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Habitat and Features of Development of Plankton Communities in Salt Lakes (South-Eastern Transbaikalia, Russia)

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Abstract: Results of studies of plankton algae and invertebrates in salt lakes of the territory of a closed runoff in the south of South-Eastern Transbaikalia (Russia) carried out in 2021–2022 are presented. Phyto- and zooplankton of sixteen saline lakes were studied during the maximum vegetation period from July to August. Lakes are different in chemical type: chloride, soda and sulfate. For chloride, sulfate and some soda lakes, data on plankton have been obtained for the first time. Fifty-four taxa of phytoplankton and twenty-seven species of zooplankton were found in soda lakes; twenty-three taxa of phytoplankton and four species of zooplankton were found in the chloride lakes; fifteen phytoplankton species and five zooplankton species were found in the sulfate lakes. For phytoplankton in soda lakes, green algae, cyanobacteria and diatoms were dominant. Green algae dominated in species composition in sulfate lakes; cryptophyte algae and cyanobacteria dominated in chloride lakes. For zooplankton, in all types of lakes, *Brachionus plicatilis*, *Moina brachiata* and *Metadiaptomus asiaticus* dominated. The abundance and biomass of algae and invertebrates in the surveyed lakes varied widely. Based on the results of the correlation analysis, total dissolved solids (TDS) are a key factor in the formation of planktonic communities in soda lakes; depth, transparency and temperature—in chloride lakes and pH—in sulfate lakes.

Keywords: phytoplankton; zooplankton; salt lakes; species diversity

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1. Introduction

Salt continental water bodies are widespread in arid zones around the world [1]. They are unique and extreme environments, inhabited by specific biota, with high conservation value [1,2].

Bacteria, algae and invertebrates are the main components both individually or in combination [3–6] which support a distinctive biotic community [1,2] in salt lakes. Low species diversity but abundant populations of aquatic organisms make salt lakes especially suitable for the study of trophic dynamics and ecosystem processes [7]. Some species of brine shrimp are crucially important zooplankton organisms in salt lakes (e.g., in Great Salt Lake) and provide numerous ecosystem services including the control of eutrophication in a naturally productive lake, an abundant energy supply to a large avian population along hemispheric flyways [8,9].

The relevance of ecological studies of the tape systems of the arid zone is associated with the dynamism of changes in climatic conditions and the influence of abiotic factors. Changes in weather conditions often lead to fluctuations in water salinity, changes in ionic composition and active pH values, which can cause a change in the hydrobiological regime of a lake.

Geoscientists and biological limnologists generally use main ions in salt lakes as the basis for the hydrochemical classification of salt lakes [10,11]. A lot of brackish and salt lakes are very common in the territory of South-Eastern Transbaikalia. Three types of lakes have been identified for this area. These are soda, chloride and sulfate lakes [12,13]. The overwhelming majority of lakes are soda-type lakes—87%. Chloride lakes are not very common in this area—10%. There are very few sulfate lakes in this area—3% [13].

Sulfate and carbonate-rich lakes dominate the Great Plains of western Canada, the salt lakes of the Qinghai-Tibet Plateau (China), the salt lakes of north Kazakhstan and the salt lakes of China and Inner Mongolia [1,11,14–17], comprising over 95% of the total lakes. The paucity of Cl-rich lakes makes the studied region unusual compared with many other areas of the world (e.g., Australia, western United States) [18].

For lakes of the studied region (South-Eastern Transbaikalia), strong seasonality of water levels gives rise to dramatic changes in salinity, pH, ion concentrations and ratios, as demonstrated by numerous studies [8,12–21].

The transformation of habitats in terms of changes in hydrophysical [19,20] and hydrochemical parameters of water bodies [20–23] determines the biological diversity of aquatic ecosystems [21–29].

The differences in ionic composition, salinity and pH between salt lakes are in turn reflected by differences in the composition and nature of the biota. Certain taxa are found in hypersaline waters dominated by a particular solute; anions including chloride, bicarbonate-carbonate and sulfate are one of the important controlling factors in the species composition of salt lakes.

Therefore, the main purposes of our study were:

- To determine the main physical and chemical parameters of lakes' various chemical types;
- To assess the plankton communities in studied lakes;
- To identify dominant species in the different types of lakes;
- To analyze the change in abundance and taxonomic diversity.

2. Materials and Methods

2.1. Study Area

A lot of brackish and salt lakes are very common in the territory of East Transbaikalia. Numerous salt lakes are located in lowlands and basins. The relief is mainly low mountains that are hilly and plain with sub-sea depths of 596 to 800 m.

The climate is sharply continental. A thin snow cover is formed in early November and thaws at the end of April before the ice melts, so there is essentially no water supply from thawed snow to the reservoirs [30–33]. Furthermore, the annual amount of precipitation is almost two times lower than evaporation. Lake levels are decreasing. The water surface of the lakes is decreasing.

The work is based on materials collected during the summer period (July–August) 2021 and 2022 in three groups of lakes that differ in chemical type: chloride (Dabosa-Nor, Hilgonta, Gorbunka), soda (I subtype—Bain-Tsagan, Balyktui, Bain-Bulak, Nozhii, Kudzhertaj, Nizhniy Mukei; II subtype—Sheluta, Haraganash; III subtype—Borzinskoe, Ukshinda, Shvarcivskoe) and sulfate (Shihalin-Nur, Barun-Shivertuj) (Figure 1).

Most of the studied soda lakes are very shallow (depth~0.03–0.2 m) and quite small (surface area up to 0.84–1.84 km^2). Exceptions are Nozhii Lake and Bain-Tsagan Lake, which are more than 2 m deep and have surface areas of 8.63 and 2.39 km^2 [32], respectively. Soda lakes represent the most stable permanent high-pH environments (pH > 9) on Earth, which clearly distinguishes them from other inland saline waters. The TDS varies between the oligo- and the hyperhaline ranges (3.49–291.61 g L^{-1}).

The main distinguishing features of these lakes are the high pH values, wide salinity variability, but low concentrations of Ca^{2+} и Mg^{2+}. Soda lakes are divided into 3 subtypes, according to the prevailing anion. The first subtype includes lakes with a predominance of HCO_3^-+CO_3^{2-}, the second subtype has a predominance of SO_4^{2-} and the third subtype has a predominance of Cl^-. The transition from subtype I to subtype III, with relatively small changes in pH, is accompanied by an increase in the average salinity [12].

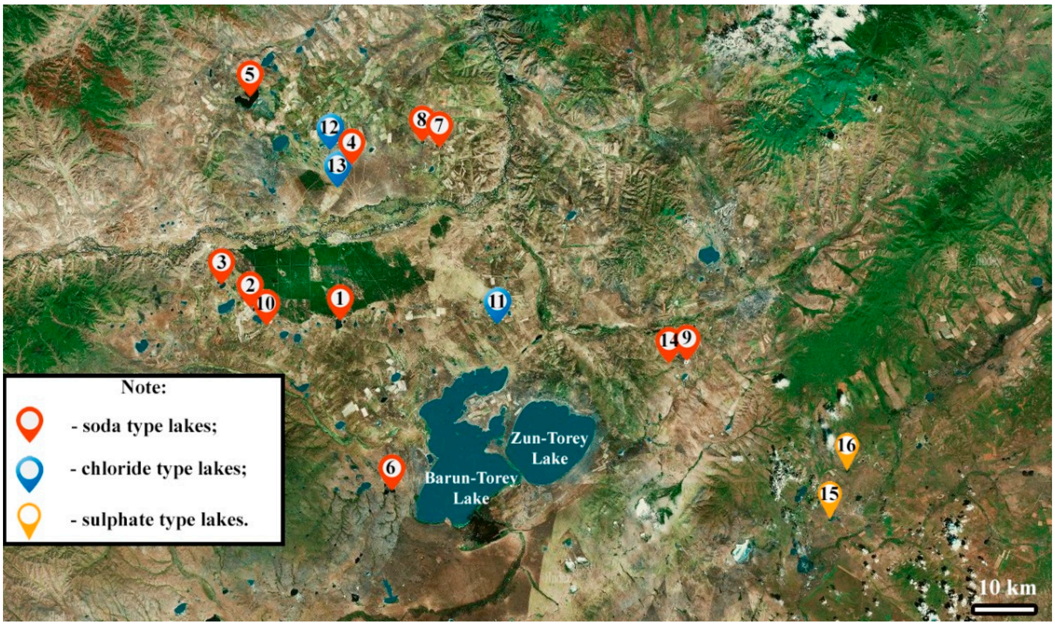

Figure 1. Map of location of the studied lakes. Note: 1—Bain-Tsagan (50°20′00′′ N 115°06′28′′ E), 2—Bain-Bulak (50°22′33′′ N 114°48′80′′ E), 3—Balyktui (50°24′55′′ N 114°42′43′′ E), 4—Kudzhertaj (50°40′36′′ N 115°8′37′′ E), 5—Nozhii (50°49′12′′ N 114°47′53′′ E), 6—Nizhniy Mukei (49°58′16′′ N 115°17′7′′ E), 7—Sheluta (50°42′48′′ N 115°23′18′′ E), 8—Haraganash (50°42′54′′ N 115°23′5′′ E), 9—Borzinskoe (50°14′57′′ N 116°16′17′′ E), 10—Ukshinda (50°20′29′′ N 114°50′0′′ E), 11—Dabosa-Nor (50°20′3′′ N 115°37′23′′ E), 12—Hilgonta (50°42′35′′ N 115°6′6′′ E), 13—Gorbunka (50°39′51′′ N 115°4′31′′ E), 14—Shvarcivskoe (50°15′17′′ N 116°16′34′′ E), 15—Shihalin-Nur (49°54′25′′ N 116°45′20′′ E), 16—Barun-Shivertuj (50°0′53′′ N 116°48′15′′ E).

Chloride-type lakes, such as Dabasu-Nur Lake, Gorbunka Lake and Khilganta Lake are located in closed basins of a round shape. Their water area does not exceed 2–6 km^2. Lakes are shallow (depth~0.2–1.5 m). The shores of water bodies are covered with salt ef-florescence and the bottom is flat. Chloride lakes are distinguished by maximum TDS (average 35.2 g/L) and minimum pH (average 8.17). The water salinity of the lakes in different years varied within a wide range. The lakes can be classified as brine, according to the ionic composition—as sodium chloride type [33–35].

Sulfate-type lakes (Shihalin-Nur and Barun-Shivertuj) are relatively small. The configurations of the water mirror are close to an elongated oval. The maximum area did not exceed 2.09 km^2, the minimum varied from 0.04 to 0.45 km^2 [32]. The depth of the lakes varies from 0.2–1.0 m. The sulfate type of lakes is characterized by a relatively low mineralization, with a small range of water pH variations and a high sulfate content. The average pH is 6.90 and the TDS is 8.74 g L^{-1}. The most mineralized in this group of water bodies, Lake Barun-Shivertui, has a minimum pH value of water and is distinguished by maximum concentrations of SO_4^{2-} (7.58 g L^{-1}), Cl^- (2.05 g L^{-1}) and HCO_3^- + CO_3^{2-} (1.70 g L^{-1}) [35,36].

2.2. Sampling Strategies

Samples were collected in the littoral and deep-water sites of the lake. A total of 48 phytoplankton samples and 39 zooplankton samples were taken in 2021–2022 (Table 1).

Table 1. Number of samples.

Type		**Soda**											**Chloride**			**Sulfate**	
Subtype		**I**						**II**		**III**							
Number of Samples	**Period**	**Bain-Tsagan**	**Bain-Bulak**	**Balyktui**	**Nozhii**	**Kudzhertaj**	**Nizhniy Mukei**	**Sheluta**	**Haraganash**	**Borzinskoe**	**Ukshinda**	**Shvarcivskoe**	**Dabosa-Nor**	**Hilgonta**	**Gorbunka**	**Shihalin-Nur**	**Barun-Shivertuj**
Phytoplankton																	
In littoral	2021	1	1	1	2	1	1	–	–	1	1	–	1	1	–	–	–
	2022	1	–	–	1	1	–	1	1	1	1	1	1	1	1	1	1
In deep-water sites	2021	3	1	1	2	1	1	–	–	1	1	–	1	1	–	–	–
	2022	3	–	–	3	1	–	1	1	1	1	1	1	1	1	1	1
Zooplankton																	
In littoral	2021	1	1	1	2	–	1	–	–	–	1	–		1	1	–	–
	2022	1	–	–	–	1	–	1	1	1	–	1	1	1	1	1	1
In deep-water sites	2021	1	1	1	1	–	1	–	–	–	1	–		1	1	–	–
	2022	1	–	–	–	1	–	1	1	1	–	1	1	1	1	1	1

Note: "–"—lack of water layer at the time of the investigation.

Abiotic environmental parameters (depth, TDS, dissolved oxygen, pH, temperature, turbidity) were measured using a multichannel monitoring probe EXO-2 (YSI, Yellow Springs, OH, USA). The environmental parameters were recorded in the same sites where hydrobiological samples were taken. The water transparency was determined with a Secchi disk.

2.3. Phytoplankton

Phytoplankton samples were taken from the surface using the Schindler–Patalas sampler. The volume of the water sample was 0.5 L. The samples were fixed with a 4% formalin solution. The samples were prepared by the sedimentary method. Each sample was processed separately. Algae were counted according to the Hansen method using a counting plate. The biomass was determined based on the volume of individual algae cells or colonies and their geometric figures. The specific weight was taken equal to one unit [37,38]. The dominant species included species whose abundance was more than 10% of the total abundance of phytoplankton [39].

2.4. Zooplankton

Zooplankton samples were collected using standard methods [40]. We used a Jedi medium-type net with an opening diameter of 25 cm and a filtering cone made of a nylon sieve with a mesh size of 0.064 mm. Samples fixed with 4% formalin solution were processed in laboratory conditions in the counting chambers of Kolkwitz and Bogorov. The biomass of zooplankters was calculated using the body length wet weight relationships [41]. Species whose abundance was at least 5% of the total number were classified as the dominant species [42].

2.5. Statistical Analysis

Data analysis of variance was performed using XLSTAT BASIC (Addisonsoft, New York, NY, USA). We performed principal correspondence analysis (PCA) for the water body groups and environmental variables using the pooled data of the samplings. Multivariate data were standardized and analyses were performed using the R program [43]. The relationship between hydrobiological and physicochemical parameters was assessed using pairwise Pearson correlations.

3. Results

3.1. Environmental Parameters

The abiotic characteristics of studied lakes are presented in Table 2.

Table 2. Physico-chemical parameters in studied lakes *.

Type	Subtype	Lake	Year	Alt	V	h	SDT	T	TDS	pH	Turb	O_2
Soda	I	Bain-Tsagan	2021	632	35.8	4.75	1.30	20.00	8.20	9.30	1.39	–
			2022			4.50	1.60	23.91	8.76	9.40	7.60	6.6
		Bain-Bulak	2021	655	33	0.80	0.80	26.40	4.68	9.22	6.67	17.2
		Balyktui	2021	750	2	0.20	0.10	27.10	7.99	9.30	139.58	13.2
		Kudzhertaj	2021	653	10	0.20	0.20	21.00	194.50	9.90	635.42	–
			2022			0.03	0.03	33.40	291.61	9.75	125.57	2,25
		Nozhii	2021	650	12	1.98	0.70	23.10	4.16	9.46	6.67	16.4
			2022			2.30	2.30	22.40	3.49	9.34	2.25	9.56
		Nizhniy Mukei	2021	700	–	0.10	0.10	24.40	128.33	9.90	927.08	8,4
	II	Sheluta	2022	669	8	1.00	0.35	23.50	6.22	9.48	18.57	9,34
		Haraganash	2022	694	14	0.15	0.10	18.40	3.65	9.04	63.07	8.61
	III	Borzinskoe	2021	654	69.2	0.05	0.05	34.9	231.30	9.40	–	3.58
			2022			0.05	0.05	29.10	138.54	9.46	16.69	1.92
		Ukshinda	2021	651	16	0.20	0.20	24.0	16.14	9.20	32.71	7.28
			2022			0.3	0.3	22.4	14.95	9.55	12.2	7.1
		Shvarcivskoe	2022	644	9	0.5	0.5	31.10	22.07	9.25	72.02	14.3
Chloride		Dabosa-Nor	2021	662	1.2	0.2	0.2	22.4	39.83	8.90	1.53	–
			2022			0.08	0.08	24.6	73.06	8.81	9.70	10.4
		Hilgonta	2021	663	0.5	0.1	0.1	20.9	33.87	8.9	8.06	–
			2022			0.1	0.1	25.10	17.13	8.87	0.92	10.6
		Gorbunka	2021	661	0.2	0.1	0.1	28.5	69.87	8.52	34.38	–
			2022			0.45	0.45	22.00	14.45	8.73	6.25	9.1
Sulfate		Shihalin-Nur	2022	652	11	0.2	0.2	24.90	21.26	8.86	2.05	5.01
		Barun-Shivertuj	2022	487	5	0.5	0.5	25.80	45.38	8.87	11.70	4.32

Note: "*"—the maximum values are given (the surface layer); "–"—no data; alt—altitude (m); V—lake volume ($\times10^{-3}$ km^3); h—sampling depth (m); SDT—Secchi transparency (m); T—temperature (°C); TDS—salinity (gL^{-1}); turb—turbidity (NTU); O_2—dissolved oxygen (g L^{-1}).

Bain-Tsagan Lake (4.5 and 4.75 m) and Nozhii Lake (1.9 and 2.3 m) were the deepest. The depths in other lakes did not exceed 1.0 m (average depth—0.78–0.81 m).

Water transparency was very low, with a Secchi reading of less than 0.65 m in soda lakes, 0.21 m—in sulfate lakes and 0.35 m—in chloride lakes.

Water temperature ranged from 20 to 34.9 °C in 2021 and from 18.4 to 33.4 °C in 2022. The water temperature in the chloride lakes increased to 28.5 °C (2021) and 25.1 °C (2022), in sulfate lakes—to 25.8 °C (2022).

The TDS varied from 4.16 to 231.30 g L^{-1} in 2021 and from 3.49 to 291.61 g L^{-1} in 2022. In soda lakes, the TDS varied from oligohaline to hyperhaline in both studied years. In chloride and sulfate lakes, salinity varied from polyhaline to hyperhaline.

The pH did not show significant variations in both studied periods. In soda lakes, the pH varied in the alkaline range (9.2–9.9 (2021) and 9.04–9.75 (2022)) with 9.44 and 9.41 median values. Values of pH between 8.52 and 8.90 were measured in chloride and sulfate lakes.

Most of the salt lakes are inorganically turbid. In 2021, turbidity changed from 1.39 to 927.08 NTU, and in 2022 from 0.92 to 125.57 NTU. The maximum values of turbidity were in soda lakes. Waters in lakes were an albescent color.

The maximum and minimum values are noted in soda lakes. Dissolved oxygen ranged from 1.92 to 17.2 mg L^{-1}. In soda lakes, the minimum values of the content of dissolved oxygen were recorded at the maximum values of TDS. In chloride lakes, the concentration of the dissolved oxygen ranged from 9.1 to 10.6 mg L^{-1}, and in sulfate—from 4.32 to 5.01 mg L^{-1}.

3.2. Principal Correspondence Analysis

PCA using environmental variables revealed two main axes that can explain most of the variations (Figure 2). The first principal component (Axis 1) accounted for 53.84 (2021) and 57.82 (2022) % of the variation and increased to 78.03 (2021) and 85.64 (2022) % when taken together with the second principal component. In 2021, the most important variables for Axis 1 ordination were pH (0.965), temperature (0.946) and Secchi transparency (0.751). Regarding Axis 2, salinity (0.701) is the most important variable for ordination. In 2022, the most important variables for Axis 1 ordination were pH (0.967), temperature (0.958), Secchi transparency (0.715) and concentration of dissolved oxygen (0.868). Regarding Axis 2, salinity (0.777) is the most important variable for ordination.

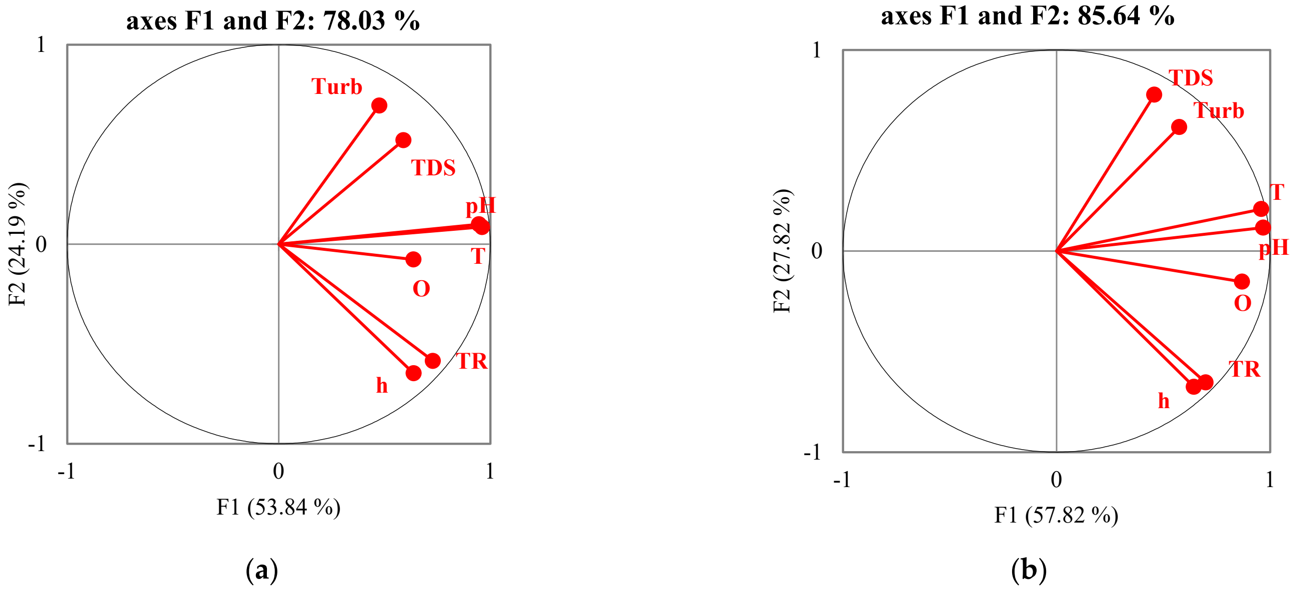

Figure 2. Principal component analysis (PCA) of the measured environmental parameters. (**a**)—2021; (**b**)—2022.

In general, the lengths of the environmental factors of pH, T, TR, TDS and O were longer than those of the others, which indicate that these five variables are the basic environmental factors in salt lakes.

3.3. Diversity of Phyto- and Zooplankton

The phyto- and zooplankton species compositions are listed in Table 3. We identified 56 algal taxa ranked below the genus level, representing the divisions Cyanobacteria (19 taxa), Bacillariophyta (13), Dinophyta (1), Cryptophyta (5), Charophyta (2), Chlorophyta (22), and Euglenophyta (2) and 27 zooplankton taxa, including 12 species and subspecies of Rotifera, 2 species of Anostraca, 5 species of Cladocera, and 8 species of Copepoda for both research years.

Table 3. Species composition of phyto- and zooplankton in 2021 (a) and 2022 (b).

Taxon	Lake Name															
	Soda I Subtype						Soda II Subtype		Soda III Subtype			Chloride			Sulfate	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Phytoplankton																
Cyanobacteria																
Anabaena sp.	ab	a	a	-	ab	-	-	b	-	-	-	-	-	-	-	-
A. sp. sp.	-	-	ab	-	-	-	-	-	-	-	-	-	-	-	-	-
Drouetiella lurida (Gomont) Mai, J.R.Johansen and Pietrasiak 2018	-	-	-	-	-	-	-	-	b	-	-	-	-	-	-	-
Gloeocapsa minor (Kutzing) Hollerbach 1937	-	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-
Jaaginema woronichinii (Anisimova) Anagnostidis and Komárek 1988	-	-	-	-	-	-	-	-	-	-	-	-	a	-	-	-
Kamptonema formosum (Bory ex Gomont) Strunecký, Komárek and J. Smarda 2014	-	-	-	-	-	-	-	-	-	-	a	-	-		-	-
Limnospira fusiformis (Voronichin) Nowicka-Krawczyk, Mühlsteinová and Hauer 2019	-	-	-	-	-	-	-	-	-	-	-	-	-	b	-	-
Merismopedia elegans A.Braun ex Kützing 1849	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nodularia spumigena Mertens ex Bornet and Flahault 1888	-	-	-	-	b	-	-	b	-	-	-	-	-	-	-	-
Oscillatoria limosa C.Agardh ex Gomont 1892	-	-	-	-	-	-	-	-	-	-	-	a	-	-	-	-
Oscillatoria major Vaucher ex Forti 1907	-	-	-	-	-	-	-	-	-	-	-	a	a	-	-	-
O. sp.	-	a	-	-	-	-	-	-	-	a	-	-	-	-	-	-
O. sp. sp.	-	a	-	-	-	-	-	-	-	a	-	-	-	-	-	-

Table 3. *Cont.*

Taxon	Lake Name															
	Soda I Subtype						Soda II Subtype		Soda III Subtype			Chloride			Sulfate	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Phormidium breve (Kützing ex Gomont) Anagnostidis and Komárek 1988	-	-	-	-	-	-	-	-	-	-	-	a	a	-	-	-
P. chalybeum (Mertens ex Gomont) Anagnostidis and Komárek 1988	-	-	-	-	-	-	-	-	-	-	-	-	a	-	-	-
P. sp.	b	-	-	-	b	-	-	-	-	-	b	b	b	-	b	b
P. sp. sp.	-	-	-	-	-	-	-	-	-	-	-	b	-	-	-	b
Spirulina major Kützing ex Gomont 1892	-	a	-	-	-	-	-	-	-	-	-	-	a	-	-	-
S. sp.	-	-	-	-	b	-	-	-	-	-	-	-	-	-	-	-
Bacillariophyta *Amphora ovalis* (Kützing) Kützing 1844	b	-	a	-	-	-	-	-	-	-	-	-	a	-	-	-
Cymbella sp.	b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragilaria crotonensis Kitton 1869	b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lindavia comta (Kützing) T.Nakov et al. 2015	a	-	-	-	-	-	-	-	b	-	-	-	a	-	-	-
Navicula sp.	ab	-	a	-	b	-	-	-	-	b	-	-	-	b	b	-
N. sp. sp.	-	-	-	-	-	-	-	-	-	b	-	-	-	-	b	-
N. sp. sp. sp.	-	-	-	-	-	-	-	-	-	b	-	-	-	b	b	-
Nitzschia sigmoidea (Nitzsch) W.Smith 1853	-	-	-	-	-	-	-	-	-	b	-	-	-	-	b	-
N. sp.	a	-	-	-	-	-	-	-	-	b	-	-	-	b	-	-
N. sp. sp.	-	-	-	-	-	-	-	-	-	b	-	-	-	b	b	-
Pinnularia sp.	a	-	-	-	-	-	-	-	a	-	-	-	-	-	-	-

Table 3. *Cont.*

Taxon	Lake Name															
	Soda I Subtype						Soda II Subtype		Soda III Subtype		Chloride				Sulfate	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot. 1999	-	-	-	-	-	-	-	-	-	-	-	-	a	-	-	-
Synedra sp.	-	-	-	-	-	-	-	-	a	-	-	-	-	-	-	-
Peridimium sp.	-	-	-	-	b	-	-	-	-	-	-	-	-	-	-	-
Cryptophyta *Chroomonas caudata* L.Geitler 1924	-	-	-	-	-	-	-	-	b	-	-	-	-	-	-	-
Cryptomonas marssonii Skuja 1948	-	-	-	-	-	-	-	-	b	-	-	-	-	-	-	-
C. erosa Ehrenberg 1832	ab	-	a	a	a	a	-	-	-	b	-	-	-	-	-	-
C. sp.	b	-	-	-	b	-	-	b	-	-	-	-	-	-	b	b
Rhodomonas salina (Wisłouch) D.R.A.Hill & R.Wetherbee 1989	-	-	-	-	-	-	-	-	b	-	-	-	-	-	-	-
Chlorophyta *Ankyra ancora* (G.M.Smith) Fott 1957	b	a	-	-	ab	-	-	b	-	a	-	-	-	-	b	b
Chlamydomonas sphagnicola (F.E.Fritsch) F.E.Fritsch and H.Takeda 1930	-	-	-	-	-	-	-	-	-	-	-	-	a	-	-	-
C. sp.	-	a	-	a	-	-	-	-	-	-	-	-	a	-	-	-
C. sp. sp.	-	-	-	-	-	-	b	-	-	-	-	-	-	-	-	-
Closteriopsis acicularis (Chodat) J.H.Belcher and Swale 1926	-	-	-	-	-	-	-	b	-	-	-	-	-	-	-	-
Coenocystis planctonica Korshikov 1953	-	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
Monoraphidium contortum (Thuret) Komárková-Legnerová in Fott 1969	-	-	-	-	b	-	-	-	-	-	-	-	-	-	-	b

Table 3. *Cont.*

Taxon	Lake Name															
	Soda I Subtype							Soda II Subtype		Soda III Subtype		Chloride			Sulfate	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
M. komarkovae Nygaard 1979	-	-	-	-	b	-	-	-	-	-	-	-	-	-	-	b
M. sp.	-	-	-	-	a	-	-	-	-	a	-	-	-	-	-	-
Lagerheimia genevensis (Chodat) Chodat 1895	-	-	-	-	-	-	-	-	-	-	b	-	b	-	-	-
Lemmermannia triangularis (Chodat) C.Bock and Krienitz 2013	-	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
L. komarekii (Hindák) C.Bock and Krienitz 2013	-	-	-	-	ab	-	-	-	-	-	-	-	-	-	-	-
Oocystis borgei J.W.Snow 1903	-	-	-	-	-	-	-	b	-	b	b	b	-	b	b	-
O. rhomboidea Fott 1933	-	-	-	-	-	-	-	-	-	-	-	a	-	-	-	-
O. sp.	-	-	-	-	b	-	-	b	-	b	-	b	-	-	b	-
Pandorina morum (O.F.Müller) Bory 1826	-	-	-	-	-	-	-	-	-	-	-	b	-	-	-	-
Pseudopediastrum boryanum (Turpin) E.Hegewald 2005	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhabdoderma sp.	-	-	-	-	b	-	-	-	-	-	-	-	-	-	-	-
Raphidocelis danubiana (Hindák) Marvan, Komárek and Comas 1984	-	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
Scenedesmus quadricauda (Turpin) Brébisson 1835	-	-	-	-	ab	-	-	-	-	-	-	-	-	-	-	-
Schroederia robusta Korshikov 1953	-	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
Tetradesmus obliquus (Turpin) M.J.Wynne 2016	-	-	-	-	-	-	-	b	-	-	-	-	-	-	-	-

Table 3. *Cont.*

Taxon	Lake Name															
	Soda I Subtype						**Soda II Subtype**		**Soda III Subtype**		**Chloride**				**Sulfate**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Charophyta *Spirogira* sp.	-	-	-	-	-	-	-	-	-	b	-	-	-	-	-	-
Staurastrum sp.	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euglenophyta *Euglena* sp.	-	-	-	-	b	-	-	b	-	-	-	-	-	-	b	-
Phacus sp.	-	-	-	-	ab	-	b	b	-	-	-	-	-	-	b	-
Zooplankton Rotifera *Eosphora najas* Ehrenberg, 1830	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lecane luna (Müller, 1776)	-	a	-	-	ab	-	-	b	-	-	-	-	-	-	-	-
Mytilina ventralis (Ehrenberg, 1832)	-		-	-	b	-	-	-	-	-	-	-	-	-	-	-
Colurella adriatica Ehrenberg, 1831	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchlanis dilatata Ehrenberg, 1832	-	a	-	-	a	-	-	-	-	-	-	-	-	-	-	-
Brachionus quadridentatus ancylognatus Schmarda, 1859	-		-	-	b	-	-	-	-	-	-	-	-	-	-	-
B. q. brevispinus Ehrenberg, 1832	-	a	a	-	-	-	-	-	-	-	-	-	-	-	-	-
B. q. cluniobicularis Skorikov, 1894	-	a	a	-	-	-	-	-	-	-	-	-	-	-	-	-
B. plicatilis Müller, 1786	-	-	a	a	b	-	b	-	-	-	b	ab	b	a	-	b
B. p. asplanchnoides Charin, 1947	-	-	-	-	-	-	-	b	b	-	-	-	-	-	b	-

Table 3. *Cont.*

Taxon	Lake Name															
	Soda I Subtype						**Soda II Subtype**		**Soda III Subtype**			**Chloride**			**Sulfate**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
B. leydigii (Cohen, 1862)	-	-	-	-	-	-	b	b	-	-	-	-	-	-	-	-
Hexarthra mira (Hudson, 1871)	ab	a	-	-	ab	-	-	b	b	ab	b	-	-	-	-	-
Anostraca Sp.	a	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
Sp. Sp.	-	-	-	-	-	-	-	-	ab	-	-	b	-	a	-	b
Cladocera *Daphnia magna* Straus, 1820	ab	a	-	-	ab	-	-	-	-	-	-	-	-	-	-	-
Moina brachiata (Jurine, 1820)	ab	a	a	-	ab	a	b	b	-	ab	-	-	b	b	b	-
Macrothrix laticornis (Jurine, 1820)	-	-	-	-	b	-	-	-	-	-	-	-	-	-	-	-
M. hirsuticornis Norman and Brady, 1867	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coronatella rectangula (Sars, 1862)	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copepoda *Metadiaptomus asiaticus* (Uljanin, 1875)	ab	-	a	b	-	-	b	-	-	ab	-	-	b	-	b	-
Hemidiaptomus ignatovi Sars, 1903	-	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
Arctodiaptomus bacillifer (Koelbel, 1885)	-	a	-	-		-	-	-	-	-	-	-	-	-	-	-
A. niethammeri (Mann, 1940)	-	-	-	-	ab	-	-	b	-	-	-	-	-	-	-	-
Mixodiaptomus incrassatus (Sars, 1903)	-	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
Eucyclops serrulatus (Fischer, 1851)	-	a	-	-	b	-	-	-	-	-	-	-	-	-	-	-
Thermocyclops dybowskii (Lande, 1890)	-	a	a	-	b	-	b	b	-	-	-	-	-	-	-	-
Copepodita Cyclopoida	b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Harpacticoida gen. sp.	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: 1—Bain-Tsagan, 2—Bain-Bulak, 3—Balyktui, 4—Kudzhertaj, 5—Nozhii, 6—Nizhniy Mukei, 7—Sheluta, 8—Haraganash, 9—Borzinskoe, 10—Ukshinda, 11—Shvarcivskoe, 12—Hilgonta, 13—Gorbunka, 14—Dabosa-Nor, 15—Shihalin-Nur, 16—Barun-Shivertuj.

In the soda lakes, phytoplankton was represented by 54 taxa from 7 divisions. The largest contributions to phytoplankton diversity were made by green algal (20 taxa), cyanobacteria (12) and diatoms (12), which together accounted for 81% of the total species composition (Figure 3a). The species number changed from 1 to 15 in both research years. Zooplankton species composition consisted of 27 species. Rotifers (44% of total species composition) dominated in lakes (Figure 3b). The species number changed from 1 to 14.

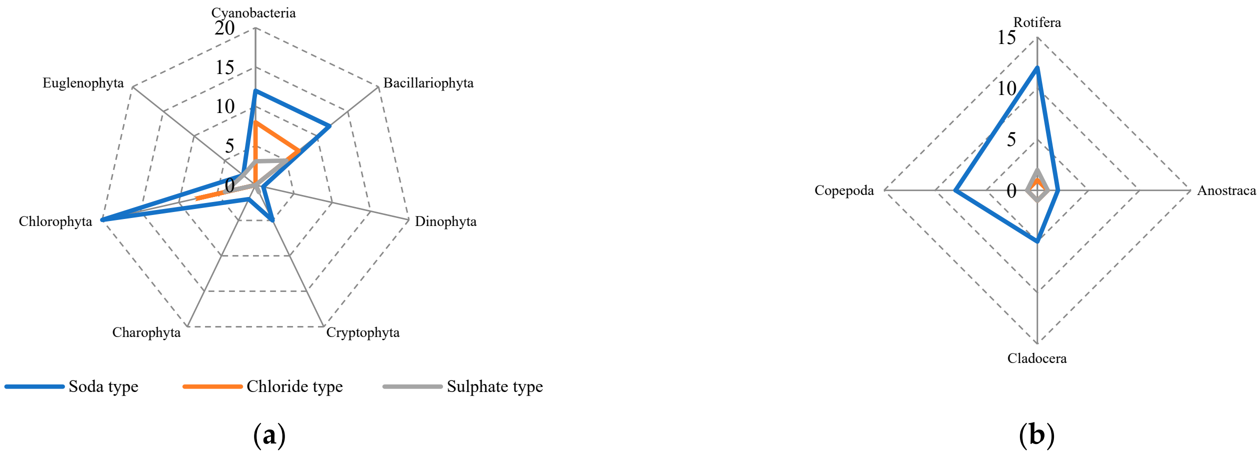

Figure 3. Number of phytoplankton (**a**) and zooplankton (**b**) taxa in different types of lakes.

In the chloride lakes, a total of 23 species of phytoplankton belonging to 3 phyla were identified. Among these species, eight species belonged to Cyanobacteria, eight species to Chlorophyta and seven species to Bacillariophyta. The species number changed from four to six. Zooplankton was characterized by low diversity and included four species: one species of Rotifera, one species of Anostraca, one species of Cladocera, and one species of Copepoda (Figure 3a,b).

In the sulfate lakes, 15 phytoplankton species (cyanobacteria (3 species), cryptomonads (1), green algae (4), diatoms (5) and euglenoids (2)) and 5 zooplankton species (2 species of Rotifera, 1 species of Copepoda, 1 species of Cladocera and 1 species of Anostraca) were found. In phytoplankton, the species number changed from 7 to 13, and in zooplankton from 2 to 5 (Table 3; Figure 3a,b).

3.4. Dominant Complex of Phyto- and Zooplankton

The composition of the dominant groups in different types of lakes was different. In soda lakes, eight taxa from three divisions (Cyanobacteria, Bacillariophyta and Chlorophyta) were established. The dominant species included *Limnospira fusiformis*, *Phormidium* sp., *Anabaena* sp., *Chroomonas caudata*, *Cryptomonas erosa*, *Chlamydomonas sphagnicola*, *Chlamydomonas* sp., *Oocystis* sp., *Closteriopsis acicularis* and *Lagerheimia genevensis*. In chloride lakes, *Phormidium* sp. dominated. In sulfate lakes, the most abundant were *Cryptomonas* sp., *Lagerheimia genevensis* and *Oocystis* sp. (Table 3).

In the studied lakes, the taxa contributing to the zooplankton community differed over the years (Table 4). One to four species dominated. The composition of dominants included species with salinity preferences: *Brachionus plicatilis*, *Moina brachiata*, *Metadiaptomus asiaticus* and *Thermocyclops dybowskii*. The species *B. plicatilis*, *M. brachiata* and *M. asiaticus* were common to all types of lakes.

Table 4. The composition of dominant species in studied lakes.

Type of Lake	Lake	Phytoplankton				Zooplankton			
		2021		2022		2021		2022	
		Number of Species	Dominant Species/Taxa	Number of Species	Dominant Species/Taxa	Number of Species	Dominant Species/Taxa	Number of Species	Dominant Species/Taxa
Soda I subtype	Bain-Tsagan	6	*Anabaena* sp.	11	*Anabaena* sp.	6	*Metadiaptomus asiaticus*	5	*Metadiaptomus asiaticus*
	Bain-Bulak	10	*Merismopedia elegans* *Anabaena* sp.	6	–	14	*Hexarthra mira* *Euchlanis dilatata* *Arctodiaptomus bacillifer* *Eucyclops serrulatuss*	–	–
	Balyktui	6	*Anabaena* sp.	–	–	5	*Moina brachiate* *Metadiaptomus asiaticus*	–	–
	Nozhii	11	*Ankyra ancora* *Anabaena* sp.	21	*Phormidium* sp.	11	*Euchlanis dilatata* *Daphnia magna* *Arctodiaptomus niethammeri* *Mixodiaptomus incrassatus*	6	*Hexarthra mira* *Thermocyclops dybowskii*
Soda II subtype	Kudzhertaj	2	*Cryptomonas erosa*	1	*Cryptomonas* sp.	1	*Brachionus plicatilis*	1	*Metadiaptomus asiaticus*
	Nizhniy Mukei	1	*Cryptomonas marsonii*	–	–	1	Ephippia	–	–
	Sheluta	–	–	18	*Closteriopsis acicularis*	–	–	7	*Thermocyclops dybowskii*
	Haraganash	–	–	3	*Ankyra ancora*	–	–	5	*Thermocyclops dybowskii* *Moina brachiata*

Table 4. *Cont.*

Type of Lake	Lake	Phytoplankton				Zooplankton			
		2021		2022		2021		2022	
		Number of Species	Dominant Species/Taxa	Number of Species	Dominant Species/Taxa	Number of Species	Dominant Species/Taxa	Number of Species	Dominant Species/Taxa
Soda III subtype	Ukshinda	4	*Ankyra ancora* *Phormidium* sp.	5	*Phormidium* sp.	3	*Moina brachiata* *Metadiaptomus asiaticus*	3	*Metadiaptomus asiaticus*
	Shvarcivskoe	–	–	4	*Limnospira fusiformis* *Cryptomonas erosa*	-	–	2	*Brachionus plicatilis*
	Borzinskoe	2	Benthic diatoms	6	*Chroomonas caudata*	1	Anostraca	4	*Metadiaptomus asiaticus*
Sulfate	Shihalin-Nur	–	–	17	*Oocystis* sp.	-	–	3	*Moina brachiata* *Metadiaptomus asiaticus*
	Brun-Shivertuj	–	–	7	*Lagerheimia genevensis* *Cryptomonas* sp.	-	–	2	*B. plicatilis*
Chloride	Gorbunka	4	*Oscillatoria major* *Phormidium* sp.	6	*Monoraphidium* sp. *Phormidium* sp.	1	Anostraca	2	*Moina brachiata*
	Hilgonta	12	*Cryptomonas* sp.	4	*Phormidium* sp.	1	*Brachionus plicatilis*	3	*Moina brachiata* *Metadiaptomus asiaticus*
	Dabosa-Nor	3	*Phormidium* sp.	6	*Phormidium* sp.	1	*Brachionus plicatilis*	2	*Brachionus plicatilis*

3.5. Abundance and Biomass of Phyto- and Zooplankton

Phytoplankton abundance and biomass values of soda lakes were greater (20.84×10^3–$59{,}616 \times 10^3$ cells·L^{-1} and 0.39–61,404.5 g m^{-3}, respectively) than in sulfate (245.1×10^3–3833.76×10^3 cells·L^{-1} and 43.2–2964.8 g m^{-3}, respectively) and chloride (13.44×10^3–324.77×10^3 cells·L^{-1} and 1.68–353.15 g m^{-3}, respectively) lakes (Figure 4).

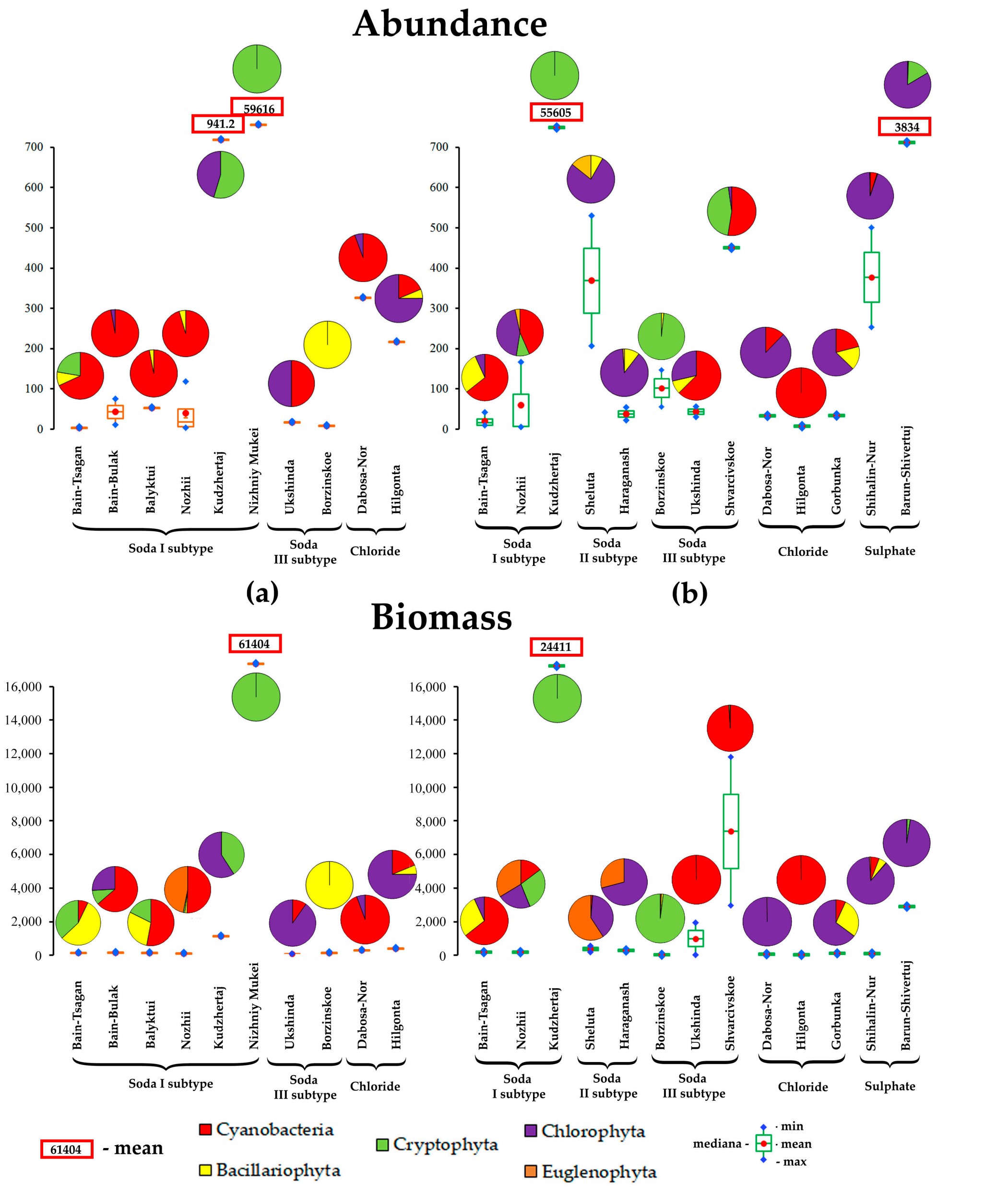

Figure 4. Boxplot showing the abundance ($\times 10^3$ cells·L^{-1}) /biomass (g m^{-3}) of phytoplankton, and relative abundance/biomass of phytoplankton groups in the studied lakes in 2021 (**a**) and 2022 (**b**). Note: 1—Bain-Tsagan, 2—Bain-Bulak, 3—Balyktui, 4—Nozhii, 5—Kudzhertaj, 6—Nizhniy Mukei, 7—Sheluta, 8—Haraganash, 9—Ukshinda, 10—Shvarcivskoe, 11—Borzinskoe, 12—Shihalin-Nur, 13—Barun-Shivertuj, 14—Gorbunka, 15—Hilgonta, 16—Dabosa-Nor.

The largest contributions to phytoplankton diversity were made by cyanobacteria (12–97% of the total species composition), green (44–95%) and cryptophyte (16–100%) algae in studied lakes. Taxa of Cyanobacteria, Cryptophyta and Chlorophyta prevailed in soda lakes. Green algae dominated in species composition in sulfate lakes, and cryptophyte and cyanobacteria in chloride lakes (Figure 4).

The maximum values of the abundance and biomass of zooplankton were noted in soda lakes. The total abundance (0.05–293,687 × 10^3 ind. m^{-3}) and biomass (0.003–255.94 g m^{-3}) of zooplankton varied widely. In sulfate lakes, zooplankton numbers ranged from 1037.71 × 10^3 ind. m^{-3} to 3649.17 × 10^3 ind. m^{-3}, and values for biomass were in the range from 10.24 g m^{-3} to 62.35 g m^{-3}. In chloride lakes, the abundance varied from 10.52 × 10^3 to 12,047.62 × 10^3 ind. m^{-3} to; the biomass varied from 0.0003 to 55.61 g m^{-3} (Figure 5).

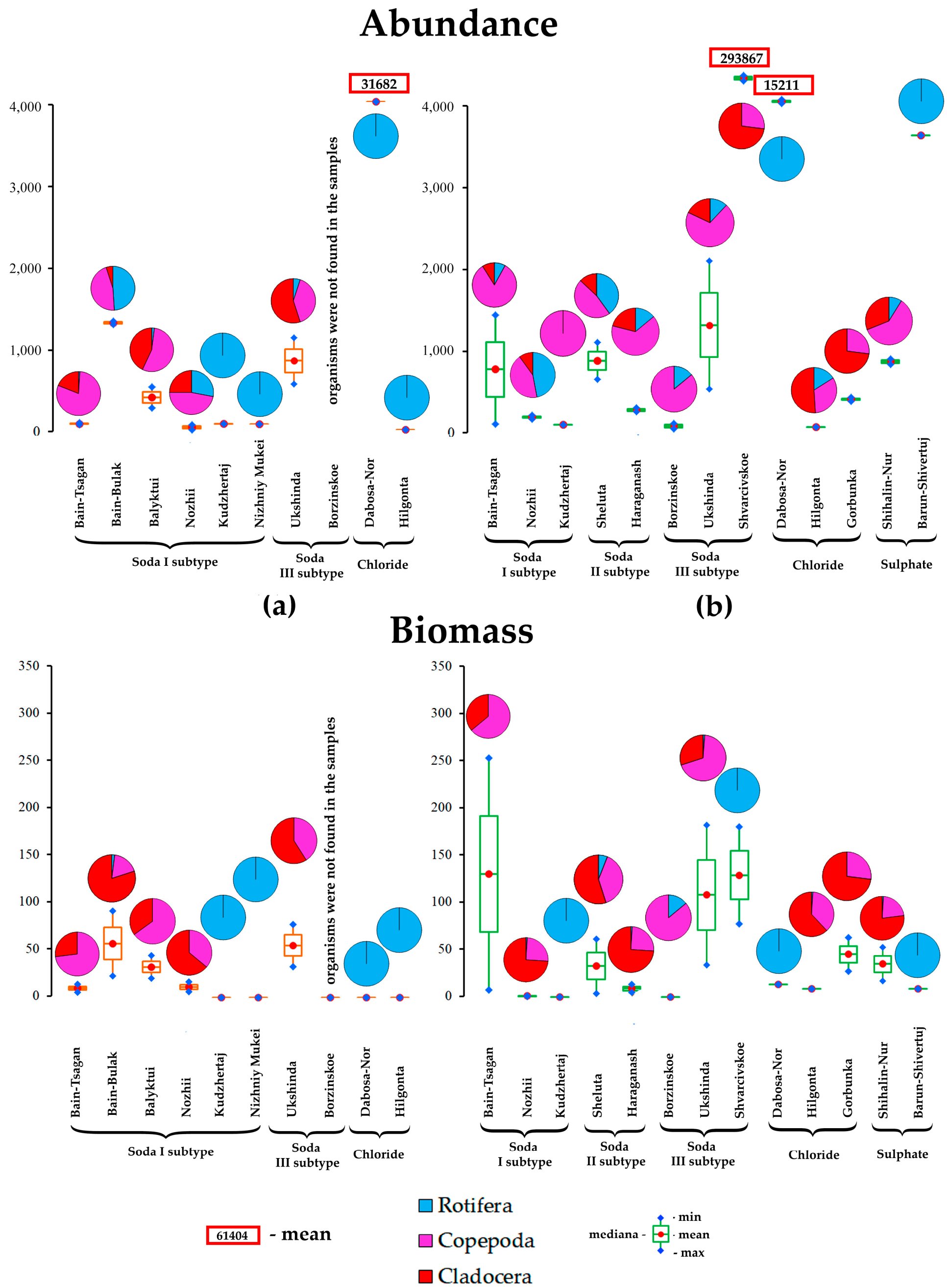

Figure 5. Boxplot showing the abundance (× 10^3 ind. m^{-3})/biomass (g m^{-3}) of zooplankton, and relative abundance/biomass of zooplankton groups in the studied lakes in 2021 (**a**) and 2022 (**b**). Note: 1—Bain-Tsagan, 2—Bain-Bulak, 3—Balyktui, 4—Nozhii, 5—Kudzhertaj, 6—Nizhniy Mukei, 7—Sheluta, 8—Haraganash, 9—Ukshinda, 10—Shvarcivskoe, 11—Borzinskoe, 12—Shihalin-Nur, 13—Barun-Shivertuj, 14—Gorbunka, 15—Hilgonta, 16—Dabosa-Nor.

Rotifers (6–100% of total abundance and biomass), Copepoda (10–77%) and Cladocera (9–100%) prevailed in the studied lakes.

3.6. Relationships between Environmental Factors and Quantitative Indicators of the Plankton

The correlation analysis of values of hydrochemical and hydrobiological indicators was found to be informative. A total of 28 pairs of reliable (significance level $p < 0.05$, $p < 0.01$ and $p < 0.001$) medium and strong correlations (correlation coefficient r = 0.5210–0.9999) between the analyzed indicators were revealed (Table 5).

Table 5. Correlations between environmental factors and quantitative indicators of the plankton in the soda, chloride and sulfate lakes.

Indicators	H	TR	pH	T	TDS	Turb	O_2
Soda lakes (n = 42)							
n_{ph}	–	0.7402 *	–	–	−0.9939 ***	–	–
N_{ph}	–	–	−0.5210 *	–	0.8984 ***	–	–
B_{ph}	0.7544 **	–	−0.5930 **	0.7912 *	0.9797 ***	–	–
n_z	–	–	–	–	−0.9239 *	–	–
N_z	–	–	−0.7736 **	–	–	–	–
B_z	–	–	0.5022 *	–	–	–	–
Chloride lakes (n = 30)							
n_{ph}	–	–	–	–	–	–	–
N_{ph}	0.9996 **	0.9996 **	–	–	–	0.7984 *	–
B_{ph}	0.9970 *	0.9617 *	–	−0.9999 ***	–	–	–
n_z	–	–	–	–	–	–	–
N_z	–	–	–	−0.9999 ***	–	–	–
B_z	0.9999 ***	0.9999 ***	–	–	–	–	–
Sulfate lakes (n = 20)							
n_{ph}	–	–	−0.9530 **	–	–	−0.7997 *	−0.7974 *
N_{ph}	–	–	0.9999 ***	–	–	–	–
B_{ph}	–	–	0.9998 **	–	–	–	–
n_z	–	–	0.9998 ***	–	–	–	–
N_z	–	–	0.9555 **	–	–	−0.7976 *	–
B_z	–	–	−0.9699 **	–	–	–	–

Note: "*" is $p < 0.05$, "**" is $p < 0.01$, "***" is $p < 0.001$; "–" is insignificant correlations; "n" is number of species, "H" is depth, "TR" is transparency, "T" is temperature, "Turb" is turbidity, "O" is oxygen concentration, "N" is abundance, "B" is biomass, "$_{ph}$" is phytoplankton, "$_z$"—zooplankton.

In soda lakes, the TDS was significantly positively correlated with the abundance and biomass of phytoplankton, and negatively correlated with the number of species of phytoplankton and zooplankton.

In chloride lakes, the abundance and biomass of algae and biomass of invertebrates were significantly correlated with depth and transparency. The temperature was negatively correlated with biomass phytoplankton and the abundance of zooplankton.

In sulfate lakes, the pH showed the strongest positive correlation with the abundance and biomass of phytoplankton and zooplankton species richness.

4. Discussion

A wide variety of ionic compositions occurs in salt lakes. A number of authors have considered the extent to which different ion combinations influence the presence and abundance of species [44–50], etc. Following W.D. Williams (1998), ionic composition can and does influence the composition of the biota of salt lakes. The manner in which this influence is exerted, however, remains unknown in most cases.

According to our data, the species composition and the ratio of divisions/groups in the phyto- and zooplankton in the studied lakes are common in the bodies of water with high salinity [29,51–60].

The greatest taxonomic richness of phytoplankton was in soda lakes (54 taxa from 7 divisions). Taxa of Cyanobacteria, Cryptophyta and Chlorophyta prevailed in these lakes.

The predominance of cyanobacteria and green algae was also noted for the soda lakes of the Kulunda steppe [51,52]. The phytoplankton of the chloride and sulfate lakes was less diverse. Green algae dominated in species composition in sulfate lakes, and cryptophyte algae and cyanobacteria dominated in chloride lakes. The predominance of these groups of algae was also noted in the sulfate lakes of Canada [53].

For all lakes with high salinity (128.33–232.3 g L^{-1}), a general trend in the dominance of cryptophyte algae in plankton was noted. In lakes with low mineralization, cyanobacteria and green algae are predominant.

Similar conditions were noted in the Aral Sea, where dinophyte and diatom algal are observed in areas of high TDS value, and blue-green algae are most conspicuous in the area of medium and lower TDS values [61]. Green and blue-green algal dominate in Chany Lake [62], Balaton Lake [63], and Utah Lake [64] with increasing salinity. In Shira Lake, when the salinity of the lake is high (about 27 g L^{-1}) only three species (diatom and green) are abundant. When the salinity of the lake decreases (to almost 18 g L^{-1}), cyanophyta dominate [65]. In Canadian saline lakes, increases in salinity and mean temperature are usually accompanied by a shift away from cyanophyte species in favor of chlorophytes, cryptophytes, and chrysophytes [66].

The zooplankton of soda, sulfate and chloride lakes did not differ and included species with saline preference: *B. plicatilis*, *M. brachiata* and *M. asiaticus*. One species of Rotifera *B. plicatilis* was found in zooplankton in all types of lakes. It is a cosmopolitan, halobiont and typical inhabitant of inland saline lakes, preferring alkaline soda (hydrocarbonate) lakes [60]. However, it can also be dominant in chloride lakes [61].

Our data showed that the quantitative characteristics of algae and invertebrates do not depend on the ionic composition. They are determined by the combined action of factors. This is also noted for the salt lakes of Australia [67], Mongolia [29] and Russia [68].

A variety of environmental factors such as salinity, dissolved oxygen concentration, pH and hydrological characteristics (water level) may, in various combinations or individually, be significant in determining the structure of the planktonic community in saline lakes [64,65,69–76]. Species in ephemeral lakes are adapted to the large variability of water chemistry, particularly salinity, temperature and cyclical droughts of varying duration [77–79].

Studies of the Crimean lakes showed that invertebrates exerted a rather wide tolerance to the variation of salinity being at the same time strongly dependent on the quality and quantity of food resources, the presence of predators and competition [77].

In the studied years, the phase of the hydrological cycle was characterized by a decrease in the area moisture content [31], which contributed to a fluctuation in the water level in the lakes and, in turn, to an increase/decrease in the total water salinity and pH.

Based on the results of the PCA (Figure 2), temperature, pH, transparency and TDS are keys physical factors that determine environmental conditions in these lakes.

In 2021–2022, salinity varied from oligohaline to hyperhaline water types and the pH ranged from 9.2–9.9 (2021) and 9.04–9.75 (2022), respectively. The decrease in the heat capacity of the lakes due to the increase in salinity caused a fast and strong heating of the water in the summer months (from 20 to 34.9 °C in 2021 and from 18.4 to 33.4 °C in 2022).

Our dates have shown that TDS is a key factor in the formation of planktonic communities in soda lakes. TDS and pH are the main drivers of plankton community dynamics [56,57] which can regulate plankton communities directly [58,59] and indirectly [60]. It is well known that an increase in the concentration of salts and an alkaline reaction of the environment leads to a decrease in the species diversity of aquatic organisms. Phyto- and zooplankton are the most richest in soda lakes. Most of the alkaline and highly alkaline lakes are not only alkaline but also saline; therefore, the effects of alkalinity and salinity cannot be separated [80]. This is indirectly confirmed by the low significant correlations obtained in our studies (Table 5).

Depth, transparency and temperature are driving factors in chloride lakes. The dependence of species richness and abundance (mainly crustaceans) on water temperature and depth was also noted in the salt chloride lakes of Argentina [81,82].

In sulfate lakes, the pH was significantly correlated with six parameters of plankton, showing a positive correlation with abundance, the biomass of phytoplankton and the number of species and the abundance of zooplankton. The number of species of algae and the biomass of invertebrates were positively correlated with the pH. Following [83,84], in the sulfate lakes of Saskatchewan, Canada salinity is the dominant influence. Other environmental factors such as water column depth, pH, transparency of the Secchi disc, water temperature and the month of sampling influenced zooplankton in sulfate lakes of Alberta and Saskatchewan, Canada [85].

To conclude, our results indicated that in three groups of lakes that differ in chemical type, the main physico-chemical drivers of plankton community dynamics are salinity, depth, transparency, temperature and pH. Our observations and analysis presented here highlight that the correlations between the structural parameters of plankton organisms (algae and invertebrates) and the environmental factors (Table 5) are not fully clear. We believe that our results should be analyzed in combination with other environmental parameters (electrical conductivity, nutrients, mineral composition of water, light, etc.) that were not studied in the current investigation [85–87].

The species composition and structure of algae in the studied lakes were different. Taxa of Cyanobacteria, Cryptophyta and Chlorophyta prevailed in soda lakes. Green algae dominated in species composition in sulfate lakes, cryptophyte algae and cyanobacteria dominated in chloride lakes. The zooplankton of soda, sulfate and chloride lakes did not differ and included species with saline preference. The quantitative characteristics of plankton did not depend on the ionic composition.

Further monitoring of these groups of lakes is necessary, as in Central Asia, saline lakes are common, yet their ecology has received little attention [26,29,73,88–91].

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References

1. Williams, W.D. The largest, highest and lowest lakes of the world: Saline lakes. *Verh. Int. Ver. Für Limnol.* **1996**, *26*, 61–79. [CrossRef]
2. Williams, W.D. Environmental threats to salts lakes and the likely status of inland saline ecosystems in 2025. *Environ. Conserv.* **2002**, *29*, 154–167. [CrossRef]
3. Zavarzin, G.A. Epicontinental alkaline water bodies as relict biotopes for the development of terrestrial biota. *Mikrobiologiâ* **1993**, *62*, 789–800.
4. Brucet, S.; Boix, D.; Gascón, S.; Sala, J.; Quintana, X.D.; Badosa, A.; Søndergaard, M.; Lauridsen, T.L.; Jeppesen, E. Species Richness Crustac. Zooplankton Trophic Struct. Brac. Lagoons Contrasting Clim. Zones: North Temp. Den. Mediterr. Catalonia (Spain). *Ecography* **2009**, *32*, 692–702. [CrossRef]
5. Felföldi, T. Microbial communities of soda lakes and pans in the Carpathian Basin: A review. *Biol. Futura* **2020**, *71*, 393–404. [CrossRef]
6. Shadrin, N.V.; Anufrieva, E.V. Dependence of halotolerance of Arctodiaptomus salinus (Calanoida, Copepoda) on exoosmolytes: New data and hypothesis. *J. Mediterr. Ecol.* **2013**, *12*, 21–26.
7. Raini, J.A. The eastern Africa flamingo Lakes: Building partnerships for sustainable resource management. In Proceedings of the 11th World Lakes Conference, Nairobi, Kenya, 31 October–4 November 2005; Volume 2, pp. 276–281.
8. Marden, B.; Brown, P.; Bosteels, T. Great Salt Lake Artemia: Ecosystem Functions and Services with a Global Reach. In *Great Salt Lake Biology*; Baxter, B., Butler, J., Eds.; Springer: Cham, Switzerland, 2020; pp. 175–237.

9. Wurtsbaugh, W.A.; Gliwicz, Z.M. Limnological control of brine shrimp population dynamics and cyst production in the Great Salt Lake, Utah. In *Saline Lakes. Developments in Hydrobiology*; Melack, J.M., Jellison, R., Herbst, D.B., Eds.; Springer: Dordrecht, The Netherlands, 2001; Volume 162, pp. 119–132.
10. Valyashko, M.G. *Regularities in the Formation of Salt Deposits*; Moscow State University: Moscow, Russia, 1962; p. 398.
11. Zheng, M.; Liu, X. Hydrochemistry of Salt Lakes of the Qinghai-Tibet Plateau, China. *Aquat. Geochem.* **2009**, *15*, 293–320. [CrossRef]
12. Borzenko, S.V.; Shvartsev, S.L. Chemical composition of salt lakes in East Transbaikalia (Russia). *Appl. Geochem.* **2019**, *103*, 72–84. [CrossRef]
13. Borzenko, S.V. The main formation processes for different types of salt lakes: Evidence from isotopic composition with case studies of lakes in Transbaikalia, Russia. *Sci. Total Environ.* **2021**, *782*, 146782. [CrossRef]
14. Chang, W.Y.B. Large lakes of China. *J. Great Lakes Res.* **1987**, *13*, 235–249. [CrossRef]
15. Last, W.M. Continental brines and evaporites of the northern Great Plains of Canada. *Sediment. Geol.* **1989**, *64*, 207–221. [CrossRef]
16. Last, W.M. Chemical composition of saline and subsaline lakes of the northern Great Plains, western Canada. *Int. J. Salt Lake Res.* **1992**, *1*, 47–76. [CrossRef]
17. Zsuga, K.; Inelova, Z.; Boros, E. Zooplankton Community Structure in Shallow Saline Steppe Inland Waters. *Water* **2021**, *13*, 1164. [CrossRef]
18. Last, W.M.; Ginn, F.M. Saline systems of the Great Plains of western Canada: An overview of the limnogeology and paleolimnology. *Aquat. Biosyst.* **2005**, *1*, 1–38. [CrossRef] [PubMed]
19. Frish, V.A. Torey "experiment". *Nature* **1972**, *2*, 60–66.
20. Zamana, L.V.; Borzenko, S.V. Hydrochemical regime of saline lakes in the southeastern Transbaikalia. *Geogr. Nat. Res.* **2010**, *31*, 370–376. [CrossRef]
21. Kuklin, A.P.; Tsybekmitova, G.T.; Gorlacheva, E.P. State of lake ecosystems in Onon-Torei 601 plain in 1983–2011 (Eastern Transbaikalia). *Arid. Ecosyst.* **2013**, *3*, 122–130. [CrossRef]
22. Zamana, L.V.; Vakhnina, I.L. Hydrochemistry of saline lakes of the southeastern Transbaikalia under climate aridization in the beginning of 20th century. *Int. J. Appl. Fundam. Res.* **2014**, *11*, 608–612.
23. Tsibekmitova, G.T.; Matveeva, M.O. Content of nutrients in the lakes of the Onon-Torey depression during the period of climatic fluctuations. *Water Sect. Russ.* **2019**, *3*, 94–108.
24. Oremland, R.S. Arsenic, prokaryotes, and closed basin soda lakes of the Western USA. *AGU Fall Meet. Abstr.* **2006**, *2006*, H51H-02.
25. Tashlykova, N.A.; Afonina, E.Y. The current species composition and ecological685 geographical characteristics of plankton communities in the littoral zone of some lakes of the 686 Uldza-Torey basin (Trans-Baikal Territory). *Acta Biol. Sib.* **2019**, *5*, 102–110.
26. Itigilova, M.T.; Dulmaa, A.; Afonina, E.Y. Zooplankton of lakes of the Uldza and Kerulen river valleys of Northeastern Mongolia. *Inland Water Biol.* **2014**, *7*, 249–258. [CrossRef]
27. Gorlacheva, E.P.; Tsybekmitova, G.T.; Afonin, A.V.; Tashlikova, N.A.; Afonina, E.Y.; Kuklin, A.P.; Saltanova, N.V. Lake-margin ecosystems of saline lakes of the Borzya group (Zabaikalsky Krai, Russia) during the initial filling phase. *Chin. J. Ocean Limn.* **2014**, *32*, 871–878. [CrossRef]
28. Bazarova, B.B.; Tashlykova, N.A.; Afonina, E.Y.; Kuklin, A.P.; Matafonov, P.V.; Tsybekmitova, G.T.; Gorlacheva, E.P.; Itigilova, M.T.; Afonin, A.V.; Butenko, M.N. Long-term fluctuations of the aquatic ecosystems in the Onon-Torey plain (Russia). *Acta Ecol. Sin.* **2019**, *39*, 157–165. [CrossRef]
29. Afonina, E.Y.; Tashlykova, N.A. Planktonic communities in the Torey Lakes (Zabaikalsky Krai) in a low water year. *J. Sib. Fed. Univ. Biol.* **2018**, *11*, 306–320.
30. Bazhenova, O.I. Modern dynamics of lacustrine-fluvial systems of the Onon-Torey high plain (Southern Transbaikalia). *Bull. TSU* **2013**, *371*, 171–177.
31. Obyazov, V.A. Change of climate and hydrological regime of the rivers and lakes in Dahurian region. In *Problems of Adaptation and Climate Change in the River Basins of Dahuria: Ecological and Hydroeconomic Aspects*; Kirilyuk, O., Ed.; Ekspress-izdatel'stvo: Chita, Russia, 2012; pp. 24–45.
32. Abiduyeva, E.Y.; Kozyreva, L.P.; Syrenzhapova, A.S.; Namsarayev, B.B. Seasonal changes in physicochemical environmental conditions of salt lake dabasu-nur (Southeastern Trans Baikalia). *Geogr. Nat. Resour.* **2008**, *2*, 177–179.
33. Tsyrenova, D.D.; Bryanskaya, A.V.; Khakhinov, V.V.; Zhavzan, C. Hydrochemical studies of brackish and saline lakes in Southern Transbaikalia. *Bull. Buryat State Univ. Chem. Phys.* **2009**, *3*, 17–19.
34. Suvorova, V.A.; Abidueva, E.Y. The environmental conditions and distribution of alkalophilic bacteria-destructor in mineral lakes in Transbaikalia and Mongolian Plateau. *Bull. Buryat State Univ. Chem. Phys.* **2012**, *3*, 67–69.
35. Borzenko, S.V. Basic conditions for the formation of the chemical composition of the waters of saline and brackish lakes in Eastern Transbaikalia. *Geochemistry* **2020**, *659*, 1212–1230.
36. Borzenko, S.V.; Zamana, L.V.; Posokhov, V.F. Isotope composition, nature and main mechanisms of formation of salt lakes in Transbaikalia. *Geol. Geophys.* **2022**, *63*, 851–874.
37. Sadchikov, A.P. *Methods of Studying Freshwater Phytoplankton*, 1st ed.; Publishing House "University and School": Moscow, Russia, 2003; pp. 67–79.
38. Kiselev, I.A. *Plankton of the Sea and Continental Reservoirs*, 1st ed.; Nauka: Leningrad, Russia, 1969; 658p.

39. Korneva, L.G. *Phytoplankton of the Reservoirs of the Volga Basin*; Kopylov, A.I., Ed.; Kostroma Printing House: Kostroma, Russia, 2015; 284p.
40. Balushkina, E.B.; Vinberg, G.G. The relationship between body weight and length in planktonic animals. In *General Principles of Study of Aquatic Ecosystems*, 1st ed.; Vinberg, G., Ed.; Nauka: Leningrad, Russia, 1979; pp. 169–172.
41. Ruttner-Kolisko, A. Suggestions for biomass calculation of plankton rotifers. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* **1977**, *8*, 71–76.
42. Fedorov, V.D.; Gilmanov, T.G. *Ecology*; Publishing House of Moscow State University: Moscow, Russia, 1980; 464p.
43. Dalgaard, P. *Introductory Statistics with R*, 1st ed.; Springer: New York, NY, USA, 2008; pp. 1–162.
44. Javor, B.J. Planktonic standing crop and nutrients in a saltern ecosystem. *Limnol. Oceanogr.* **1986**, *28*, 153–159. [CrossRef]
45. Edgerton, M.E.; Brimblecombe, P. Thermodynamics of halobacterial environments. *Can. J. Microbiol.* **1981**, *27*, 899–909. [CrossRef] [PubMed]
46. Baas-Becking, L.G.M. Salt effects on swarmers of Dunaliella viridis Teod. *J. Gen. Physiol.* **1931**, *14*, 765–779. [CrossRef]
47. Bayly, I.E.A. The occurrence of calanoid copepods in athalassic saline waters in relation to salinity and anionic proportions. *Verh. Int. Ver. Limnol.* **1969**, *17*, 449–455. [CrossRef]
48. Vesnina, L.; Bezmaternykh, D.; Moruzi, I.; Pishenko, E. Seasonal and interannual dynamics of zooplankton from Lake Kulundinskoye in 2017–2020. In *XV International Scientific Conference "INTERAGROMASH 2022" Global Precision Ag Innovation 2022*; Springer International Publishing: Cham, Switzerland, 2023; Volume 2.
49. Timms, B.V. Drivers restricting biodiversity in Australian saline lakes: A review. *Mar. Freshw. Res.* **2020**, *72*, 462–468. [CrossRef]
50. Csitári, B.; Bedics, A.; Felföldi, T.; Boros, E.; Nagy, H.; Máthé, I.; Székely, A.J. Anion-type modulates the effect of salt stress on saline lake bacteria. *Extremophiles* **2022**, *26*, 2–14. [CrossRef]
51. Zhao, W.; Zheng, M.P.; Xu, X.Z.; Liu, X.F.; Guo, G.L.; He, Z.H. Biological and ecological features of saline lakes in northern Tibet, China. *Hydrobiologia* **2005**, *541*, 189–203.
52. Vizer, L.S. Zooplankton Communities of Saline Reservoirs of the South of Western Siberia by Example of Chany Lake System. Doctoral Biology Dissertation, Digital Science & Education LP, Novosibirsk, Russia, 2016. Available online: https://www.dissercat.com/content/soobshchestva-zooplanktona-solonovatykh-vodoemov-yuga-zapadnoi-sibiri-na-primere-chanovskoi/read (accessed on 9 March 2022).
53. Hammer, U.T.; Shamess, J.; Haynes, R.C. The distribution and abundance of algae in saline lakes of Saskatchewan, Canada. *Hydrobiologia* **1983**, *105*, 1–26. [CrossRef]
54. Hammer, U.T.; Parker, J. Limnology of a perturbed highly saline Canadian lake. *Arch. Fur Hydrobiol.* **1984**, *102*, 31–42. [CrossRef]
55. Larson, C.A.; Belovsky, G.E. Salinity and nutrients influence species richness and evenness of phytoplankton communities in microcosm experiments from Great Salt Lake, Utah, USA. *J. Plankton Res.* **2013**, *35*, 1154–1166. [CrossRef]
56. Ivanova, M.B.; Kazantseva, T.I. Effect of Water pH and Total Dissolved Solids on the Species Diversity of Pelagic Zooplankton in Lakes: A Statistical Analysis. *Rus. J. Ecol.* **2006**, *37*, 264–270. [CrossRef]
57. Boronat, L.; Miracle, M.R.; Armengol, X. Cladoceran assemblages in a mineralization gradient. *Hydrobiologia* **2001**, *442*, 75–88. [CrossRef]
58. Frisch, D.; Moreno-Ostos, E.; Green, A. Species richness and distribution of copepods and cladocerans and their relation to hydroperiod and other environmental variables in Doñana, south-west Spain. *Hydrobiologia* **2006**, *556*, 327–340. [CrossRef]
59. Williams, W.D.; Boulton, A.J.; Taffee, R.G. Salinity as a determinant of salt lake fauna: A question of scale. *Hydrobiologia* **1990**, *197*,'257–266. [CrossRef]
60. Nedli, J.; De Meester, L.; Major, A.; Schwenk, K.; Szivak, I.; Forro, L. Salinity and depth as structuring factors of cryptic divergence in Moina brachiata (Crustacea: Cladocera). *Fundam. Appl. Limnol.* **2014**, *184*, 69–85. [CrossRef]
61. Kawabata, Y.; Nakahara, H.; Katayama, Y.; Ishida, N. The phytoplankton of some saline lakes in Central Asia. *Int. J. Salt Lake Res.* **1997**, *6*, 5–16. [CrossRef]
62. Popova, T.G. The main features of the algal distribution and composition in the lakes Chany and Yarkul during the high water period 1947–1948. In *Algae, Mushrooms and Lichens of the South of Siberia*; Naplekova, N.N., Levadnaya, G.D., Eds.; Nauka: Moscow, Russia, 1980; pp. 146–147.
63. Dokulil, M. Impact of climate warming on European inland waters. *Inland Waters* **2013**, *4*, 27–40. [CrossRef]
64. Stephens, D.W. Changes in lake levels, salinity and the biological community of Great Salt Lake (Utah, USA), 1847–1987. *Hydrobiologia* **1990**, *197*, 139–146. [CrossRef]
65. Zotina, T.A.; Tolomeyev, A.P.; Degermendzhy, N.N. Lake Shira, a Siberian salt lake: Ecosystem structure and function. 1. Major physico-chemical and biological features. *Int. J. Salt Lake Res.* **1999**, *8*, 211–232. [CrossRef]
66. Evans, J.C.; Prepas, E.E. Potential effects of climate change on ion chemistry and phytoplankton communities in prairie saline lakes. *Limnol. Ocean.* **1996**, *41*, 1063–1076. [CrossRef]
67. Conte, F.P.; Geddes, M.C. Acid brine shrimp: Metabolic strategies in osmotic and ionic adaptation. *Hydrobiologia* **1988**, *158*, 191–200. [CrossRef]
68. Ermolaeva, N.I.; Fetter, G.V. Influence of the ionic composition of water on the structure of the zooplankton of the lakes of the Tazheran Steppe (Western Baikalia). *Arid. Ecosyst.* **2021**, *11*, 411–420. [CrossRef]
69. Derry, A.; Prepas, E.; Hebert, P. A comparison of zooplankton communities in saline lakewater with variable anion composition. *Hydrobiologia* **2003**, *505*, 199–215. [CrossRef]

70. Tashlykova, N.A.; Afonina, E.Y. Diversity of plankton communities of chloride lakes of Southeastern Transbaikalia. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1112*, 012108. [CrossRef]
71. Geddes, M.C.; De Deckker, P.; Williams, W.D.; Morton, D.W.; Topping, M. On the chemistry and biota of some saline lakes in Western Australia. *Hydrobiologia* **1981**, *82*, 201–222. [CrossRef]
72. Comin, F.A.; Alonso, M.; Lopez, P.; Comelles, P. Limnology of Gallocanta Lake, Aragón, NE. *Spain Hydrohiol.* **1983**, *105*, 207–221. [CrossRef]
73. Stephens, D.W. A summary of biological investigations concerning the Great Salt Lake, Utah (1861–1973). *Great Basin Natural.* **1974**, *34*, 221–229.
74. Seaman, M.T.; Ashton, P.J.; Williams, W.D. Inland salt waters of southern Africa. *Hydrobiologia* **1991**, *210*, 75–91. [CrossRef]
75. Zhao, W.; He, Z. Biological and ecological features of inland saline waters in North Hebei, China. *Int. J. Salt Lake Res.* **1999**, *8*, 267–285.
76. Gao, Q.; Xu, Z.; Zhuang, P. The relation between distribution of zooplankton and salinity in the Changjiang Estuary. *Chin. J. Oceanol. Limnol.* **2008**, *26*, 178–185. [CrossRef]
77. Hammer, M.L.; Appleton, C.C. Physical and chemical characteristics and phyllopod fauna of temporary pools in north-eastern Natal, RSA. *Hydrobiologia* **1991**, *212*, 95–104. [CrossRef]
78. McCulloch, G.P.; Irvine, K.; Eckardt, F.D.; Bryant, R. Hydrochemical fluctuations and crustacean community composition in an ephemeral saline lake (Sua Pan, Makgadikgadi Botswana). *Hydrobiologia* **2008**, *596*, 31–46. [CrossRef]
79. Litvinenko, L.I.; Litvinenko, A.I.; Boyko, E.G.; Kutsanov, K.V. Effect of environmental factors on the structure and functioning of biocoenoses of hyperhaline water reservoirs in the South of Western Siberia. *Contemp. Probl. Ecol.* **2013**, *6*, 252–261. [CrossRef]
80. Reynolds, C.S.; Huszar, V.; Kruk, C.; Naselli-Flores, L.; Melo, S. Towards of functional classification of the freshwater phytoplankton. *J. Plankton Res.* **2002**, *24*, 417–428. [CrossRef]
81. Echaniz, S.A.; Vignatti, A.M.; De Paggi, S.J.; Paggi, J.C.; Pilati, A. Zooplankton seasonal abundance of south American Saline shallow lakes. *Int. Rev. Hydrob.* **2006**, *91*, 86–100. [CrossRef]
82. Echaniz, S.A.; Vignatti, A.M. Seasonal variation and influence of turbidity and salinity on the zooplankton of a saline lake in central Argentina. *Lat. Am. J. Aquat. Res.* **2011**, *39*, 306–315. [CrossRef]
83. Rawson, D.S.; Moore, J.E. The saline lakes of Saskatchewan. *Can. J. Res.* **1944**, *22*, 141–201. [CrossRef]
84. Hammer, U.T. Zooplankton distribution and abundance in saline lakes of Alberta and Saskatchewan, Canada. *Int. J. Salt Lake Res.* **1993**, *2*, 111–132. [CrossRef]
85. Salm, C.R.; Saros, J.E.; Martin, C.S.; Erickson, J.M. Patterns of seasonal phytoplankton distribution in prairie saline lakes of the northern Great Plains (U.S.A.). *Aquat. Biosyst.* **2009**, *5*, 1–13. [CrossRef] [PubMed]
86. Ionescu, V.; Năstăsescu, M.; Spiridon, L.; Bulgăreanu, V.A.C. The biota of Romanian saline lakes on rock salt bodies: A review. *Int. J. Salt Lake Res.* **1998**, *7*, 45–80. [CrossRef]
87. Harper, D.M.; Childress, R.B.; Harper, M.M.; Boar, R.R.; Hickley, P.; Mills, S.C.; Otieno, N.; Drane, T.; Vareschi, E.; Nasirwa, O.; et al. Aquatic biodiversity and saline lakes: Lake Bogoria National Reserve, Kenya. *Hydrobiologia* **2003**, *500*, 259–276. [CrossRef]
88. Alimov, A.F. (Ed.) *Soda Lakes of Transbaikalia: Ecology and Productivity*; Nauka: Novosibirsk, Russia, 1991; 216p.
89. Namsaraev, B.B.; Gorlenko, V.M.; Namsaraev, Z.B.; Garmaev, E.Z.; Abidueva, E.Y.; Dambaev, V.B.; Barkhutova, D.D.; Khahinov, V.V.; Zamana, L.V.; Borzenko, S.V.; et al. *Brackish and Saline lakes of Transbaikalia: Hydrochemistry, Biology*, 1st ed.; Buryat State University Publication: Ulan-Ude, Russia, 2009; 340p.
90. Krylov, A.V.; Mendsaihan, B.; Ayushsuren, C.; Tsvetkov, A.I. Zooplankton of pulsating lakes Orog and Tatsyn-Tsagaan (West Mongolia) in the period of the beginning of the stabilization of water-level regime. *Inland Water Biol.* **2020**, *13*, 242–250. [CrossRef]
91. Zadereev, E.; Lipka, O.; Karimov, B.; Krylenko, M.; Elias, V.; Pinto, I.S.; Alizade, V.; Anker, Y.; Feest, A.; Kuznetsova, D.; et al. Overview of past, current, and future ecosystem and biodiversity trends of inland soda lakes of Europe and Central Asia. *Inland Waters* **2020**, *10*, 438–452. [CrossRef]