is the optimal indicator of the environmental factor for the particular species; A_i – the number of the particular species at point i; S_i – the value of the factor at point i; n – the number of samples with the detected species. Tolerance limits are calculated as the standard deviation of the weighted average number of the species. All of the listed indicators were calculated only for the species found in more than 10 out of 237 lakes.

Results and discussion

Natural mineralized lakes with high pH values are of interest to researchers worldwide, who consider salinity and pH level as important factors strongly affecting the composition and abundance of the zooplankton communities (Balushkina et al., 2009; Hammer, 1986; Khlebovich, 1971, 1974; Lazareva, 1994, 1996; Zadereev et al., 2021). However, the quantitative evaluation of salinity and pH effects on individual species number in natural conditions is usually made for single water bodies. Moreover, such estimates vary largely in different studies that hinders their comparison. When discussing the effect of salinity, active water reaction and other factors on a particular zooplankton species, rather rigid boundaries of their occurrence are often mentioned without specifying regional features. For small lakes of Western Siberia, such evaluations are rare (Kozlov et al., 2018; Vesnina, 2003; Zadereev et al., 2021).

Some classical research report about the salinity limits for the existence of certain species. According to the published data, the salinity limit, for example, for most copepods makes up 20 g/l (Hammer, 1986; Khlebovich, 1971, 1974). The analyzed by Q. Lin et al. (2017) halotolerance limits for 53 zooplankton species from 45 lakes of the Tibetan Highlands are within 0.1–76.0 g/l. Interestingly, that 30 out of 53 species are present in the regional taxonomic list of zooplankton from the south of Western Siberia. At the same time, in the lakes of the Tibetan Highlands, most cladocerans are not found at salinity above 5 g/l, copepods existence is limited by salinity of 15 g/l (*Arctodiapomus salinus* – 20 g/l; *Metadiaptomus asiaticus* – 26 g/l), and rotifers – by 45 g/l.

Salinity in the study lakes in the south of Western Siberia ranges as 0.01–67.88 g/l, pH values – from 6.3 to 9.96, dissolved oxygen – from 3 to 13 mg/dm^3 (Table 1). Fluctuations in concentrations of individual ions (mainly HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+) and the ratio of their shares are significant. Thus, the implemented investigations expand the understanding about the halotolerance levels of some planktonic organisms.

Our research suggest that most Cladocera and Rotifera from small lakes in the south of Western Siberia do not tolerate salinity above 5 g/l (Table 2). Note that the optimum values turned out to be even lower.

In terms of salinity, *Brachionus plicatilis*, *Brachionus asplanchnoides* and *Brachionus urceus* demonstrate the widest range of habitat. Among the species, which prefer high salinity, are *Hexarthra mira* (optimum salinity 9.7 g/l) and *Hexarthra fennica* (optimum salinity: 22.3 g/l). In fact, both species live and reproduce quite successfully in freshwater bodies.

The upper halotolerance limit for *Daphnia magna* reached 18.5 g/l; the maximum species abundance was noted at salinity of 4.0–5.0 g/l. Salinity levels above 5.0 g/l were not lethal, and even at extreme upper limits parthenogenetic females with eggs and embryos were found in the lakes. Among the cladocerans, *Moina mongolica*, which often formed a monodominant community in some salt lakes, demonstrated the highest halotolerance.

Among the representatives of the order Cyclopoida, only six species tolerated salinity levels above 5.0 g/l, though the optima for most species were still much lower. *Thermocyclops crassus* showed the highest halotolerance. *Apocyclops dengizicus* can be attributed to brackish water species reaching its highest abundance at salinity above 2 g/l.

For species of the order Calanoida, the level of halotolerance and the percentage of halotolerant or halophilic species were much higher. Also, there were species confined exclusively to freshwater bodies: *Arctodiaptomus dudichi*, *Hemidiaptomus ignatovi*, *Mixodiaptomus theeli*, *Heterocope appendiculata*.

The pH values for most of the studied zooplankton species from small lakes in the south of Western Siberia vary widely; the optima range is from 7.5 to 8.5 (Table 2).

In description of acidic lakes in Europe and the European part of Russia (Fryer, 1980; Lazareva, 1994, 1996; Svirskaya, 1991; Vandysh, 2002), a number of zooplankton species are repeatedly discussed as acidophilic. For example, *Scapholeberis mucronata*, *Polyphemus pediculus*, *Alonella nana* are listed as typical inhabitants of acidic waters with pH from 4.7 to 6.5. *Lathonura rectirostris* and *Eucyclops serrulatus* prefers highly acidic waters (3.5–6.0). In our studies, *S. mucronata*, *P. pediculus*, and *A. nana* are characterized by much wider range of pH limits, i.e. pH optimum for all three species is above 7.5. *E. serrulatus* shows the optimum at 8.2 with existence conditions ranging as 6.8–9.4. So far, *L. rectirostris* has been found only in three water bodies and dropped out of the list of calculating the boundary conditions. In three studied lakes, pH values were within 6.4–7.1.

In a number of publications, *Diaphanosoma brachyurum*, *Holopedium gibberum*, *Ceriodaphnia quadrangula*, *Eudiaptomus graciloides*, *Polyarthra vulgaris* and *Conochilus hippocrepis* are indicated as dominant in the lakes with pH ≤ 5.3 (Lazareva, 1994, 1996; Vandysh, 2002). Meanwhile, some

Table. 1. Limits of abiotic factors fluctuations for 237 lakes in the south of Western Siberia (mean, maximum and minimum values are given for lakes in each landscape zone).

Indicator	Zone											
	Dry steppe			Steppe			Forest-steppe			Taiga		
	Mean	min	max	Mean	min	max	Mean	min	max	Mean	min	max
Latitude	N 51°21'	N 51°19'	N 51° 38'	N 53°22'	N 51°58'	N 53º74'	N 54°41'	N 54°24'	N 55°71'	N 56°86'	N 56°37'	N 57°34'
Longitude	E 80°29'	E 80°12'	E 80°43'	E 78°44'	E 77°90'	E 79°42'	E 77°52'	E 76°99'	E 79°36'	E 79°86'	E 75°24'	E 84°48'
Depth, m	1.45	0.60	2.30	1.46	1.20	2.50	1.59	0.45	3.10	4.85	2.80	7.00
Area, ha	307.4	61.2	1344.1	1296.1	276.0	6058.1	296.5	30.1	1108.4	82.3	0.4	368.5
Salinity, g/l	12.73	1.36	29.15	10.80	0.65	67.88	0.67	0.09	2.30	0.18	0.01	0.44
pH	8.94	8.00	9.83	8.66	7.10	9.52	9.00	8.20	9.96	6.61	5.02	8.80
Temperature °C	24.0	20.4	28.0	20.4	16.0	25.2	19.7	11.2	26.2	22.5	21.2	23.2
Dissolved oxygen, mg/l	6.38	3.00	10.50	7.73	6.1	12.6	8.3	4.4	13.0	7.7	7.1	8.8

Table 2. Minimum (min) and maximum (max) indicators, including the calculated optimum points (W_{opt}) of salinity and pH for a number of zooplankton species from the drainless lakes in the south of Western Siberia.

Taxon	Salinity, mg/l			pH		
	min	max	W_{opt}	min	max	W_{opt}
Rotifera						
Anuraeopsis fissa (Gosse, 1851)	296	8720	1794	7.09	9.89	8.37
Asplanchna priodonta Gosse, 1850	94	3640	807	6.59	9.61	8.29
Asplanchna herricki de Guerne, 1888	80	10320	7693	6.30	9.61	8.36
Brachionus angularis Gosse, 1851	203	5920	1309	7.00	9.68	8.55
Brachionus angularis bidens Plate, 1886	526	3066	1849	7.26	9.10	8.00
Brachionus asplanchnoides Charin, 1947	751	269700	13778	7.75	9.21	8.68
Brachionus calyciflorus Pallas, 1766	230	22236	2407	7.12	9.60	8.10
Brachionus diversicornis (Daday, 1883)	230	719	412	7.12	8.55	7.59
Brachionus quadridentatus Hermann, 1783	160	2630	2433	6.59	9.30	8.66
Br. quadr. var. *ancylognathus* Schmarda, 1859	230	15750	1884	6.60	9.57	8.59
Br. quadr. f. *brevispinus* Ehrenberg, 1832	229	1524	1185	7.12	9.47	8.14
Br. quadr. f. *cluniorbicularis* Skorikov, 1894	177	5920	2944	6.96	9.57	9.05
Br. quadr. melheni Bar. et Dad., 1894	148	38000	5686	6.60	9.60	8.39
Brachionus leydigii Cohn, 1862	177	3630	534	7.55	9.40	8.48
Brachionus plicatilis Müller, 1786	765	69400	20500	7.95	9.83	9.49
Brachionus urceus (Linnæus, 1758)	296	269700	56209	7.60	9.57	8.62
Brachionus variabilis Hempel, 1896	260	6940	2065	6.79	9.58	8.86
Cephalodella gibba (Ehrenberg, 1832)	181	3066	936	7.16	9.10	8.34
Colurella obtusa (Gosse, 1886)	148	2850	1282	7.16	8.90	8.10
Conochilus unicornis Rousselet, 1892	10	513	161	6.30	9.30	7.60
Euchlanis deflexa Gosse, 1851	160	1843	855	6.59	9.60	8.58
Euchlanis dilatata lucksiana Hauer, 1930	200	3724	800	6.60	9.44	8.27
Euchlanis dilatata Ehrenberg, 1832	112	5720	846	6.59	9.68	8.59
Euchlanis lyra Hudson, 1886	150	2588	801	7.55	9.57	8.76
Euchlanis lyra f. *larga* Kutikova, 1959	150	1498	636	7.12	8.80	8.04
Filinia longiseta (Ehrenberg, 1834)	148	67877	896	7.10	9.68	8.39
Filinia terminalis maior Colditz, 1924	148	2980	1055	7.13	9.47	8.51
Filinia terminalis (Plate, 1886)	80	40450	2182	6.30	10.00	8.69
Hexarthra mira (Hudson, 1871)	200	24300	9685	6.60	9.89	8.35
Hexarthra fennica (Levander, 1892)	1820	68500	22281	7.95	9.60	9.26
Keratella cochlearis (Gosse, 1851)	10	2980	423	6.30	10.00	8.86
Keratella tecta (Gosse, 1851)	100	3066	467	6.80	9.68	8.35
Keratella hiemalis Carlin, 1943	177	1010	588	7.55	8.65	8.31
Keratella quadrata (Müller, 1786)	94	38000	1262	6.60	10.00	8.52

Taxon	Salinity, mg/l			pH		
	min	max	W_{opt}	min	max	W_{opt}
K. quadrata f. *dispersa* Carlin, 1943	160	69400	2984	7.21	9.96	8.76
K. quadrata var. *longispina* (Thiébaud, 1912)	222	3724	1024	8.25	9.10	8.32
Keratella valga (Ehrenberg, 1834)	439	3640	1399	7.00	9.40	8.78
Lecane luna (Müller, 1776)	148	3080	842	6.96	9.17	8.13
Lecane lunaris (Ehrenberg, 1832)	440	1170	968	7.00	9.01	7.60
Lepadella obtusa Wang, 1961	148	5920	960	7.47	8.96	8.15
Lepadella ovalis (Müller, 1786)	148	1918	873	7.12	9.10	8.45
Lophocharis oxysternon (Gosse, 1851)	333	3030	1427	7.09	9.30	8.12
Mytilina mucronata (Müller, 1773)	296	1843	1472	7.13	9.30	8.42
Mytilina ventralis (Ehrenberg, 1832)	148	8850	1411	6.96	8.90	8.01
Mytilina videns (Levander, 1894)	230	981	835	7.14	8.65	8.33
Notholca acuminata (Ehrenberg, 1832)	232	15750	5271	6.96	9.60	8.90
Platyias quadricornis (Ehrenberg, 1832)	218	2005	931	7.09	9.47	8.14
Polyarthra dolichoptera Idelson, 1925	200	3090	2030	6.60	8.66	7.90
Polyarthra euryptera Wierzejski, 1891	210	2630	703	7.09	8.71	7.45
Polyarthra major Burckhard, 1900	10	2588	277	6.30	9.90	7.59
Polyarthra minor Voigt, 1904	10	3724	285	6.30	9.44	8.26
Polyarthra remata Skorikov, 1896	103	9239	385	6.80	10.00	8.52
Polyarthra vulgaris Carlin, 1943	100	3066	911	6.80	9.20	8.19
Pompholyx sulcata Hudson, 1885	94	1683	193	7.26	9.68	8.18
Synchaeta oblonga Ehrenberg, 1832	125	5260	787	6.59	9.30	8.20
Synchaeta pectinata Ehrenberg, 1832	122	5920	811	7.44	9.96	8.08
Testudinella patina (Hermann, 1783)	148	8850	1553	6.59	9.96	8.32
Trichocerca cylindrica (Imhof, 1891)	10	894	201	6.30	8.86	7.24
Trichocerca capucina (Wierz. & Zach., 1893)	10	2588	291	6.30	9.31	7.12
Trichocerca elongata (Gosse, 1886)	160	2588	636	6.59	9.90	8.24
Trichocerca similis (Wierzejski, 1893)	10	965	247	6.30	10.00	7.70
Trichotria truncata (Whitelegge, 1889)	148	15750	603	6.59	9.10	7.21
Cladocera						
Acroperus harpae (Baird, 1834)	94	400	249	6.59	9.53	7.81
Alona (Biapertura) affinis (Leydig, 1860)	122	3724	1442	6.59	9.96	8.15
Alona intermedia Sars, 1862	94	1053	588	6.59	9.96	8.36
Alona (Coronatella) rectangula (G.O. Sars, 1862)	203	15750	6380	7.13	9.68	8.41
*Bosmina longirostris (*O.F. Müller, 1785)	94	5531	460	6.96	9.61	8.08
Bythotrephes longimanus Leydig, 1860	290	2588	774	8.30	10.00	8.43
Bythotrephes cederströemi Schödler, 1863	177	1483	508	7.55	9.00	8.05
Ceriodaphnia quadrangula (O.F. Müller, 1785)	10	8850	968	6.30	9.96	8.37

Taxon	Salinity, mg/l			pH		
	min	max	W_{opt}	min	max	W_{opt}
Ceriodaphnia reticulata (Jurine, 1820)	181	24200	2508	7.13	9.17	8.88
Chydorus sphaericus (O.F. Müller, 1776)	10	8850	1091	6.50	9.96	8.48
Chydorus ovalis Kurz, 1874	94	10320	872	6.59	9.96	7.89
Ctenodaphnia carinata King, 1853	1399	18455	4334	8.38	9.89	8.80
Ctenodaphnia magna Straus, 1820	587	18455	4438	8.20	9.89	8.78
Daphnia cucullata G.O. Sars, 1862	94	7200	8123	6.96	9.96	8.94
Daphnia longispina (O.F. Müller, 1776)	80	3724	8696	6.30	10.00	8.40
Daphnia pulex Leydig, 1860	10	24200	1014	6.30	10.00	8.06
Diaphanosoma brachyurum (Liévin, 1848)	10	3090	1482	6.30	9.61	8.14
Disparalona rostrata (Koch, 1841)	10	860	294	6.30	8.80	7.81
Eubosmina coregoni Baird, 1857	10	1200	555	6.30	9.10	8.07
Eurycercus lamellatus (O.F. Müller, 1776)	94	2588	230	6.59	9.61	7.48
Graptoleberis testudinaria (Fischer, 1851)	94	2007	587	6.60	9.96	7.69
Holopedium gibberum Zaddach, 1855	10	100	99	6.20	6.80	6.59
Lathonura rectirostris (O.F. Müller, 1785)	434	10320	5750	7.10	9.82	8.49
Leptodora kindti (Focke, 1844)	100	3066	820	6.80	10.00	8.19
Moina brachiata (Jurine, 1820)	150	2980	2727	9.12	7.87	9.05
Moina mongolica Daday, 1901	800	67877	22240	7.75	9.89	9.18
Peracantha truncata (O.F. Müller, 1785)	112	840	181	6.60	9.31	7.77
Polyphemus pediculus (Linnaeus, 1761)	94	8850	785	6.60	9.61	8.45
Sida crystallina (O.F. Müller, 1776)	125	2731	480	6.60	9.44	8.75
Simocephalus vetulus (O.F. Müller, 1776)	94	5200	1794	6.59	9.96	8.91
Scapholeberis mucronata (O.F. Müller, 1776)	203	24200	1565	6.60	9.17	7.72
Copepoda						
Acanthocyclops vernalis (Fischer, 1853)	80	1918	550	6.30	9.30	7.27
Apocyclops dengizicus (Lepeshkin, 1900)	571	9239	2074	7.58	9.60	8.84
Cryptocyclops bicolor (Sars G.O., 1863)	94	951	238	7.09	9.96	8.23
Cyclops furcifer Claus, 1857	232	3066	1038	8.00	9.30	8.75
Cyclops kolensis Lilljeborg, 1901	10	8050	1294	6.50	9.96	8.59
Cyclops scutifer Sars G.O., 1863	10	3640	184	6.30	9.10	6.90
Cyclops strenuus Fischer, 1851	80	3640	1033	6.30	9.47	8.43
Cyclops vicinus Uljanin, 1875	230	2870	681	7.09	9.47	9.02
Eucyclops macruroides (Lilljeborg, 1901)	94	2005	1300	6.79	9.61	8.12
Eucyclops serrulatus (Fischer, 1851)	103	2007	857	6.80	9.44	8.25
E. serrulatus proximus (Lilljeborg, 1901)	148	1928	225	7.14	8.60	7.73
E. serrulatus speratus (Lilljeborg. 1901)	160	1330	590	6.50	7.80	7.21
Macrocyclops albidus (Jurine, 1820)	112	3300	1067	6.80	9.31	8.54

Taxon	Salinity, mg/l			pH		
	min	max	W_{opt}	min	max	W_{opt}
Macrocyclops fuscus (Jurine, 1820)	160	1434	1108	6.59	8.65	8.41
Megacyclops gigas (Claus, 1857)	10	8850	1613	6.50	9.30	8.56
Megacyclops viridis (Jurine, 1820)	160	15750	1704	6.59	9.89	8.60
*Mesocyclops leuckart*i (Claus, 1857)	10	3640	752	6.50	10.00	8.64
Paracyclops fimbriatus (Fischer, 1853)	94	10320	1333	6.59	9.89	8.61
P. fimbriatus abnobensis Kiefer, 1929	229	1691	1075	6.96	8.65	8.04
Thermocyclops crassus (Fischer, 1853)	94	24200	2085	7.35	9.96	8.71
Thermocyclops dybowskii (Landé, 1890)	103	2870	1472	6.60	8.81	8.72
Thermocyclops oithonoides (G.O. Sars, 1863)	10	3300	1009	6.30	10.00	8.68
Acanthodiaptomus denticornis Wierz.	103	38000	3249	6.60	9.96	8.68
Arctodiaptomus acutilobatus (G.O. Sars, 1903)	290	24200	2752	8.40	10.00	8.84
Arctodiaptomus dentifer (Smirnov, 1928)	94	29145	3551	7.35	9.61	8.77
Arctodiaptomus salinus (Daday, 1885)	333	36900	7205	7.90	9.12	8.75
Eudiaptomus gracilis (G.O. Sars, 1863)	112	24300	2224	6.79	9.68	8.36
Eudiaptomus graciloides Lilljeborg, 1888	123	69400	1745	6.60	9.96	8.67
Eudiaptomus transylvanicus (Daday, 1890)	103	69400	2425	6.80	10.00	8.50
Hemidiaptomus ignatovi G.O. Sars, 1903	300	2587	871	8.20	9.30	8.40
Mixodiaptomus theeli (Lilljeborg, 1889)	123	2502	847	7.47	9.96	8.20
Neutrodiaptomus incongruens (Poppe, 1888)	378	99800	24100	7.47	9.89	8.81
Heterocope appendiculata G.O. Sars, 1863	125	1010	918	6.80	8.34	8.03

studies devoted to water bodies of Finland (Uimonen-Simola and Tolonen, 1987) or Canada (Confer et al., 1983) with a wider pH range state that many of these species may form a dominant complex in the lakes with pH values exceeding the limits. Our findings show that *D. brachyurum* reaches its maximal abundance in lakes with pH close to 8.1. *C. quadrangula, E. graciloides* and *P. vulgaris* also develop most successfully at pH 8.0–8.5. Water bodies with pH below 7.0 are favorable only for *C. hippocrepis* and *H. gibberum*.

In the Euro-Arctic region, *Heterocope appendiculata* was detected only in the water bodies with pH > 7.0 (Vandysh, 2002). In some taiga lakes of the south of Western Siberia, *H. appendiculata* formed the basis of zooplankton population in winter at pH 6.4–6.6.

When analyzing the boundary conditions for a species existence, one parameter is not enough. For example, low salinity combined with increased pH is optimal for *H. appendiculata*, while *M. mongolica* prefers salty alkaline waters, etc. (Table 2).

An extreme (or low) level of one factor can sometimes be partially compensated for by appropriate levels of other factors. For example, the lakes in the south of Western Siberia have a similar effect previously described by E.V. Balushkina et al. for saline lakes of the Crimea (2009). For instance, at concurrent increase of pH and salinity, an alkalinity growth compensates for the negative effect of salinity that allows the zooplankton community to achieve higher development rates than at the increase of solely one of these environmental factors.

A decrease/increase in concentrations of any other ion, temperature, oxygen content, including changes in the microbial loop structure, etc. requires significant corrections of the estimate indicators. When a condition changes, a tangible shift in the species preference is probable (Kaufman, 1987). Tolerance limits to physical environmental conditions can alter greatly under the influence of biotic factors

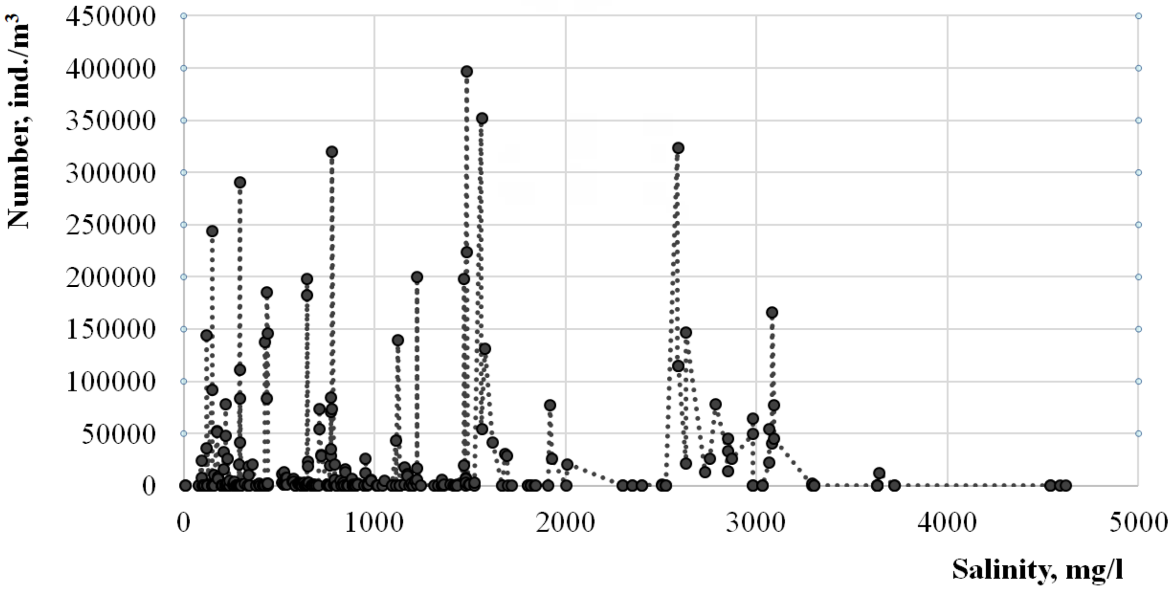

Fig. 2. Abundance of *Keratella quadrata* in the optimal salinity gradient.

(the presence of predators, interspecific competition, disappearance of food when external conditions change, etc.). Therefore, our data may assist in predicting (without a guarantee) the species able to exist in certain conditions. A vivid example is our graph demonstrating the abundance of one of the most widespread species – *Keratella quadrata* (Fig. 2). Even in the interval of optimal salinity (from 100 to 3500 mg/l), there are many abundance peaks of *Keratella quadrata* along with its absence in the community of a particular lake.

Conclusion

The structure of zooplankton communities depends on joint and concurrent effects of numerous local factors in a particular water body. In different regions, zooplankton organisms develop different limits of tolerance to individual environmental factors.

In the closed lakes of the south of Western Siberia, the optimal pH values for most common zooplankton species are mainly in the range from 7.5 to 8.5. The majority of Rotifera, Cladocera and Cyclopoida do not survive at salinity above 5 g/l; for Calanoida, the level of halotolerance is much higher. It should be noted that the calculated limits of occurrence and ecological optima for each indicator are not absolute since they do not take into account the whole variety of factors that ensures the development or suppression of a particular species.

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