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Assessment of the Zooplankton Community and Water Quality in an Artificial Freshwater Lake from a Semi-Arid Area (Irbid, Jordan)

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Abstract: Zooplankton play a crucial role in aquatic food chains and contain many species, which could be bioindicators of water quality and ecosystem health. The ecological impacts of eutrophication on zooplankton composition in freshwater lakes have recently gained wide interest. Geographic location and water-body size influence zooplankton diversity in freshwaters; meanwhile, less is known about the composition and dynamic of the zooplankton community and their relationship with the trophic status in artificial water in semi-arid areas. The present study aimed to assess the physical–chemical parameters and to document the seasonal distribution of zooplankton species and their relationship with environmental factors and trophic state in the artificial freshwater lake JUST, in a semi-arid area. The high concentrations of nutrients and the trophic level index (TLI) classified the lake as eutrophic–hypertrophic. The zooplankton in the JUST lake were composed of twenty-six species, with eleven Rotifera, ten Copepoda, and five Cladocera. Copepoda was numerically the most abundant taxon, accounting for 64% of the total zooplankton abundance, in both seasons. However, the second most abundant taxon in summer was Rotifera (28.26%) while in winter it was Cladocera (25.88%). The community structure seemed to be influenced, most likely, by trophic state, phytoplankton abundance, water temperature, dissolved oxygen, and nutrient loading. The zooplankton were largely dominated by bioindicator species of high trophic levels. Zooplankton could be used as a tool to monitor the trophic state of the lake. For sustainable development, the introduction of phytoplanktivorous, aquaculture species, such as carp and koi, will strengthen the top-down control of the phytoplankton concentration, leading to a reduced trophic state.

Keywords: zooplankton; physical–chemical parameters; artificial lake; trophic state monitoring

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Citation: Guermazi, W.; El-khateeb, M.; Abu-Dalo, M.; Sallemi, I.; Al-Rahahleh, B.; Rekik, A.; Belmonte, G.; Ayadi, H.; Annabi-Trabelsi, N. Assessment of the Zooplankton Community and Water Quality in an Artificial Freshwater Lake from a Semi-Arid Area (Irbid, Jordan). *Water* **2023**, *15*, 2796. https://doi.org/10.3390/w15152796

Academic Editor: Achim A. Beylich

Received: 6 July 2023
Revised: 28 July 2023
Accepted: 30 July 2023
Published: 2 August 2023

1. Introduction

Zooplankton include diverse microscopic taxa, such as Rotifera, Copepoda, and Cladocera [1]. These organisms are useful as bioindicators; thus, they are helpful for driving recovery or amelioration actions in polluted water [2]. Hence, quantitative and qualitative studies of zooplankton are of great importance [3,4]. Zooplankton represent an important component of fish food in aquatic ecosystems; as such, the investigation of their production and abundance is essential for the successful management of fisheries.

The diversity of zooplankton, apart from contributing towards the relative stability of the ecosystem, acts as an indicator of water quality [5].

Because eutrophication is one of the main effects of anthropogenic activities on lakes, a clear understanding of how zooplankton changes along with the eutrophication grade is important for environmental management. Eutrophication is the most important source of contamination in freshwater ecosystems [6]. It derives from increased concentrations of nitrogen and phosphorus in aquatic environments [7]. Eutrophication in lakes is of special interest and is marked by the severe pollution of the water with nutrients that accumulate over time due to the complicated nature of the ecosystems, which, in essence, favour limited self-removal mechanisms. The effect of these factors is assessed by the trophic state, which is an essential attribute of aquatic ecosystems [8].

Zooplankton are very sensitive to environmental changes and, hence, are considered good indicators of ecosystems [9]. Many previous studies have focused on zooplankton structure in relation to environmental factors [10–14] and the basin age [15]. A change in the physical–chemical and biotic parameters in aquatic systems resulted in a change in the relative composition and abundance of organisms thriving in the water. Therefore, they can be used as a tool in monitoring aquatic ecosystems. Freshwater zooplankton are mainly composed of Rotifera and small Crustacea (Cladocera and Copepoda). An increase in the lake trophic status shifts the dominance from Copepoda Cyclopoida and Rotifera to Copepoda Calanoida and Cladocera [16–18]. Specific cladocerans are associated with the different trophic states of the water body; *Bosmina* is associated with eutrophic ecosystems while Daphnia is associated with oligotrophic ecosystems [19,20].

The studies of the relationship between zooplankton and trophic status are scarce and not well understood under semi-arid climates. The present work was carried out to assess the species diversity and population density of the zooplankton of the JUST lake; this was coupled with physical–chemical parameters, phytoplankton abundance, and chlorophyll *a* in order to evaluate its trophic state for suitability for fish culture in a water shortage area.

2. Materials and Methods

2.1. Study Site and Sampling

The JUST lake is located within the campus of the Jordan University of Science and Technology at latitude 32°28′36.77″ N and longitude 35°58′24.05″ E, east of Irbid (Figure 1). The site is an artificial basin realized in 1983 and is characterized by its hot summer and cold winter. The average annual rainfall of the site is 465 mm. The morphometric and other basic characteristics of the JUST lake are described elsewhere [21]. Samples were collected in winter (February 2019) and summer (July 2019) from ten stations equidistant of an average of 50 m (Figure 1). The distance of stations from the water's edge was about 20 m. The depth of stations varied between 0.80 $\pm$ 0.28 m (S1) and 3.75 $\pm$ 3.89 m (S4) (Table 1). In the summer, the water body is characterized by the growth of submerged macrophyte plants.

2.2. Physical–Chemical and Chlorophyll a (Chl a) Analysis

Water samples for the physical–chemical analyses were collected on the surface (at 30–50 cm depth) using a Van Dorn bottle (1 L) at all stations. Water temperature and salinity were measured using an UltraPen PT1 126 (Myron L, Carlsbad, CA, USA). Dissolved oxygen (DO) and pH were measured using a DO portable meter (HACH HQd, Loveland, CO, USA) and a pH meter (Thermo Scientific Orion Star A111, Banten, Indonesia), respectively. Nutrients (nitrites, nitrates, ammonium, orthophosphates, total nitrogen (TN), and total phosphorus (TP)) were analyzed using a spectrophotometer (Lov-ibond SpectroDirect, Berlin, Germany) at 330–900 nm.

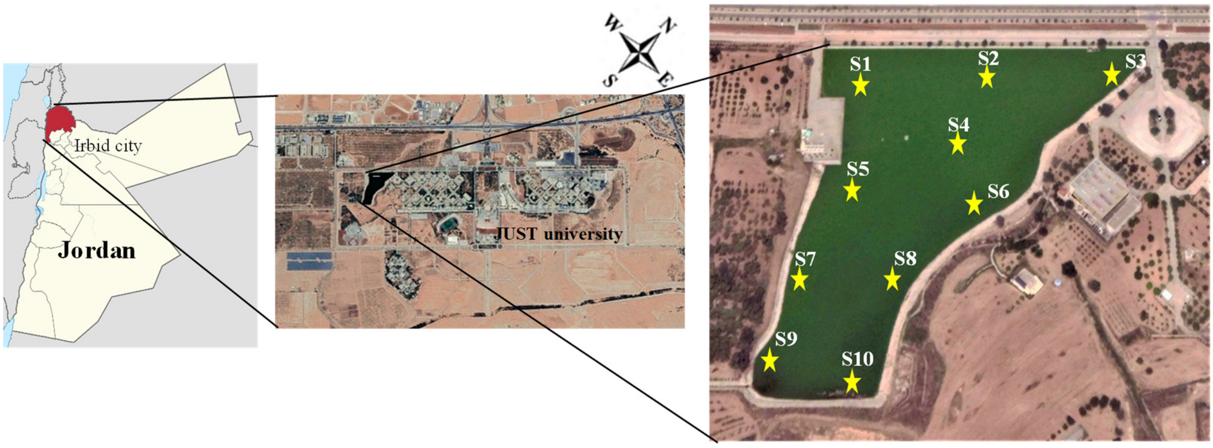

Figure 1. Location of the study area (Jordan University of Science and Technology: JUST) and of the ten sampling stations in the lake.

Table 1. Coordinates of sampled stations and their corresponding mean depths.

Stations	Longitude	Latitude	Depth (m)
S1	35°58′59.34″ E	32°29′22.00″ N	0.80 ± 0.28
S2	35°59′0.59″ E	32°29′23.38″ N	2.75 ± 1.06
S3	35°59′2.02″ E	32°29′25.11″ N	1.75 ± 0.35
S4	35°59′1.56″ E	32°29′22.14″ N	3.75 ± 3.89
S5	35°59′1.61″ E	32°29′20.18″ N	1.50 ± 0.71
S6	35°59′3.73″ E	32°29′21.78″ N	1.50 ± 0.71
S7	35°59′2.93″ E	32°29′18.34″ N	2.00 ± 1.41
S8	35°59′3.82″ E	32°29′19.33″ N	2.75 ± 1.77
S9	35°59′4.62″ E	32°29′16.83″ N	1.50 ± 0.71
S10	35°59′5.43″ E	32°29′17.51″ N	2.00 ± 1.41

Sub-samples (0.5 L) for the quantification of chlorophyll *a* concentration (Chl *a*) were filtered by vacuum filtration onto a 0.45 µm pore size and 25 mm-diameter glass Whatman GF/F. Chl *a* was estimated via spectrophotometry, after pigment extraction in acetone (90%) [22], and expressed as µg L^{-1}.

2.3. Trophic State

In order to assess the trophic state of the water of the JUST lake, the Trophic Level Index (TLI) was calculated [23] using the following equations:

$$\text{TL (Chl } a\text{)} = 2.22 + 2.54 \text{ Log (Chl } a\text{)}$$

$$\text{TL(TP)} = 0.218 + 2.92 \text{ Log (TP)}$$

$$\text{TL(SD)} = 5.10 + 2.27 \ \log\left(\frac{1}{\text{SD}} - \frac{1}{40}\right)$$

$$\text{TL(TN)} = -3.61 + 3.01 \log \text{(TN)}$$

$$\text{TLI} = \frac{\text{TL(Chl}a) + \text{TL(TP)} + \text{TL(SD)} + \text{TL(TN)}}{4}$$

Based on the values of the TLI, Burns et al. [24] classified lakes as:
Oligotrophic (low productive): TLI < 3;
Mesotrophic (moderately productive): 3 < TLI < 5;
Eutrophic (highly productive): 5 < TLI < 6;
Hypertrophic (very highly productive): 6 < TLI < 8.

2.4. Zooplankton Analysis

Samples for zooplankton determination were collected using a Juday plankton net with a mesh size of 55 µm at the ten stations during summer and winter. The net was towed vertically from a depth near to the bottom up to the surface at each station. After collection, zooplankton samples were rapidly preserved in a 4% buffered formalin solution. They were stained with rose bengal to identify the internal tissues of the different zooplankton species and, also, to facilitate the dissection of the Copepoda. Samples were stored in the dark and analyzed within two weeks after sampling. The zooplankton components were identified and counted in a Dolffus chamber under a vertically mounted deep-focus dissecting microscope (Olympus TL 2). The taxonomic identification was carried out according to the literature [25–28]. Zooplankton abundances were expressed as individuals per cubic meter (ind. m^{-3}). The abundance and the species richness of the zooplankton at each station were assessed in triplicate.

The community structure of the zooplankton was assessed by using the Shannon-Weaver Index (H) for species diversity [29]. The evenness (J) was calculated as proposed by Pielou [30] to prevent the weighting of the H index by rare species.

Phytoplankton samples were taken using a 1-litre Van Dorn bottle. Phytoplankton enumeration was performed with an inverted microscope using the Utermöhl method after fixation with a Lugol's solution [31]. Cell numbers were expressed as cells L^{-1}.

2.5. Statistical Analysis

For each season, the physical–chemical and biological parameter distributions were presented using the box plots graphical method. Moreover, the Student's *t*-test was applied to understand the significant effect of seasons on biotic and abiotic parameters ($p < 0.05$). The mean and standard deviation of the mean (SD) were reported when appropriate. Spearman's correlation analysis was performed to evaluate potential relationships between the abundance of total zooplankton and their different groups and abiotic and biotic variables. This test was chosen because of the non-normal distribution of the data.

Data recorded in this study were examined using a normalized principal component analysis (PCA). Physical–chemical variables, such as temperature, salinity, dissolved oxygen, pH, nutrients concentrations, 12 biological parameters (total zooplankton, total Copepoda, total Calanoida, total Cyclopoida, total Rotifera, other zooplankton, Copepoda nauplii, Copepoda species, Rotifera species, Cladocera species, Chl *a*, total phytoplankton), trophic state (TLI), and diversity indices (H′, E), were assessed by examining the projection of the plots of the extracted factors on a factorial plan consisting of the statistically significant axis of the PCA. A simple log (x + 1) transformation was applied to the data in order to correctly stabilize the variance [32]. All analyses were performed using XlStat software version 19.0.

3. Results

3.1. Physical–Chemical Parameters and Trophic State

The mean values of the physical and chemical parameters measured at the lake are shown in Figure 2. The physical parameters varied significantly between winter and summer (Student's *t*-test, $p < 0.01$). The water temperature varied from 11.7 °C (winter, S2) to 32.3 °C (summer, S10). Salinity was significantly higher in summer (0.95 ± 0.11 g L^{-1}) than in winter (0.63 ± 0.03 g L^{-1}). Salinity ranged from 0.53 g L^{-1} at S3 in winter to 1.07 g L^{-1} at S10 in summer (Figure 2). The average pH varied with the seasons. The highest values were recorded in summer (average ± SD = 10.29 ± 0.32); however, in winter, the pH did not exceed 7.87. Dissolved oxygen (DO) concentrations were found to be within the range of 5.97–7.38 mg L^{-1} during winter. The concentration increased significantly ($|t| = 5.48$, d.f = 9, $p < 0.001$) in summer, reaching 11.54 ± 2.87 mg L^{-1}.

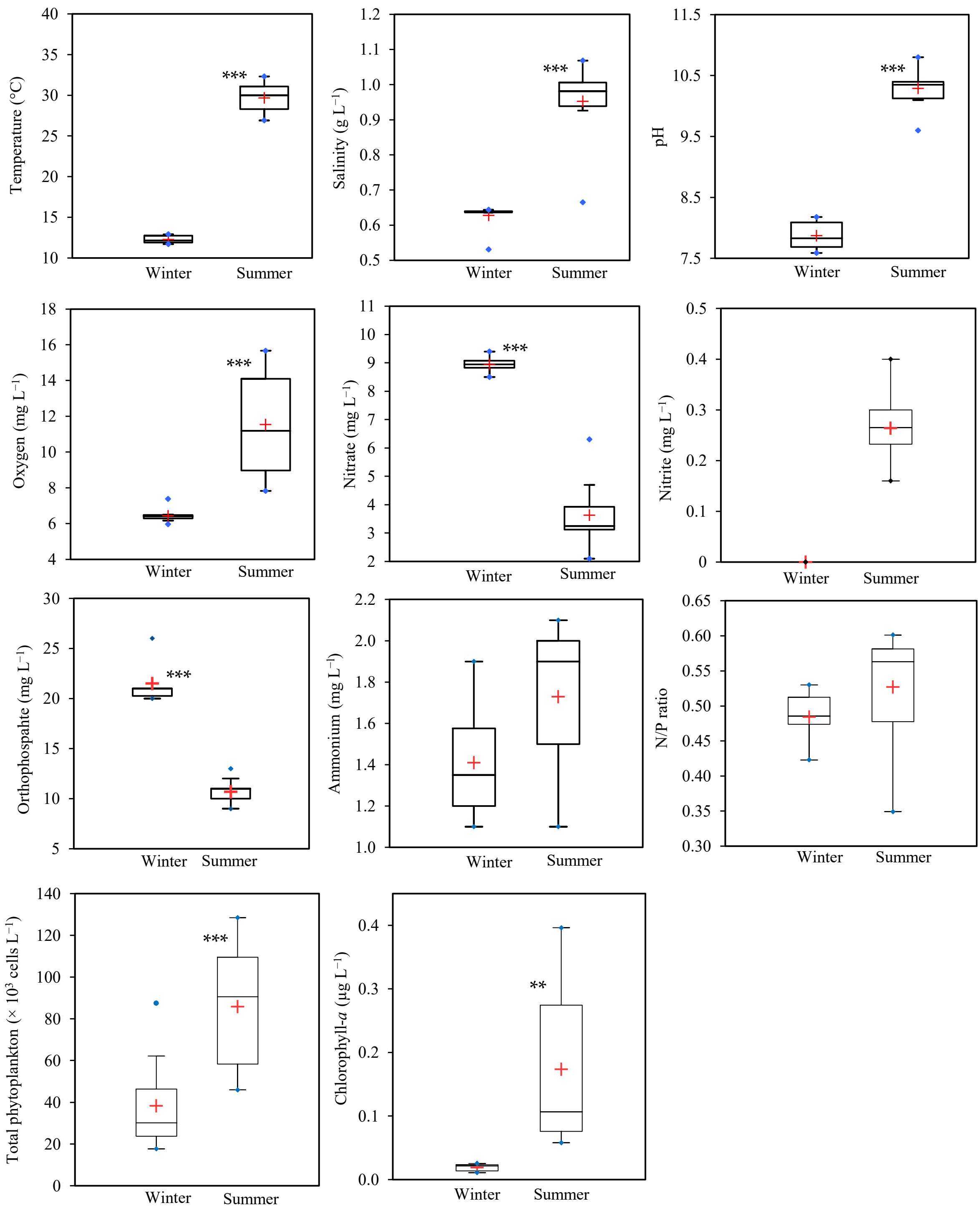

Figure 2. Box-and-whisker plot of physical–chemical parameters recorded in the JUST artificial lake during winter and summer. Red asterisks are the means of the values. Horizontal lines within the boxes are the medians of the parameters. Blue dots explain the minimum and maximum values of each variable. Difference between variables assessed by the Student's *t*-test at the 0.05% level. ** $p < 0.01$; *** $p < 0.01$.

Nutrients showed significant differences among the seasons, except for ammonium and total phosphorus (Figure 2). Nitrates, which accounted for up to 75% of the total dissolved inorganic nitrogen (DIN = ammonium + nitrates + nitrites), constituted the most important fraction of the total nitrogen. Nitrates exhibited the highest values in winter, ranging from 8.50 to 9.40 mg L^{-1} and averaging at 8.94 ± 0.25 mg L^{-1}; whereas, their concentration in summer were significantly different ($|t|$ = 11.22; d.f = 9; $p < 0.0001$) and did not exceed 3.63 ± 1.17 mg L^{-1}. Nitrites that were detected only in summer exhibited low values and varied from 0.16 mg L^{-1} (S8) to 0.40 mg L^{-1} (S10), with an average of 0.26 ± 0.07 mg L^{-1}. Ammonium concentrations varied slightly between 1.1 mg L^{-1} in winter and 2.1 mg L^{-1} in summer. Orthophosphate concentrations varied from 9 mg L^{-1} (S5, summer) to 26.40 mg L^{-1} (S4, winter). The N/P (DIN/orthophosphates) ratio, as an indicator of nutrient limitation, was strongly low (0.48 ± 0.03 (winter) and 0.52 ± 0.1 (summer)), being below the value optimal for phytoplankton growth (the Redfield ratio = 16) and suggesting a potential N limitation. The amounts of most nutrients varied slightly between the stations (Figure 2).

Figure 3 shows the pattern of the trophic level of the water at each station in the JUST lake during summer and winter. The TLI varied between 5.16 ± 0.20 in winter and 6.11 ± 0.39 in summer, with a high significant difference ($|t|$ = 7.41, d.f = 9, $p < 0.0001$). The temporal and spatial ranges of the TLI categorize the JUST artificial lake as being in a eutrophic–hypertrophic condition (Figure 3).

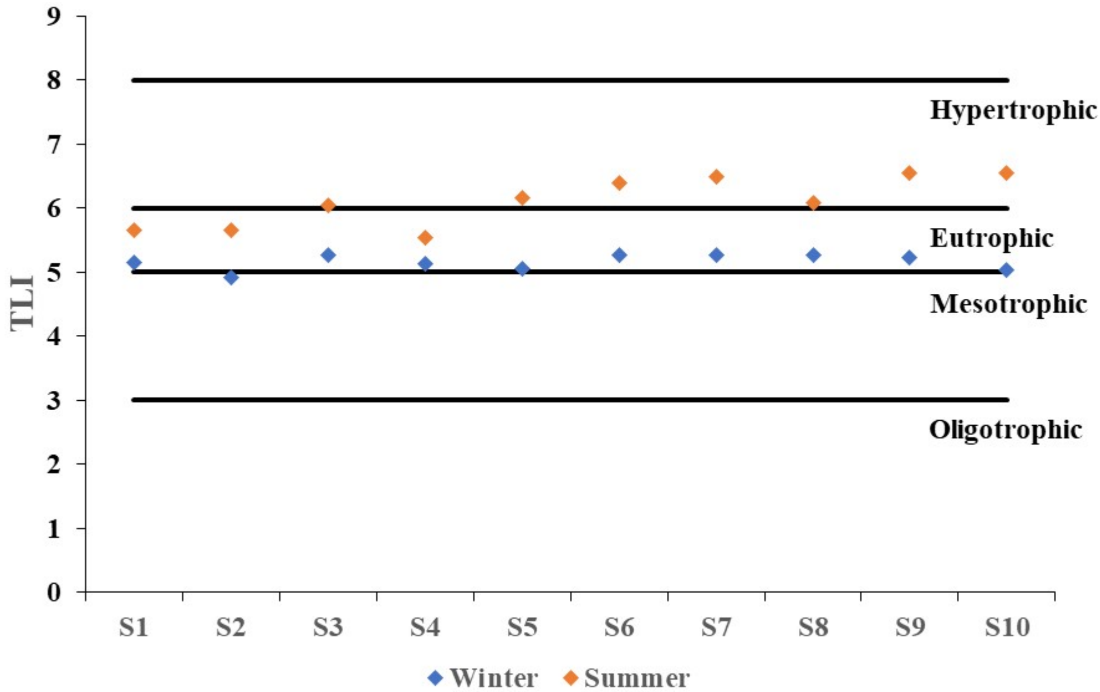

Figure 3. Seasonal trend of trophic level index (TLI). Eutrophy is recognized for TLI values between 5 and 6 and hypertrophy is recognized for TLI values above 6.

3.2. *Phytoplankton and Chl a*

As shown in Figure 2, the total phytoplankton abundance varied from 17,300 to 87,500 cells L^{-1} (Mean ± SD = 38.30 ± 22.17 × 10^3 cells L^{-1}) in winter; meanwhile it fluctuated between 46,000 and 128,500 cells L^{-1} (Mean ± SD = 85.85 ± 30.38 × 10^3 cells L^{-1}) in summer. The Chl *a* concentration was higher in summer (0.17 ± 0.13 µg L^{-1}) than in winter (0.02 ± 0.01 µg L^{-1}). The Student's *t*-test showed that both total phytoplankton abundance and Chl *a* varied significantly between the seasons (Phytoplankton: $|t|$ = 5.179; d.f = 9; p = 0.001; Chl *a*: $|t|$ = 3.924; d.f = 9; p = 0.003).

3.3. Spatial and Temporal Distribution of Zooplankton

A total of thirty-two taxa of zooplankton (eleven species of Rotifera, ten of Copepoda, five of Cladocera, plus six heterogenous categories) were recorded during the survey period (Table 2). The Copepoda were numerically the most abundant, accounting for 64% of the total zooplankton abundance, in both seasons. This was followed by Rotifera in summer and Cladocera in winter, represented by 28.3% and 25.9%, respectively (Figure 4). The total zooplankton abundance ranged from 1.770 to 116.350 ind. m^{-3} (Average ± S.D = 21.74 ± 34.42 × 10^3 ind. m^{-3}) during winter. In summer, the average abundance of zooplankton increased, but not significantly ($|t|$ = 1.43; d.f = 9; $p > 0.05$), reaching 203.96 ± 373.84 × 10^3 ind. m^{-3}.

Table 2. Taxonomic composition and quantitative aspects of the zooplankton community found in the JUST artificial lake. (-) not detected; (R) rare 0–100 ind. m^{-3}; (C) common 100–1000 ind. m^{-3}; (A) abundant 1000–10,000 ind. m^{-3}; (V) very abundant > 10,000 ind. m^{-3}.

Zooplankton Taxa		Winter										Summer									
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Copepoda																					
Calanoida																					
Arktodiaptomus wierzejskii	Aw	C	C	C	A	C	A	A	A	A	A	C	A	-	V	A	A	V	-	-	-
Neolovenula alluaudi	N a	C	A	C	V	A	A	A	A	A	V	C	A	-	V	A	A	A	-	-	-
Metadiaptomus chevreuxi	M c	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eudiaptomus gracilis	E g	C	C	-	A	C	C	C	C	C	C	-	R	-	C	-	-	-	-	-	-
Cyclopoida																					
Mesocyclops leuckarti	M l	-	-	A	-	R	-	-	-	-	-	R	C	-	-	-	-	R	R	-	-
Eucyclops macrurus	Em	-	-	R	-	-	-	-	-	-	-	C	C	R	-	-	-	-	A	-	-
Diacyclops bicuspidatus	D b	R	-	-	-	-	-	C	C	R	R	V	V	A	V	V	V	V	V	A	V
Cyclops scutifer	C s	-	-	-	R	-	-	-	-	-	R	V	V	A	V	-	-	V	A	-	A
Cyclops gigas	C g	R	R	C	C	-	-	R	-	R	R	-	-	-	-	-	-	-	R	-	-
Ancanthocyclops vernalis	A v	R	-	R	-	-	-	-	-	-	-	-	R	-	-	R	-	R	-	-	-
Cladocera																					
Daphnia longispina	D l	C	A	C	V	C	A	A	A	A	A	-	A	-	-	-	-	A	C	-	-
Daphnia pulex	D p	-	C	C	V	-	C	-	-	C	A	-	-	-	-	-	-	-	-	-	-
Ceriodaphnia dubia	C d	-	C	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diaphanosoma sp.	Dbr	-	C	C	A	R	R	-	-	-	A	-	A	-	A	-	-	-	-	-	-
Eurycercus lamellatus	E l	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-
Rotifera																					
Brachionus calyciflorus willeyi	B c	R	-	-	-	-	-	-	-	-	-	A	V	C	V	A	A	V	V	A	V
Brachionus calyciflorus spinosus	B c s	-	-	-	-	-	-	-	-	-	-	-	A	-	V	-	-	-	A	C	-
Brachionus rubens	B r	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	C	A
Brachionus bidentata	B b	-	-	-	-	-	-	-	-	-	-	-	A	A	-	-	-	-	A	R	V
Ascomorpha saltans	A s	C	C	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Asplanchna brightwellii	A b	-	-	-	R	-	-	R	-	-	-	C	-	-	-	-	-	-	-	C	-
Filinia longiseta	F l	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	R	-	-	-
Euchlanis dilatata	E d	-	-	-	-	-	-	-	-	-	-	C	A	-	A	A	C	-	C	-	A
Platyas quadricornis	P q	-	-	-	-	-	-	-	-	-	-	-	-	-	V	-	-	V	V	C	A
Lecane luna	L l	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	C	-	A
Keratella quadrata	K q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Other Zooplankton																					
Eggs	Egg	-	C	C	C	R	-	R	C	R	R	-	-	-	-	-	-	C	-	-	-
Chironomidae larvae	I la	-	R	C	-	-	-	R	R	-	R	R	R	R	-	-	-	C	-	R	R
Ostracoda	Ost	-	C	-	C	-	-	-	-	-	-	R	C	R	-	-	-	C	R	C	C
Gastropod veliger	Gvi	R	-	R	-	R	R	R	R	-	R	-	-	-	-	-	-	-	-	-	-
Bivalvia veliger	Biv	-	C	-	A	-	-	C	C	R	R	-	-	-	-	-	-	-	-	-	-

Zooplankton abundance was positively correlated with water temperature (ρ = 0.61, d.f = 19, $p = 0.005$), salinity (ρ = 0.55, d.f = 19, $p < 0.05$), pH (ρ = 0.45, d.f = 19, $p < 0.05$,), and dissolved oxygen (ρ = 0.47, d.f = 19, $p < 0.05$). Zooplankton abundance was also positively correlated with nitrites (ρ = 0.67, d.f = 19, $p = 0.001$) and negatively correlated with nitrates (ρ = −0.51, d.f = 19, $p = 0.023$).

During winter, Calanoida (62.8% of total zooplankton) were represented by *Arktodiaptomus wierzejskii*, *Neolovenula alluaudi*, and *Eudiaptomus gracilis* (Table 2). Their contributions were 43.7% (S8), 60.0% (S10), and 8.5% (S1), respectively, of the total zooplankton (Figure 5). Species of the *Daphnia* genus were the most abundant Cladocera (Table 2). Indeed, the contributions of *D. longispina* and *D. pulex* varied from 5.7 (S3) to 37.2% (S5) and from 0 (S1) to 11.3% (S10) of the total zooplankton, respectively (Figure 5A). At S3, the community was largely dominated by *Mesocyclops leuckarti*, accounting for 22.7% of the total zooplankton (Figure 5A). Rotifera were well represented, in terms of abundance, by only three species in a few sampled stations (Table 2). *Aschomorpha saltans* was the most abundant, accounting for 10% of the total zooplankton at stations S1 and S2 (Figure 5A). *Brachionus calyciflorus*, *Asplanchna brightwellii*, and *Filinia longiseta* were sporadically encountered with a low abundance, not exceeding 100 ind. m^{-3} (Table 2, Figure 5A).

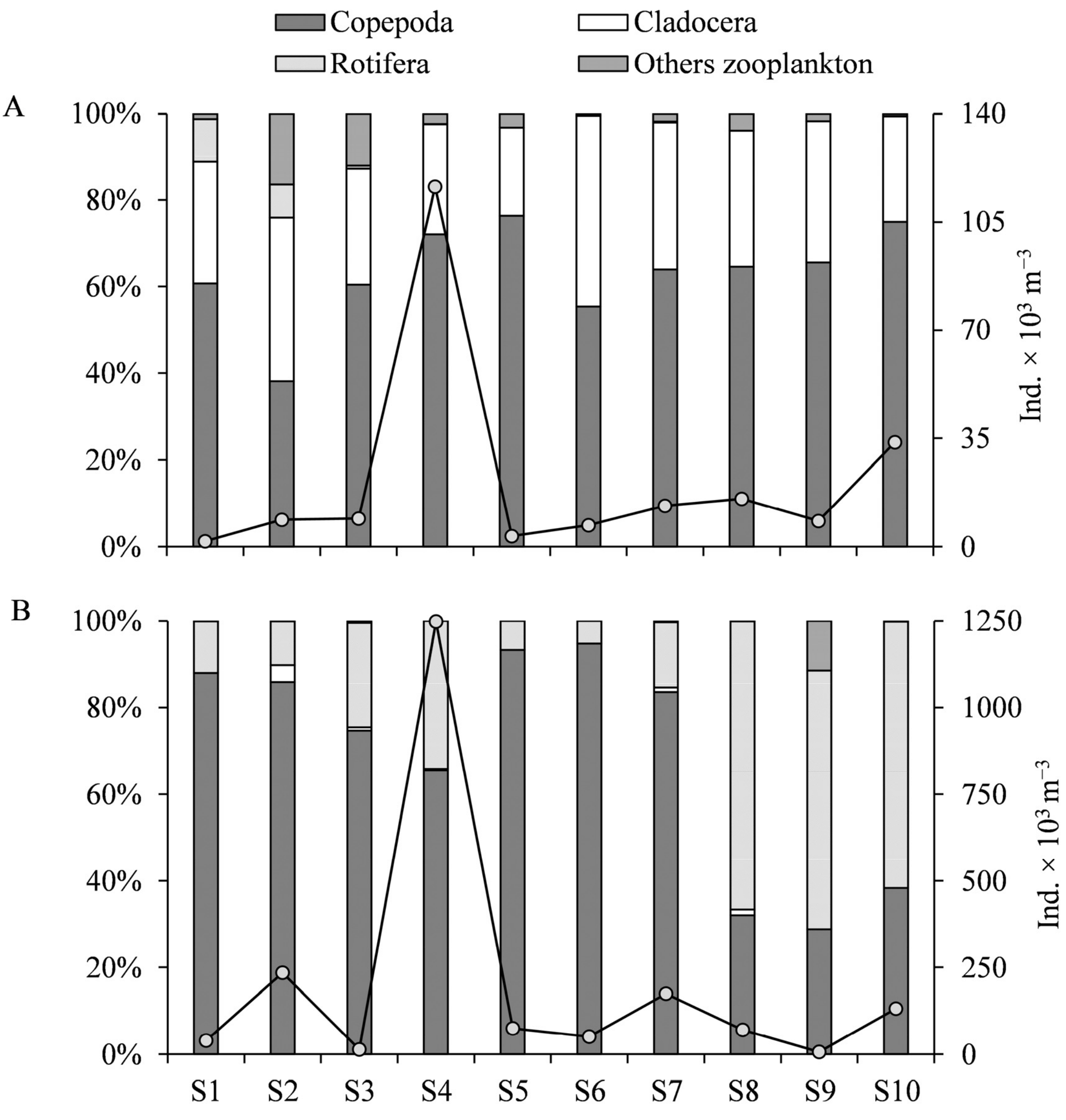

Figure 4. Spatio-temporal variations of the total zooplankton abundance and the percentage of different groups recorded in winter (**A**) and summer (**B**) in the JUST artificial lake.

During summer, the community was dominated by Copepoda Cyclopoida, with 90.44×10^3 ind. m^{-3} corresponding to 44.4% of total zooplankton abundance (Table 2). *Diacyclops bicuspidatus* and *Cyclops scutifer* were the most abundant species in all sampling stations, with an abundance exceeding 10^4 ind. m^{-3} (Table 2). *C. scutifer* dominated at S1 and contributed 41.1% of the total zooplankton abundance (Figure 5B). *D. bicuspidatus* was the dominant species at S2 (62.9% of the total zooplankton), S3 (57.7%), S4 (69.7%), S5 (85.1%), and S7 (50.4%) (Figure 5B).

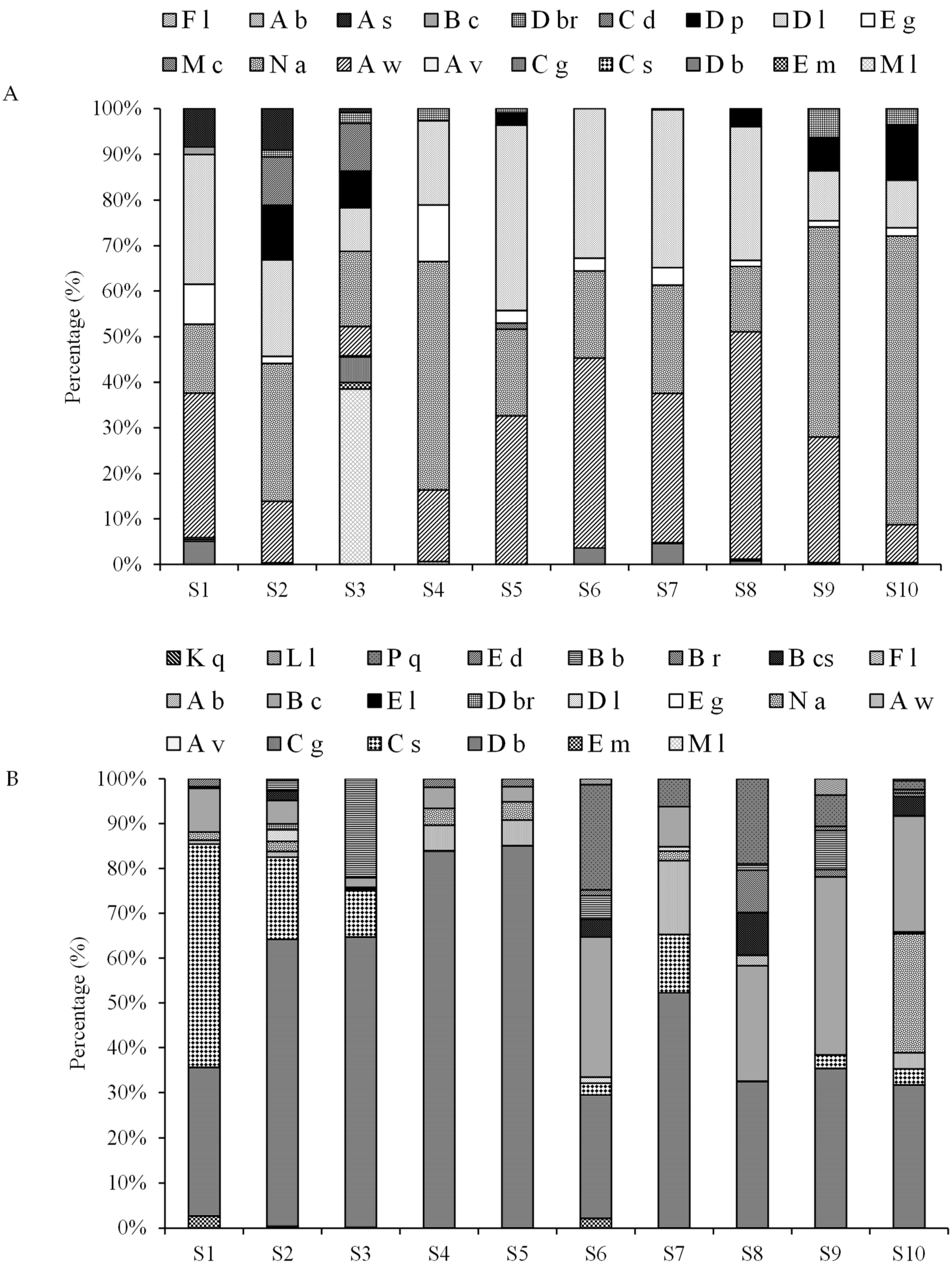

Figure 5. Spatio-temporal variations of the percentages of zooplankton species recorded in winter (**A**) and summer (**B**) in the JUST artificial lake. Species abbreviations are shown in Table 2.

Rotifera were represented by 10 species, recorded in almost all stations (Table 2). *B. calyciflorus willeyi* and *Platyas quadricornis* were the most abundant species, contributing 19.7% of the total zooplankton abundance (from 1.8 (S3) to 39.7% (S9)) and 2.9% (0% (S1) to 22.3% (S6)) of the total zooplankton abundance (Figure 5B). The contributions of the other Rotifera species were low and ranged between 0 and 2.8% (Figure 5B).

The zooplankton not identified at the species level, such as eggs, Chironomidae larvae, and Ostracoda, were more diversified in winter and contributed to 2.7% of total zooplankton abundance (Table 2). The maximum contributions of this fraction were 14.9% (S2) and 8.4% (S8) in the winter and summer, respectively (Figure 4).

The values of diversity indices of zooplankton were higher in winter than in summer (Figure 6). The values of the Shannon–Weaver index (H′) recorded in summer ranged between 0.89 (S6) and 2.44 (S7) (average ± S.D = 1.82 ± 0.57); meanwhile, it increased in winter, with values ranging from 1.74 (S4) to 2.69 (S3) and the average being 2.10 ± 0.35 (Figure 6). The average value of the Pielou evenness index (J) was higher in winter (0.71) than that in summer (0.58) (Figure 6). The Student's *t*-test revealed that the seasons did not significantly affect diversity indices ($p > 0.05$).

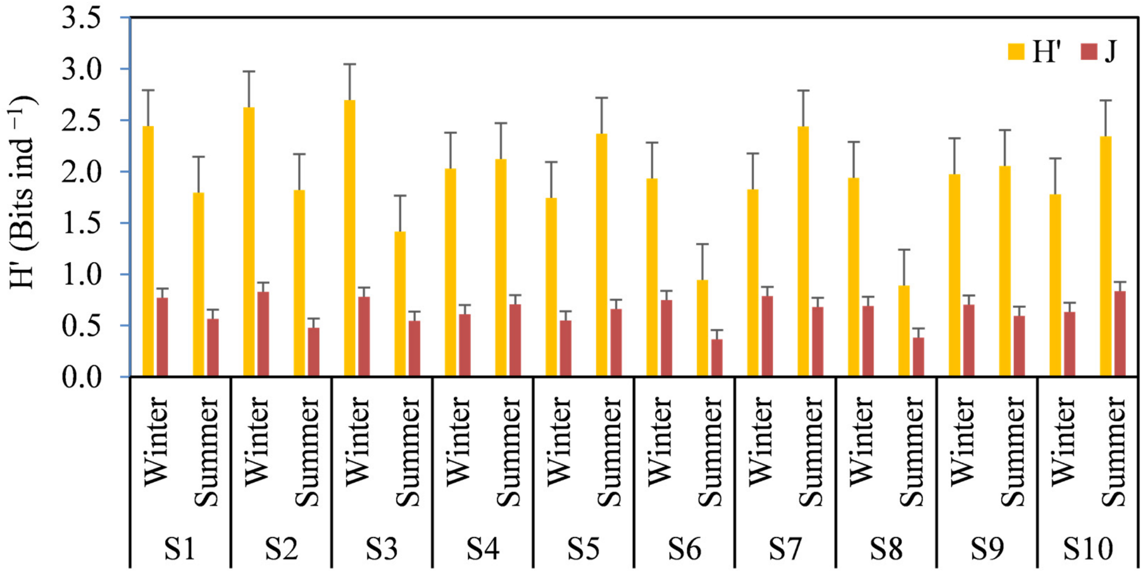

Figure 6. Diversity indices (Shannon-weaver: H′ and Pielou evenness: J) of zooplankton communities recorded in winter and summer in JUST artificial lake.

3.4. Multivariate Analysis

The first two axes of PCA I and II explain 45.53% of the total variance (Figure 7). Axis I positively selected Cyclopoida, Rotifera Copepoda, total zooplankton, single species of Rotifera and Cyclopoida, temperature, salinity, pH, DO, ammonium, Chl *a*, TLI, and total phytoplankton (G1). However, Axis I negatively selected the diversity indices, other zooplankton, Cladocera *D. pulex*, *D. longispina* and *Ceriodaphnia dubia*, Cyclopoida *Cyclops gigas*, Calanoida *Mixodiaptomus chevreuxi*, *Eudiaptomus gracilis*, and Rotifera *Aschomorpha saltans*, and were coupled with orthophosphates and nitrates (G2). Axis II, explaining 15.85% of the total variance, positively grouped (G3) Copepoda nauplii, Calanoida *A. wierzejskii*, *N. alluaudi*, Cyclopoida *M. leuckarti*, *A. vernalis*, Rotifera *Filinia longiseta*, and *Keratella quadrata* and opposed total phosphorus (Figure 7). The plot of field observations showed a clear segregation between the observations made in summer and in winter at the JUST Lake. The winter observations were grouped in the negative part of Axis I, together with the highest values of diversity indices (H′ and E), Cladocera and Calanoida species, "other zooplankton", nitrates, and orthophosphates; this was in contrast to the observations made in summer, which tended to group in the positive part of Axis I, together with Cyclopoida, Rotifera, temperature, salinity, pH, DO, TN, total phytoplankton, and Chl *a* (Figure 7).

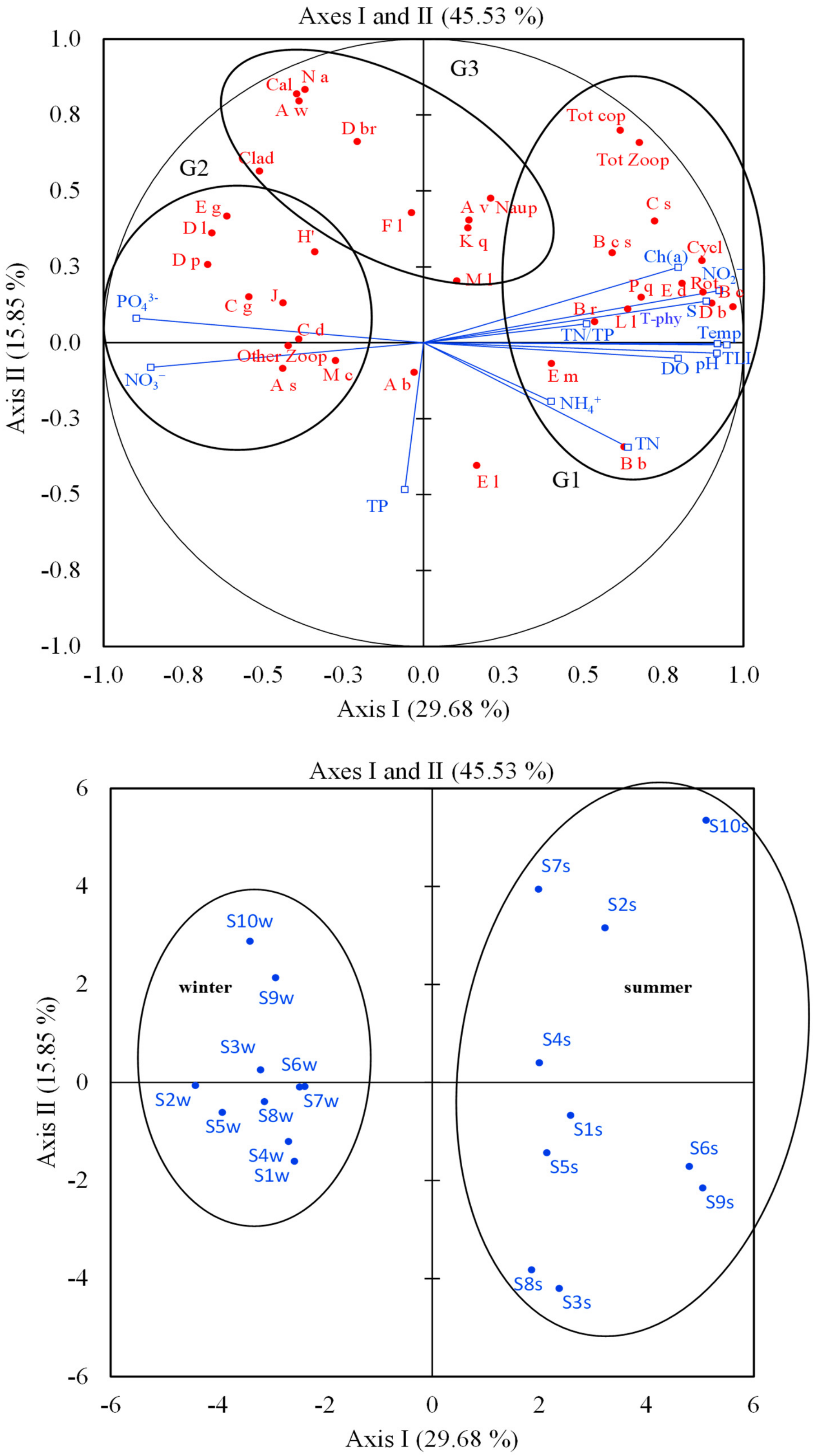

Figure 7. Principal component analysis (PCA) (axes I and II) on the mean values of biological variables (red colour). Explicative variables are in blue, which are represented by physical–chemical parameters and the TLI. Temperature (Temp), Salinity (S), Total phytoplankton (T-phy). Species abbreviations are shown in Table 2. Below, the biplot of observations represented by the sampled stations in winter (w) and summer (s) are presented.

4. Discussion

The quality of natural water is generally indicated via various physical–chemical and biological parameters. In the JUST lake, the temperature showed a marked seasonal variation in accordance with the values of arid to semi-arid zones [33]. According to EPA [34], water temperatures ranging from 15.1 to 32.6 °C in lake water are considered suitable for aquaculture purposes. During the hot season (summer), a higher pH level was recorded. This could be correlated, at least partially, to the increase in CO_2 subtraction from the environment because of the rise in photosynthetic activity, which leads to high pH values [35]. In fact, phytoplankton abundances (Mean ± SD = 85.85 ± 30.38 × 10^3 cells L^{-1}) during summer were higher than they were in winter. The lower pH values during the winter recorded in this study remain within the range of normality for freshwater lakes throughout the world [36,37].

The higher values of oxygen concentrations during summer represent a situation already reported elsewhere (e.g., lake Manzalah [36]). In the present study, a significant correlation (positive) was found between temperature and dissolved oxygen in summer (ρ = 0.74; d.f = 9; $p < 0.05$). Taking into account that our measures are relative to the surface layer, the higher oxygen concentration during the summer compared to that in winter could probably be due to the higher photosynthetic activities justified by the high phytoplankton abundance during the summer, when there is more solar energy available to the lake. The PCA-plot illustrates a close relationship between the DO concentration and both pH (ρ = 0.82; d.f = 9; $p < 0.001$) and Chl *a* (ρ = 0.81; d.f = 9; $p < 0.001$) (Figure 7). The high DO concentration recorded in summer was most likely linked to phytoplankton, which proliferate during this season (Figure 7, Table 1).

The levels of nutrients in the JUST lake were high. The nutrient content of water is an indication of the degree of the ecosystem's trophic state. At very high concentrations of nutrients, eutrophication in water bodies is an associated factor. Carvalho et al. [38] reported that phosphorus levels of >20 µg L^{-1} in freshwater ecosystems resulted in eutrophication and increased levels of Cyanobacteria thus, leading to a deterioration in water quality. In the JUST lake, the high concentrations of orthophosphates recorded in the present study positioned all of the stations at a level of eutrophication. In lakes, N and P concentrations of surface water are closely controlled by external loading from the catchment area, climate forcing, and internal nutrient cycling [39,40]. Human beings influence lake ecosystems by increasing the concentration of nutrients, primarily phosphorus [7,41]. Sudeep et al. [42] have found that TLI is an important aspect of lake classification and water quality. The TLI indicators definitively classified the trophic status of the artificial JUST lake as eutrophic–hypertrophic, in agreement with the magnitude of the nutrient concentration in the lake. The eutrophication of the artificial JUST lake probably emanates from the pressure caused by the anthropogenic presence, erosion and siltation, and heavy agricultural fertilizer use in the catchment area. The TLI was significantly higher in summer (6.11 ± 0.39) than in winter (5.16 ± 0.12). Increasing temperatures can also alter nutrient concentrations; phytoplankton growth rates and corresponding dissolved nutrient uptake rates generally increase with temperature [43]. Warmer temperatures can also directly accelerate water column mineralization, thereby increasing nutrient concentrations [44]. Internal nutrient cycling has been demonstrated to be a crucial factor influencing the seasonal patterns of nutrient concentrations and limitations in eutrophic lakes, globally [45,46].

Zooplankton is a key component of the aquatic environment and it is essential to maintaining natural processes in freshwater ecosystems [47]. In the JUST lake, the zooplankton were diversified and were mainly composed of Copepoda (copepodids and nauplii), Rotifera, and Cladocera, accounting, respectively, for 70.9%, 25.6%, and 3.2% of the total zooplankton throughout the studied period. The zooplankton diversity index in the JUST lake was higher in winter (H′ = 2.10 bits. ind^{-1}, J = 0.71) than in summer (H′ = 1.82 bits. ind^{-1}, J = 0.58). Arab et al. [48] stated that the increased values of these diversity indices could mainly be considered a signal of community stability and improved trophic status. The increase in the TLI leads to taxonomic shifts, which has a negative effect on the diversity of all groups of zooplankton [49]. Increasing the trophic status in natural lakes shifts the dominance from Copepoda Cyclopoida and Rotifera to Copepoda Calanoida and Cladocera [16–18]. However, in the artificial lake (JUST), the summer increase of TLI enhanced the proliferation of Rotifera and Cyclopoida (ρ = 0.84, d.f = 9; $p < 0.0001$) but affected the growth of Cladocera and Calanoida (Figure 7).

The total number of species (twenty-six) was relatively high for an artificial basin (see comparable data in [15]) and, interestingly, a high number of co-existing Calanoida (four species) was there to underline a high level of biodiversity. The deterioration of the environment, consequent to eutrophication, is probably only related to the summer season, with the winter period able to re-propose a well-structured and diversified community. Understanding the relationships between diversity indices and trophic state aspects remains a challenge in hydrologic research; at the same time, is essential for establishing a water management database on a larger spatial and temporal scale.

The average abundance of total zooplankton was $104.44 \pm 250.60 \times 10^3$ ind. m^{-3}. It is noteworthy that a general consistency exists between zooplankton abundance recorded in the JUST lake and those recorded in the arid-area and semi-arid-area lakes in the world [50–52]; although, variations could be affected by the sampling season, regional spatio-temporal physical patterns, and sampling methods. The zooplankton abundance data of the present study are in the upper range of the literature's data for the world's lakes; but, the results have probably been affected by the use of a narrow mesh-sized net (55 µm) that enhanced the capture of very abundant nauplii and small sized organisms.

Generally, Copepoda, Rotifera, and Cladocera are useful indicators of lake trophic status [49,53,54]. Numerous investigations have shown that some species of Cyclopoida have invaded the pelagic zone of lakes during eutrophication [53]. Zooplankton are dominated by Rotifera [54] in high trophic state conditions [55] and are characteristic of shallow lakes [56]. At the JUST lake, certain zooplankton species characteristic of eutrophic communities were recorded. They included *Mesocyclops leuckarti*, *Daphnia longispina*, *D. pulex*, *Ceriodaphnia dubia*, *D.* sp., *Brachionus calyciflorus willeyi*, *B. c. spinosus*, *B. rubens*, *B. bidentata*, *Asplanchna brightwellii*, *Filinia longiseta*, and *Keratella quadrata*. Most species of Cyclopoida and Rotifera were associated with TLI indices in the summer (Figure 7). *B. calyciflorus* is considered pollution-tolerant, a good indicator of eutrophication and the accumulation of organic matter [51,57]. In winter, *D. longispina*, *D. pulex*, and *C. dubia* were associated with trophic condition variables, such as orthophosphates and nitrates (Figure 7). These species have been found to be useful bioindicators of high eutrophic freshwater areas [58,59].

In freshwater ecosystems, abiotic and biotic conditions play a vital role in determining local taxonomic diversity [60]. Many researchers have noted that water temperature, nutrients, pH, the bottom-up effect of phytoplankton, and species interaction, on the one hand, andthe top-down control of predators, are essential factors in shaping zooplankton community composition [61,62]. Similarly, our study showed that the zooplankton composition was diversified and influenced by environmental factors that vary with the seasons, such as water temperature, salinity, pH, and dissolved oxygen. Water temperature is a factor that can positively or negatively affect the growth of some zooplankton species [63]. Furthermore, the development of zooplankton in summer was associated with the increase in the dissolved oxygen, salinity, and pH. The highest values of dissolved oxygen recorded in summer could explain the proliferation of the zooplankton. Furthermore, our analysis has shown that nutrients are a main factor correlated with zooplankton dynamics. Nutrients can indirectly impact zooplankton growth through their influence on phytoplankton productivity.

The lowest Chl *a* concentrations and phytoplankton abundances were observed during winter in the JUST lake; this may be due to the high-pressure grazing of Cladocera on phytoplankton. Cladocera are typically considered predominant phytoplankton grazers in lakes, mainly due to their high ingestion rates [64]. In zooplankton grazing estimations, Cladocera and Copepoda are mostly taken into account while the impact of Rotifera is neglected [65]. The introduction of aquaculture species, such as carp and koi, which are phytoplanktivorous, will strengthen the top-down control over phytoplankton, resulting in a decrease in their biomass [21] and a successive reduction of the lake's trophic status. In fact, fish can control the trophic state of a lake [66]; a preceding study showed that fish koi and common carp were successfully reared in outdoor tanks filled with water from the JUST lake [21]. To avoid any accidental interaction (ingestion) between fish and zooplankton, however, a plant could be realized using water from the JUST lake, where fish could decrease the phytoplankton content of the water; it could be contemporaneously reared for aquaculture while avoiding participation in the trophic charge of the lake. The water subject to such phytoplankton deprivation, opportunely depurated, should be re-introduced into the JUST basin with an increase in its quality and conservation of its biodiversity.

5. Conclusions

The zooplankton in the JUST lake showed spatial and temporal variations in abundance in relation to environmental parameters. Calanoida and Cladocera dominated in winter; meanwhile, in summer, Cyclopoida dominated. Most of the species of zooplankton were correlated with TLI indices, particularly *Daphnia* species, which were associated with the highest amounts of orthophosphates and nitrates. The spatial and temporal ranges of the TLI classified the JUST artificial lake as being in a eutrophic–hypertrophic condition and reflected the high magnitude of nutrient concentrations in this lake, overall, during summer. The eutrophic state of the lake should be a clarion call for initiating restoration programs that can conserve its ecological status. The proposal of a parallel basin for fish aquaculture could be interpreted as a way to organize the system of biological conservation, other than through aquaculture revenues. The deprivation of water from phytoplankton, due to ingestion by fish, could produce a continuous cycle of a trophic water supply for fish and depurated water supply for the JUST lake, where an interesting concentration of biodiversity appears to have been established. In addition, the use of zooplankton as bioindicators of trophic states and the TLI could be valuable during future assessments for evaluating the effectiveness of these programs in remedying the ecological status of the lake.

Author Contributions: Conceptualization, M.A.-D., M.E.-k. and H.A.; methodology, M.A.-D., W.G., I.S., A.R. and B.A.-R.; validation W.G. and N.A.-T.; formal analysis, M.A.-D., W.G. and M.E.-k.; investigation, B.A.-R. and W.G.; data curation, M.A.-D., M.E.-k. and W.G.; writing—original draft preparation, I.S., W.G. and N.A.-T.; writing—review and editing, N.A.-T., M.A.-D., M.E.-k. and G.B.; supervision, M.A.-D. and H.A.; project administration, M.A.-D. and M.E.-k.; funding acquisition, M.A.-D., M.E.-k. and H.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Scientific Research Support Fund, Ministry of Higher Education and Scientific Research, grant number WE/01/12/2017.

Data Availability Statement: Data collected for the present study are all considered and graphically showed in the text.

Acknowledgments: We gratefully acknowledge support from the Scientific Research Support Fund, Ministry of Higher Education (WE/01/12/2017). Jordan University of Science and Technology (Jordan) and the Tunisian Ministry of Scientific Research and Technology are also thanked for their support.

Conflicts of Interest: The authors declare no conflict of interest.

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