DYNAMICS OF ZOOPLANKTON COMMUNITIES AND IDENTIFICATION OF PIVOTAL ENVIRONMENTAL FACTORS IN ULANSUHAI LAKE, INNER MONGOLIA, CHINA

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Abstract. This study investigated the dynamic shifts and diversity of zooplankton communities in Ulansuhai Lake over several years. Surveys of the lake's zooplankton and associated water environmental factors were conducted from September 2021 to 2023, spanning three consecutive years. The study found an annual variation in the number of surveyed zooplankton species, tallying 48, 55, and 34 in 2021, 2022, and 2023 respectively. Rotifer species were predominant each year, while the occurrence of protozoa was relatively minimal. Six species emerged as dominant, with *Cyclops strenuus* exhibiting the highest level of dominance. The average zooplankton density was highest in 2022 (1835.9 ind./L), followed by 2021 (1302.3 ind./L) and 2023 (210.0 ind./L), while the average biomass was highest in 2023 (2.302 mg/L), followed by 2021 (1.623 mg/L) and 2022 (1.403 mg/L). A single-factor analysis of variance (ANOVA) and Tukey test demonstrated significant variations in the zooplankton density and biodiversity indices (Shannon-Wiener diversity index, Margalef species richness index, Pielou evenness index) across different years ($P<0.05$) but not in biomass ($P>0.05$). According to the evaluation grading standard analysis, zooplankton biodiversity in 2021 and 2022 was assessed as moderate to good, whereas in 2023 it was assessed as poor to moderate. The Pearson correlation results and RDA analysis suggested that pH, total nitrogen (TN), arsenic (As), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), and conductivity (COND) are the principal environmental factors impacting the structure of the zooplankton community in Ulansuhai Lake from 2021 to 2023.
Keywords: *lake wetland, zooplankton, dynamic changes, influencing factors, redundancy analysis*

Research background

Zooplankton, serving as both primary producers and consumers within lakes, reservoirs, and various watersheds, play an instrumental role in preserving the integrity of aquatic ecosystem structures and functions (Li et al., 2023). These factors not only profoundly impact the transparency of waters in lakes and reservoirs but they also play a crucial role in their ecological restoration. Owing to their diminutive size, ubiquitous distribution, and the susceptibility of their community structure characteristics to environmental changes in water, they may undergo community succession when disturbances are sufficiently intense (Wang et al., 2022). Given these attributes, zooplankton are frequently employed as indicator organisms to assess and reflect the condition of water bodies (Liu et al., 2019).

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As the largest lake wetland in the Yellow River Basin, Ulansuhai Lake has experienced a gradual decline in its natural water replenishment since the 1990s, leading to notable water shortages. This situation has been further exacerbated by urban sewage, industrial wastewater, and agricultural runoff which have resulted in significant water pollution and a subsequent decline in ecological functions (Shi et al., 2025). These factors have indirectly intensified eutrophication of the lake's waters. Concurrently, there has been a marked proliferation of both emergent and submerged plants, accelerating the lake's marshification process. Entering the 21st century, the implementation of water ecosystem restoration measures such as "integrated management of three waters" and "combining internal and external repairs" (Shi et al., 2025) has contributed to an improvement in Ulansuhai Lake's water quality. From 2011 to 2015, the water quality was classified as below Class V. However, from 2016 to 2019, there was a notable improvement, achieving Class V status (Gou et al., 2025). The lake has transitioned from a state of severe eutrophication to a mild eutrophic state, and the ecological replenishment of water has gradually increased more than two-fold, reaching 600 million m^3. The evident improvements in water quality, along with ongoing recovery of the ecological environment and biodiversity of Ulansuhai Lake, underscore the importance of continued research. Research into the health of Ulansuhai Lake's water ecosystem across different years is crucial for promoting environmental improvement in this basin. Aquatic organisms, a key component of the water ecosystem, have community structures that respond directly to changes in the water environment. However, research on the dynamic relationship between the zooplankton community in Ulansuhai Lake and environmental factors remains relatively limited.

This study conducted an in-depth survey and analysis of the zooplankton community and diversity within Ulansuhai Lake from 2021 to 2023. The aim was to delineate the dynamic variations in the zooplankton community across different years, assess the biodiversity of Ulansuhai Lake post-ecological restoration, and employ Pearson correlation analysis and redundancy analysis to investigate the relationship between the structure of the zooplankton community and water environmental factors. The objective is to provide a scientific foundation for the protection and restoration of the aquatic ecosystem of Ulansuhai Lake.

Materials and methods

Study area overview

The Ulansuhai Lake, situated within the Urad Front Banner of Bayannur City in the Inner Mongolia Autonomous Region (coordinates 40°36′ to 41°03′N and 108°43′ to 108°57′E), spans from the Hu-Bao-E triangle region in the east to the Hou Plain in the west. It is delineated by the Yellow River to the south and the Lang Mountains to the north. The lake's morphology is notably elongated, extending 293 square kilometers with a water storage capacity ranging between 400 and 500 million cubic meters. The ecosystem is primarily composed of submerged vegetation, notably Longxuyan Zicai and Zhucao, complemented by emergent reed beds. Post-ecological restoration efforts introduced 28 novel species of phytoplankton, zooplankton, fish, and birds, leading to an increase in the bird population by over 200,000 (Shi et al., 2025). The region is characterized by a semi-arid monsoon climate, indicative of the mid-temperate continental arid zone. This climate is marked by limited rainfall, with distinct seasonal variations in both climatic conditions and precipitation patterns (Yang et al., 2025).

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Sampling sites

This study undertook ecological surveys of Ulansuhai Lake from September 2021 to 2023 (*Fig. 1*), spanning three consecutive years. A total of 12 sampling sites (*Table 1*) were established in the lake area, designated as W1-W12 (*Fig. 2*). Each sampling station was distributed relatively evenly and possessed representative characteristics, thereby reflecting the overall condition of aquatic organisms within each respective water area.

Figure 1. *The sampling sites and habitats in the Ulansuhai Lake from 2021-2023*

Table 1. *The distribution coordinates of sampling sites for zooplankton in Ulansuhai Lake*

Site No.	Longitude	Latitude	Water depth(m)		
			2021	2022	2023
W1	108°51′52.11″	41°02′11.18″	2.9	2.5	2.4
W2	108°53′19.74″	41°02′27.87″	2.8	2.2	2.5
W3	108°50′06.72″	40°59′23.70″	2.0	1.7	1.4
W4	108°54′35.76″	40°59′21.08″	1.9	1.6	1.5
W5	108°51′17.09″	40°58′18.21″	2.7	2.1	2.3
W6	108°54′27.97″	40°57′18.63″	1.9	1.5	1.5
W7	108°48′25.19″	40°55′46.33″	1.1	1.3	2.0
W8	108°52′30.71″	40°55′41.28″	1.5	1.0	1.3
W9	108°44′47.11″	40°53′26.59″	1.8	1.6	1.9
W10	108°48′45.03″	40°53′09.77″	1.7	2.5	2.5
W11	108°44′40.47″	40°50′03.03″	2.2	2.0	3.4
W12	108°42′32.74″	40°47′30.54″	2.2	1.9	1.8

Sample collection and measurement

Collection and measurement of zooplankton

The quantitative sample water collection levels are determined based on the vertical distribution characteristics of zooplankton in the study area combined with the water depth at each site: for waters less than 5 m deep or well-mixed, one sampling site is set at 0.5 m below the water surface; for waters between 5 m and 10 m deep, sampling sites are set at both 0.5 m below the water surface and at the bottom of the photic zone (the depth is calculated as 3 times the transparency), with stratified sampling or mixed samples taken; for waters deeper than 10 m, sampling sites are set at 0.5 m below the water surface, at

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half the photic zone, and at the bottom of the photic zone, with stratified sampling or mixed samples taken.

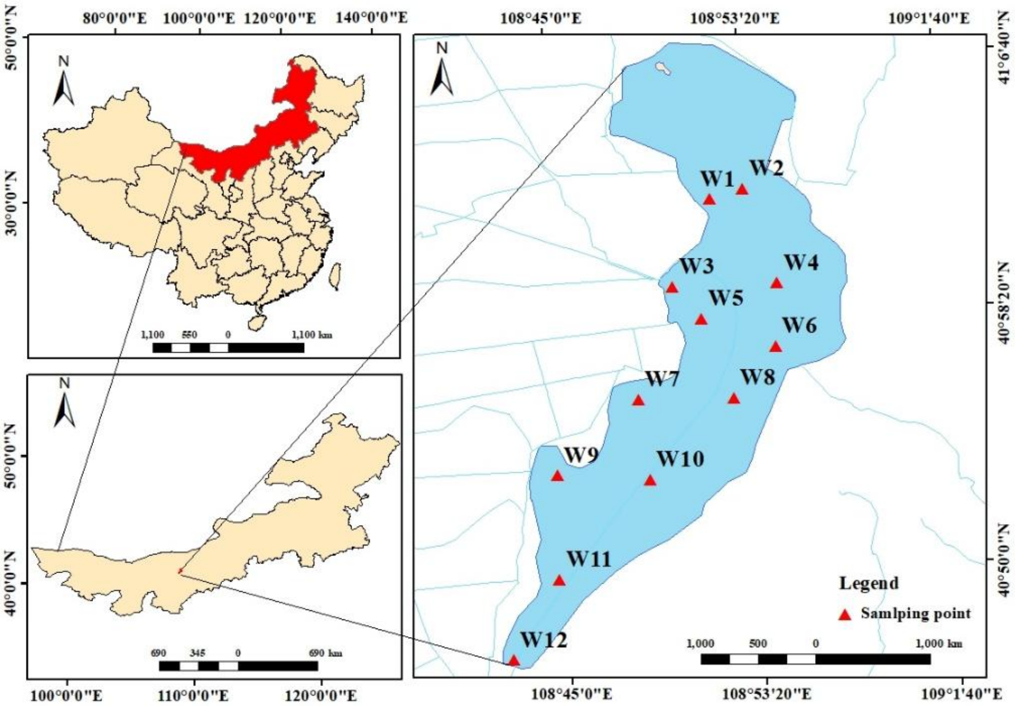

Figure 2. *Distribution map of zooplankton sampling sites in Ulansuhai Lake*

For quantitative samples of cladoceras and copepodas: Take 20 L of water samples with a water sampler according to the conventional water sampling method, and after filtering with a No. 13 zooplankton net, dilute to 30 ml. Fix with 3-5 ml of formaldehyde solution for every 100 ml of water sample; For quantitative samples of protozoans and rotifers: Collect 1 L of water sample, add 10-15 ml of Lugol's reagent, and after being placed in the laboratory for 48 hours, siphon off the supernatant and concentrate to 30 ml.

Counting and identification were performed using a pipette and a MoticBA400 (China) optical microscope. Cladoceras and copepodas samples were counted in a 1 ml counting frame under a 10× objective lens (diluted when density was too high); protozoans and rotifers concentrated samples were evenly mixed, and 0.1 ml and 1 ml were taken respectively in corresponding counting frames, and counted in full view under a 20× objective lens. The same sample was counted in 2 frames, and if the error exceeded 15%, a third frame was counted, and the result was averaged. The density was converted by combining the counting volume, and the biomass was calculated using the volume method. Identification of the zooplankton was facilitated by reference to resources such as "New Technology of Microorganism Monitoring" (Shen et al., 2000), "Records of Chinese Freshwater Rotifers" (Wang, 1961), "Records of Chinese Animals: Freshwater Cladocera", and "Records of Chinese Animals: Freshwater Copepoda" (Jiang and Du, 1979).

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Collection and measurement of environmental factors in water

During the collection of zooplankton samples, a portable water quality analyzer (YSI6600-02 USA) was employed to gauge environmental factors such as pH, transparency (SD), dissolved oxygen (DO), conductivity (COND), and water temperature (WT). Subsequently, water samples were gathered and transported for further experimentation. These samples were analyzed using a Hach water quality testing instrument (DR1900, HACH) to determine parameters including total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), and chlorophyll-a (Chla).

Data analysis and processing

Using Excel 2021 to conduct statistical calculations on the biomass, density, and dominant zooplankton species (McNaughton, 1968), and drawing for the composition of planktonic animal species and line graphs for biodiversity indices. Zooplankton biodiversity indices were calculated using PAST (326b) software (Shannon, 1948; Margalef, 1951; Pielou, 1966). Box plot analysis, one-way analysis of variance (ANOVA), and the Turkey test were conducted with the ggplot2 package of R 4.3.2 to ascertain significant differences in zooplankton density, biomass, biodiversity index, and water physicochemical concentration at different times within the Ulansuhai Lake community. The Pearson correlation coefficient was calculated between the zooplankton community structure and water environmental factors using Origin 2024, and correlation heat maps were subsequently drawn. Detrending correspondence analysis (DCA) was applied to the community structure data of zooplankton, revealing that the maximum gradient length was less than 3. Redundancy analysis (RDA) was then performed using Canoco5.0 software. The relationship between the community structure of Ulansuhai Lake and water environmental factors was explored in conjunction with the results of the RDA and Pearson correlation analysis. The map of zooplankton sampling sites in Ulansuhai Lake was created using ArcGIS 10.8 software.

In the formula: P_i represents the number of individuals of a specific species among all species; N represents the total number of individuals of all species in the sample; S represents the total number of species in all samples. Through the evaluation of grading standards, the biodiversity of zooplankton in Ulansuhai Lake is evaluated and graded (*Table 2*), which can be divided into five levels(Ministry of Ecology and Environment of the People's Republic of China, 2023).

$$H' = -\sum_{i=1}^{S} P_i \, log_2 \, P_i \tag{Eq.1}$$

$$D = (S\text{-}1)/\, log_2 \, N \tag{Eq.2}$$

$$J = H'/H_{max} \tag{Eq.3}$$

Table 2. *Grading criteria for the evaluation of zooplankton diversity index*

Index	Bad	Poor	Moderate	Good	Excellent
H′	H′=0	0<H′≤1.0	1.0<H′≤2.0	2.0<H′≤3.0	3.0<H′
J	J=0	0<J≤0.3	0.3<J≤0.5	0.5<J≤0.8	0.8<J≤1.0

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Results and analysis

Water quality characteristics of Ulansuhai Lake

The primary environmental data (mean ± standard deviation) for Ulansuhai Lake from 2021-2023 are presented in *Table 3*. Significant differences were observed in pH, water temperature (WT), ammonia nitrogen (NH_3-N), heavy metal arsenic (As), chlorophyll a (Chla), conductivity (COND), and chemical oxygen demand (COD) across the years (*ANOVA, df=2, P < 0.01*). Notably, transparency (SD) and chlorophyll a (Chla) exhibited a decreasing trend, while pH, water temperature (WT), dissolved oxygen (DO), and conductivity (COND) demonstrated an increasing trend during the period 2021-2023.

Table 3. *The water environmental factors (mean ± SD) of Ulansuhai Lake from 2021-2023*

Environmental factor	2021	2022	2023	P
SD (cm)	$99.583±34.306^a$	$93.333±31.710^a$	$77.917±42.203^a$	0.366
COND (μS/cm)	$270.766±75.156^a$	$297.492±72.749^b$	$298.367±87.074^b$	<0.010
WT (°C)	$21.945±1.032^b$	$21.708±1.314^b$	$25.042±2.061^a$	<0.010
pH	$8.247±0.346^b$	$8.708±0.480^a$	$8.883±0.496^a$	<0.050
DO (mg/L)	$5.888±4.016^a$	$6.429±2.34^a$	$7.791±3.479^a$	0.401
COD (mg/L)	$29.917±4.890^a$	$23.167±5.928^b$	$32.583±8.057^a$	<0.050
COD_{Mn} (mg/L)	$7.183±1.709^a$	$5.758±1.724^b$	$6.550±0.617^{ab}$	0.084
TN (mg/L)	$1.153±0.212^a$	$1.277±0.535^a$	$1.057±0.180^a$	0.345
TP (mg/L)	$0.043±0.020^a$	$0.036±0.010^a$	$0.049±0.0160^a$	0.238
NH_3-N (mg/L)	$0.209±0.087^a$	$0.100±0.024^b$	$0.107±0.035^b$	<0.010
As (μg/L)	$4.683±0.001^a$	$2.317±0.001^b$	$3.325±0.001^b$	<0.010
Chla (μg/L)	$0.019±0.016^a$	$0.013±0.005^b$	$0.009±0.001^b$	<0.010

The superscript letters in the same row denote significant differences in environmental factors between different years (ANOVA, N=12, df=2, P < 0.05 means significant difference, P < 0.01 means extremely significant difference, P > 0.05 means no significant difference)

Community structure of zooplankton

Species composition of zooplankton

The number of zooplankton species in Ulansuhai Lake for 2021, 2022, and 2023 showed a decreasing trend (*Fig. 3*). In 2021, there were 48 species of zooplankton, including 3 species of protozoans, 25 species of rotifers, 11 species of copepods, and 9 species of cladocerans, accounting for 6.25%, 52.08%, 22.92%, and 18.75% of the total species, respectively. In 2022, the total number increased to 55 species, consisting of 5 species of protozoans, 35 species of rotifers, 5 species of copepods, and 10 species of cladocerans, representing 9.09%, 63.63%, 9.09%, and 18.18% of the total species, respectively. However, in 2023, the number decreased significantly to 34 species, including 2 species of protozoans, 18 species of rotifers, 4 species of copepods, and 10 species of cladocerans, accounting for 5.88%, 52.94%, 11.76%, and 29.41% of the total species, respectively. During all three periods, the number of rotifer species was dominant, while the number of protozoans species was the least.

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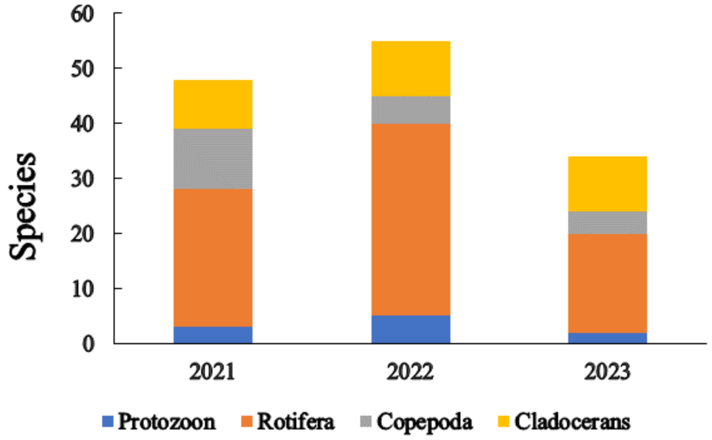

Figure 3. *Composition of zooplankton species in the Ulansuhai Lake from 2021 to 2023*

Zooplankton density and biomass

In 2021, the zooplankton density in Ulansuhai exhibited a range from 20.5 ind./L to 5126.4 ind./L, with an average of 1302.3 ind./L. The biomass was even more variable, ranging from 0.029 mg/L to 9.863 mg/L, with a mean value of 1.623 mg/L. In 2022, the zooplankton density showed a range from 16.1 ind./L to 6045.9 ind./L, averaging at 1835.9 ind./L; the biomass varied from 0.191 mg/L to 5.780 mg/L, with an average of 1.403 mg/L. For 2023, the range of zooplankton density was from 16.2 ind./L to 925.7 ind./L, with an average of 210.0 ind./L; the biomass ranged from 0.253 mg/L to 10.880 mg/L, averaging at 2.302 mg/L. In conclusion, the highest average density of zooplankton in Ulansuhai occurred in 2022, followed by 2021, then 2023. However, the highest average biomass was observed in 2023, followed by 2021, then 2022.

The boxplot analysis and one-way ANOVA results for the density and biomass of zooplankton in Ulansuhai Lake from 2021 to 2023 are presented in *Fig. 4*. For density, the differences between 2021 and 2023 were highly significant (ANOVA, $df=2, P < 0.01$), those between 2022 and 2023 were significant (ANOVA, $df=2, P < 0.05$), while no significant difference was observed between 2021 and 2022 (ANOVA, $df=2, P > 0.05$). Regarding biomass, there were no significant differences across the years.

Dominant species of zooplankton

The predominant zooplankton species in Ulansuhai Lake from 2021 to 2023 are detailed in *Table 4*. In 2021, 12 species dominated the ecosystem of the lake, encompassing 1 protozoan, 5 rotifers, 2 branchiopods, and 4 copepods, with their dominance ranging from 0.024 to 0.390. The following year, 2022, saw an increase to 16 dominant species, including 3 protozoans, 6 rotifers, 3 branchiopods, and 4 copepods, and a dominance range of 0.023 to 0.673. By 2023, the number of dominant species returned to 12, comprising 1 protozoan, 4 rotifers, 3 branchiopods, and 4 copepods, with a dominance range of 0.023 to 0.629. Common dominant species from 2021 to 2023 included the green swimming (*Strombidium viride*), curved-legged turtle rotifer (*Keratella valga*), rectangular sharp-headed cladoceran (*Alona rectangula*), straight-nosed bare-belly cladoceran (*Moina rectirostris*), heroic swordfish (*Cyclops strenuus*), and widespread medium swordfish (*Mesocyclops leuckarti*). Among these, the heroic swordfish (*Cyclops strenuus*) exhibited the highest dominance over these years.

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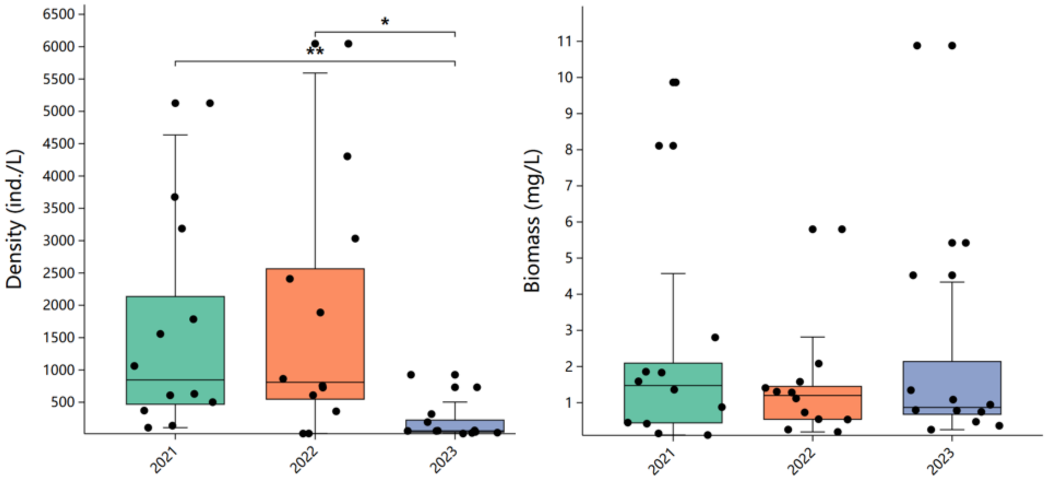

Figure 4. *Analysis of differences in zooplankton density and biomass in the Ulansuhai Lake from 2021-2023. * Means significant difference between groups (ANOVA, N=12, df=2, * represents P < 0.05 for significant difference, ** represents P < 0.01 for extremely significant difference)*

Table 4. *Dominant species and degree of zooplankton dominance in Ulansuhai Lake from 2021-2023*

Dominant species	**Dominance**		
	2021	**2022**	**2023**
Strombidium viride	0.321	0.419	0.219
Tintinnopsis wangi	-	0.029	0.010
Euglypha laevis	-	0.029	-
Polyarthra trigla	0.373	-	-
Monostyla furcata	0.063	-	-
Monostyla hamata	0.027	-	-
Brachionus angularis	-	0.248	-
Keratella valga	0.034	0.215	0.064
Brachionus urceus	-	0.058	0.053
Brachionus calyciflorus	-	0.046	0.074
Keratella cochlearis	0.013	0.026	-
Trichotria tetractis	-	0.025	-
Trichocerca gracilis	0.033	-	-
Asplanchna priodonta	-	0.019	0.083
Alona rectangula	0.017	0.289	0.107
Alona intermedia	-	-	0.036
Chydorus ovalis	0.044	0.073	-
Moina rectirostris	0.166	0.057	0.048
Daphnia longispina	0.024	-	-
Cyclops strenuus	0.390	0.673	0.629
Schmackeria forbesi	0.030	-	-
Mesocyclops leuckarti	0.311	0.079	0.116
Cyclops vicinus vicinus	0.032	-	-
Sinocalanus dorrii	-	0.032	-
Neutrodiaptomus genogibbosus	0.013	-	0.039
Metadiaptomus asiaticus	-	0.023	-
Microcyclops longiramus	0.016	-	0.023

"-" indicates that the species is not dominant

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Zooplankton biodiversity index

The trend in the mean value of the Shannon-Wiener diversity index (H') for zooplankton in Ulansuhai Lake was observed to be 2022 (1.641) > 2021 (1.611) > 2023 (1.088). For the Margalef richness index (D), the mean values followed the order 2022 (3.565) > 2021 (2.594) > 2023 (1.928). The Pielou evenness index (J) displayed a sequence of 2021 (0.593) > 2022 (0.542) > 2023 (0.469). Analysis of the H' data revealed no significant difference between 2021 and 2022 (ANOVA, $df=2$, $P > 0.05$); however, significant differences were noted between 2023 and both 2021 and 2022 (ANOVA, $df=2$, $P < 0.05$). The J data indicated significant differences only between 2021 and 2023. For the D data, significant differences were observed among all years (ANOVA, $df=2$, $P < 0.05$). In conclusion, the biodiversity index of zooplankton exhibited significant variations across different years (*Fig. 5*).

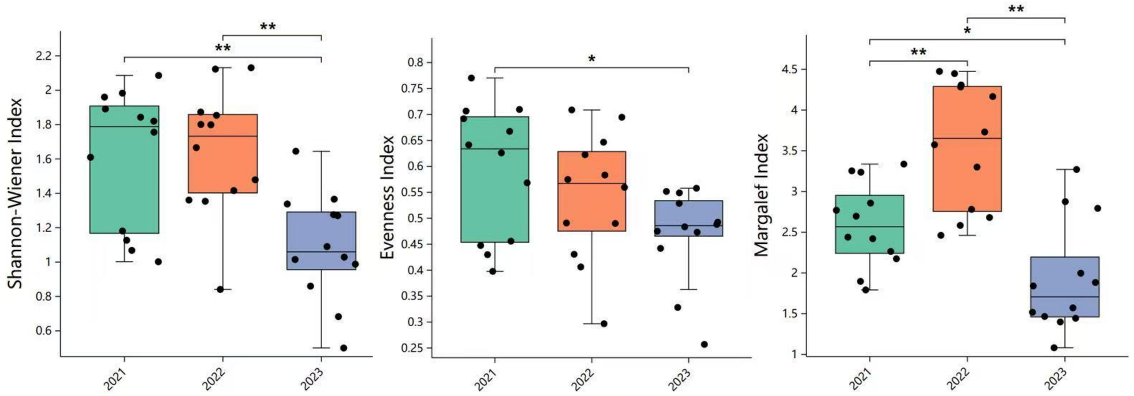

***Figure 5.** Analysis of the differences in biodiversity index of zooplankton in the Ulansuhai Lake from 2021-2023. * Means significant difference between groups (ANOVA, N=12, df=2, * represents P < 0.05 for significant difference, ** represents P < 0.01 for extremely significant difference)*

The evaluation and grading of the biological conditions in Ulansuhai Lake, based on the Shannon-Wiener diversity index (H') and the Pielou evenness index (J), are presented in *Fig. 6*. The H' results indicate that the biodiversity of Ulansuhai Lake from 2021 to 2023 was on the lower spectrum, ranging from poor to moderate. Notably, four sample sites in 2023 (W3, W4, W5, W9) were classified as poor, constituting 33.3% of the total sample sites. On the other hand, the J results suggest a more optimistic outlook, with the biodiversity of the lake during the same period largely falling within the good to moderate range. The majority of the sample sites in 2021 and 2022 were assessed as good, whereas most of the sites in 2023 were rated as moderate, albeit with one exception—a poor level sample point (W3).

Relationship between zooplankton community structure and water environmental factors

The Pearson correlation analysis, assessing the community structure of zooplankton in relation to water physicochemical factors in Ulansuhai Lake from 2021-2023, is presented in *Fig. 7*. In 2021, both H' and J exhibited highly significant positive correlations with TN (ANOVA, $df=2$, $P < 0.01$). In 2022, no marked correlation was observed between water physicochemical factors and the community structure of zooplankton (ANOVA,

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df=2, P > 0.05). However, in 2023, Density demonstrated a highly significant positive association with NH_3-N and a significant negative association with TN (ANOVA, *df=2, P < 0.05*).

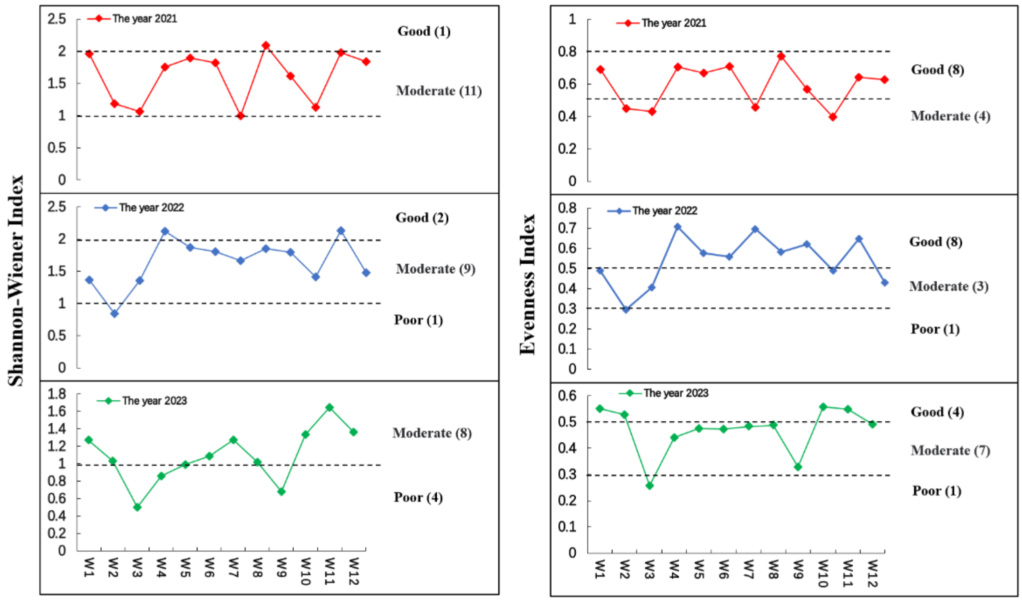

Figure 6. *Evaluation of Zooplankton Diversity Index in Ulansuhai Lake from 2021-2023. Good indicates $2.0 < H' \leq 3.0, 0.5 < J \leq 0.8$; Moderate indicates $1.0 < H' \leq 2.0, 0.3 < J \leq 0.5$; Poor indicates $0 < H' \leq 1.0, 0 < J \leq 0.3$, and the numbers in parentheses represent the number of sample sites included*

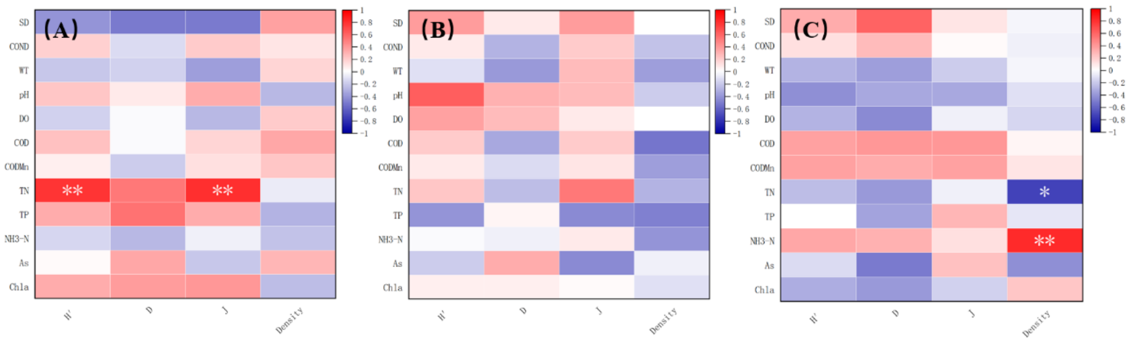

Figure 7. *Pearson correlation analysis between the community structure of zooplankton and water physicochemical factors in Ulansuhai Lake from 2021 to 2023. A is 2021, B is 2022, C is 2023. * Means significant difference between groups (ANOVA, N=12, df=2, * represents P < 0.05 for significant difference, ** represents P < 0.01 for extremely significant difference)*

The RDA analysis of the zooplankton community structure in Ulansuhai Lake from 2021-2023, along with its relationship with water physicochemical factors, is depicted in *Fig. 8*. In 2021, the explanatory rates of the first and second axes were 63.71% and 27.11% respectively, together accounting for 90.82% of the total variables. Density exhibited a positive correlation with DO and COD, while it was negatively correlated with COND and COD_{Mn}. Additionally, *D* showed a positive correlation with pH. Both *H'* and *J* were positively associated with TN and Chla but negatively with WT and SD. In 2022, the explanatory rates of the first and second axes were 60.28% and 26.50% respectively, jointly explaining 86.78% of the total variables. Density was negatively correlated with pH and DO, while both *H′* and D displayed negative correlations with NH_3-N, COND, and COD_{Mn}. However, *D* was positively correlated with Chla, and *H′* showed a positive correlation with pH and DO. For 2023, the explanatory rates of the first and second axes reached 67.00% and 27.33%, respectively, together elucidating 94.33% of the total variables. Density was positively correlated with NH_3-N and negatively correlated with DO, pH, and COD. On the other hand, *H′*, *J*, and *D* were all positively correlated with As, COND, and COD_{Mn}, while they were all negatively correlated with DO, pH, WT, and Chla.

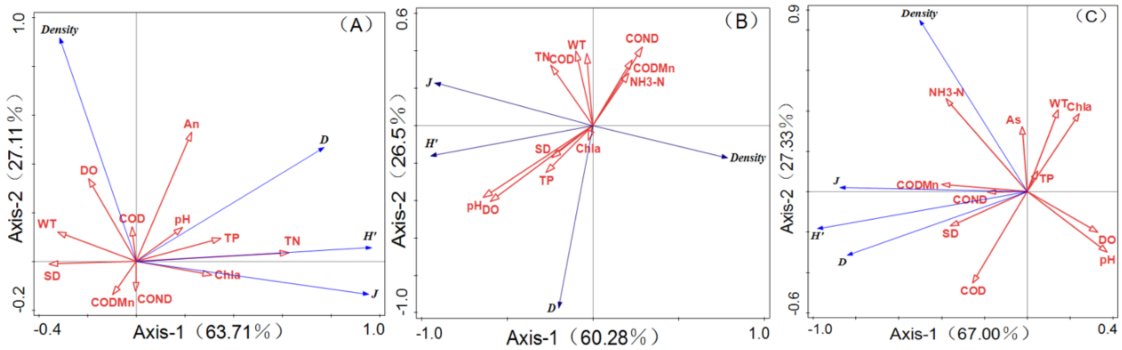

Figure 8. *RDA analysis of the community structure of zooplankton in the Ulansuhai Lake from 2021 to 2023 and the relationship with water physicochemical factors. A is 2021, B is 2022, C is 2023*

Discussion

From 2021 to 2023, rotifers dominated the species and density of plankton in Ulansuhai Lake. Their ability to reproduce asexually, their short growth cycle, and their environmental sensitivity (Rizo et al., 2020; Simões et al., 2022) allowed them to rapidly gain an ecological advantage. This is consistent with the findings of other domestic lake and reservoir studies (Jiang et al., 2014; Yang et al., 2020). The research determined that Ulansuhai Lake has transitioned from severe to mild eutrophication (Gou et al., 2025). Eutrophic water fosters phytoplankton growth and provides ample organic matter, conditions that are favorable for the proliferation of rotifers (Yang et al., 2017; Wentzky et al., 2018). Furthermore, the increasing trend of fish miniaturization in the lake (Hu et al., 2023), coupled with an imbalanced population structure, resulted in underutilization of the aquatic productivity. This top-down effect altered the structure and function of the aquatic ecosystem, prompting the miniaturization of the plankton community. Such changes reinforced the dominant position of rotifers, reducing predation pressure on them and solidifying their central role in the food web and water quality recovery—findings that align with this study's results. Notably, in 2023, there was a significant decline in the rotifer population (*Fig. 3*), triggering a cascade of effects: the main predators of phytoplankton were absent, causing the latter to proliferate extensively. This led to food shortages for small fish that depend on rotifers, resulting in an imbalanced food web and disrupted material energy circulation. Rotifers, which feed on phytoplankton and detritus, played a role in inhibiting eutrophication. However, their precipitous decline resulted in

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frequent algal blooms, diminished self-purification capabilities of the water, and obstacles to the lake's progression from mild eutrophication to a healthier state (Hu et al., 2023; Wang, 2024).

Typically, there is a positive correlation between density and biomass (Zhang et al., 2022). However, this study found diverging trends in the average density and biomass of plankton in Ulansuhai. Specifically, the average density of plankton followed the pattern 2022 > 2021 > 2023, while the average biomass was in the order of 2023 > 2021 > 2022. This divergence necessitates further exploration of the underlying ecological mechanisms. On one hand, in late May 2023, local yellow algae proliferated (Wang, 2024), forming a layer that impeded sunlight and oxygen exchange. This led to a decrease in dissolved oxygen and a subsequent deterioration in water quality, factors that indirectly suppressed plankton density. On the other hand, the change in biomass could be attributed to a shift in community structure. If the proportion of larger individual plankton increased in 2023, this would have resulted in a lower density but higher individual biomass, potentially leading to an overall increase in total biomass. This suggests an adaptive adjustment of the plankton community in response to environmental changes, closely linked to the ecological mechanisms governing interspecific interactions and resource allocation.

The notable fluctuations and significant annual variations in the zooplankton diversity index between 2021 and 2023 are intricately linked to the cumulative impact of human disturbances and diverse environmental factors. Pollution from point sources, surface sources, and internal contaminants within the watershed contribute significantly to this impact. Non-point source pollution, stemming largely from agricultural and livestock wastewater, is pervasive (Mao et al., 2014; Du et al., 2019). Notably, the pesticide atrazine, prevalent in these wastewaters, is toxic to zooplankton (Zhao et al., 2025; Qiu and Shi, 2025). In the fall season, the irrigation return water from the Hetao Irrigation District introduces nutrients such as NO_3-N and NH_3-N, exacerbating eutrophication. This leads to the homogenization of phytoplankton communities and increases the concentrations of TN and TP, creating favorable conditions for algal reproduction (Li et al., 2013; Du et al., 2019). Such changes constrain the food resources available to zooplankton and their ecological niches through top-down effects (Jürgens and Jeppesen, 2000), potentially serving as a key factor in maintaining moderate biodiversity levels. Concurrently, pH, TN, As, COD, NH_3-N, and COND are principal environmental factors that influence community dynamics. Notably, pH plays a pivotal role in zooplankton distribution: alkaline waters support the growth of rotifers and copepods, whereas acidic, neutral, or slightly alkaline waters favor cladocerans (Gao et al., 2013). The study recorded average pH values of 8.25, 8.71, and 8.88 for the water body between 2021 and 2023, indicating alkaline conditions conducive to the survival of rotifers and copepods. The rising pH levels may mitigate the toxicity of heavy metals (Ma, et al., 2023), thus reducing stress on cyanobacteria. However, excessive cyanobacterial reproduction can indirectly alter the zooplankton community structure (Zhao, 2024), a finding that aligns with previous research and underscores the validity of these results (Li et al., 2013; Yang et al., 2025).

The biodiversity outcomes of this study are intimately linked to the restoration efforts at Ulansuhai Lake. Following the initiation of projects such as the "integrated management of three waters and systematic governance" and ecological water replenishment, there has been a discernible improvement in water quality (Gou et al., 2025). This enhancement has fostered a habitat relatively conducive for planktonic animals, thereby supporting a medium level of biodiversity. Nevertheless, the establishment of a stable food chain remains elusive, and biodiversity has not achieved

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its optimal potential. This suggests that while current management strategies are effective, their efficacy is constrained by ecosystem intricacies and persistent anthropogenic pressures. Consequently, it becomes imperative to amalgamate research insights with adaptive management approaches, drawing from the extensive research conducted on lakes such as Taihu and Chaohu (Sun et al., 2024; Tao et al., 2025). Implementation of strategies like adjusting farmland wastewater treatment and monitoring yellow moss growth based on community dynamics and environmental parameters is recommended. Furthermore, management practices should be refined by incorporating insights from the "ecological buffer zone" developments in Taihu Lake (Tao et al., 2025). Given the intricate nature of aquatic ecosystems, ongoing comprehensive assessments centered on water quality and aquatic organism composition are essential, along with continued exploration of innovative technical solutions for the ecological preservation and enhancement of Ulansuhai Lake.

Conclusion

During the period of 2021-2023, surveys were conducted on zooplankton species in Ulansuhai Lake, with findings of 48, 55, and 34 species respectively. Each year, rotifers were the most prevalent, while protozoans were the least common. Six species emerged as dominant, with *Cyclops strenuus* exhibiting the highest level of dominance. Notable differences were observed in the density and biodiversity indices (H', J, D) of zooplankton across the years, although the biomass remained consistent. The evaluation grading standards analysis revealed that the biodiversity of zooplankton ranged from moderate to good in 2021 and 2022, and poor to moderate in 2023. The Pearson correlation analysis and RDA results indicated pH, TN, As, COD, NH_3-N, and COND as the primary environmental factors influencing the community structure of zooplankton in Ulansuhai Lake during 2021 to 2023.

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