Maejo Int. J. Sci. Technol. **2025**, *19*(01), 36-52

Maejo International Journal of Science and Technology

e- ISSN 2697-4746
Available online at www.mijst.mju.ac.th

Full Paper

Spatio-temporal variation of zooplankton community in Al-Asfar Lake, Saudi Arabia

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Received: 13 November 2024 / Accepted: 28 February 2025 / Published: 19 March 2025

Abstract: Zooplankton diversity serves as a widely utilised ecological indicator of aquatic ecosystems due to the plankton's capacity to promptly adapt to environmental alterations. This study investigates the influence of environmental factors on zooplankton diversity in Al-Asfar Lake, Saudi Arabia. Zooplankton and water samples were seasonally collected from three distinct locations in the lake at different depths: station 1 (intermediate), station 2 (deep) and station 3 (shallow). A total of 39 zooplankton species were identified, comprising 16 *Rotifera*, 8 *Cladocera*, 8 *Copepoda* and 7 *Ostracoda*. The abundance of *Rotifera* was found to be highest at 88%, followed by *Ostracoda* at 6%, *Cladocera* at 4% and *Copepoda* at 2%. There was a notable difference in the average density of the zooplankton across seasons and study sites. The total density of zooplankton species showed positive correlations with salinity, chlorophyll a, temperature and transparency while negative correlations were observed with pH, dissolved oxygen, silicates, phosphate, total dissolved solids, nitrate and conductivity. Station 2 had the highest average density of zooplankton while station 3 had the lowest. The ecological status, as determined by various hydrological parameters, indicates that the stations under investigation exhibit either eutrophic or hypereutrophic characteristics. These findings indicate that the discharge of sewage and other domestic pollutants into the lake may lead to a decline in zooplankton diversity.

Keywords: Al-Asfar Lake, zooplankton diversity, ecological indicator, environmental factors, seasonal variation, *Rotifera*, *Cladocera, Copepoda, Ostracoda*

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INTRODUCTION

Al-Asfar Lake, also known as Yellow Lake, is a notable shallow wetland (340 square kilometres) located in a desert environment within the eastern province of Saudi Arabia. This region includes the expansive agricultural area known as the Al-Ahsa Oasis (Figure 1), which has been officially designated as a UNESCO World Heritage Site. The area's population is around 1.3 million, with the predominant land use focused on date palm plantations. The main water source for Al-Asfar Lake is drainage water from the irrigation system established in the oasis in 1971.

Wetlands such as lakes, rivers and estuaries are crucial components of urban systems because they contribute to such ecosystem services as air purification, flood prevention, groundwater recharge, water management following heavy precipitation, and climate regulation [1]. They also significantly improve the quality of life in terms of aesthetic value and recreation [2]. One of the ecosystems most impacted by human activity is the aquatic ecology found in cities [3]. The primary cause of the decline in the ecosystems is urbanisation [4]. The aquatic biodiversity may decline or disappear as a result of this [5]. Keeping these systems healthy is one of the most crucial things to do for the long-term utilisation of water resources [6].

Figure 1. Map showing location of study sites (stations 1-3 in red spots) at Lake Al-Asfar

Zooplankton diversity serves as a vital indicator of the aquatic ecosystem health, indicating its overall ecological balance [7]. Each species holds a unique role in nutrient cycling, acting as sustenance for others, contributing to soil fertility and upholding the natural ecosystem's well-being [8, 9]. The community structure of zooplankton is influenced by various abiotic factors such as temperature, light, pollutants and nutrients, as well as biotic factors including predators, parasites, and competition [10, 11]. For instance, organic contaminants can impact individuals' survival, reproductive potential and alter the sex ratio and population dynamics [12-14]. Moreover, hazardous substances may affect predation risk by modifying swimming behaviour and body structure, thereby influencing population dynamics [15]. As primary consumers, zooplankton play a crucial role in transferring contaminants such as heavy metals, microplastics and organic pollutants through the food web, amplifying their effects on other freshwater biological populations [16]. Additionally, the toxicity of these contaminants may intensify during the diffusion process [17]. Furthermore, because zooplankton populations are vulnerable to human effects, investigating the former might help predict long-term changes in the lake's ecosystem [18]. The number, variety and community makeup of zooplankton can reflect how the environment is changing or being disturbed. Understanding the spatio-temporal fluctuation of zooplankton populations is crucial for assessing the ecosystem's overall health and ecological functioning.

Al-Asfar Lake provides an optimal research site to study zooplankton population transitions. The region's freshwater body serves as a habitat for numerous aquatic species that are essential to local biodiversity. Zooplankton serves as central ecological regulators in Al-Asfar Lake by adapting to its unique dynamic environment that involves seasonal changes in temperature, water quality and nutrient composition. Research in zooplankton variation patterns in Al-Asfar Lake may help scientists determine the ecosystem's health and assess the productivity levels. These findings also influence broader water resource management decisions in arid and semi-arid environments which face increasing threats from climate change and human activities.

MATERIALS AND METHODS

Study Area

Al-Asfar is a shallow wetland and an evaporated lake with a mean depth of 45 cm and a maximum depth of 150 cm. It is specifically designed to facilitate the efficient removal of surplus irrigation water. For this study, three sampling stations (station 1, station 2 and station 3) were chosen within the vicinity of the lake area and with careful consideration to ensure an adequate distance between the sampling locations in order to acquire representative samples and identify potential variations in ecological conditions among the samples. The graphic shows the locations of the sample sites (Figure 1).

Collection of Water Samples

Water and plankton specimens were gathered over 12 months, representing four distinct seasons—winter, spring, summer and autumn—from three distinct locations. Different water quality parameters, i.e. water temperature, dissolved oxygen (DO), pH, conductivity, transparency and total dissolved solids (TDS), were directly assessed in the field using suitable digital instruments. Simultaneously, analyses of ammonia, nitrite, nitrate, chlorophyll a, phosphate and silicate were performed in a laboratory, adhering to the standard procedures outlined by APHA [19].

Collection of Zooplankton

The collection of zooplankton samples was done by filtering 100 litres of water from the surface layer (0-1.0 m) using a zooplankton net with a mesh size of 80-100 µm. Swiftly, the collected samples were preserved in sealed bottles containing 5% formalin.

The zooplankton was categorised into groups such as *Rotifera*, *Cladocera*, *Copepoda*, *Ostracoda* and Meroplankton. The specimens were separated with a tiny needle and brush using a binocular stereo-zoom dissecting microscope (model M165, Leica Japan). Individual plankton species were put on microscope slides with a drop of 20% glycerin after staining with eosin or rose Bengal. Each zooplankton species was recognised using identification manuals [20-24]. Each sample was mixed thoroughly and small aliquots were collected using a Stempel pipette. These aliquots were then examined and enumerated using a Sedgwick Rafter counting chamber and a binocular microscope. Three replicate aliquots were collected for each site. The formula for estimating the total zooplankton cell count (N) per litre is $N = n \times v/V$ [20], where N denotes the total number of zooplankton per litre of filtered water, n denotes the average number of zooplankton in 1 ml of zooplankton sample, v denotes the volume of concentrated zooplankton in ml, and V denotes the volume of total water filtered in litres.

Statistical Analyses and Diversity Indices

Statistical analyses were conducted to examine the relationships between zooplankton diversity and environmental factors. One-way analysis of variance (ANOVA) was used to assess seasonal variations in zooplankton species diversity, with F-values and corresponding P-values reported to determine statistical significance. Additionally, Spearman's rank correlation was applied to evaluate the relationships between zooplankton abundance and key environmental variables. These statistical analyses were performed using PAST version 4.03 software. Shannon and Weaner's formula helped in constructing the species diversity index (H), which computes species diversity in bits per individual using the equation $H_1 = pi \sum \log2\ pi$ [25]. For species richness (S), Gleason's method was employed [26]. The dissimilarity index (D) was calculated using the formula $D = 1 - C$, where C is the sum of pi2, with pi representing ni/N, ni representing N/S, N being the total number of individuals and S is the number of species. The evenness index (J1) was determined using Pielou's formula: $J1 = H_1 / \log2S$, where H_1 represents species diversity in bits of information per individual and S represents the number of species [27]. Taxonomic composition similarities based on a presence-absence matrix of zooplankton species at various research locations were measured using Bray-Curtis' similarity index [28]. Canonical correspondence analysis was utilised to evaluate the relationship between environmental factors and zooplankton species [29].

RESULTS AND DISCUSSION

Understanding lake hydrology holds immense importance for effective conservation and management strategies. The physical and chemical properties of the lake water, including nutrient levels, significantly influence the distribution and diversity of plankton species [30, 31]. Additionally, surface water significantly influences various limnological processes such as stratification, gas solubility, pH levels, conductivity, and the dispersion of planktonic organisms [32]. Water temperature also affects the biochemical oxygen requirements, which influences the life cycle of microorganisms [33].

Identified zooplankton species are classified into four main groups: *Rotifera, Cladocera*, *Copepoda* and *Ostracoda*, highlighting the diverse composition of these ecological categories (Table 1). In the *Rotifera* group, several species such as *Brachionus calyciflorus*, *B. angularis*, *B. falcatus* and others are recorded across the sampling stations. The *Cladocera* group includes species such as *Moina micrura, Bosmina longirostris, Daphnia longispina, Daphnia magna and Cirrodaphnia reticulata,* contributing to the richness of microcrustacean diversity in the studied ecosystem. The presence of *Copepoda* species at different stations, as shown in Table 1, provides insights into their distribution patterns and ecological roles within the aquatic ecosystems. In the

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Ostracoda group, species including *Neglecandona neglecta*, *Cypridopsis vidua* and *Ilyocypris inermis* are identified, contributing to the understanding of their occurrence and ecological significance in the studied habitat.

Table 1. Abundance of zooplankton species observed at different sampling site stations

Group	Species	Station 1	Station 2	Station 3
Rotifera	*Brachionus calyciflorus*	*	*	*
	Brachionus angular	*	*	*
	Brachionus falcatus	*	*	
	Brachionus longirostris	*		
	Brachionus urceolaris		*	
	Brachionus plicatilis	*	*	*
	Brachionus quadridentatus	*	*	
	Keratella cochlearis	*	*	*
	Keratella quadrata		*	
	Dicronophorus forcipate	*	*	
	Lecane closteceracoid	*		
	Notholca squamula	*	*	
	Testudinella patina	*	*	
	Polyarthra vulgaris	*		*
	Asplanchna intermedia		*	*
	Ploesoma truncatum	*	*	
Cladocera	*Moina micrura*	*	*	*
	Bosmina longirostris	*	*	*
	Daphnia longispina	*	*	
	Daphnia magna	*	*	*
	Cirrodaphnia reticulata		*	
	Stomocephalus exspinosus	*		
	Diaphanosoma excisum	*		
	Coronatella rectangula	*	*	
Copepoda	*Heliodiaptomus viduus*	*	*	*
	Sinodiaptomus indicus	*	*	
	Calanoida sp	*	*	*
	Eubranchipus vernalis	*		*
	Mesocyclops hyalinus	*		*
	Mesocyclops leuckarti	*	*	*
	Acanthocuclops tragani	*		*
	Thermocyclops hyalinus	*	*	
Ostracoda	*Neglecandona neglecta*	*	*	*
	Cypridopsis vidua	*	*	
	Ilyocypris inermis	*	*	*
	Ilyocypris bradyi		*	
	Cypris protubera	*	*	
	Potramocypris pallida	*		
	Potamocypris fallax	*	*	*

Note: The sign * indicates presence of each species at respective station.

Water temperature has a significant impact on all metabolic activities, physiological activity and life processes such as feeding, reproduction, movement and dispersal of aquatic organisms. This study reveals that lower temperatures result in the dominance of zooplankton species. The recorded water temperature ranges from 19.7 to 38.4ºC among the study stations (Figure 2).

Although the study area is generally considered a freshwater lake, the observed salinity levels are relatively high, ranging from 4 to 36 ppt among the sites. A decline in salinity during winter appears to be associated with lower temperature which slows down evaporation, and an increased influx of freshwater from agricultural farms due to seasonal precipitation and run-off, further diluting salinity.

The recorded pH levels of water range from 7.2 to 8.8 (Figure 2), with the highest value observed at station 2 during winter and the lowest at station 3 in spring. The changes consistently indicate a trend toward alkaline, which may be attributed to increased photosynthetic activity by planktonic algae, as noted in a previous study [34].

DO is an essential characteristic for distinguishing between various water masses and shows seasonal variation. Higher DO levels are recorded during winter and spring, while lower levels are noticed in summer. The maximum DO value of 8.09 mg/L was recorded at station 3 during winter, whereas the minimum value of 2.8 mg/L was also observed at the same site in summer. Oxygen supersaturation owing to photosynthetic activity is common in areas with numerous phytoplankton [35].

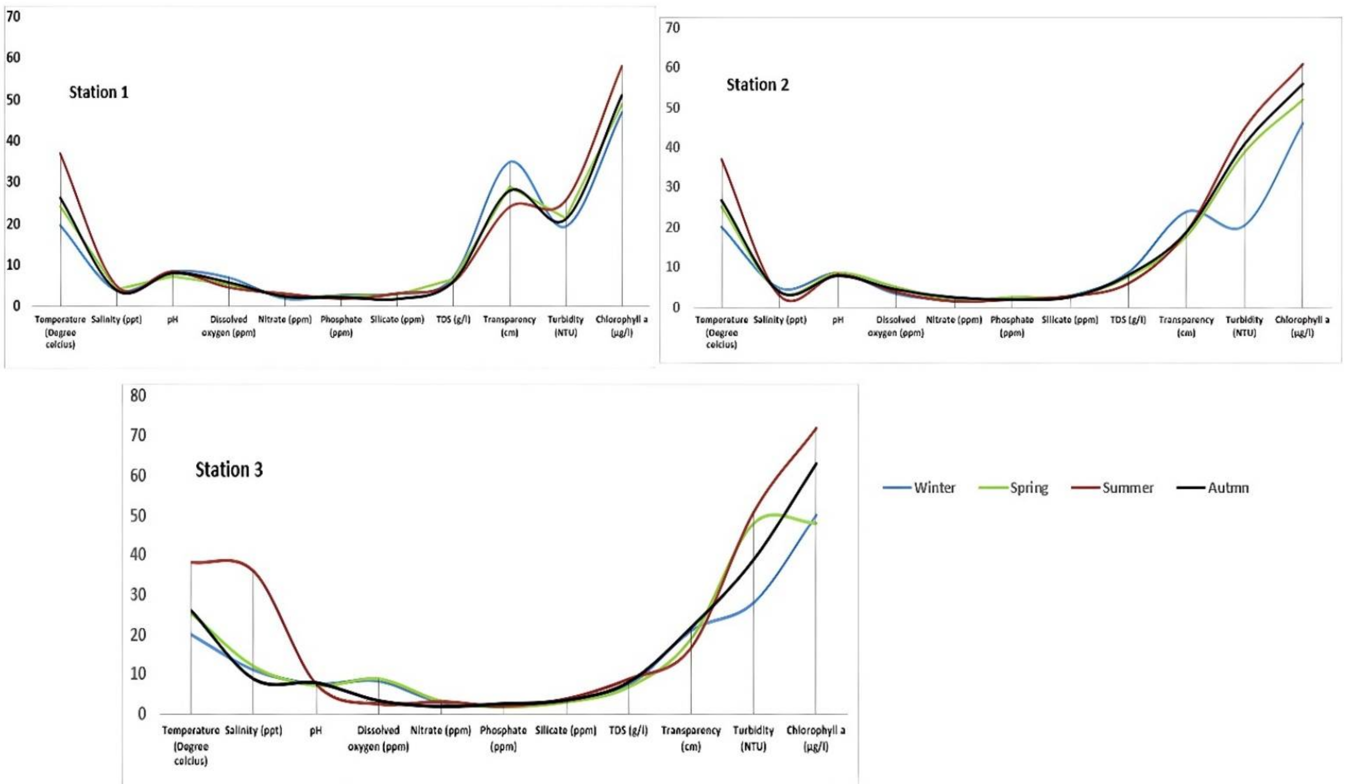

Figure 2. Seasonal variations in major water quality parameters observed at study sites

The highest nitrate concentration is measured (3.41 ppm) at station 3 in summer while the lowest is 1.9 in spring. The greatest nitrate-N levels in summer are a direct result of agricultural run-off [36] or reduced phytoplankton nutrient uptake.

The distribution of planktonic species at the site appears to be influenced by nutrient availability. While nitrate-N levels were relatively low at other sites, phosphate concentrations were higher during winter but declined in other seasons. This seasonal variation suggests that phosphate may be released from sediment or introduced through drainage water inflow [37]. Silicate concentrations varied marginally across seasons, possibly due to changes in diatom silicate ingestion [38].

Water conductivity, TDS, turbidity, and transparency are notably higher in summer, likely due to increased pollution from wastewater nutrient loads [39]. Chlorophyll-a levels peak in summer at sampling location 3, suggesting robust phytoplankton growth. Zooplankton species vary significantly across location and time, totalling 39 species: 16 *Rotifera*, 8 *Cladocera*, 8 *Copepoda* and 7 *Ostracoda*. *Rotifera* dominates at 88%, followed by *Ostracoda* at 6%, *Cladocera* at 4% and *Copepoda* at 2%. The environment's physicochemical properties may influence zooplankton distribution and density (Table 2). Zooplankton density notably differs across seasons and study sites with a larger population during winter, likely due to favourable environmental conditions and phytoplankton availability. High nutrient levels may stimulate phytoplankton production, supporting zooplankton abundance [40].

The seasonal variation in zooplankton species diversity in Al-Asfar Lake (Table 2) reveals statistically significant differences across seasons, as indicated by the F-values and corresponding P-values ($P < 0.05$). Shannon diversity index (H) is highest for *Rotifera* in spring (2.292±0.037) and lowest in summer (1.867±0.027), while evenness (J) remains relatively stable across groups. Richness (S) shows notable seasonal fluctuations, particularly for *Rotifera*, with a significant decline in summer (0.812±0.038). These findings suggest that environmental factors influencing seasonal changes play a critical role in shaping zooplankton diversity and distribution in the lake ecosystem.

Copepoda displays a peak in diversity during summer (1.692) and a dip in winter (1.264). *Cladocera* exhibits a decrease in diversity from spring to autumn. *Ostracoda* has the highest diversity in spring (2.092) and the lowest in winter (1.312). Meroplankton shows a decline in diversity from spring to autumn. Evenness, representing how evenly individuals are distributed among species, remains relatively stable for *Rotifera* and *Cladocera* across seasons. *Copepoda* and *Ostracoda* show higher evenness in summer while Meroplankton exhibits its peak in winter. Richness, reflecting the number of different species present in each zooplankton group during different seasons, reveals that *Rotifera* richness is highest in spring (1.218) and lowest in summer (0.812) while *Copepoda* and *Cladocera* exhibit varied richness, with no clear trend. However, *Ostracoda* and Meroplankton show fluctuations in richness across seasons (Figures 3a and 3b).

The findings obtained from Al-Asfar Lake demonstrate noticeable seasonal variations in both the quality and quantity of zooplankton communities (Table 2, Figures 3a and 3b). Overall, the phytoplankton population shows a significant surge, signalling a high level of eutrophication in the lake sector. Similar outcomes were observed by other researchers [41]. Table 2 data indicates that the highest diversity index (2.142) is recorded in winter, while the lowest (1.112) is noted in summer. It is worth noting that biological diversity indices, focusing on zooplankton composition, can provide insight into water pollution levels [42, 43]. Various attempts to gauge oligotrophy and eutrophy levels through species compositions rather than nutrient levels have been made [44]. Based on water quality parameters, it is apparent that Al-Asfar's water is eutrophic. When the

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clustering pattern of these sites is portrayed based on the identified zooplankton species, it serves as a visual representation of the ecological heterogeneity within the lake (Figure 3c).

Figure 4 depicts the relationship between zooplankton communities and environmental variables across different seasons. The analysis highlights the impact of factors such as salinity, chlorophyll, temperature and transparency on zooplankton diversity (Figure 4a). The analysis reveals distinct seasonal patterns, indicating the ecological impact of environmental variations on zooplankton diversity in the lake and the significance of monitoring these organisms as ecological indicators in aquatic ecosystems subject to environmental changes (Figure 4b).

Figure 4c also reveals the influence of factors such as salinity, chlorophyll a, temperature and transparency on zooplankton diversity. The positioning of zooplankton points in the diagram indicates their response to the environmental conditions. Table 3 illustrates Spearman's correlation between zooplankton and environmental variables in Al-Asfar Lake, Saudi Arabia. Positive correlations are observed with salinity, chlorophyll a, temperature and transparency while negative correlations are found with pH, DO, silicates, phosphate, TDS, nitrate and conductivity.

Table 2. Seasonal variation in zooplankton species diversity in Al-Asfar Lake during study period

Diversity Index	Group	Winter	Spring	Summer	Autumn	F-value	P-value
Shannon - H	*Rotifera*	2.142±0.031	2.292±0.037	1.867±0.027	2.092±0.043	8.85	0.0007
	Copepoda	1.264±0.039	1.413±0.018	1.692±0.021	1.297±0.017	10.32	0.0004
	Cladocera	1.392±0.023	1.292±0.011	1.112±0.033	1.592±0.024	7.68	0.0012
	Ostracoda	1.312±0.041	2.092±0.034	1.218±0.033	1.561±0.036	9.41	0.0006
	Meroplankton	1.012±0.014	1.231±0.011	1.331±0.027	1.092±0.035	6.89	0.0021
Evenness (J)	*Rotifera*	0.882±0.011	0.816±0.018	0.894±0.023	0.819±0.011	12.09	0.0001
	Copepoda	0.941±0.011	0.931±0.022	0.911±0.013	0.947±0.009	9.62	0.0005
	Cladocera	0.983±0.022	0.971±0.011	0.941±0.015	0.955±0.022	8.32	0.0009
	Ostracoda	0.933±0.012	0.926±0.014	0.914±0.027	0.917±0.013	7.95	0.0011
	Meroplankton	0.962±0.040	0.927±0.040	0.918±0.040	0.962±0.040	6.57	0.0023
Richness (S)	*Rotifera*	1.192±0.037	1.218±0.043	0.812±0.038	1.092±0.029	8.62	0.0008
	Copepoda	0.984±0.033	0.892±0.029	0.903±0.034	0.894±0.022	7.71	0.0013
	Cladocera	0.719±0.024	0.872±0.013	0.701±0.033	0.727±0.061	8.11	0.0010
	Ostracoda	0.832±0.039	0.864±0.041	0.882±0.022	0.876±0.071	7.35	0.0015
	Meroplankton	0.711±0.031	0.792±0.054	0.711±0.061	0.732±0.042	6.98	0.0020

Note: Significant seasonal variation in zooplankton diversity is observed ($P < 0.05$) across most groups, indicating influence of seasonal changes on species diversity in Al-Asfar Lake.

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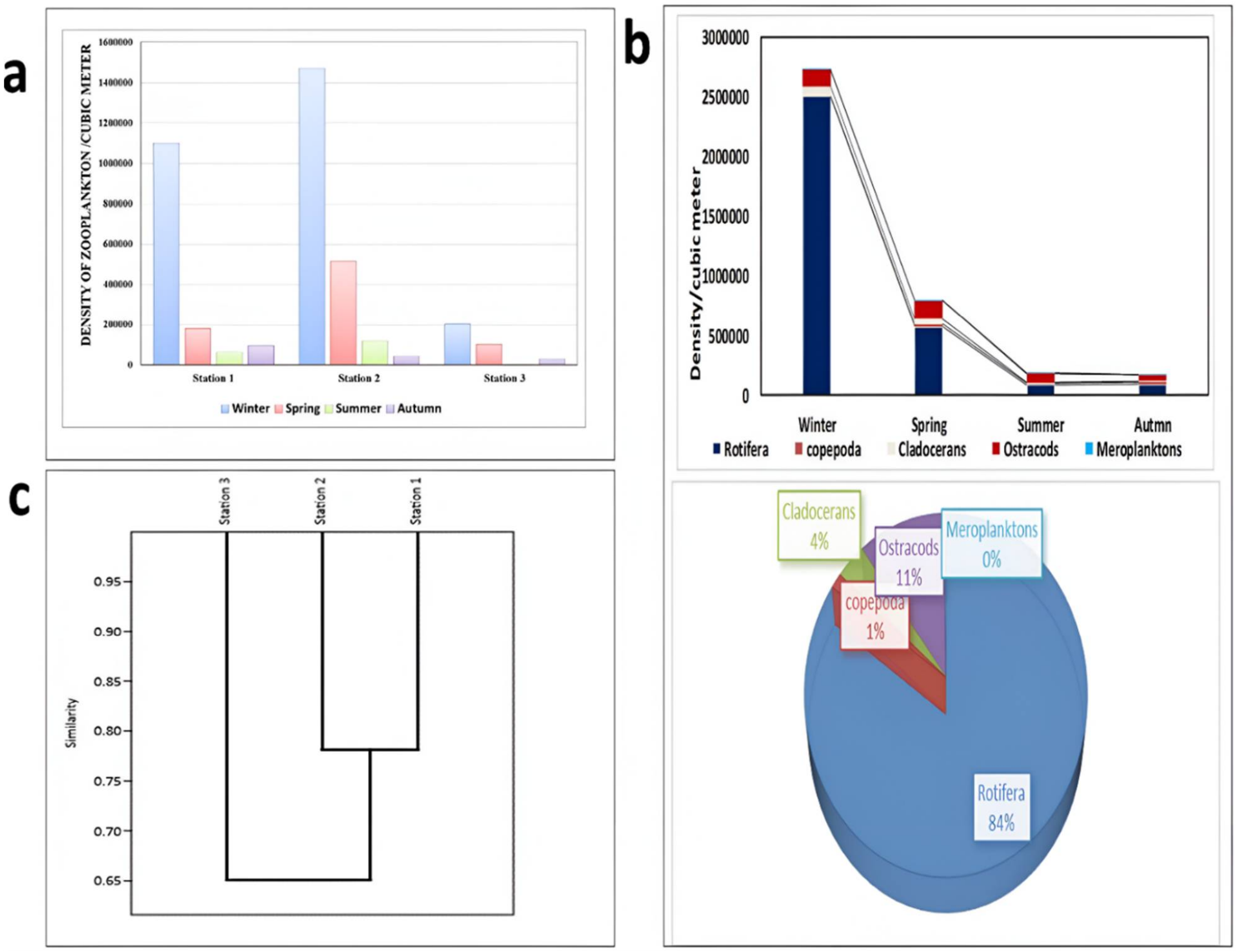

Figure 3. (a) Station-wise seasonal density of zooplankton species observed during study period; (b) Seasonal distribution pattern of zooplanktonic groups observed at the sampling site; (c) Dendrogram showing similarity of sampling sites based on their zooplankton composition in Lake Asfar during study period

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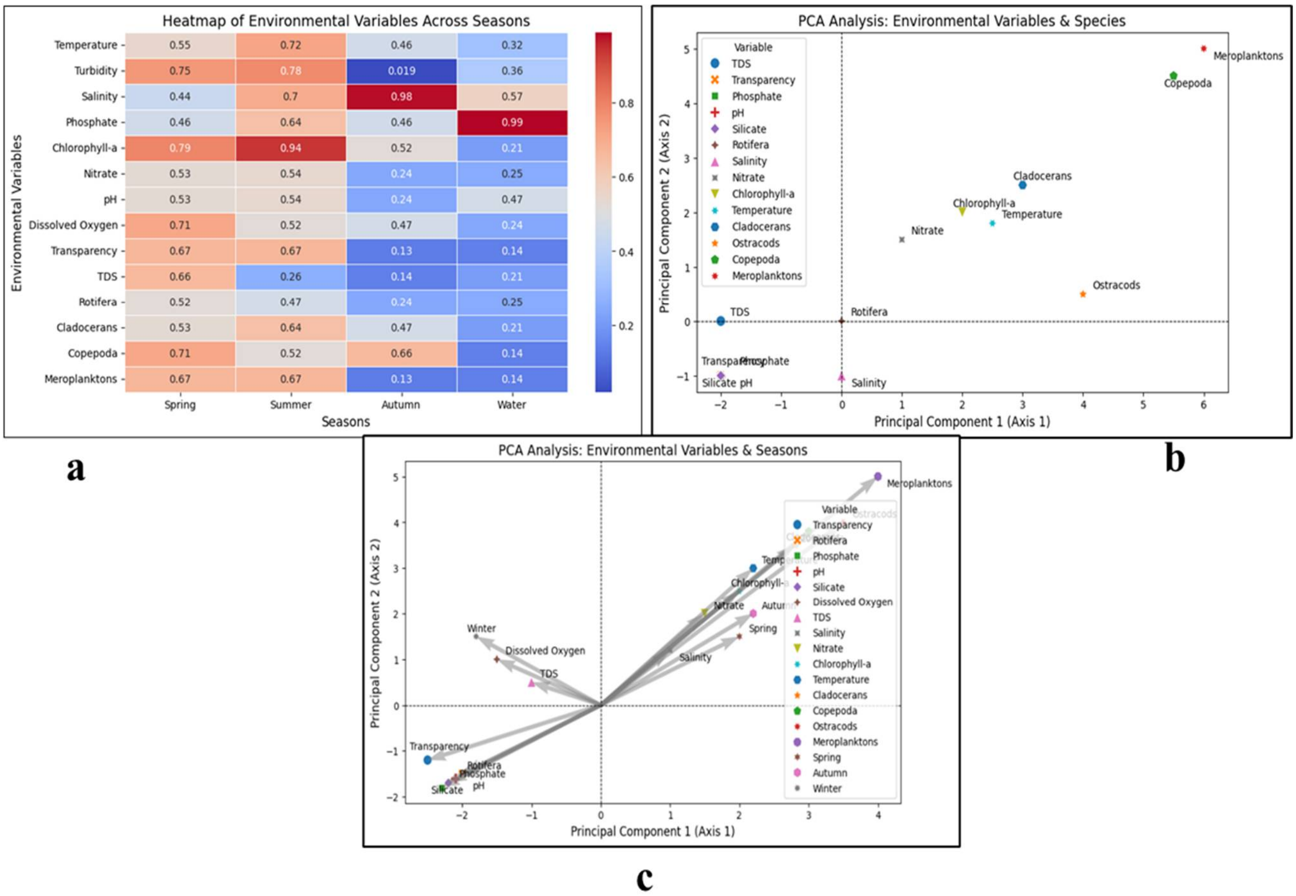

Figure 4. (a) Canonical correspondence analysis showing zooplankton distribution and their relationship to environmental variables during different seasons at station 1 in the Heat map chart; (b) Canonical correspondence analysis showing zooplankton distribution and their relationship to environmental variables during different seasons at station 2; (c) Canonical correspondence analysis showing zooplankton distribution and their relationship to environmental variables during different seasons at station 3

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Table 3. Spearman's correlation rank between zooplankton species and environmental variables at different study sites

Site1	Temperature	Salinity	pH	Dissolved oxygen	Nitrate	Phosphate	Silicate	TDS	Conductivity	Transparency	Turbidity	Chlorophyll a (µg/l)	Rotifera	Copepoda	Cladocerans	Ostracods	Meroplankton
Temperature																	
Salinity	0.92427																
pH	0.15128	0.38597															
Dissolved oxygen	-0.87711	-0.71592	0.33543														
Nitrate	0.99846	0.91298	0.17113	-0.86201													
Phosphate	-0.98166	-0.85921	0.039937	0.95113	-0.97639												
Silicate	0.03095	0.36322	0.21001	-0.00703	-0.01531	0.011371											
TDS	-0.87616	-0.66009	-0.08959	0.75065	-0.89869	0.86943	0.45126										
Conductivity	0.80217	0.76665	0.60858	-0.44319	0.82833	-0.69424	-0.20228	-0.84319									
Transparency	-0.93433	-0.73324	0.15541	0.94631	-0.9367	0.97485	0.22125	0.92388	-0.66625								
Turbidity	0.98925	0.94649	0.11442	-0.89591	0.9797	-0.97759	0.16184	-0.80023	0.7282	-0.90775							
Chlorophyll a (µg/l)	0.99531	0.94002	0.24529	-0.82657	0.9964	-0.95882	0.037937	-0.87416	0.85005	-0.90369	0.97935						
Rotifera	-0.72767	-0.42031	0.45384	0.87793	-0.7346	0.82391	0.46834	0.84517	-0.43087	0.92431	-0.68618	-0.67456					
copepoda	-0.80776	-0.84196	-0.68335	0.42693	-0.82625	0.68507	0.012476	0.75935	-0.98133	0.61482	-0.75631	-0.86045	0.32445				
Cladocerans	-0.80575	-0.51889	0.28053	0.8651	-0.81842	0.86953	0.48019	0.93015	-0.59065	0.95768	-0.75061	-0.76858	0.98239	0.48811			
Ostracods	0.10768	0.43045	0.93992	0.32088	0.10898	0.073176	0.52945	0.10929	0.43248	0.24515	0.12137	0.19227	0.58404	-0.56343	0.43972		
Meroplankton	-0.50553	-0.52453	-0.80982	0.056814	-0.54255	0.3558	0.26093	0.62215	-0.91965	0.33423	-0.4112	-0.58001	0.11239	0.89952	0.29479	-0.59804	-0.598746

Site2	Temperature	Salinity	pH	Dissolved oxygen	Nitrate	Phosphate	Silicate	TDS	Conductivity	Transparency	Turbidity	Chlorophyll a (µg/l)	Rotifera	copepoda	Cladocerans	Ostracods	Meroplankton
Temperature																	
Salinity	-0.97329																
pH	-0.51256	0.48886															
Dissolved oxygen	-0.06956	-0.16128	0.062847														
Nitrate	-0.52606	0.48564	-0.44799	0.16709													
Phosphate	-0.51163	0.36927	0.84507	0.58233	-0.2152												
Silicate	-0.38359	0.5	0.80769	-0.5376	-0.48564	0.36927											
TDS	-0.97323	0.96039	0.30547	0.014752	0.69295	0.32087	0.2401										
Conductivity	0.95227	-0.97639	-0.66378	0.15314	-0.29428	-0.50676	-0.64422	-0.89111									
Transparency	-0.58519	0.75378	0.36529	-0.76184	0.11714	-0.07423	0.75378	0.58948	-0.75571								
Turbidity	0.82172	-0.92024	-0.58903	0.47039	-0.18462	-0.27111	-0.76938	-0.7803	0.94376	-0.92791							
Chlorophyll a (µg/l)	0.95345	-0.96523	-0.6996	0.10032	-0.26876	-0.56238	-0.64349	-0.88065	0.99783	-0.71787	0.92513						
Rotifera	-0.74502	0.84429	0.71852	-0.47383	-0.02071	0.36302	0.88242	0.66158	-0.91193	0.90149	-0.97773	-0.90105					
copepoda	-0.58131	0.74454	0.46667	-0.74063	0.017283	0.014833	0.82754	0.55778	-0.77264	0.99259	-0.93877	-0.74064	0.93623				
Cladocerans	-0.64981	0.61872	0.98547	0.090466	-0.28983	0.85939	0.77747	0.46033	-0.76944	0.42092	-0.67111	-0.80246	0.77054	0.51024			
Ostracods	-0.40261	0.27057	0.87043	0.54073	-0.35748	0.98889	0.41664	0.19516	-0.43071	-0.10085	-0.2199	-0.48816	0.33893	-0.00064	0.85965		
Meroplankton	-0.41207	0.49915	0.88272	-0.41273	-0.51044	0.49537	0.9898	0.2464	-0.65833	0.6781	-0.74176	-0.66676	0.86593	0.76237	0.85203	0.5418	0.5419

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Table 3 (continued).

Site3	Temperature	Salinity	pH	Dissolved oxygen	Nitrate	Phosphate	Silicate	TDS	Conductivity	Transparency	Turbidity	Chlorophyll a (µg/l)	Rotifera	copepoda	Cladocerans	Ostracods	Meroplankton
Temperature																	
Salinity	0.92091																
pH	0.13969	-0.01135															
Dissolved oxygen	-0.75139	-0.5822	-0.75676														
Nitrate	0.49566	0.65793	-0.76045	0.18963													
Phosphate	15395	-0.09699	0.95691	-0.75083	-0.78143												
Silicate	0.79074	0.76017	0.64078	-0.93306	0.010937	0.5418											
TDS	0.83136	0.73708	0.65077	-0.97404	-0.01026	0.59993	0.98557										
Conductivity	0.95985	0.86731	0.40523	-0.89868	0.26021	0.38885	0.92367	0.95384									
Transparency	-0.78793	-0.87401	0.47326	0.19602	-0.92512	0.48712	-0.36069	-0.36057	-0.60588								
Turbidity	0.80524	0.63042	-0.26485	-0.3751	0.6146	-0.10442	0.29796	0.40391	0.64094	-0.77751							
Chlorophyll a (µg/l)	0.86022	0.74927	0.61914	-0.97449	0.02196	0.58589	0.97321	0.9975	0.96842	-0.39491	0.46524						
Rotifera	-0.74734	-0.43685	-0.18865	0.64786	-0.14852	-0.38632	-0.44116	-0.58054	-0.70058	0.42058	-0.86872	-0.63439					
copepoda	-0.68911	-0.36557	-0.14057	0.58051	-0.13877	-0.35788	-0.35444	-0.50189	-0.62973	0.38694	-0.86642	-0.55895	0.99542				
Cladocerans	-0.73645	-0.41568	-0.28662	0.70543	-0.06086	-0.47712	-0.48885	-0.62685	-0.71815	0.35432	-0.81784	-0.67631	0.99486	0.98632			
Ostracods	-0.60197	-0.58806	-0.78555	0.90168	0.21099	-0.65514	-0.96465	-0.93143	-0.79419	0.12305	-0.04736	-0.90354	0.26732	0.17999	0.33504		
Meroplankton	-0.77294	-0.4752	-0.49629	0.86186	0.059475	-0.63394	-0.67336	-0.7887	-0.81898	0.28858	-0.69954	-0.82364	0.93969	0.91094	0.96647	0.5593	0.5587

The study indicates an alkaline pH trend (7.2-8.8) favouring phytoplankton growth, and DO concentrations are relatively high during winter and spring, indicating favourable conditions for aquatic organisms [45-47]. However, lower DO levels in summer, potentially linked to increased photosynthetic activity, can affect aquatic fauna. Nutrient concentrations, particularly nitrate and phosphate, exhibit seasonal variations, impacting zooplankton composition [48].

The zooplankton community's diversity indices vary seasonally, with higher diversity observed in winter and lower diversity in summer [49-51]. The comprehensive assessment of Al-Asfar Lake's zooplankton community and associated environmental parameters highlights the impact of human activities on the lake's ecological health [52].

The use of canonical correspondence analysis across different stations and seasons provides a nuanced perspective on the ecological heterogeneity within the lake [53, 54], emphasising the impact of salinity, temperature and chlorophyll on zooplankton diversity [55], highlighting the sensitivity of zooplankton to water quality parameters. This study's comprehensive approach complements existing literature, emphasising the need for continuous monitoring and management strategies in aquatic ecosystems facing anthropogenic pressures [56, 57].

CONCLUSIONS

Examining zooplankton provides valuable insights into the dynamics and health of a city's lake ecosystems. These organisms respond swiftly to alterations in water quality. The comprehensive analysis of zooplankton distribution and water quality parameters in Al-Asfar Lake underscores the intricate interplay between the zooplankton communities and their aquatic environment. These findings contribute to our understanding of the lake's ecological dynamics conservation strategies and sustainable water management practices in the region. Further research exploring additional environmental factors that may influence the zooplankton community and investigating potential cascading effects on higher trophic levels within the lake is warranted.

ACKNOWLEDGEMENTS

This work was supported by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia [Grant No. 5578]. Also, we appreciate Mr. Rashed Saleh Alngada's invaluable support in field sampling and lab work. Additionally, we extend our gratitude to Dr. Sheikh Mustafiz Rahman for his unwavering assistance throughout the research period.

REFERENCES

1. A. M. Abdel-Moneim, "Histopathological and ultrastructural perturbations in tilapia liver as potential indicators of pollution in Lake Al-Asfar, Saudi Arabia", *Environ. Sci. Pollut. Res. Int.*, **2014**, *21*, 4387-4396.
2. Y. Al-Dakeel, A. Hussien, A. El Mahmoudi and M. Masoud, "Soil, water chemistry and sedimentological studies of Al Asfar evaporation lake and its inland Sabkha, Al Hassa Area, Saudi Arabia", *Asian J. Earth Sci.*, **2009**, *2*, 1-21.
3. M. E. Assiri, M. A. Ali, M. H. Siddiqui, A. AlZahrani, L. Alamri, A. M. Alqahtani and A. S. Ghulam, "Remote sensing assessment of water resources, vegetation, and land surface temperature in eastern Saudi Arabia: Identification, variability, and trends", *Remote Sens. Appl. Soc. Environ.*, **2024**, *36*, Art.no.101296.

4. S. Alikhani, P. Nummi and A. Ojala, "Urban wetlands: A review on ecological and cultural values", *Water*, **2021**, *13*, Art.no.3301.
5. M. A. Al-Kahtani, A. M. Youssef and A. A. Fathi, "Ecological studies on Al-Khadoud springe, Al-Hassa, Saudi Arabia", *Pak. J. Biol. Sci.*, **2007**, *10*, 4063-4068.
6. H. Al-Sheikh and A. A. Fathi, "Ecological studies on Lake Al-Asfar (Al-Hassa, Saudi Arabia) with special references to the sediment", *Res. J. Environ. Sci.*, **2010**, *4*, 13-22.
7. G. L. F. Benachio, Md. C. D. Freitas and S. F. Tavares, "Circular economy in the construction industry: A systematic literature review", *J. Cleaner Prod.*, **2020**, *260*, Art.no.121046.
8. U. I. Daniel, C. C. Duru, O. E. Oriakpono and M. O. E. Iwuala, "Impacts of organic wastes on plankton population of Woji Creek, Port Harcourt, Rivers State, Nigeria", *Ambient Sci.*, **2018**, *5*, DOI:10.21276/ambi.2018.05.1.ra03.
9. A. Das and T. Basu, "Assessment of peri-urban wetland ecological degradation through importance-performance analysis (IPA): A study on Chatra Wetland, India", *Ecol. Indic.*, **2020**, *114*, Art.no.106274.
10. B. H. Dussart, C. H. Fernando, T. Matsumura-Tundisi and R. J. Shiel, "A review of systematics, distribution and ecology of tropical freshwater zooplankton", *Hydrobiologia*, **1984**, *113*, 77-91.
11. A. S. El Mahmoudi, M. A. Massoud, Y. Y. Al-Dakheel and A. H. A. Hussien, "Studies of Al Asfar and Al Uyoun evaporation lakes water quality and the potential of its reuse in agriculture activities, Al Hassa Area, KSA", *J. King Abdulaziz Univ. - Meteorol. Environ. Arid Land Agric. Sci.*, **2011**, *22*, 67-85.
12. I. Elsohaby, A. Samy, A. Elmoslemany, M. Alorabi, M. Alkafafy, A. Aldoweriej, T. Al-Marri, A. Elbehiry and M. Fayez, "Migratory wild birds as a potential disseminator of antimicrobial-resistant bacteria around Al-Asfar lake, Eastern Saudi Arabia", *Antibiotics*, **2021**, *10*, Art.no.260.
13. M. El-Sheekh, E. Ali and H. El-Kassas, "Phytoplankton ecology along the Egyptian Northern lakes: Status, pressures and impacts", in "Egyptian Coastal Lakes and Wetlands, Part I: Characteristics and Hydrodynamics" (Ed. A. M. Negm, M. A. Bek and S. Abdel-Fattah), Springer Nature Switzerland, Cham, **2019**, pp.133-172.
14. O. Ferrara, D. Vagaggini and F. G. Margaritora, "Zooplankton abundance and diversity in Lake Bracciano, Latium, Italy", *J. Limnol.*, **2002**, *61*, 169-175.
15. K. A. Ger, P. Urrutia-Cordero, P. C. Frost, L. A. Hansson, O. Sarnelle, A. E. Wilson and M. Lürling, "The interaction between cyanobacteria and zooplankton in a more eutrophic world", *Harmful Algae*, **2016**, *54*, 128-144.
16. M. A. Elrashidi, C. A. Seybold and J. A. Delgado, "Annual precipitation and effects of runoff nutrient from agricultural watersheds on water quality", *Soil Sci.*, **2013**, *178*, 679-688.
17. N. Guo, M. Zhang, Y. Yu, S. Qian, D. Li and F. Kong, "Crustacean zooplankton communities in 13 lakes of Yunnan-Guizhou plateau: Relationship between crustacean zooplankton biomass or size structure and trophic indicators after invasion by exotic fish", *Ann. Limnol. - Int. J. Limnol.*, **2009**, *45*, 279-288.
18. Ø. Hammer, D. A. T. Harper and P. D. Ryan, "PAST: Paleontological statistics software package for education and data analysis", *Palaeontol. Electron.*, **2001**, *4*, 1-9.
19. L. S. Clesceri, A. E. Greenberg and A. D. Eaton (Ed.), "Standard Methods for the Examination of Water and Wastewater", 20th Edn., American Public Health Association (APHA), Washington, D.C., **1999**.

20. J. M. Elliott and A. Ruttner-Kolisko, “Plankton Rotifers: Biology and taxonomy”, *J. Anim. Ecol.*, **1976**, *45*, 617-627 (DOI: 10.2307/3912).
21. W. Koste and M. Voigt, “Rotatoria, die Radertiere Mitteleuropas: Uberordnung Monogononta: ein Bestimmungswerk”, Gebrüder Borntraeger Verlag, Berlin, **1978** (in German).
22. D. Sheil, D. F. R. P. Burslem and D. Alder, “The interpretation and misinterpretation of mortality rate measures”, *J. Ecol.*, **1995**, *83*, 331-333.
23. U. Einsle, “*Cyclops heberti n. sp.* and *Cyclops singularis n. sp.*, two new species within the genus *Cyclops* (‘*strenuus*-subgroup’)(Crust. Copepoda) from ephemeral ponds in southern Germany”, *Hydrobiologia*, **1996**, *319*, 167-177.
24. A. V. Smirnov, “*Stygamoeba regulata* n. sp. (Rhizopoda)—A marine amoeba with an unusual combination of light-microscopical and ultrastructural features”, *Arch. für Protistenkd.*, **1996**, *146*, 299-307.
25. K. A. Nolan and J. E. Callahan, “Beachcomber biology: The Shannon-Weiner species diversity index”, Proceedings of 27th Workshop/Conference of the Association for Biology Laboratory Education, **2006**, New Haven (CT), USA, pp.334-338.
26. O. V. Petin, “Experience in the use of Gleason’s model: How the parameters of species richness obtained in sample plots of different sizes can be compared”, *Russ. J. Ecol.*, **2011**, *42*, 110-114.
27. C. Ricotta and G. Avena, “On the relationship between Pielou’s evenness and landscape dominance within the context of Hill’s diversity profiles”, *Ecol. Indic.*, **2003**, *2*, 361-365.
28. J. R. Bray and J. T. Curtis, “An ordination of the upland forest communities of southern Wisconsin”, *Ecol. Monogr.*, **1957**, *27*, 325-349.
29. C. J. F. ter Braak and P. F. M. Verdonschot, “Canonical correspondence analysis and related multivariate methods in aquatic ecology”, *Aquat. Sci.*, **1995**, *57*, 255-289.
30. A. H. Ismail and A. A. M. Adnan, “Zooplankton composition and abundance as indicators of eutrophication in two small man-made lakes”, *Trop. Life Sci. Res.*, **2016**, *27*, 31-38.
31. J. García-Chicote, X. Armengol and C. Rojo, “Zooplankton species as indicators of trophic state in reservoirs from Mediterranean river basins”, *Inland Waters*, **2019**, *9*, 113-123.
32. J. Wang, J. Soininen and J. Heino, “Ecological indicators for aquatic biodiversity, ecosystem functions, human activities and climate change”, *Ecol. Indic.*, **2021**, *132*, Art.no.108250.
33. S. S. Kometa, J. N. Kimengsi and D. M. Petiangma, “Urban development and its implications on wetland ecosystem services in Ndop, Cameroon”, *Environ. Manag. Sustain. Dev.*, **2018**, *7*, 21-36.
34. R. Liao, Z. Jin, M. Chen and S. Li, “An integrated approach for enhancing the overall performance of constructed wetlands in urban areas”, *Water Res.*, **2020**, *187*, Art.no.116443.
35. L. N. de S. Domis, J. J. Elser, A. S. Gsell, V. L. M. Huszar, B. W. Ibelings E. Jeppesen, S. Kosten, W. M. Mooij, F. Roland, U. Sommer, E. van Donk, M. Winder and M. Lürling, “Plankton dynamics under different climate conditions in tropical freshwater systems (a reply to the comment by Sarmento, Amado & Descy,)”, *Freshwater Biol.*, **2013**, *58*, 2211-2213.
36. N. Manickam, P. S. Bhavan, P. Santhanam, R. Bhuvaneswari, T. Muralisankar, V. Srinivasan, A. Asaikkutti, G. Rajkumar, R. Udayasuriyan and M. Karthik, “Impact of seasonal changes in zooplankton biodiversity in Ukkadam Lake, Coimbatore, Tamil Nadu, India, and potential future implications of climate change”, *J. Basic Appl. Zool.*, **2018**, *79*, Art.no.15.

37. A. J. G. Neto, L. C. da Silva, A. A. Saggio and O. Rocha, “Zooplankton communities as eutrophication bioindicators in tropical reservoirs”, *Biota Neotrop.*, **2014**, *14*, Art.no.e20140018.
38. C. Ricotta and J. Podani, “On some properties of the Bray-Curtis dissimilarity and their ecological meaning”, *Ecol. Complex.*, **2017**, *31*, 201-205.
39. S. Patra, S. Sahoo, P. Mishra and S. C. Mahapatra, “Impacts of urbanization on land use/cover changes and its probable implications on local climate and groundwater level”, *J. Urban Manag.*, **2018**, *7*, 70-84.
40. E. C. Pielou, “The measurement of diversity in different types of biological collections”, *J. Theor. Biol.*, **1966**, *13*, 131-144.
41. H. Sarmento, A. M. Amado and J.-P. Descy, “Climate change in tropical fresh waters (comment on the paper ‘Plankton dynamics under different climate conditions in space and time’ by de Senerpont Domis et al.)”, *Freshwater Biol.*, **2013**, *58*, 1-3
42. S. Seifollahi-Aghmiuni, M. Nockrach and Z. Kalantari, “The potential of wetlands in achieving the sustainable development goals of the 2030 Agenda”, *Water*, **2019**, *11*, Art.no.609.
43. A. F. Nojavan, B. J. Kreakie, J. W. Hollister, and S. S. Qian, "Rethinking the lake trophic state index," *PeerJ*, **2019**, *7*, Art.no.e7936.
44. T. R. Kumaraswamy, S. Javeed, M. Javaid and K. Naika, “Impact of pollution on quality of freshwater ecosystems”, in “Fresh Water Pollution Dynamics and Remediation” (Ed. H. Qadri, R. A. Bhat, M. A. Mehmood and G. H. Dar), Springer Nature Singapore, Singapore, **2019**, pp.69-81.
45. H. Al-Sheikh and A. A. Fathi, “Ecological studies on Lake Al-Asfar (Al-Hassa, Saudi Arabia) with special references to the sediment”, *Res. J. Environ. Sci.*, **2010**, *4*, 13-22.
46. F. Giomi, A. Barausse, A. Steckbauer, D. Daffonchio, C. M. Duarte and M. Fusi, “Oxygen dynamics in marine productive ecosystems at ecologically relevant scales”, *Nat. Geosci.*, **2023**, *16*, 560-566.
47. W. Xiong, X. Huang, Y. Chen, R. Fu, X. Du, X. Chen and A. Zhan, “Zooplankton biodiversity monitoring in polluted freshwater ecosystems: A technical review”, *Environ. Sci. Ecotechnol.*, **2020**, *1*, Art.no.100008.
48. W. Xiong, P. Ni, Y. Chen, Y. Gao, B. Shan and A. Zhan, “Zooplankton community structure along a pollution gradient at fine geographical scales in river ecosystems: The importance of species sorting over dispersal”, *Mol. Ecol.*, **2017**, *26*, 4351-4360.
49. W. C. Wang, S. Sun, X. X. Sun, G. T. Zhang and F. Zhang, “Spatial patterns of zooplankton size structure in relation to environmental factors in Jiaozhou Bay, South Yellow Sea”, *Mar. Pollut. Bull.*, **2020**, *150*, Art.no.110698.
50. J. Yin, J. Xia, Z. Xia, W. Cai, Z. Liu, K. Xu, Y. Wang, R. Zhang and X. Dong, “Temporal variation and spatial distribution in the water environment helps explain seasonal dynamics of zooplankton in river-type reservoir”, *Sustainability.*, **2022**, *14*, Art.no.13719.
51. A. M. Youssef, M. A. Al-Fredan and A. A. Fathi, “Floristic composition of lake Al-Asfar, Alahsa, Saudi Arabia”, *Int. J. Bot.*, **2009**, *5*, 116-125.
52. T. Nandy and S. Mandal, “Unravelling the spatio-temporal variation of zooplankton community from the river Matla in the Sundarbans Estuarine system, India”, *Oceanologia*, **2020**, *62*, 326-346.

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53. C. Zhang, Z. Zhu, M. Špoljar, N. Kuczyńska-Kippen, T. Dražina, M. Cvetnić and M. Mleczek, "Ecosystem models indicate zooplankton biomass response to nutrient input and climate warming is related to lake size", *Ecol. Model.*, **2022**, *464*, Art.no.109837.
54. M. P. Hébert, B. E. Beisner and R. Maranger, "A meta analysis of zooplankton functional traits influencing ecosystem function", *Ecology*, **2016**, *97*, 1069-1080.
55. D.-P. Häder, A. T. Banaszak, V. E. Villafañe, M. A. Narvarte, R. A. González and E. W. Helbling, "Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications", *Sci. Total Environ.*, **2020**, *713*, Art.no.136586.
56. L. Hare and J. C. H. Carter, "Zooplankton populations and the diets of three *Chaoborus* species (Diptera, Chaoboridae) in a tropical lake", *Freshwater Biol.*, **1987**, *17*, 275-290.
57. K. D. Dickerson, K. A. Medley and J. E. Havel, "Spatial variation in zooplankton community structure is related to hydrologic flow units in the Missouri River, USA", *River Res. Appl..*, **2010**, *26*, 605-618.