

## Article

# Species Diversity and Community Assembly of Cladocera in the Sand Ponds of the Ulan Buh Desert, Inner Mongolia of China

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**Abstract:** In deserts, pond cladocerans suffer harsh conditions like low and erratic rainfall, high evaporation, and highly variable salinity, and they have limited species richness. The limited species can take advantage of ephippia or resting eggs for being dispersed with winds in such habitats. Thus, environmental selection is assumed to play a major role in community assembly, especially at a fine spatial scale. Located in Inner Mongolia, the Ulan Buh desert has plenty of temporary water bodies and a few permanent lakes filled by groundwater. To determine species diversity and the role of environmental selection in community assembly in such a harsh environment, we sampled 37 sand ponds in June 2012. Fourteen species of Cladocera were found in total, including six pelagic species, eight littoral species, and two benthic species. These cladocerans were mainly temperate and cosmopolitan fauna. Our classification and regression tree model showed that conductivity, dissolved oxygen, and pH were the main factors correlated with species richness in the sand ponds. Spatial analysis using a PCNM model demonstrated a broad-scale spatial structure in the cladoceran communities. Conductivity was the most significant environmental variable explaining cladoceran community variation. Two species, *Moina cf. brachiata* and *Ceriodaphnia reticulata* occurred commonly, with an overlap at intermediate conductivity. Our results, therefore, support that environmental selection plays a major role in structuring cladoceran communities in deserts.

**Keywords:** sand pond; cladocera; environmental selection; spatial process; indicator species



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## 1. Introduction

A metacommunity is defined as a set of local communities in which species may exchange through dispersal [1]. Concept and theory of metacommunities not only help to explain patterns of distribution and interaction of local communities, but also provide a realistic framework for understanding ecological processes at a regional scale.

Cladocerans disperse passively over long distances with wind, water birds, and similar media [2,3]. With their abundant propagules and large population size, cladocerans easily colonize new habitats [4]. In a local community, species richness and abundance are regulated by environmental conditions, biotic interactions, and dispersal [4,5]. Environmental processes usually dominate at the finest spatial scale (e.g., a single wetland), whereas dispersal and neutral processes contribute to beta diversity at broader scales [6]. The assembly of local cladoceran communities in a well-connected landscape is determined more by environmental or ecological than by spatial processes. Predation, conductivity, primary productivity, and pH are ecological factors directly affecting cladoceran community

structure [5,7,8]. As cladocerans rapidly respond to environmental change, they are used as indicators of ecological change [4,9]. The concept of indicator species has been widely applied in niche analysis and assessment of habitat quality [10,11]. It has been developed to explore complex associations between species and habitats [12–16].

Desert ponds are ecologically distinct. In such ponds, cladocerans suffer harsh conditions, low and erratic rainfall, high evaporation, and high and variable salinity. A few well-adapted species thrive there. For example, in a saline lake (salinity 5.5%) studied by He [17], a single species of *Moina* dominated the cladoceran community. As sand ponds are filled by rainwater within a very short period of the year, desert cladocerans have rarely been investigated. As a result, spatial distribution and species diversity of desert cladocerans remain unclear. Systematic surveys in such habitats are required to explore regional endemism and understand species diversity. For example, a new ctenopod, *Diaphanosoma bopingi*, was identified from Sahara [18]. Given the slow evolution of this group, this species was assumed to be the result of local speciation [18,19].

Ulan Buh desert is located near Bayan Nur city, Inner Mongolia, China, and has a mean annual precipitation of around 100 mm. In this desert, a number of temporary dune ponds occur, many of which have formed artificially in the last decade. Although individual dune ponds are physically isolated, strong winds, cattle, and birds visiting the area should promote cladoceran dispersal and colonization. Although the ponds are at slightly different altitudes within the desert, they can be influenced significantly by winds with very different densities. In the perspective of metacommunities, environmental selection could explain variation in the cladoceran community structure.

In the present study, we aimed to identify cladoceran species diversity and explored processes structuring the community mainly with the detailed investigation in 2012. Our study will greatly improve our understanding of species diversity and community assembly of Cladocera in the desert, and may have important guidance for species investigation and conservation of desert aquatic systems.

## 2. Materials and Methods

### 2.1. Study Object

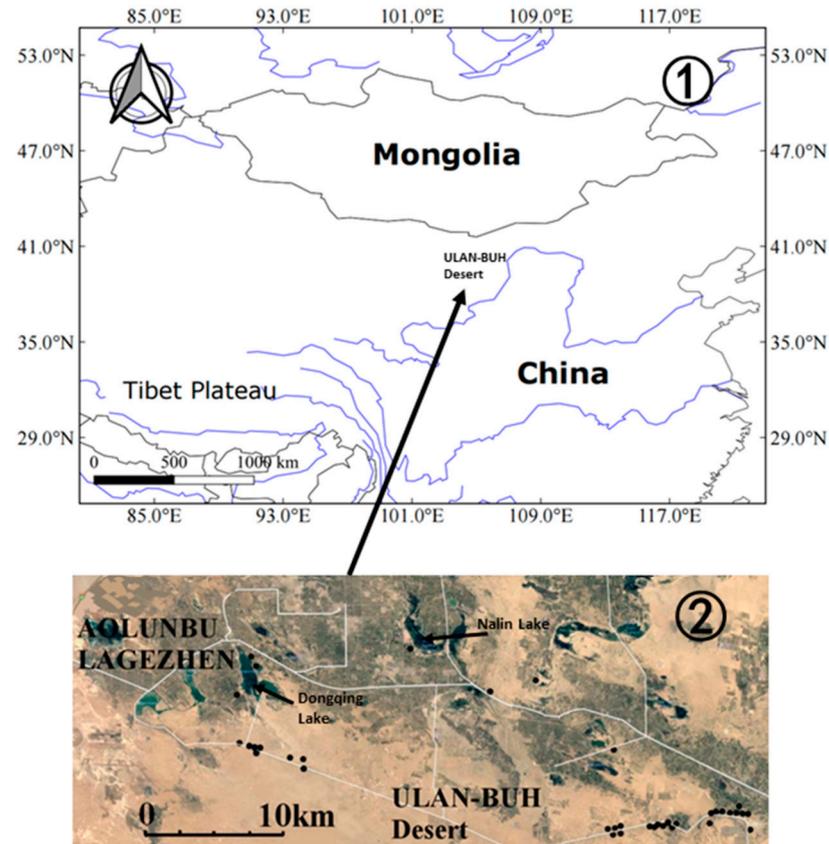
Ulan Buh desert is located in the east of Inner Mongolia. It harbors a series of permanent lakes fed by groundwater and a large number of temporary ponds surrounding the permanent lakes. More ponds were artificially created beside roads connecting local villages. We took surveys from 2011 to 2013 but had enough samples only in 2012. We performed our sampling after a rainfall when many temporary ponds were filled. Cladocera in a few permanent lakes, more or less, could form a species pool for the temporary ponds in some cases. Winds, water birds, and local livestock are the potential medium for dispersal.

In 2012, we investigated 37 ponds and 4 permanent lakes in an area of 15 km (west to east) × 40 km (north to south) (Figure 1). Physical coordinates ranged from 40.4019° N to 40.5264° N latitude and 106.4817° E to 106.9269° E longitude. Altitude ranged from 1025 m to 1055 m.

### 2.2. Field Sampling and Laboratory Work

We sampled cladocerans with a dip plankton net (diameter of the net edge was 40 cm) with a mesh size of 120 µm, one sample was taken for each pond by horizontal tows 5 m over the pond surface area. Geographical coordinates and altitude data were recorded by a hand-held GPS device. Water chemistry at 0.5–1.0 m below the water surface was measured by a portable analyzer (YSI: PRO-PLUS), including water temperature (T), pH, dissolved oxygen (DO), and conductivity (Cond). Pond surface size (S), maximum depth (D), and vegetation coverage rate (V) were measured, fish and tadpole presence were recorded visually. Two states of water quality (N) were estimated de visu: “1” represents clean or high transparency, “2” represents turbid or low transparency.

Samples were preserved in formaldehyde with a final concentration of 5%. All samples were examined under a dissecting microscope (Olympus: SZXZ-ILLB) to determine the species diversity per sampling site. Species were identified using an optical microscope (Olympus U-LH100-3). Relative abundance was counted under an optical microscope using a Sedgewick Rafter counting chamber. At least 500 individuals or at least 50% volume of each sample were counted depending on the cladoceran abundance.



**Figure 1.** Map of study area of this study: ① The geographical location of Ulanbu desert; ② The location of each sampling site (represented by back spots) in the desert. Two permanent lakes are indicated with arrows.

### 2.3. Statistical Analysis

Environmental variables included lake surface size (S), depth (D), conductivity (Cond), DO, pH, tadpole presence, fish presence, vegetation coverage (V in %), and water quality (N); geographic variables including latitude, longitude, and altitude. Salinity was represented as conductivity [20]. Two types of species matrices were built based on species presence/absence and relative abundance.

We applied a classification and regression tree model (CART) to determine which environmental variables correlated with species richness [21]. The species occurrence data were further used for species richness estimation. Chao 2 and Jackknife estimators were used, as these models are particularly suitable for small sample sizes [22]. Other estimators are presented as alternative results. Log transformation was used for all estimators so that the lower bound of the resulting interval is at least the number of observed species [23]. The lowest ratio of variance/estimator was used as the best estimation [24].

Redundancy analysis (RDA) was used to examine the variation of cladoceran community structure along environmental gradients. lake or pond size (S) was log-transformed (S ranges from 10 m<sup>2</sup> to 4000 m<sup>2</sup>). All environmental variables were used in the RDA model to fit the species occurrence matrix and relative abundance matrix. Unadjusted R<sup>2</sup> was calculated through “Ezekiel’s equation” to create an adjusted R<sup>2</sup> (Peres-Neto et al., 2006).

Variables with VIF (variance inflation factors)  $<20$  were used as these variables are not significantly collinear with other variables. Based on the permutation test's  $p$ -value and AIC value, the forward selection was performed to select significant variables ( $p < 0.05$ ).

A PCNM method (principal coordinate of neighbor matrices) [25,26] was used to construct spatial structures that can represent all scales. The first PCNM variables (e.g., V1) describe broad-scale processes covering the whole research area, like strong dispersal. The last variables describe fine-scale processes, which cannot be related to environmental descriptors but community dynamics, such as neutral processes. All positive eigenvectors were selected to build a PCNM variable matrix. These PCNM variables were used as spatial explanatory variables in RDA analysis with species occurrence matrix and relative abundance matrix. Variance partitioning was performed to determine how much variation was explained by each of the explanatory variables.

Classification of habitat types was performed by k-means clustering for each variable independently, including pond size, depth, conductivity, DO, pH, and vegetation coverage. The number of habitat groups was decided by using the maximal "ssi" value. The habitat types for predation were grouped into two types: presence and absence. As more species combinations create too many possibilities, only one species and two species combinations were used as species indicators. "Indval" index was calculated for the association between single species or two species combination and associated habitat types. The significance of maximum "Indval" index was tested using a permutation test (per = 999). "Indval" index contains two components: specificity and fidelity. High specificity indicates species associated with specific habitats, and high fidelity reflects a high probability of seeing a species in a specific kind of habitat.

All statistical analyses were done using Rstudio (Version 1.0.136), and the packages "indicpecies", "rpart", "SoDA", "SpadeR", and "vegan" [27–30].

### 3. Results

#### 3.1. Environmental Variables and Spatial Landscape

The size of the ponds varied from 10 to 4000 m<sup>2</sup>, but only two ponds had an area of more than 1000 m<sup>2</sup>, and half of the ponds (56%) were smaller than 100 m<sup>2</sup>. Pond depth ranged from 0.3 to 3 m, with a mean of 1.01 m. Conductivity was high, from 1404 μS/cm to 12,619 μS/cm, with mean of 4243 μS/cm. pH values ranged from 7.98 and 10.06. DO was between 2.92 to 15.0 mg/L, with an average 9.76 μg/L. Tadpoles occurred in 15 ponds, and small fishes were only observed in 2 ponds. Except for one pond, aquatic plants were abundant, with an average cover 71%. Among 37 investigated ponds, 15 ponds were high-transparency or clean-water.

Altitude has a negative correlation with latitude ( $R^2 = 0.34$ ,  $p < 0.001$ ) and a positive correlation with longitude ( $R^2 = 0.51$ ,  $p < 0.001$ ). Thus, eastern ponds (23) were located at a higher altitude than western ponds (14) (Table 1).

The two groups significantly differed in altitude and conductivity. Eastern ponds had higher conductivity. Even though a smaller number of ponds are located in the western region, it contained more species. *Moina* cf. *brachiata* was the most common species in the ponds, but it was only found in the western group.

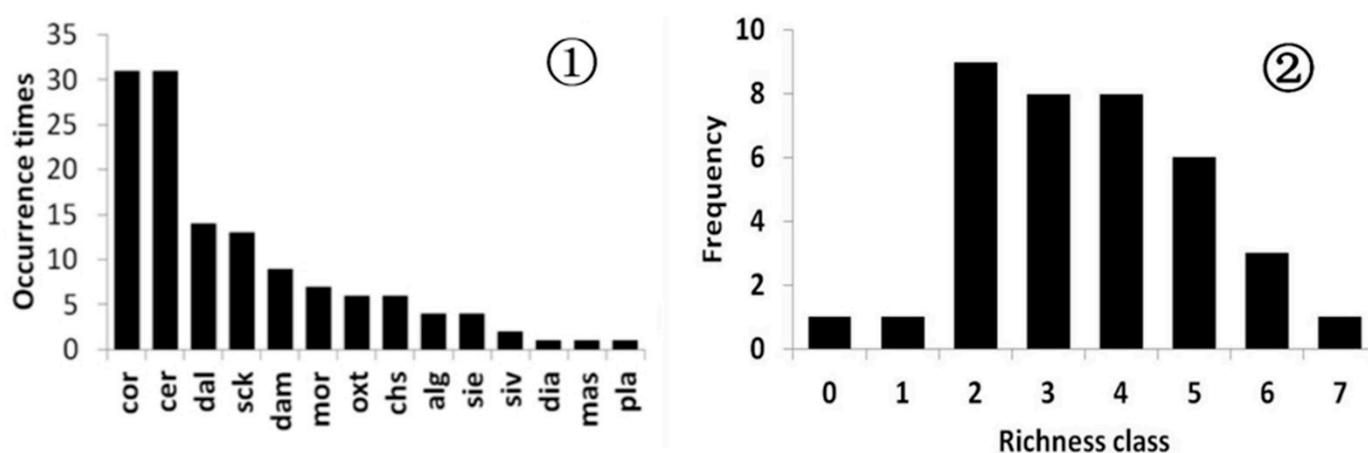
#### 3.2. Species Diversity

A total of 14 Cladocera species were identified, including 5 pelagic, 8 littoral, and 1 benthic species. They represent five families, viz. Daphniidae (6), Chydoridae (5), Sididae (1), Macrothricidae (1), and Moinidae (1). Five species had occurrence frequency above 20%: *Ceriodaphnia reticulata* (84%), *Coronatella rectangula* (84%), *Daphnia longispina* (38%), *Scapholeberis smirnovi* (35%), and *Daphnia magna* (24%). *Diaphanosoma mongolianum*, *Macrothrix spinosa* and *Pleuroxus aduncus* occurred only in one pond. *Oxyurella tenuicaudis*, *Alona guttata*, and *Simocephalus exspinosus* were also common (occurrence frequency  $>10\%$ ). *C. reticulata*, *D. longispina* and *M. cf. brachiata* were dominant (more than 90% in relative

abundance) in pelagic habitats while *C. rectangularis* and dominated in littoral habitats (more than 50%) (See Figure 2).

**Table 1.** Average values of environmental variables and endemic species in western and eastern ponds. t-tests were performed for the two pond groups.

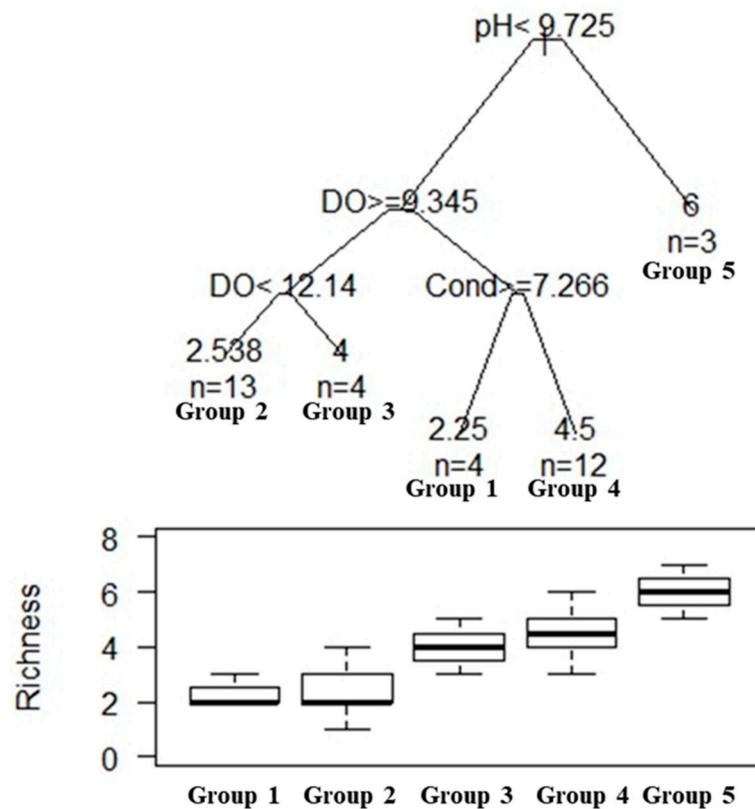
	Western	Eastern	p Value
Altitude	1032.5	1044.86	$p < 0.001$
Pond size (m <sup>2</sup> )	151.43	311.36	$p = 0.492$
Depth (m)	0.87	1.1	$p = 0.203$
Conductivity(mS/cm)	6.15	3.03	$p < 0.001$
DO (mg/L)	9.12	10.17	$p = 0.238$
pH	9.06	9.22	$p = 0.322$
Vegetation coverage	0.66	0.75	$p = 0.233$
Average richness	3.43	3.73	$p = 0.557$
Total species richness	13	11	
Restricted species	<i>Diaphanosoma mongolianum</i> <i>Moina cf brachiata</i> <i>Pleuroxus aduncus</i>	<i>Macrothrix spinosa</i>	



**Figure 2.** ① Frequency of each species for all ponds; ② Bar plot of cladoceran species richness ranks. Abbreviations codes of each species, see Appendix A.

Cladoceran species richness for each pond varied from 0 to 7. One of the ponds did not have any cladocerans. On average, a pond had four species. The classification and regression tree model (CART) showed that pH, DO, and conductivity were the main variables affecting cladoceran richness (Figure 3). Three ponds with the highest species richness had a high pH value ( $\geq 9.73$ ). When  $pH < 9.725$ , ponds were classified into two groups according to  $DO \geq 9.345$  mg/L.

Eight estimators of species richness were applied to the incidence data (Table 2). The homogeneous model was the lowest, with 13 species (14 species were actually observed). The second-order Jackknife model produced a high estimator of 19 species, similar to Chao2 (Chao, 1987) (18 species). The Chao2 model (Chao, 1987) offered the largest 95% confidence interval: 14.480 to 53.842 species. Most estimators recovered a larger prediction than the actual observation. The 1st order Jackknife estimator showed the lowest variance/estimator: 17 species at least and 26 species at most should live in the study area.



**Figure 3.** Regression tree of environmental variables on cladoceran richness of dune ponds. The pond without cladocerans was excluded from the analysis.

**Table 2.** Species richness estimation based on the observed species presence/absence data.

	Estimate	SE	95% Lower	95% Upper
Homogeneous Model	12.767	1.063	14.101	19.838
Chao2 (Chao, 1987)	18.375	7.003	14.480	53.842
Chao2-bc	15.458	2.534	14.145	28.716
iChao2 (Chiu et al., 2014)	18.375	5.940	14.590	46.445
ICE (Lee & Chao, 1994)	15.954	2.437	14.293	27.046
ICE-1 (Lee & Chao, 1994)	16.441	3.274	14.334	31.826
1st order jackknife	16.917	2.398	14.713	25.930
2nd order jackknife	18.833	4.086	15.146	34.385

### 3.3. Species Association and Coexistence

Among all 105 combinations of species, 16 showed significant associations with corresponding pond groups. These contained 6 species and 10 species combinations (Table 3). *M. cf brachiata* occurred in ponds with high conductivity (6630–12619  $\mu\text{S}/\text{cm}$ ), while *C. reticulata* only occurred in the ponds with lower conductivity ( $\leq 7430$   $\mu\text{S}/\text{cm}$ ). The two species coexisted in ponds with conductivity from 6630 to 7430  $\mu\text{S}/\text{cm}$ . As for species combinations, *C. rectangula* + *M. cf brachiata* are significantly associated with tadpole presence ( $p = 0.040$ ), while *C. rectangula* + *D. longispina* are associated with tadpole absence ( $p = 0.033$ ). Two species of *Daphnia* coexist in two neighboring ponds, while *D. magna* was dominant in a 400  $\text{m}^2$  pond with conductivity 2943  $\mu\text{S}/\text{cm}$ . *D. longispina* built up a dominant population in a 40  $\text{m}^2$  pond with a conductivity of 1996  $\mu\text{S}/\text{cm}$ .

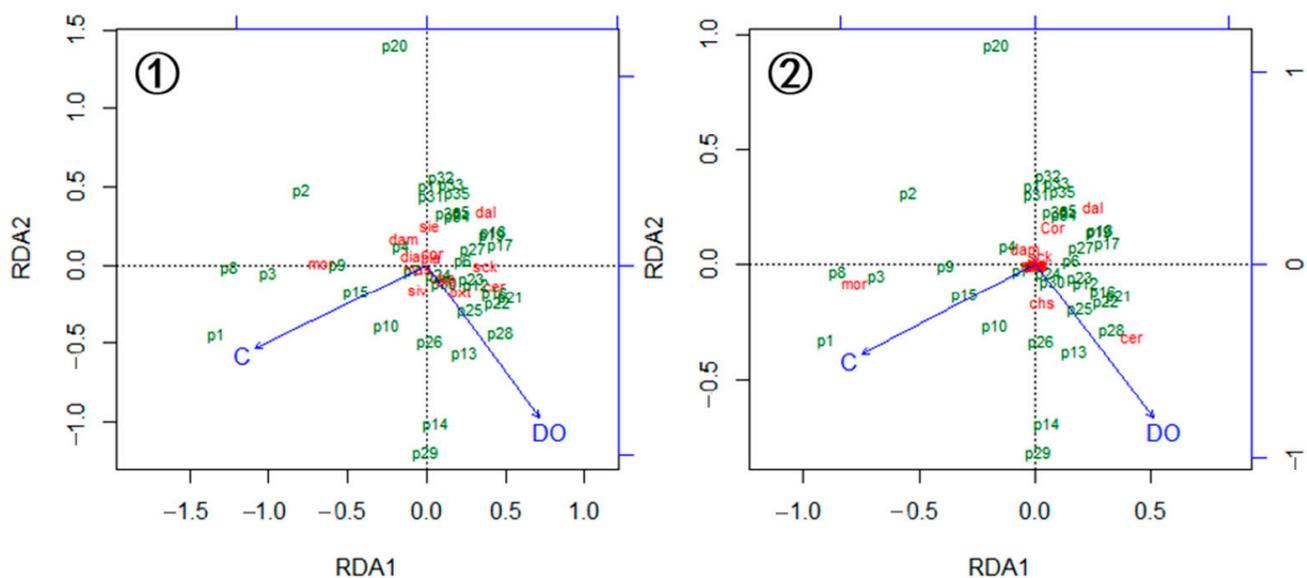
**Table 3.** Selected indicators (species and species combinations) and associated environmental variables. Significance codes: ‘\*\*\*’ 0.001, ‘\*\*’ 0.01, ‘\*’ 0.05.

Indicator Species	Associated Environment	Specificity	Fidelity	p-Value
mor	Conductivity: 6630–12619 $\mu\text{S}/\text{cm}$	0.947	0.667	0.005 **
cor + mor	Conductivity: 6630–12619 $\mu\text{S}/\text{cm}$	0.933	0.556	0.004 **
cer + mor	Conductivity: 6630–7430 $\mu\text{S}/\text{cm}$	0.857	0.500	0.040 *
cer	Conductivity: 1404–7430 $\mu\text{S}/\text{cm}$	1.000	0.939	0.001 ***
cor + cer	Conductivity: 1404–7430 $\mu\text{S}/\text{cm}$	1.000	0.818	0.025 *
dal	Conductivity: 1404–5415 $\mu\text{S}/\text{cm}$	1.000	0.519	0.05 *
chs + sck	pH:9.82–10.06	0.909	1.000	0.001 ***
chs	pH:8.92–8.94 & 9.82–10.06	0.811	0.800	0.012 *
cor + chs	pH:8.92–8.94 & 9.82–10.06	0.811	0.800	0.012 *
cer + chs	pH:8.92–8.94 & 9.82–10.06	0.811	0.800	0.012 *
cor + sck	pH:8.36–8.5 & 9.13–9.19 & 9.82–10.06	0.769	0.778	0.028 *
cor + mor	Tadpole present	0.875	0.333	0.040 *
cor + dal	Tadpole absent	0.797	0.524	0.033 *
cor + mor	Fish present	0.895	1.000	0.025 *
mor	Fish present	0.872	1.000	0.036 *
mor	Vegetation coverage: 50%	0.706	1.000	0.049 *

Notes: Abbreviations codes of each species, see Appendix A.

### 3.4. Variation of Cladoceran Communities along Environmental Gradients

For the incidence data, all environmental variables together explained 12.8% of the total variance (Figure 4). The first two constrained axes explained 5.5% and 2.4% of total variance. The first constrained axis was mainly contributed to by conductivity, fish, and tadpole presence, pond size, pH, DO, and vegetation coverage. Occurrence of *M. cf brachiata* positively correlated with conductivity, while *D. longispina* negatively correlated with it; the occurrence of *S. smirnovi* and *C. reticulata* positively correlated to DO and vegetation coverage. *Chydorus sphaericus* positively correlated with pond size. Forward selection showed that conductivity and DO were the most significant explanatory variables, which together explained 12.4% of the variance. Conductivity explained 9% of the variance and DO explained 4.5% of the variance.



**Figure 4.** Redundancy analysis of cladoceran communities with presence/absence data ① and relative abundance ② Abbreviation of species see Appendix A. Sampling sites in green font: p1–p37; species in red font, abbreviations codes, see Appendix A; blue arrows: significantly explaining environmental variables.

Redundancy analysis (RDA) for relative abundance data showed that the environmental variables together explained 29.2% of the variance; the first two constrained axes explained 26.8% (Figure 4). The first constrained axis is mainly related to conductivity, fish and tadpole presence, pond size, pH, DO, and vegetation coverage. Ponds dominated by *M. cf brachiata* were mainly situated along the first constrained axis, while ponds dominated by *C. reticulata* and *D. longispina* were situated along the second constrained axis. Relative abundance of *M. cf brachiata* positively correlated with conductivity, fish and tadpole presence. Relative abundance of *C. reticulata* were positively correlated with DO and vegetation coverage, while relative abundance of *D. longispina* was affected by water pH and depth. Forward selection of variables also showed conductivity and DO as significant explanatory variables. Conductivity and DO together explained 25.8% of total variance; conductivity explained 17.5%, DO explained 10.3%.

### 3.5. Variation of the Cladoceran Community along Spatial Gradients

The PCNM model produced 36 PCNM variables. When applied to species presence/absence data, 17 spatial eigenvectors were positive while only the first two spatial eigenvectors (V1 and V8) were significant. This suggests that broad-scale spatial processes affect cladoceran occurrence; variance partitioning shows that PCNM variables (V1 and V8) explained 5.8% of the total variance and 4.3 % was purely explained by PCNM variables (V1 and V8). Three significant PCNM variables (V1, V4, and V5) were selected for cladoceran relative abundance, indicating only broad-scale spatial processes. They explained 15.9% of the total variance (See Table 4).

**Table 4.** Variance partitioning of cladoceran community structure. (E, selected environmental variables base on forward selection in redundancy analysis including conductivity and DO; S1, significant positive PCNM variables, including V1 and V8; S2, significant positive PCNM variables, including “V1”, “V4”, and “V5”).

	Df	R	Radj	Testable
Presence/Absence				
E	2	17.4%	12.4%	TRUE
S1	2	13.9%	8.7%	TRUE
E + S1	4	26.5%	17.0%	TRUE
Shared	0		4.1%	FALSE
E   S1	2		8.3%	TRUE
S1   E	2		4.6%	TRUE
Residuals			83.0%	FALSE
Relative abundance				
E	2	30.0%	25.8%	TRUE
S2	3	23.2%	15.9%	TRUE
E + S2	5	45.6%	36.5%	TRUE
shared	0		5.2%	FALSE
E   S2	2		20.6%	TRUE
S2   E	3		10.7%	TRUE
Residuals			63.5%	FALSE

## 4. Discussion

### 4.1. Cladocera Diversity

Our investigation suggests limited species richness of Cladocera in the dune ponds of the Ulan Buh desert. Temporary ponds contained more species (16) than large permanent lakes (14) (see species list in Appendix A). Generally, cladoceran species changed at both temporal and spatial scales, thus, further sampling is needed to better describe species diversity in permanent lakes in the region. However, studying adjoined temporary ponds collectively provided species information to understand species diversity and distribution in the permanent lakes. Both temporary ponds and permanent ponds play important roles in maintaining total zooplankton species diversity [31].

As 37 dune ponds were investigated, estimators could be calculated. Chao2, first-, and second-order Jackknife suggested that more species can be expected. Similar estimators were used in extrapolating species numbers for 212 samples with 72 observed species in Thailand. Some 76–82 species were expected to be present even for such a large sample size [32]. ATBI (All Taxa Biological Inventory) suggested that any lowland lake is expected to have around 50 species, and species lists should be based on a minimum of three samples through seasons and years to minimize the under/overestimation [24,33]. In the present study, we sampled all ponds we could find, yet curiously, all Bosminidae and Ilyocryptidae, widespread all over the world, were absent here.

There are a few cladoceran studies in desert waters that showed high variation in species richness. Green (1976) described a sand-dune lake from New Zealand with only 1 species, *Bosmina meridionalis*, but the species of *Bosmina* were absent in our study [34]. A desert study from Xinjiang (China) also showed low Cladoceran diversity, with 7 species from 5 lakes between Tarim floodplain and Konchedarya river [35]. In contrast, high richness (34 species) was observed in 12 wet and 2 mud samples in Lençóis Maranhenses, a tropical desert in northeast Brazil. Six species were only found by hatching resting eggs/ephippia from collected mud samples resulting in a total of 15 species [36]. The Lençóis Maranhenses is a coastal strip of 155,000 ha with thousands of temporary freshwater pools fed by seasonal rains (November–May). The case study in the Brazilian desert revealed a great diversity in sediment, partly supported by hatching methods. Our study employed plankton sampling but no sediment work. Further surveys using more comprehensive sampling methods might therefore yield additional species.

In 2005, Alonso and colleagues started a lake survey of Mongolia. Until 2017, 1123 lakes have been cataloged and investigated in fourteen expeditions, almost covering the whole country. In total, 73 cladoceran species have been found, including 1 haplopod, 3 ctenopod, 1 onychopod, 16 members of Daphniidae, 5 Moinidae, 6 Macrothricidae, 5 Bosminidae, 36 Chydoridae ([http://www.geodata.es/mongolian\\_lakes](http://www.geodata.es/mongolian_lakes) accessed on 23 April 2018). The present study area is about 250 km away from Mongolia, and it has geomorphic features similar to that country. Its cladoceran fauna is expected to be more or less similar too. Three of the six cladoceran species found in a study of northeast Mongolia appeared in our study. Even though their sampling period was quite similar to ours, the low cladoceran diversity may be due to the high salt concentrations of lakes [37]. Long-term studies in drainless saline lakes of the Uldza-Torey basin reported 13 cladoceran species, and frequently occurring three species, *D. magna*, *M. brachiata*, and *D. mongolianum* all occurred in our study [38]. The study in Badain Jaran desert (located about 400 km northwest of our study area) showed diverse littoral cladocerans [39], among which four of these cladoceran species were present in our samples. A study in Jili lake located in north Xinjiang, China, reported 12 cladoceran species [40], and only three of them appeared in our samples.

Environmental variables such as conductivity, water pH, and DO were the main variables correlated with species richness in our study. Conductivity functions as one of the most important environmental filters, reflecting local environmental conditions. Environmental selection, as well as spatial processes affected cladoceran communities of the ponds. Three pelagic species, viz. *C. reticulata*, *D. longispina*, and *M. cf brachiata*, dominated, but with a clear niche partitioning. *M. cf brachiata* appears to be good indicator of high salinity and is adapted to tadpole predation, while *D. longispina* is absent under tadpole predation. Interspecific differences in colonization and competitive abilities may also determine the species composition, which was revealed in rock pools on the Baltic islands off the south coast of Finland [41].

Deserts are mobile, and dunes move with the wind. The maximum between-pond altitude difference was 30 m within our area (40 × 15 km<sup>2</sup>). Significant correlations between altitude and longitude as well as latitude tell that eastern ponds are at higher altitudes than western ponds. This implies that the wind effect is strong in our study area. Furthermore, Cladocera produce ephippia that can be dispersed more or less easily by wind [3,42]. A study on the rock pools of the Appledore islands showed differences between ephippia

of *Daphnia* and *Moina* in the ease with which they were dispersed [3]. Large numbers of *Daphnia* ephippia occurred in besides rock pools, against a few of *Moina*. Compared to *Daphnia*, ephippia of *Moina* have lower buoyancy, resulting in low dispersal. The *M. cf brachiata* in the present study was limited to the western ponds by environmental selection (high conductivity), even under the prevailing northwest winds. However, *M. cf brachiata* was still able to colonize the east ponds with high conductivity, given enough time. Louette and De Meester (2005) measured colonization by Cladocera of 25 newly dug pools in an area in Belgium of 200 km length and 50 km width [4]. In the built-up communities, a total of 20 Cladocera species were identified after 15 months; *C. sphaericus*, *Daphnia obtusa*, and *Simocephalus vetulus* were in more than half of the pools, but Moinidae and Sididae were absent. Daphniids represented almost 50% of the colonization events, with *Daphnia* always the pioneer cladoceran species. *D. mongolianum*, a sidid, was only present in two permanent lakes and one linked temporary pond, implying that this species is limited to permanent lakes. *Diaphanosoma* tolerates fluctuations in water salinity and is found in up to 15 g/L salinity [43]. The explanation of its restricted distribution in our study might therefore be low dispersal ability.

*C. rectangula*, *C. sphaericus*, *C. reticulata*, and *S. smirnovi* were the common species in the present study, and their combinations associated with habitats with different pH values, suggesting they all can be found in a wide range of water types. Walseng (2003) identified littoral microcrustaceans as indicators of acidification in Canadian ponds, and species richness increased when aquatic ecosystems recovered from acidic to nonacidic [7]. Among 64 identified Cladoceran species, *Sinobosmina* sp. and *Sida crystallina* were good indicators of acidification. This may be the reason why these two genera were absent from our study area. Chen et al. (2010) examined the impact of lake trophic state on the Cladoceran communities in 33 Irish ponds, highlighting that cladoceran functional structure strongly shifted with nutrient enrichment and should be considered as multiple biotic indicators [8]. Even though the nutrient level was not a significant variable to Cladoceran communities in the current study, it may potentially impact Cladoceran functional structure.

#### 4.2. Community Assembly

Forward selection in RDA analysis suggested that conductivity and DO significantly explained community variation. Ponds in the present study were all shallow water bodies, thus their DO level was controlled by phytoplankton and aquatic vegetation, and varies throughout the day. In this kind of habitat, cladoceran communities are not significantly altered by DO level. Water conductivity is usually related to salinity, which strongly affects zooplankton communities [44,45]. Zooplankton species richness decreased with lake salinization in the lakes of Tibet, and the zooplankton community shifted from the dominance of copepods and small cladoceran species to large saline filter-feeding cladocerans and phyllopod species [46]. A similar pattern emerged in our study, which dominant cladoceran species in our sand ponds shifted from smaller *C. reticulata* to larger *M. cf brachiata*. Salinity is a serious stress factor for freshwater cladocerans, thus, species must either adapt to it or perish. *M. cf brachiata* is able to survive at high salinity, while *C. reticulata* only appeared in lower salinity ponds. Several species of *Moina* have a good tolerance to salinity. Their tolerance can even reach 15‰ and they still dominate in lakes with 5.5‰ salinity [17].

In general, mineralization, salinization, and eutrophication all had a significant effect on the cladoceran community [40]. In our study, significant environmental variables, conductivity, and DO together explained the majority (12.4%) of the variations in the cladoceran community. The other environmental variables such as pH, temperature, and water depth are important, but did not significantly contribute to the variation of the cladoceran community.

## 5. Conclusions

Our study presented a brief outlook on species richness, fine spatial distribution, and community structure of cladocerans in a desert setting. *C. reticulata* and *C. rectangula* were

the most common cladocera in the studied region, while *C. reticulata*, *D. longispina*, and *M. cf brachiata* all formed dominant populations. *M. cf brachiata* and *C. reticulata* were suggested as good indicators of ponds with high conductivity and lower conductivity, respectively. The combination of these two species coexisted in ponds with moderate conductivity. Species richness is limited by harsh habitats and the community structure was shaped by environmental selection as expected. Conductivity was the most important environmental variable, and a broad-scale spatial structure was significant. Large permanent lakes function as a species pool for temporal ponds nearby. The species diversity and local community in temporal ponds demonstrate environmental filtering or species sorting of local habitats for species dispersed from the permanent lakes.

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**Institutional Review Board Statement:** Sampling and all work did not have any visible adverse effects on zooplankton in natural waters. No any permissions or ethics approval are required for sampling and monitoring zooplankton in lakes and reservoirs. Our field sampling follows and obeys Wildlife Protection Law of the People’s Republic of China (revised in 2018).

**Data Availability Statement:** The data presented in this study are openly available in [Researchgate] at [[https://www.researchgate.net/publication/355283457\\_sand\\_pondsoriginal\\_data](https://www.researchgate.net/publication/355283457_sand_pondsoriginal_data)].

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## Appendix A

**Table A1.** Checklist of species from 37 sand ponds, species from 4 neighboring permanent lakes was also listed. Lake: cladoceran species present in ponds, Pond: cladoceran species present in ponds; + means present, - means absent.

Family	Species	Codes	Lake	Pond
Sididae Bard, 1850	<i>Diaphanosoma mongolianum</i> Uéno, 1938	dia	+	+
Daphniidae (Straus, 1820)	<i>Daphnia magna</i> Straus, 1820	dam	+	+
	<i>Daphnia longispina</i> (O. F. Müller, 1776)	dal	+	+
	<i>Simocephalus exspinosus</i> (De Geer, 1778)	sie	+	+
	<i>Simocephalus vetulus</i> (O. F. Müller, 1776)	siv	+	+
	<i>Scapholeberis smirnovi</i> Garibian et al., 2020	sck	+	+
	<i>Ceriodaphnia reticulata</i> (Jurine, 1820)	cer	+	+
Moinidae Goulden, 1968	<i>Moina cf brachiata</i> (Leydig, 1860)	mor	+	+
Macrothricidae Norman & Brady, 1867	<i>Macrothrix rosea</i> (Jurine, 1820)	mar	+	-
	<i>Macrothrix spinosa</i> King, 1853	mas	-	+
Chydoridae Stebbing, 1902	<i>Oxyurella tenuicaudis</i> (Sars, 1862)	oxt	-	+
	<i>Alona guttata</i> Sars, 1862	alg	+	+
	<i>Coronatella rectangula</i> (Sars, 1862)	cor	+	+
	<i>Alonella nana</i> (Baird, 1843)	aln	+	-
	<i>Pleuroxus aduncus</i> (Jurine, 1820)	pla	-	+
	<i>Chydorus sphaericus</i> (O. F. Müller, 1776)	chs	+	+

## References

1. Leibold, M.A.; Holyoak, M.; Mouquet, N.; Amarasekare, P.; Chase, J.M.; Hoopes, M.F.; Holt, R.D.; Shurin, J.B.; Law, R.; Tilman, D.; et al. The metacommunity concept: A framework from multi-scale community ecology. *Ecol. Lett.* **2004**, *7*, 601–613. [CrossRef]
2. Figuerola, J.; Green, A.J. Dispersal of aquatic organisms by waterbirds: A review of past research and priorities for future studies. *Freshw. Biol.* **2002**, *47*, 483–494. [CrossRef]
3. Sirianni, K.M. Differential wind dispersal of cladoceran ephippia in a rock pool metacommunity. *Aquat. Ecol.* **2017**, *51*, 1–16. [CrossRef]
4. Louette, G.; De Meester, L. High dispersal capacity of cladoceran zooplankton in newly founded communities. *Ecology* **2005**, *86*, 353–359. [CrossRef]
5. Dodson, S.I.; Newman, A.L.; Willwolf, S.; Alexander, M.L.; Woodford, M.P.; Egeren, S.V. The relationship between zooplankton community structure and lake characteristics in temperate lakes (Northern Wisconsin, USA). *J. Plankton Res.* **2009**, *31*, 93–100. [CrossRef]
6. Declerck, S.A.J.; Coronel, J.S.; Legendre, P.; Brendonck, L. Scale dependency of processes structuring metacommunities of cladocerans in temporary pools of High-Andes wetlands. *Ecography* **2011**, *34*, 296–305. [CrossRef]
7. Walseng, B.; Yan, N.D.; Schartau, A.K. Littoral microcrustacean (Cladocera and Copepoda) indicators of acidification in Canadian Shield lakes. *AMBIO* **2003**, *32*, 208–213. [CrossRef]
8. Chen, G.; Dalton, C.; Taylor, D. Cladocera as indicators of trophic state in Irish ponds. *J. Paleolimnol.* **2010**, *44*, 465–481. [CrossRef]
9. Jeppesen, E.; Jensen, J.P.; Søndergaard, M.; Lauridsen, T.; Landkildehus, F. Trophic structure, species richness and biodiversity in danish lakes: Changes along a phosphorus gradient. *Freshw. Biol.* **2000**, *45*, 201–218. [CrossRef]
10. Canterbury, G.E.; Martin, T.E.; Petit, D.R.; Petit, L.J.; Bradford, D.F. Bird Communities and Habitat as Ecological Indicators of Forest Condition in Regional Monitoring. *Conserv. Biol.* **2000**, *14*, 544–558. [CrossRef]
11. Valero, E.; Álvarez, X.; Picos, J. An assessment of river habitat quality as an indicator of conservation status. A case study in the Northwest of Spain. *Ecol. Indic.* **2015**, *57*, 131–138. [CrossRef]
12. Bakker, J.D. Increasing the utility of Indicator Species Analysis. *J. Appl. Ecol.* **2008**, *45*, 1829–1835. [CrossRef]
13. Cáceres, M.D.; Legendre, P. Associations between species and groups of sites: Indices and statistical inference. *Ecology* **2009**, *90*, 3566–3574. [CrossRef] [PubMed]
14. Cáceres, M.D.; Legendre, P.; Moretti, M. Improving indicator species analysis by combining groups of sites. *Oikos* **2010**, *119*, 1674–1684. [CrossRef]
15. Cáceres, M.D.; Legendre, P.; Wisser, S.K.; Brotons, L. Using species combinations in indicator value analyses. *Methods Ecol. Evol.* **2012**, *3*, 973–982. [CrossRef]
16. Urban, N.A.; Swihart, R.K.; Malloy, M.C.; Dunning, J.B., Jr. Improving selection of indicator species when detection is imperfect. *Ecol. Indic.* **2011**, *15*, 188–197. [CrossRef]
17. He, Z.; An, S. The adaptation to salinity in *Moina brachiata*. *Chin. J. Zool.* **1986**, *2*, 27–30. (In Chinese)
18. Guo, F.F.; Dumont, H.J. Relict populations of *Diaphanosoma* (Cladocera: Ctenopoda) in the Chadian Sahara, with the description of a new species. *Zootaxa* **2014**, *3856*, 135–142. [CrossRef]
19. Kotov, A.A. Jurassic Cladocera (Crustacea, Branchiopoda) with a description of an extinct Mesozoic Order. *J. Nat. Hist.* **2007**, *41*, 13–37. [CrossRef]
20. Rhoades, J.D. Salinity: Electrical conductivity and total dissolved solids. *Chem. Methods* **1996**, *142*, 31–33.
21. Breiman, L.; Friedman, J.H.; Olshen, R.A.; Stone, C.J. Classification and Regression Trees. *Wadsworth* **1984**, *20*, 582–588.
22. Magurran, A.E. *Measuring Biological Diversity*; Blackwell Science Ltd.: Victoria, UK, 2004; pp. 1–215.
23. Chao, A. Estimating the population size for capture-recapture data with unequal catchability. *Biometrics* **1987**, *43*, 783. [CrossRef] [PubMed]
24. Dumont, H.J.; Segers, H. Estimating lacustrine zooplankton species richness and complementarity. *Hydrobiologia* **1996**, *341*, 125–132. [CrossRef]
25. Borcard, D.; Legendre, P. All-scale spatial analysis of ecological data by means of principal coordinates of neighbour matrices. *Ecol. Model.* **2002**, *153*, 51–68. [CrossRef]
26. Borcard, D.; Legendre, P.; Avoisjacquet, C.; Tuomisto, H. Dissecting the spatial structure of ecological data at multiple scales. *Ecology* **2004**, *85*, 1826–1832. [CrossRef]
27. Chambers, J.M. SoDA: Functions and Examples for “Software for Data Analysis”. R package version 1.0-6.1. 2020. Available online: <https://CRAN.R-project.org/package=SoDA> (accessed on 28 October 2020).
28. Chao, A.; Ma, K.H.; Hsieh, T.C.; Chiu, C.H. SpadeR: Species-Richness Prediction and Diversity Estimation with R. R package version 0.1.1. 2016. Available online: <https://CRAN.R-project.org/package=SpadeR> (accessed on 6 September 2016).
29. Oksanen, J.; Blanchet, F.G.; Friendly, M.; Kindt, R.; Legendre, P.; McGlinn, D.; Minchin, P.R.; O’Hara, R.B.; Simpson, G.L.; Solymos, P.; et al. vegan: Community Ecology Package. R package version 2.5-7. 2020. Available online: <https://CRAN.R-project.org/package=vegan> (accessed on 28 November 2020).
30. Therneau, T.; Atkinson, B. rpart: Recursive Partitioning and Regression Trees. R package version 4.1-15. 2019. Available online: <https://CRAN.R-project.org/package=rpart> (accessed on 12 April 2019).
31. Drenner, S.M.; Dodson, S.I.; Drenner, R.W.; Pinder, J.E. Crustacean zooplankton community structure in temporary and permanent grassland ponds. *Hydrobiologia* **2009**, *632*, 225–233. [CrossRef]

32. Maiphae, S.; Pholpunthin, P.; Dumont, H.J. Species richness of the Cladocera (Branchiopoda: Anomopoda and Ctenopoda) in southern Thailand, and its complementarity with neighboring regions. *Hydrobiologia* **2005**, *537*, 147–156. [[CrossRef](#)]
33. Dodson, S. Predicting crustacean zooplankton species richness. *Limnol. Oceanogr.* **1992**, *37*, 848–856. [[CrossRef](#)]
34. Green, J.D. Plankton of lake Ototoa, a sand-dune lake in Northern New Zealand. *N. Z. J. Mar. Fresh.* **1976**, *10*, 43–59. [[CrossRef](#)]
35. Chertoprud, E.S.; Sinev, A.Y.; Dimante-Deimantovica, I. Fauna of Cladocera and copepoda from Xinjiang Uyghur autonomous region (China). *Zootaxa* **2017**, *4258*, 561–573. [[CrossRef](#)]
36. Van Damme, K.; Dumont, H.J. Cladocera of the Lençóis Maranhenses (NE-Brazil): Faunal composition and a reappraisal of Sars' Method. *Braz. J. Biol.* **2010**, *70*, 755–779. [[CrossRef](#)] [[PubMed](#)]
37. Afonina, E.Y.; Tashlykova, N.A. Plankton community and the relationship with the environment in saline lakes of Onon-Torey plain, Northeastern Mongolia. *Saudi. J. Biol. Sci.* **2018**, *25*, 399–408. [[CrossRef](#)] [[PubMed](#)]
38. Afonina, E.Y.; Tashlykova, N.A. Plankton of Saline Lakes in Southeastern Transbaikalia: Transformation and Environmental Factors. *Contemp. Probl. Ecol.* **2019**, *12*, 155–170. [[CrossRef](#)]
39. Li, Y.; Zhao, H.; Hu, L.; Leppänen, J.J. Cladoceran communities in soda lakes of the Badain Jaran desert, NW China. *J. Arid Environ.* **2020**, *177*, 104133. [[CrossRef](#)]
40. Hu, L.; Li, Y.; Leppänen, J.J.; Chen, G.; Lang, W.; Wang, X.; Qiang, M. Human impacts on the cladoceran community of Jili Lake, arid NW China, over the past century. *J. Paleolimnol.* **2021**, 1–12.
41. Hanski, I.; Ranta, E. Coexistence in a Patchy Environment: Three Species of *Daphnia* in Rock Pools. *J. Anim. Ecol.* **1983**, *52*, 263–279. [[CrossRef](#)]
42. De Meester, L.; Gómez, A.; Okamura, B.; Schwenk, K. The Monopolization Hypothesis and the dispersal–gene flow paradox in aquatic organisms. *Acta Oecol.* **2002**, *23*, 121–135. [[CrossRef](#)]
43. Korovchinsky, N.M. Sididae & Holopediidae (Crustacea: Daphniiformes). In *Guides to the Identification of the Microinvertebrates of the Continental Waters of the World 3*; SPB Academic: Hague, The Netherlands, 1992; pp. 1–82.
44. Horváth, Z.; Vad, C.F.; Tóth, A.; Zsuga, K.; Boros, E.; Vörös, L.; Ptacnik, R. Opposing patterns of zooplankton diversity and functioning along a natural stress gradient: When the going gets tough, the tough get going. *Oikos* **2014**, *123*, 461–471. [[CrossRef](#)]
45. Yılmaz, G.; Çolak, M.A.; Özgencil, İ.K.; Metin, M.; Korkmaz, M.; Ertuğrul, S.; Soyluer, M.; Bucak, T.; Tavşanoğlu, Ü.N.; Özkan, K.; et al. Decadal changes in size, salinity, waterbirds, and fish in lakes of the Konya Closed Basin, Turkey, associated with climate change and increasing water abstraction for agriculture. *Inland Waters* **2021**, 1–18. [[CrossRef](#)]
46. Lin, Q.Q.; Xu, L.; Hou, J.Z.; Liu, Z.W.; Jeppesen, E.; Han, B.P. Responses of trophic structure and zooplankton community to salinity and temperature in Tibetan lakes: Implication for the effect of climate warming. *Water Res.* **2017**, *124*, 618–629. [[CrossRef](#)]