

## Article

# Zooplankton Community Structure in Shallow Saline Steppe Inland Waters

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**Abstract:** Several shallow saline waters can be found in Central Asia in arid steppe climate, but our knowledge of their zooplankton community has been so far rather limited. The aim of our research was to provide data on the steppe zooplankton community in a large-scale regional study. Therefore, a baseline survey was carried out in 23 shallow inland waters of different salinity in Northern Kazakhstan. We measured the quantity and identified the taxonomic composition of zooplankton in the spring period and examined changes in community structure in correlation with salinity. Lesser salt concentration of the hyposaline–mesosaline waters was indicated by the presence of halophilic rotifer species: *Brachionus asplanchnoides*, *Br. dimidiatus*, *Br. plicatilis*. Mesosaline and hypersaline waters were indicated by the presence of halobiont crustaceans: *Moina salina*, *Arctodiaptomus salinus*, *Cletocamptus retrogressus*. Very high concentration of salt was indicated by presence of *Artemia* alone which is the only group, that can tolerate and adapt to this extreme environment. In the hypersaline waterbodies at over 79 gL<sup>−1</sup> high TDS conditions a very simple tropical structure was found. *Artemia* playing monopolistic ecological function in the zooplankton community. We identified three characteristic groups of shallow inland saline waters based on their zooplankton composition.

**Keywords:** saline water; halophilic; halobiont zooplankton organisms; species richness; taxonomical diversity



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## 1. Introduction

Inland saline waters are special aquatic ecosystems in arid and semi-arid zones, with important ecological nature conservation values. Many human activities cause irreversible changes in, the ecosystem, like salinization, decrease of biodiversity, drying up, etc. According to Williams [1], “it is a little doubt that by 2025 the natural character of most of the world’s salt lakes will have changed.” Therefore, it is very important to enumerate these waters, survey their condition, and preserve their natural values.

Zooplankton communities play an important role in the aquatic ecosystem as primary and secondary consumers; they transfer energy generated from primary productivity to higher trophic levels. Water salinity is one of the most important environmental factors which regulates the distribution and composition of zooplankton. The zooplankton structure of inland saline waters differs substantially from freshwater [2] and thalassohaline aquatic ecosystems. [3].

In Central Asia, there are several large saline lakes (e.g., the Caspian Sea, Aral Sea, Lake Balkhash, Lake Alakol, and Lake Tengiz). Aladin and Plotnikov [4] published a summary review about their physical and chemical features and water ecosystems. The zooplankton community of the Lake Balkhash was represented by 54 species in the 1970s.

In the more saline eastern part, *Arctodiaptomus salinus*, *Polyphemus pediculus*, and *Syda cristallina* were the predominant species (Saduakasova [5]). Lake Alakol is in the semi-desert zone of Kazakhstan. Its zooplankton community is very diverse (Loginovskikh and Dyusengaliev [6]; the predominant species are *Arctodiaptomus salinus*, *Ceriodaphnia reticulata*, *Eudiaptomus graciloides*, *Brachionus plicatilis*, and *Hexarthra oxyuris*. Lake Tengiz is a saline waterbody in the Tselinogra region of Kazakhstan. Data on its zooplankton composition were published by Burlibajeva et al. [7].

Besides these large lakes, there are more than 2,800,000 small and medium sized (1–500 km<sup>2</sup>) shallow saline waters in the region which are important aquatic habitats within the steppe ecosystems. Most of them can be characterized by a surface area of less than 1 km<sup>2</sup> [4]. Yermolaeva [8] published the zooplankton data of 16 mostly, subsaline lakes of Northern Kazakhstan lakes in 2013. According to her results, the species diversity in zooplankton starts decreasing at a water salinity of over 3.0 gL<sup>−1</sup>, by halophilic species replacing freshwater species. Aubakirova et al. [9] researched zooplankton in three medium sized lakes in the Kostanay Region. They concluded that zooplankton diversity in these waterbodies is poor and there is a negative correlation between salinity and zooplankton biomass. Boros et al. [10,11] studied the salinity and the trophic state of 25 shallow saline steppe waters in North Kazakhstan. Their results showed that the trophic state of these waters regarding total phosphorus (TP) and chlorophyll-a (CHL) concentrations exceeds the hypertrophic level in most cases.

Although much data are available from larger lakes, there are no regional overviews on zooplankton of smaller inland saline waters. Global climate change projections suggest that arid and semiarid regions are becoming warmer. As a result, the number of small waters of shallow athalassohaline origin can be drastically reduced in the future. Taking this fact into account, it is important to take stock of these waters, to study their aquatic ecosystem.

Therefore, the main purposes of our study were:

- to assess the less known zooplankton assemblages of representative shallow inland saline waters of North Kazakhstan on a large spatial scale (1000 km) in the arid steppe region;
- to survey and identify dominant and indicator species among rotifer and microcrustacean taxa, and contribute to the available literature;
- to analyze the change in abundance and taxonomic diversity along salinity gradient;
- to determine the salt concentration ranges where significant quantitative and qualitative changes occur in the zooplankton community structure of shallow waters.

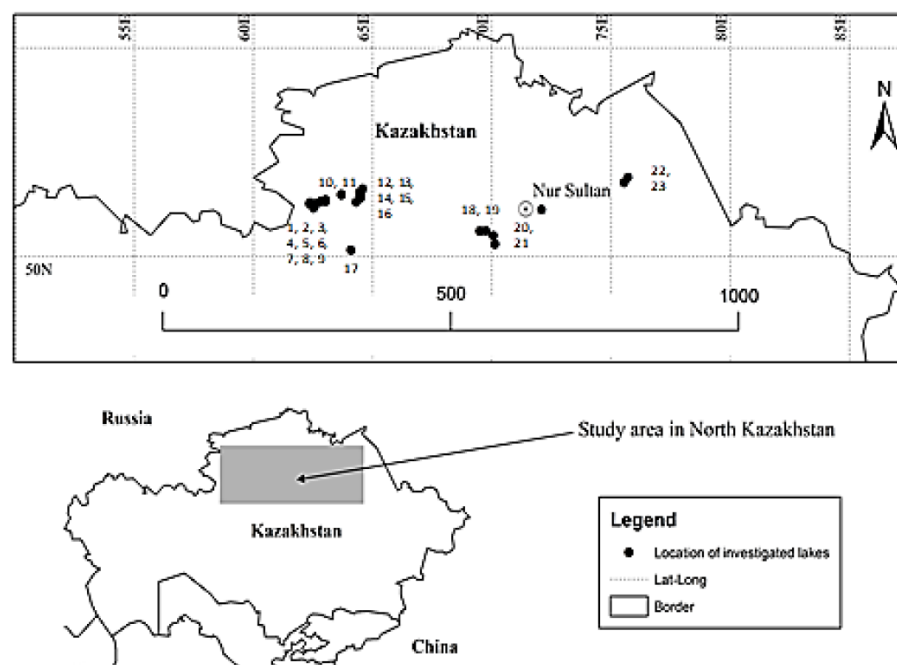
## 2. Materials and Methods

### 2.1. Study Area

The area of North Kazakhstan has a typical arid steppe climate, saline soils are present almost everywhere in Kazakhstan [12]. There are many types and sizes of endorheic inland saline waters in this steppe zone, however most of them are shallow with small or medium surface areas. The chemical and biological conditions of these waters are significantly influenced by the climate, the hydrological cycle, the level of groundwater, and the soil mineralization.

In the steppe zone of North Kazakhstan along a 1000-km long east-west line (the geographical region of 50° N, 60° E and 50° N, 80° E) 23 small and medium sized (<1–454 km<sup>2</sup>), shallow, saline, inland waters were investigated (Figure 1, Table 1). In terms of water balance, the aquatic ecosystems studied are classified as semistatic and astatic intermittent shallow waters including lakes, ponds pans, and playas according to the terminological classification. Due to the shallow depth, most waterbodies have no fish. They may occur in small numbers in some waters, but as potential zooplankton predators, they do not play a significant role in this environment. However, many and varied birds visit the waterbodies, and their trophic role is significant. The investigated waters are located away from agricultural and residential areas. Tourism, ecotourism is not typical in this region.

Thus, these water bodies can be considered as undisturbed, natural aquatic ecosystems, therefore, their conservation value is high. Three waterbodies—Shoshkakol, Zharkol, and Little Aqsuat—are situated in Naurzum Nature Reserve which is one of the oldest Nature Reserves in Kazakhstan [13].



**Figure 1.** Geographical distribution of shallow saline steppe waters investigated in North Kazakhstan.

**Table 1.** Summary of the main physical, chemical, and biological characters of the waters.

No.	Name of Water Body	WGS (X)	WGS (Y)	Area (km <sup>2</sup> )	Depth (cm)	TOC (mgL <sup>-1</sup> )	CHL (µgL <sup>-1</sup> )	TDS (g/L)	ZOO SUM (ind.100 L <sup>-1</sup> )	TAX NUM	TD
1	Teniz	64.588	51.682	6.4	70	56	378	6	5845	15	1.63
2	Sukyrkol	64.446	51.589	1.4	60	51	169	4	83,983	7	0.16
3	Kaiyndsor	64.515	51.524	5.4	20	48	23	131	799	1	0
4	Asubastysor	64.460	51.520	1–1.5	20	66	41	88	1865	1	0
5	Ukrash	64.494	51.505	11.5	10	48	6	322	17	1	0
6	Zharsor	64.502	51.461	6.0	10	25	9	70	383	1	0
7	Unnamed	64.311	51.357	1.5–2	20	125	10	79	3623	1	0
8	Unnamed	63.693	51.548	1–1.5	70	43	8	14	5428	4	0.47
9	Unnamed	63.691	51.534	3–4	10	74	10	149	200	1	0
10	Unnamed	63.683	51.535	<1	10	79	47	23	11,523	6	1.56
11	Unnamed	63.023	51.411	<1	20	63	57	16	1818	6	2.15
12	Shoshkakol	63.030	51.370	5.1	25	38	34	6	3144	19	2.67
13	Little Aqsuat	62.807	51.368	1.3	5	25	26	9	108	5	1.88
14	Unnamed	62.673	51.329	0.5–1	20	48	6	49	40	2	0.91
15	Zharman Koli	62.526	51.210	56.9	5	32	11	54	14	5	2.24
16	Zharkol	62.393	51.342	3–6	100	25	10	2	7740	15	1.46
17	Saryqopa Koli	62.357	51.322	336	50	61	10	45	6361	5	0.73
18	Little Tengiz	64.093	50.160	454	5	109	5	131	118	1	0
19	Kalmakty	69.504	50.640	7–8	10	51	5	147	310	1	0
20	Balyksor	69.744	50.643	6–7	10	24	27	15	4400	5	1.17
21	Boshchesor	70.058	50.526	5.5–6	10	52	8	70	96	6	1.98
22	Big Saryoba	70.134	50.313	12–13	50	43	9	18	21,132	7	1.54
23	Karazor	72.084	51.171	55–60	30	12	13	12	1002	5	1.15

The serial number of waters corresponds with labels in Figure 1. The source of physical and chemical data used: [11] Legend for abbreviations: TOC—total organic carbon; CHL—chlorophyll-a; TDS—total dissolved solids; ZOO SUM—zooplankton abundance; TAX NUM—taxa number; TD—taxonomic diversity.

## 2.2. Water Sampling and Zooplankton Identification

Considering their hydrological regime, the studied waters are intermittent and semistatic with small volumes, their water level can significantly decrease in July, while some of them might even dry out [12]. All water bodies were sampled once, and taking into account the hydrological nature of the water flow in the water bodies, the sampling was done in spring. We sampled the waterbodies No. 12–23 (Table 1) between 29 May and 8 June 2014. Samples from pools numbered 1–11 were collected between 29 April and 4 May 2015. The weather conditions (temperature, precipitation) in both periods were similar.

Water samples were taken from the open water surface area, far from the shoreline, in order to sample at a place where water depth had not changed significantly anymore.

For the zooplankton analysis, 5–10 subsamples of 50–100 L water were filtered through a plankton net with 50  $\mu\text{m}$  mesh size, the samples were fixed in 70% ethanol solution on the field. From the zooplankton community, the Rotifera, Cladocera, Copepoda, and Anostraca taxa were examined. For the preparation of rotifers' trophi, household bleach (NaOCl) was used. Since the identification on genus or species level for most of the bdelloid rotifers would not have been reliable from the preserved samples, the category "bdelloid unidentified" was applied in the taxon list. The genus *Artemia* is a complex of sibling species and superspecies, defined by reproductive isolation. It has a high degree of genetic variability. For the exact species identification, biochemical, cytogenetic, and morphological examinations would be necessary—following Van Stappen [14]. For this reason, the denomination of *Artemia* was used generally.

## 2.3. Data Analysis

In order to distribute the inland waters according to the salinity gradient, we applied the international classification of waters on the basis of TDS by Hammer [15]. We tested the relationships among local environmental parameters with a pairwise Spearman rank correlation. In order to show any possible relationship among the parameters from all waters ( $n = 23$ ), the Spearman rank correlations were carried out by using OriginPro 9 (OriginLab, Northampton, MA, USA) software with significance levels of  $p < 0.05$ . The taxonomic diversity was analyzed by the Shannon–Wiener index [16]. The statistical analyses were carried out in OriginPro 2021 (OriginLab, Northampton, MA, USA) [17] with significance levels of  $p < 0.05$ . Quantile regression was performed to explore the relation between TDS and specified quantiles of H-Diversity variable [17].

## 3. Results and Discussion

The TDS concentration varied in extreme wide range between 2–322  $\text{gL}^{-1}$  (Table 2). The studied waters fall into 4 salinity categories according to Hammer classification [15].

**Table 2.** Distribution of waterbodies according to the salinity gradient.

Salinity Category	Name of Water Body
Subsaline $0.5\text{--}3\text{ gL}^{-1}$	Zharkol
Hyposaline $>3\text{--}20\text{ gL}^{-1}$	Teniz, Sukyrkol, No.8. Unnamed, No.11. Unnamed, Shoshkakol, Little Aqsuat, Balyksor, Big Saryoba, Karasor
Mesosaline $>20\text{--}50\text{ gL}^{-1}$	No.10. Unnamed, No.14. Unnamed, Saryqopa Koli
Hypersaline $>50\text{ gL}^{-1}$	Kaındysor, Asubastysor, Ukrash, Zharsor, No.7. Unnamed, No.9. Unnamed, Zharman Koli, Little Tengiz, Kalmaty, Boshchesor

Only one water belonged to the subsaline group, the deepest being Zharkol (100 cm), covering an area of 3–6  $\text{km}^2$ .

In the *hyposaline group* (TDS 3–20  $\text{gL}^{-1}$ ), there were 9 waters, their chemical characters were very different.

In the *mesosaline group* (TDS 20–50  $\text{gL}^{-1}$ ), there were three waters, noting that the salinity of No.14. Unnamed, and Saryqopa Koli also approaches the hypersaline category. In the *hypersaline category* (TDS  $> 50\text{ gL}^{-1}$ ), ten waterbodies were grouped, these were very

shallow (of 5–20 cm water depth), and transparent to bottom. Most of them are intermittent playas, the highest salt concentration was  $322 \text{ gL}^{-1}$  in Ukrash (Table 1).

### 3.1. Relationship among the Zooplankton Community, Physical, Chemical, and Trophic Properties

The salinity tolerance of species is determined by both physiological and ecosystem factors. The high salt concentration is toxic for many organisms, but halophiles and halotolerants can adapt very well to the extreme environment and can physiologically maintain proper osmotic balance, described in the work of Anufrieva [18].

We tested the relationship within the zooplankton community, including physical (Z), chemical (ion composition, TDS), and trophic (TOC, TN, TP, CHL) parameters with a pairwise Spearman rank correlation. The ion-composition had an important role in the community structure [19].

Two groups were very different from each other according to the Spearman rank correlation. Rotifers, cladocerans, and copepods (representatives of the first group) were in significant negative correlation with TDS, Na, and Cl ions. They were in positive correlation with others, significantly with Ca and  $\text{HCO}_3\text{-CO}_3$  ions. The second group was represented by *Artemia* with positive correlation with Na and Cl ions and TDS. For water depth, pH, and trophic water quality components (TOC, TN, TP, CHL), the Spearman rank correlation shows a less close correlation (Table 3).

**Table 3.** Spearman rank correlation among zooplankton groups, physical (Z), chemical (ion composition, TDS), and trophic (TOC, TN, TP, CHL) properties.

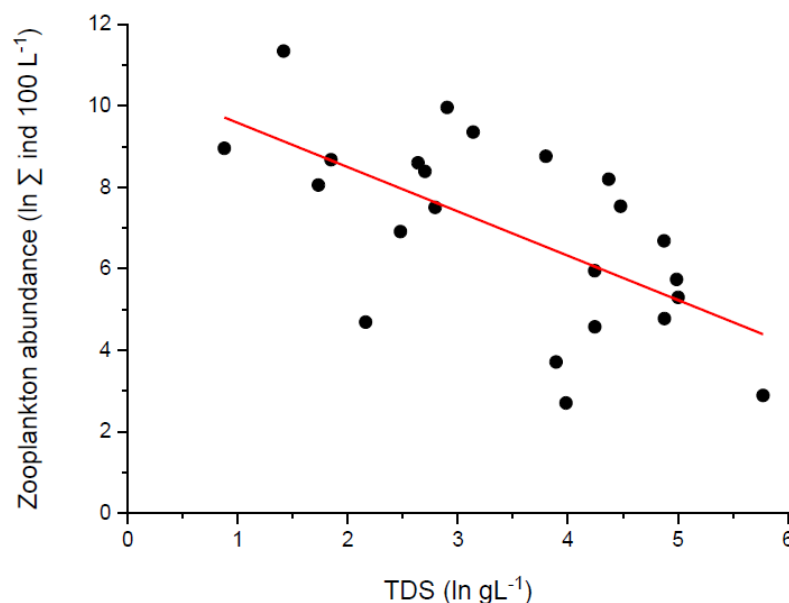
	Rotifera	Cladocera	Copepoda	Artemia	ZOO SUM	Tax Num
Z	0.30152	<b>0.43239</b>	<b>0.45722</b>	−0.24425	<b>0.49704</b>	0.32947
pH	0.30115	0.05342	0.32491	0.04822	0.36876	0.30047
TDS	− <b>0.83494</b>	− <b>0.69204</b>	− <b>0.6944</b>	0.37294	− <b>0.58103</b>	− <b>0.82013</b>
Na	− <b>0.47061</b>	− <b>0.63707</b>	− <b>0.41634</b>	0.36991	−0.24111	− <b>0.57075</b>
K	0.30152	<b>0.43239</b>	<b>0.45722</b>	−0.24425	0.49704	0.32947
Ca	<b>0.5931</b>	<b>0.56692</b>	<b>0.55663</b>	− <b>0.50667</b>	0.21146	<b>0.61941</b>
Mg	0.30833	<b>0.45542</b>	0.27251	−0.12011	0.25395	<b>0.46532</b>
Cl	− <b>0.45595</b>	−0.34759	− <b>0.52686</b>	0.32298	−0.24308	− <b>0.4567</b>
SO <sub>4</sub>	0.3523	0.29629	<b>0.43703</b>	−0.30178	0.15316	0.35836
HCO <sub>3</sub> + CO <sub>3</sub>	<b>0.78783</b>	<b>0.52871</b>	<b>0.62325</b>	−0.08327	0.82016	<b>0.65894</b>
TOC	<b>0.5931</b>	<b>0.56692</b>	<b>0.55663</b>	− <b>0.50667</b>	0.21146	<b>0.61941</b>
TN	0.30833	<b>0.45542</b>	0.27251	−0.12011	0.25395	<b>0.46532</b>
TP	− <b>0.45595</b>	−0.34759	− <b>0.52686</b>	0.32298	−0.24308	− <b>0.4567</b>
CHL	0.3523	0.29629	<b>0.43703</b>	−0.30178	0.15316	0.35836
Rotifera	1	<b>0.55685</b>	<b>0.67478</b>	−0.13929	<b>0.58001</b>	<b>0.86545</b>
Cladocera	<b>0.55685</b>	1	<b>0.73413</b>	− <b>0.5256</b>	<b>0.55855</b>	<b>0.79349</b>
Copepoda	<b>0.67478</b>	<b>0.73413</b>	1	− <b>0.55309</b>	<b>0.76001</b>	<b>0.77169</b>
Artemia	−0.13929	− <b>0.5256</b>	− <b>0.55309</b>	1	−0.07873	−0.35025
ZOO SUM	<b>0.58001</b>	<b>0.55855</b>	<b>0.76001</b>	−0.07873	1	<b>0.54844</b>
Tax Num	<b>0.86545</b>	<b>0.79349</b>	<b>0.77169</b>	−0.35025	<b>0.54844</b>	1

Legend for abbreviations: z—water depth, TDS—total dissolved solids, TOC—total organic carbon, TN—total nitrogen, TP—total phosphorous, CHL—chlorophyll-a, ZOO SUM—zooplankton abundance, Tax Num—taxon number. Significant ( $p < 0.05$ ) correlations are in bold.

### 3.2. The Influence of Salinity on Zooplankton Abundance and Structure

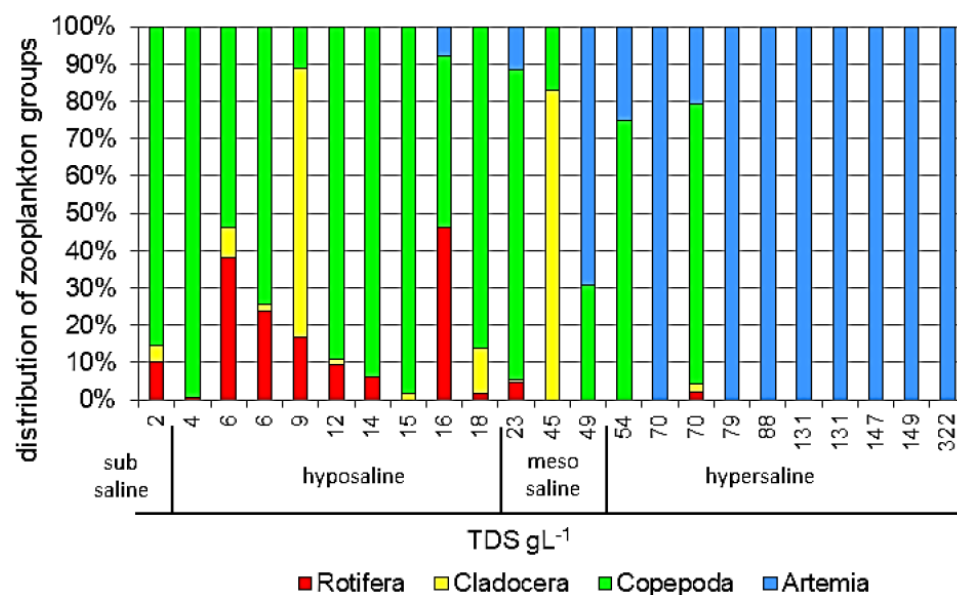
Zooplankton density varied on a very wide range in the 23 waterbodies. Abundance was higher in the subsaline and hyposaline waters, while in meso- and hypersaline waters, it was lower. The maximum value ( $83,983 \text{ ind } 100 \text{ L}^{-1}$ ) was registered in Sukyrkol (TDS  $4 \text{ gL}^{-1}$ ), where copepods nauplii were present in a remarkably high proportion (98%) in shallow waters, having large water surface.

The minimum value was found in the case of hypersaline Zharman Koli (14 and 100 L<sup>-1</sup>). The salinity seemingly reduced the abundance; we registered negative influence of dissolved solid concentration (TDS) on zooplankton abundance (Figure 2).



**Figure 2.** Relationship between zooplankton abundance and TDS. Legend: each dot represents a waterbody.  $\ln \text{zooplankton abundance} = -1.087 \times \ln(\text{TDS}) + 10.668$ ,  $n = 23$ ,  $df = 21$ ,  $r^2 = 0.389$ ,  $p < 0.001$ .

Salinity affected not only the abundance but also the structure of the zooplankton community, which was different in waters with disparate salinity. In the sub-hypo-mesosaline environment, with a few exceptions, the Copepoda group had the highest abundance rate (Figure 3).

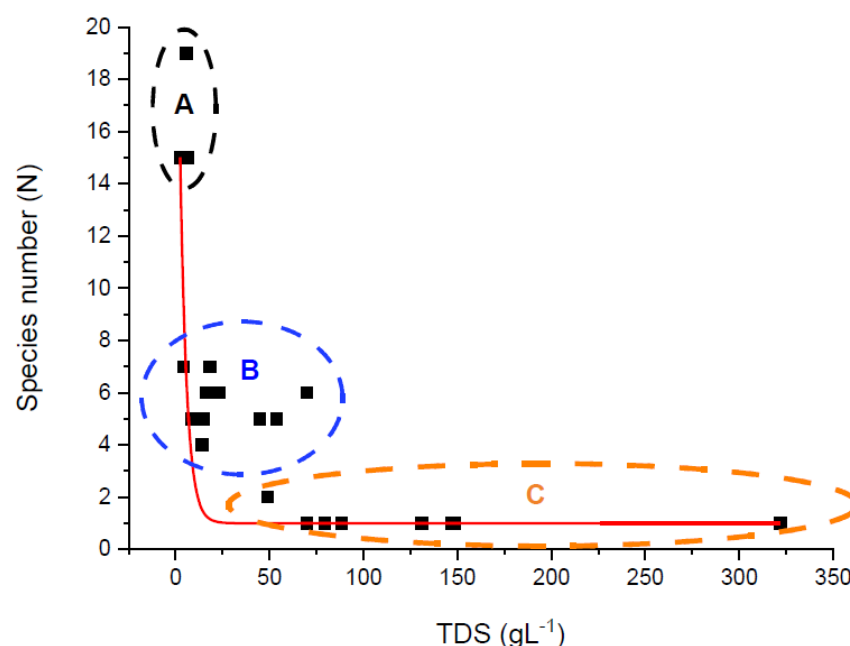


**Figure 3.** Percent abundance of zooplankton groups in waterbodies along the salinity gradient.



Rotifera assemblage was present in 38% in Shoshkakol (TDS  $6 \text{ gL}^{-1}$ ) with the dominance of euryhaline *Notholca acuminata*, and in playa No.11. Unnamed in 46%, with the dominance of halophylic indicators *Brachionus dimidiatus* and *Brachionus plicatilis*. In other water bodies, rotifers were present in a smaller amount. The proportion of cladocerans was low in almost all water bodies, they dominated only two waters. The zooplankton structure of the three mesosaline waters differed significantly. These waters belong to the same cluster according to Hammer's classification of salinity [15], which highlights the fact that in addition to salinity, other abiotic components are also important influencing factors in the evolution of plankton associations (Table 1). In mesosaline waters, the strictly haline *Moina salina* dominates, representing the Cladocera community. In Copepoda assemblage, *Arctodiaptomus salinus* [20], *Metadiaptomus asiaticus* [21] are dominant saltwater indicators, rate of *Cletocamptus rectirostris* is less. In hypersaline waters with salinity exceeding  $79 \text{ gL}^{-1}$ , a significant change in the structure of zooplankton can be registered. In these water bodies, *Artemia* genus typically forms the zooplankton community as a monodominant element (Figure 3).

At the time of the study, 21 Rotifera, 14 Cladocera, 11 Copepoda (6 Cyclopoida, 4 Calanoida, 1 Harpacticoida), and 1 Anostraca taxa were present in the 23 waters. Increased salinity caused decline in taxon richness. Significant negative correlation was detected between the number of species and dissolved solids. Belmonte et al. [22] verified similar results in the hypersaline lakes of the Crimea. During our research, we have identified three groups of waters (Figure 4).



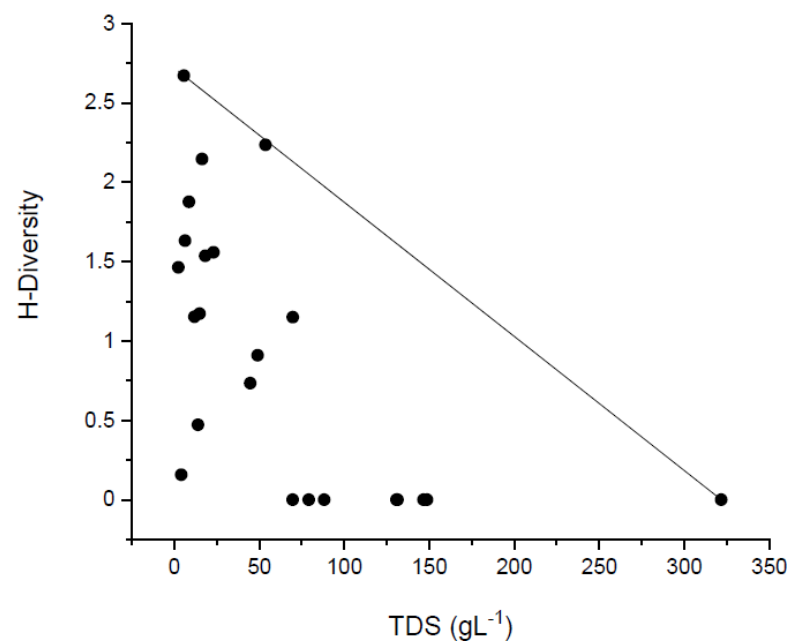
**Figure 4.** The influence of salinity on taxon richness. Legend: each datapoint represents a waterbody's species number.  $n = -27.595 \times 0.754 - \text{TDS}$ ,  $n = 23$ ,  $df = 20$ ,  $r^2 = 0.997$ ,  $p < 0.05$ .

The first group (A) was the richest in species, the number of taxa changed between 19–15 in the subsaline and hyposaline waters with low TDS concentration ( $2\text{--}6 \text{ gL}^{-1}$ ). These waterbodies had mainly euryhaline freshwater species with some halotolerant organisms. In the zooplankton assemblage, the Rotifera and Cladocera taxa were dominant. The maximum number of species (19) was found in the Shoshkakol (TDS  $6 \text{ gL}^{-1}$ ). Most waters fell into the second group (B), where the number of species was detected between 4–7. In these waters, the main taxonomic group was Copepoda. Here, the halophylic species replaced the function of the freshwater species in the zooplankton assemblage; as they have wide tolerance to salinity. Yermoleva [9] observed similar results in other medium sized inland waters of Kazakhstan. According to her research, “the zooplankton species

composition becomes poorer upon an increase in water mineralization over  $3 \text{ g/dm}^3$ . The third group (C) was represented by those hypersaline waters, in which the typical halobiont organisms, the large-bodied *Artemia* genus was registered in different developmental stages. Here, the environmental conditions undergo a complete change regarding differ significantly due to the high salt concentration and the osmotic state.

The increase in salinity caused the decline in taxonomic diversity [20]. The zooplankton structure of subsaline and hyposaline environment was diverse, the highest taxonomic diversity ( $H = 2.67$ ) was registered in Shoshkakol ( $\text{TDS} = 6 \text{ gL}^{-1}$ ).

In those extreme hypersaline waters ( $\text{TDS}: 70\text{--}322 \text{ gL}^{-1}$ ), where the zooplankton community was represented by only the genus *Artemia*, the diversity was zero (Figure 5). Afonina and Tashlykova [23] obtained similar results in Southeastern Transbaikalian waters.



**Figure 5.** Quantile regression between salinity and taxon diversity. Legend: each datapoint represent a waterbody's H-diversity.  $\text{Tau} = 0.99$ ,  $n = 84$ ,  $\text{df} = 82$ ,  $\text{pseudo } r^2 = 0.277$ ,  $p < 0.0001$ .

### 3.3. Salt Tolerance of Registered Zooplankton Species

The zooplankton organisms with various salt tolerances can adapt to the environment. Fontaneto et al. [24] reported a review of the literature concerning rotifers from saline (inland and marine) environments. They distinguished 443 taxa falling into three categories: stenohaline species (they live only in saltwater—37%), euryhaline species (they can be found in both freshwater and saltwater—39.1%), and haloxenous species (freshwater species with occasional findings in saltwater—23.9%).

#### 3.3.1. Rotifera Assemblage

In our study, 21 taxa were recorded in the Rotifera assemblage (Table 4). Rotifers had a low percentage share in the zooplankton community, their presence was over 40% only in the water No.11. Unnamed. From these, 7 species occurred in subsaline environment, two species were found in both sub- and hyposaline waters, and 13 taxa were present only in hyposaline waters, most of them being euryhaline organisms.



Table 4. List of Rotifera taxa along the salinity gradient.

Name of Inland Water	Zharkol	Sukyrkol	Shoshkakol	Teniz	Little Aqsuat	Karasor	No.8. Unnamed	No.11. Unnamed	Big Saryoba	No.10. Unnamed	Boshchesor
salinity TDS gL <sup>-1</sup>	2	4	6	6	9	12	14	16	18	23	70
Bdelloid unidentified		267	12	67							
<i>Brachionus asplanchnoides</i> Charin, 1947							266		200	133	
<i>Brachionus dimidiatus</i> Bryce, 1931				17				513			
<i>Brachionus plicatilis</i> Müller, 1786							67	93			
<i>Brachionus quadridentatus</i> Hermann, 1783	40		180	17							
<i>Brachionus urceolaris</i> Müller, 1773			36								
<i>Cephalodella catellina</i> Müller, 1786			12	100							
<i>Colurella adriatica</i> Ehrenberg, 1831	40										
<i>Colurella colurus</i> Ehrenberg, 1830						12			120		
<i>Eosphora ehrenbergii</i> Weber and Montet, 1918	120										
<i>Hexarthra fennica</i> Levander, 1892						84					
<i>Keratella quadrata</i> Müller, 1786	360										
<i>Keratella</i> sp.											2
<i>Lecane luna</i> Müller, 1776	40										
<i>Lophocharis oxysternon</i> Gosse, 1851			36	36							
<i>Lophocharis salpina</i> Ehrenberg, 1834			12								
<i>Mytilina ventralis</i> Ehrenberg, 1830	40										
<i>Notholca acuminata</i> Ehrenberg, 1832	160	266	912	33	18						
<i>Paradicranophorus hudsoni</i> Glascott, 1893				33				233			
<i>Paradicranophorus sordidus</i> Donner, 1968				200						400	
<i>Synchaeta oblonga</i> Ehrenberg, 1832				932							
SUM ROTIFERA ind 100 L <sup>-1</sup>	800	569	1200	1399	18	96	333	839	320	533	2

Comment: the salt tolerant halophylic and halobiont species are marked in blue.

In terms of taxonomic composition, euryhaline species were predominant in 2–9 TDS saline waters. There are: *Colurella adriatica*, *Colurella colurus*, *Notholca acuminata*, *Paradicranophorus sordidus*, and *Paradicranophorus hudsoni*. Their habitats include freshwater, inland, and marine saltwater as well [24]. Above 12 TDS gL<sup>-1</sup> salinity, the saltwater environment indicator species can also be found in the community. *Brachionus plicatilis* is the most ubiquitous halobiont rotifer in saline waters in the whole world. The registered *Brachionus asplanchnoides* is a strictly halobiont species by the review of Fontaneto et al. [24]. Both species were registered also in astatic soda pans in the Carpathian Basin [25]. The halophylic *Brachionus dimidiatus* (salinity upper value 70 gL<sup>-1</sup>) and *Hexarthra fennica* (salt-tolerant 3–80 gL<sup>-1</sup>) are widespread organisms. In the hypersaline pond Boschchesor (TDS: 70 gL<sup>-1</sup>), *Keratella* sp. occurred in low abundance. It is very similar in shape to *Keratella quadrata*, but according to the present knowledge, this species does not live in such highly saline environments. It was probably accidentally introduced into the pond, probably by wind or by birds. Because the sampling happened only at one time, there was no possibility to survey and control its further presence.

### 3.3.2. Cladocera Assemblage

The proportion of cladocerans was low in the studied waters. In the cladoceran assemblage, 13 taxa were registered (Table 5). Most of them were euryhaline organisms, which live in subsaline and hyposaline waters between 2–18 gL<sup>-1</sup> salinity. The salt tolerance of *Daphnia magna* occurred as a dominant or subdominant element in the salinity range of 2–9 gL<sup>-1</sup>. In the mesosaline water, No. 10. Unnamed *Alona affinis* was found, it tolerates a wide spectrum of salinity, up to 30 gL<sup>-1</sup> of salt concentration [23]. With greater abundance

*Moina salina*, was recorded, which has the highest halotolerance among all species. It lives in a hyposaline–hypersaline environment as a real halobiont organism.

**Table 5.** List of Cladocera taxa along the salinity gradient.

Name of Inland Water	Zharkol	Sukyrkol	Shoshkakol	Teniz	Little Aqsuat	Karasor	Balyksor	Big Saryoba	No.10. Unnamed	Saryqopa Koli	Boshchesor
salinity TDS gL <sup>−1</sup>	2	4	6	6	9	12	15	18	23	45	70
<i>Alona affinis</i> Leydig, 1860									67		
<i>Alona rectangular</i> Sars, 1861			12		24						
<i>Ceriodaphnia reticulata</i> Jurine, 1820			84								
<i>Chydorus latus</i> Sars, 1862			24								
<i>Chydorus sphaericus</i> Müller, 1776	40										
<i>Daphnia curvirostris</i> Eylmann and Johnson	160		36								
<i>Daphnia longispina</i> O.F.Müller, 1776	40		24								
<i>Daphnia magna</i> Straus, 1820	80	33		100	54						
<i>Moina brachiata</i> Jurine, 1820			12								
<i>Moina salina</i> Daday, 1888						12	48	2584		5280	2
<i>Moina</i> sp.							32				
<i>Scapholeberis rammeri</i> Dumont and Pensaert,			12								
<i>Simocephalus exspinosus</i> De Geer, 1776			48								
SUM CLADOCERA ind 100 L <sup>−1</sup>	320	33	252	100	78	12	80	2584	67	5280	2

Comment: the salt tolerant halophylic and halobiont species are marked in blue.

### 3.3.3. Copepoda Assemblage

In the subsaline and hyposaline waters, the zooplankton abundance was generally represented by copepods. Their proportion exceeds 50% in most studied waters. We registered 11 taxa in the Copepoda assemblage (Table 6), most of them were euryhaline species. All developmental forms were recorded, with a particularly high proportion of nauplii in waterbody Sukyrkol. In the mesosaline Balyksor, the ratio of copepods was registered at 83.2%, with the dominant halotolerant *Metadiaptomus asiaticus*, which is a typical brackish water copepod (Wang et al. [21]). Two species with the highest halotolerance, *Arctodiaptomus salinus* and *Cletocamptus retrogressus*, occurred from hyposaline to hypersaline habitats. They are the most widespread copepods in hypersaline inland waters [21,22,26,27]. According to the monography of Hammer [15], the salinity spectrum is 3–78 gL<sup>−1</sup> for *A. salinus* and 6–120 gL<sup>−1</sup> for *C. retrogressus*.

Members of genus *Artemia* are widely distributed around the world, they are typical inhabitants in meso- and hypersaline environments, with low species diversity and simple trophic structures [25]. In our study, they were present in the salinity range of 16–322 gL<sup>−1</sup>, with all forms of development occurring in the population. The presence of the monodominant zooplankton community was recorded at salinity above 79 gL<sup>−1</sup> in the salt waters of North Kazakhstan studied by us where the zooplankton population consisted of the members from the genus *Artemia* in 100% (Table 7).

**Table 6.** List of Copepoda taxa along salinity gradient.

Name of Inland Water	Zharkol	Sukyrkol	Shoshkakol	Teniz	Little Aqsuat	Karasor	No.8. Unnamed	Balyksor	No.11. Unnamed	Big Saryoba	No.10. Unnamed	Saryqopa Koli	No.14. Unnamed	Zharman Koli	Boshchesor
salinity TDS gL <sup>-1</sup>	2	4	6	6	9	12	14	15	16	18	23	45	49	54	70
COPEPODA-Calanoidea															
<i>Arctodiaptomus bacillifer</i> Koelbel, 1885	360		132												
<i>Arctodiaptomus salinus</i> Daday, 1885						756				7600		996			4
<i>Hemidiaptomus amblyodon</i> Marenzeller, 1873	20		360						746						
<i>Metadiptomus asiaticus</i> Uljanine, 1875								2432			7060				
Cyclopoida															
<i>Cyclops furcifer</i> Claus, 1857		266													
<i>Cyclops strenuus</i> Fischer, 1851		33		33											
<i>Cyclops scutifer</i> G.O.Sars, 1863				17											
<i>Cyclops vicinus</i> Uljanine, 1875				33											
<i>Diacyclops bisetosus</i> Rehberg, 1880							67								
<i>Megacyclops viridis</i> Jurine, 1820	200			133						20					
Harpacticoida															
<i>Cletocamptus retrogressus</i> Schmankevitch, 1875					6					48		72			6
coepodites		534	48	34	6			32						4	
nauplii	6040	82,548	1152	4096		138	5028	1856	93	10,560	2531	12	13	6	62
SUM COPEPODA ind 100 L <sup>-1</sup>	6620	83,381	1692	4346	12	894	5095	4320	839	18,228	9591	1080	13	10	72

Comment: the salt tolerant halophylic and halobiont species are marked in blue.

**Table 7.** Artemia abundance along salinity gradient.

Name of Inland Water	No.11. Unnamed	No.10. Unnamed	Saryqopa Koli	No.14. Unnamed	Zharman Koli	Zharsor	Boshchesor	No.7. Unnamed	Abubastysor	Kalyndsor	Little Tengiz	Kalmakty	No.9 Unnamed	Ukrash
salinity TDS gL <sup>-1</sup>	16	23	45	49	54	70	70	79	88	131	131	147	149	322
SUM ARTEMIA ind 100 L <sup>-1</sup>	140	1332	1	27	2	383	20	3623	1865	799	118	310	200	17

### 3.3.4. Grouping of Waters according to Zooplankton Species Composition

We investigated whether the shallow inland salt waters of the North Kazakhstan region can be divided into characteristic groups based on the combined composition of zooplankton.

Based on the results of our analysis, 3 groups can be distinguished:

1. In the first group, one can find the low-salt sub-and hyposaline waters. The zooplankton community consists of euryhaline copepod and rotifer species with a wide ecological valence.
  - There are: Teniz, Sukyrkol, Shoshkakol, Little Aqsuat, Zharkol.
2. In the second group, there are those meso- and hyposaline waters, in which micro-crustaceans are the main constituents, sometimes with large numbers of individuals.

*Brachionus asplanchnoides*, *Brachionus dimidiatus*, *Brachionus plicatilis*, *Hexarthra fennica*, *Moina salina*, *Arctodiaptomus salinus*, and *Cletocamptus rectirostris* are present as saltwater indicator species.

- There are: No.8. Unnamed, No.10. Unnamed, No.11. Unnamed, No.14. Unnamed, Zharman Koli, Saryqopa Koli, Balyksor, Big Saryoba, Karasor.
- 3. In the third group, there are the shallow, hypersaline water bodies, with few species, the characteristic organism is *Artemia*, which is present as a constituent of a dominant or monodominant association.
  - There are: Kaiyndor, Abubastysor, Ukrash, Zharsor, No.7. Unnamed, No.9. Unnamed, Little Tengiz, Kalmakty, Boshchesor.

#### 4. Conclusions

In our study, we selected 23 representative water bodies from the inland saline waters of Northern Kazakhstan, with no available data on their zooplankton association before. We analyzed the species composition of investigated waters. Further, 21 Rotifera, 13 Cladocera, 11 Copepoda taxa, as well as *Artemia* genus represented the spring zooplankton association in the Northern Kazakhstan's shallow steppe inland saline waters. We found that 3 types of communities can be isolated in the study region. In sub- and hyposaline aquatic environments, species of wide ecological valence are the main associators. This can ensure adaptation to environmental change, and secure the survival of these aquatic ecosystems. In hypo-mesosaline waters, beside euryhaline species, we identified some characteristic saltwater indicator organisms, such as *Brachionus asplanchnoides*, *Br. dimidiatus*, *Br. plicatilis*, *Moina salina*, *Arctodiaptomus salinus*, and *Cletocamptus retrogressus*. In the hypersaline water bodies, *Artemia* genus is the monodominant element. We found that in the waters of the region, above 79 gL<sup>-1</sup> salinity, there is a significant change in the quantitative and qualitative structure of zooplankton. The change of the zooplankton structure corresponds to the regularities of undisturbed natural systems, so it is recommended to support the survival of these valuable habitats. Our results are the first data on mapping the zooplankton fauna of undisturbed natural shallow inland waters of the Central Asian steppe.

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