Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 53, No. 4 December 2024
pages (396-409)

sciendo

ISSN 1730-413X
eISSN 1897-3191

Driving factors affecting zooplankton functional groups in a shallow eutrophic lake

by

Bura Uğur Sorguç[1,*] (ORCID: https://orcid.org/0000-0001-9995-0441),
Fatma Yıldız Demirkalp[1] (ORCID: https://orcid.org/0000-0003-3788-9387),
Yasemin Saygı[1,2] (ORCID: https://orcid.org/0000-0001-8007-9158)

DOI: **https://doi.org/10.26881/oahs-2024.4.07**
Category: **Original research paper**
Received: **May 14, 2024**
Accepted: **July 23, 2024**

[1]*Biology Department, Faculty of Science, Hacettepe University, 06800 Ankara, Türkiye*

[2]*Hacettepe University, Biological Diversity Advanced Research Center (HUBIOM), 06800 Ankara, Türkiye*

* Corresponding author: *bugrasorguc@gmail.com*

Abstract

The important role of zooplankton in linking different trophic levels has been the subject of extensive research, highlighting their crucial contribution to aquatic ecosystems and energy flow. Classification of organisms into functional groups using a method that combines taxonomic assessments with direct functional measurements is very effective in understanding their interactions with the environment. Our objective was to determine the seasonal changes of zooplankton in Lake Yeniçağa using zooplankton functional groups. A total of 19 zooplankton species were identified in the lake and classified into six functional groups. Medium-sized cladoceran and copepod carnivorous feeders (MCC) accounted for 45.74% of all functional groups and were the dominant group in the lake. Throughout the year, medium and large zooplankton generally dominated in the lake, with smaller functional groups briefly dominating in spring and autumn. Statistical analysis indicates that medium-sized cladoceran and copepod filter feeders (MCF) and large-sized cladoceran and copepod filter feeders (LCF) showed a positive relationship with Secchi depth and a negative relationship with chlorophyll a. Other groups exhibited relatively lower correlations with environmental parameters. It can be concluded that the observed seasonal changes in these groups are affected not only by environmental parameters, but also by the availability of food resources.

Key words: functional groups, zooplankton, biomass, Lake Yeniçağa, eutrophication

online at www.oandhs.ug.edu.pl

1. Introduction

Since the early days of mankind's history, human populations have impacted lake ecosystems for numerous reasons (Bradshaw et al. 2005; Søndergaard, Jeppesen 2007). One major consequence of this impact is eutrophication, which is the deterioration of water quality due to excessive enrichment with nutrients (Bennett et al. 2001). The nutrients that contribute most to eutrophication are phosphorus and nitrogen (Anderson et al. 2002). In freshwater, these two nutrients are essential substances for photosynthetic organisms and act as limiting factors for the growth of these organisms (Schindler 1977; Lewis, Wurtsbaugh 2008). The most common problems that eutrophication can cause in a lake ecosystem is excessive growth of phytoplanktic organisms, followed by increased turbidity and deoxygenation of the water (Schindler et al. 2008). In addition, phytoplankton organisms, which become abundant as eutrophication increases, can affect the abundance, biomass and structure of zooplankton communities (McCauley, Kalff 1981; Chislock et al. 2013; Ger et al. 2014).

Zooplankton are microscopic heterotrophic organisms that play a critical role in the trophic interactions of aquatic ecosystems. They are a crucial link in the pelagic food web, transferring energy and materials from primary producers to higher trophic levels (Hairston, Hairston 1993; Hébert et al. 2016). Zooplankton are sensitive to various biological and physicochemical parameters, making them effective indicators of environmental change. They are highly responsive to changes in water levels, toxic chemicals, climate change, and shifts in the trophic level of water (Hanazato 2001; Jeppesen et al. 2011; Litchman et al. 2013; Ochocka, Pasztaleniec 2016). The importance of zooplankton as a link between primary production and higher trophic levels is one of the biggest motivations for zooplankton research (John et al. 2001).

Freshwater zooplankton research has traditionally focused on classifying organisms into taxonomic groups (Barnett et al. 2007). However, this approach struggles to capture the complex dynamics of entire ecosystems. To address this, researchers have proposed a shift toward trait-based approaches (Litchman et al. 2013). One effective technique within this framework involves classifying aquatic organisms into functional groups based on their interactions with the environment (Hébert et al. 2016; Krztoń, Kosiba 2020). These groups are created by linking traditional taxonomic classifications with direct measurements of an organism's function (Pomerleau et al. 2015). Functional traits, which can be morphological, physiological, or behavioral characteristics are then identified through these measurements of functions (Litchman et al. 2013). This shift in perspective provides a more comprehensive view of how zooplankton communities function in freshwater ecosystems (Fintelman-Oliveira et al. 2023).

Lake Yeniçağa is a shallow and eutrophic freshwater lake considered one of the important wetlands in Turkey due to the presence of many bird species and plant taxa. The catchment area of the lake is classified as a high biodiversity habitat and a threatened natural habitat according to the criteria of Important Plant Areas in Turkey (Saygı, Demirkalp 2004). Furthermore, the catchment area connected to the lake has one of the largest peatlands in Turkey, with a depth of 2 m (Evrendilek et al. 2011). Lake Yeniçağa is a potential candidate for the Ramsar Convention on Wetlands due to its diversity of plants and birds (Saygı, Demirkalp 2004).

The pioneering research on functional traits of zooplankton is attributed to Bogdan & Gilbert (1984), and the number of studies based on this approach increased in the 2000s, covering many inland waters throughout the world (Sun et al. 2010; Ma et al. 2019; Wang et al. 2022). However, only two studies have been conducted on functional groups of zooplankton in Turkey. These studies were conducted in a river ecosystem and in a eutrophic shallow wetland (Tavsanoglu, Akbulut 2019; Dorak et al. 2023). Previous studies of zooplankton in Lake Yeniçağa primarily focused on zooplankton abundance and species composition (Saygı 2005; Saygı, Yiğit 2005). No studies have been conducted to investigate the relationship between eutrophication parameters and zooplankton biomass in the lake, nor have any studies been conducted on zooplankton functional groups. Therefore, in order to elucidate the functional dynamics of the Lake Yeniçağa ecosystem, we investigated the structure of the zooplankton community by classifying functional groups and analyzing the environmental parameters affecting these groups. We hypothesized that seasonal changes in zooplankton functional groups could be explained by environmental parameters. Zooplankton were sampled in the same time series, focusing on six different functional groups defined by their size and feeding behavior. The results of this study may serve as a pioneering reference for future research aimed at preventing further deterioration of the ecological environment of Lake Yeniçağa.

2. Materials and methods

2.1. Study area

Lake Yeniçağa (40°47′N; 32°01′E) is a tectonic, eutrophic, shallow lake with a maximum depth of 6 m (average depth of about 3.8 m). It is located 991 m above sea level and has a surface area of 1800 ha (Saygı et al. 2023). The lake is mainly fed by two streams (Deliler and Kuzuviran), as well as annual rainfall, spring water, municipal waterworks and artesian wells that discharge into the lake through streams or surface drainage (Saygı, Yiğit 2012). For most of the year, the lake is subject to massive cyanobacterial blooms (Kılınç 2003; Saygı, Demirkalp 2004; Saygı, Yiğit 2012). The phytoplankton of the limnetic zone of Lake Yeniçağa consists mainly of Cyanobacteria, Dinoflagellata and Bacillariophyta (Kılınç 2003). A total of four fish species have been identified in the lake during research carried out so far. These are *Cyprinus carpio*, *Carassius gibelio*, *Squalius cephalus* and *Tinca tinca* from the Cyprinidae family. In recent years, high abundance of *C. carpio* and *S. cephalus* has been reported (Zengin et al. 2021). Due to cyanobacterial blooms, especially in the summer months (personal communication, unpublished data), fish mortality is observed in the lake. The lake is under threat from human activities, including excessive expansion of residential areas and drainage of agricultural areas. The main threats to the lake are domestic, urban and industrial wastewater discharges, agricultural activities and eutrophication.

2.2. Sampling design and data collection

The study was conducted in the limnetic zone of Lake Yeniçağa, which lacks vegetation. Three sampling sites were selected: site 1 located at a distance of 100 m from the main stream inlet, site 3 located 100 m from the sewage outfall, and site 2 located in the middle of the lake (Fig. 1). Samples were collected

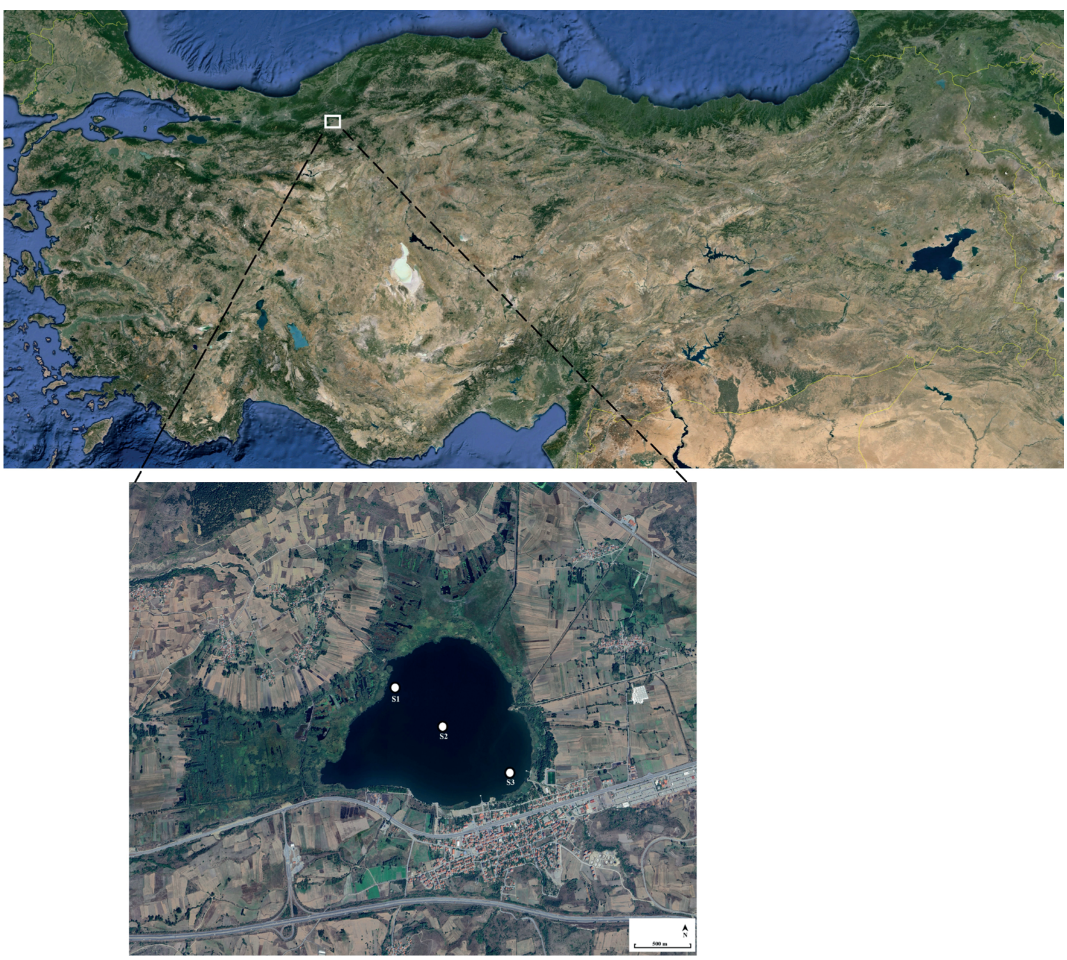

Figure 1

Locations of the sampling sites where field studies were carried out in Lake Yeniçağa. Site 1: 40°46′59.952″N; 32°1′11.496″E; Site 2: 40°46′50.664″N; 32°1′32.987″E; Site 3: 40°46′37.848″N; 32°2′2.184″E.

monthly from December 2021 to November 2022, excluding winter 2022 (January and February) due to the completely ice-covered lake surface. Zooplankton samples were collected at each sampling site using a plankton net with a mesh size of 30 µm (HYDRO-BIOS, Althengolz, Germany). Samples were obtained by filtering 100 l of water samples and concentrated to 50 ml through the plankton net. The concentrated zooplankton samples were gently preserved with a 4% (v/v) formaldehyde solution. A Leica DMR imaging microscope (Wetzlar, Germany) equipped with a camera was used to count, identify and measure zooplankton. Identification of zooplankton species was performed to the lowest taxonomic level according to the following sources: Koste (1978), Negrea (1983), Dussart & Defaye (2001). Zooplankton counts were carried out in triplicate from 1 ml subsamples using a Sedgewick Rafter counting cell to determine abundance. Zooplankton length and volume were used to calculate biomass. At least 30 individuals of all taxa were measured to estimate zooplankton biomass (Bottrell et al. 1976; Telesh et al. 2009; Błędzki, Rybak 2016). Biomass estimation was performed using the methods outlined by Dumont et al. (1975), Bottrell et al. (1976) and Ejsmont-Karabin (1998).

Zooplankton functional groups were classified based on feeding behavior and size spectrum using the method described by Sun et al. (2010), Ma et al. (2019) and Wang et al. (2022). According to this method, the zooplankton of Lake Yeniçağa were classified into six functional groups. These six groups are rotifer filter feeders (RF), rotifer carnivorous feeders (RC), small-sized cladoceran and copepod filter feeders (SCF), medium-sized cladoceran and copepod filter feeders (MCF), medium-sized cladoceran and copepod carnivorous feeders (MCC), and large-sized cladoceran and copepod filter feeders (LCF). While rotifers were classified based solely on their feeding behavior, cladocerans and copepods were classified based on both their feeding behavior and size spectrum. Cladocerans and copepods with a body length < 0.7 mm were classified as small, 0.7 – 1.5 mm as medium, and > 1.5 mm as large (Table 1). In addition, the guild ratio (GR’) was calculated to assess the feeding strategies of rotifers. GR’ was calculated as follows: GR’ = (raptorial biomass – microphagous biomass) / total rotifer biomass, and its value ranges between –1 and +1. Positive values indicate a predominance of raptorial feeders, while negative values indicate a predominance of microphagous feeders (Obertegger et al. 2011; Tavsanoglu, Akbulut 2019; Dorak et al. 2023).

Water temperature (°C), dissolved oxygen (mg l^{-1}), electrical conductivity (µS cm^{-1}) and pH were measured in situ using a portable multiparametric analyzer (YSI Proplus, USA). A Secchi Disk (SD) was used to measure water transparency. Turbidity was measured using an ORION AQ3010 turbidimeter. Water samples were collected from each site at depths of 0, 2, 4 m of the water column using a 2 l Hydro-Bios Ruttner water sampler for both chlorophyll *a* and chemical analyses. Total Nitrogen (TN) (mg l^{-1}) and Total Phosphorus (TP) (mg l^{-1}) were measured according to the standard methods: 4500 NO2-B, 4500-Norg-B, 4500P-B and 4500PE (Apha 1992). Chlorophyll *a* (µg l^{-1}) was determined according to Marker (1994). The trophic status of Lake Yeniçağa was determined based on Carlson’s Trophic State Index (Carlson 1977).

2.3. Statistical analysis

The dominant taxa of the zooplankton fauna were calculated according to the formula: D = (ni/N) x 100, where N is the abundance of zooplankton and ni is the species abundance. The following ranges were adopted: > 10% for eudominant, 5.1–10% for dominant, and 2.1 – 5% for subdominant species (Paturej et al. 2017). To test seasonal variations in zooplankton biomass and environmental parameters, one-way analysis of variance (ANOVA) with Bonferroni correction was applied to the data set. The relationship between the environmental parameters and zooplankton biomass values was analyzed using Pearson correlation analysis. In addition, correlation analysis was used to determine food competition between zooplankton functional groups. Before statistical analyses, all variables were tested for normality (Kolmogorov–Smirnov test), homogeneity (Levene’s test). All data were then transformed to log (x+1) to ensure normality (Zar 2010).

The effects of limnological conditions on the seasonal distribution of biological data (zooplankton functional groups) were determined using the ordination method in R Statistical Software (v4.3.2) and the ‘vegan’ package (Oksanen et al. 2024). To determine the most suitable analysis for the data set, DCA (Detrended Correspondence Analysis) was applied first. Axis length values obtained from DCA analysis are < 4. According to Jongman et al. (1995), if the axis length is shorter than 4, RDA (Redundancy Analysis) should be applied to the data set. A Monte Carlo permutation test (999 unrestricted permutations) was used to identify significantly correlated environmental variables ($p < 0.05$). Multicollinearity of variables was assessed using the variance inflation factor (VIF < 10). The significance of the RDA axes was assessed through permutation analyses, and statistical significance was determined at $p < 0.05$.

Journal owner: Faculty of Oceanography and Geography, University of Gdańsk, Poland

Table 1

Functional classification of zooplankton species in Lake Yeniçağa.

Functional group	Abbreviation	Feeding habits	Body size	Species
Rotifer carnivorous feeders	RC	Raptorial feeding, feeding on bacteria, phytoplankton, protozoan, other rotifers and small crustaceans	< 0.7 mm	*Asplanchna priodonta*, *Polyarthra vulgaris*, *Synchaeta pectinata*, *Trichocerca pusilla*,
Rotifer filter feeders	RF	Filter feeding, feeding on bacteria, phytoplankton and organic detritus	< 0.7 mm	*Brachionus calyciflorus*, *Brachionus urceolaris*, *Filinia longiseta*, *Keratella quadrata*, *Lepadella patella*, *Notholca acuminata*, *Notholca squamula*, *Testudinella patina*
Small-sized cladoceran and copepod filter feeders	SCF	Filter feeding, feeding on bacteria, phytoplankton, organic detritus and protozoans	< 0.7 mm	*Ceriodaphnia dubia*, *Diaphonosoma brachyurum*, *Eucyclops serrulatus*, Copepodit, Nauplii
Medium cladoceran and copepod filter feeders	MCF	Filter feeding, feeding on bacteria, phytoplankton, organic detritus and protozoans	0.7–1.5 mm	*Daphnia pulex*
Large-sized cladoceran and copepod filter feeders	LCF	Filter feeding, feeding on bacteria, phytoplankton, organic detritus and protozoans	> 1.5 mm	*Daphnia magna*
Medium-sized cladoceran and copepod carnivorous feeders	MCC	Raptorial feeding, feeding on rotifers, cladocerans, Diptera (Chironomidae larvae) and Oligochaeta	0.7–1.5 mm	*Acanthodiaptomus denticornis*, *Cyclops strenuus*

3. Results

3.1. Environmental parameters

Environmental parameters measured in the lake showed significant monthly variations during the sampling period, and the values are presented in Table 2. Variations in all environmental variables were found to be statistically significant by month (ANOVA, $p < 0.05$). Water temperature values recorded during the study varied between 2.5°C and 25.0°C. No permanent temperature stratification was observed between the surface and bottom. However, in the summer months, temperature differences between the surface and the bottom occasionally resulted in non-permanent stratification. Furthermore, the low temperatures observed in the lake during the winter months resulted in the lake surface being completely covered with ice in January and February. The pH values ranged from a minimum of 7.3 to a maximum of 8.8. In terms of pH values, the lake exhibited slightly alkaline characteristics. Dissolved oxygen concentration measured in the water column varied between 0.5 mg l^{-1} and 15.2 mg l^{-1} throughout the year, dropping below 1 mg l^{-1} at the bottom during the summer months. Electrical conductivity varied between 294 µS cm^{-1} and 678 µS cm^{-1}.

Table 2

Environmental parameters of Lake Yeniçağa between December 2021 and November 2022.

	Unit	December	March	April	May	June	July	August	September	October	November	P value
Temperature	°C	6.9 ± 0.1	2.9 ± 0.1	10.9 ± 0.3	16.7 ± 0.6	21.5 ± 0.1	21.3 ± 0.3	23.4 ± 0.1	17.3 ± 0.1	15.0 ± 0.2	11.0 ± 0.4	.00
pH		8.0 ± 0.2	8.1 ± 0.1	8.1 ± 0.1	8.0 ± 0.4	7.9 ± 0.2	7.9 ± 0.1	8.3 ± 0.0	8.7 ± 0.1	8.6 ± 0.1	8.4 ± 0.1	.00
Dissolved oxygen	mg l^{-1}	10.1 ± 0.3	9.3 ± 0.8	13.4 ± 0.6	8.4 ± 0.6	7.7 ± 1.0	6.8 ± 0.7	7.9 ± 0.8	12.0 ± 1.7	11.9 ± 0.7	10.7 ± 1.2	.00
Electrical conductivity	µS cm^{-1}	579.2 ± 81.0	353.3 ± 54.1	438.3 ± 2.9	510.7 ± 4.2	668.3 ± 2.5	605.3 ± 9.8	627.7 ± 2.9	554.7 ± 3.5	503.7 ± 2.1	460.0 ± 3.6	.00
Secchi depth	cm	68 ± 7.63	133 ± 2.88	115 ± 0	257 ± 70.76	293 ± 11.54	300 ± 0.00	83 ± 7.63	60 ± 18.02	215 ± 8.66	110 ± 15.00	.00
Turbidity	NTU	8.12 ± 0.86	4.12 ± 0.24	7.21 ± 2.89	1.83 ± 1.09	1.17 ± 0.08	2.55 ± 1.19	6.06 ± 0.71	41.53 ± 16.45	2.57 ± 0.22	6.74 ± 0.71	.00
Chlorophyll *a*	µg l^{-1}	59.32 ± 1.50	32.10 ± 2.37	35.92 ± 3.58	32.47 ± 3.23	15.00 ± 0.46	17.27 ± 0.51	45.34 ± 1.00	114.44 ± 52.30	24.87 ± 3.70	43.79 ± 7.26	.00
Total nitrogen	mg l^{-1}	0.60 ± 0.17	1.27 ± 0.05	1.29 ± 0.13	1.45 ± 0.65	1.20 ± 0.20	1.99 ± 0.24	1.02 ± 0.57	0.09 ± 0.07	0.17 ± 0.04	0.79 ± 0.20	.00
Total phosphorus		0.16 ± 0.03	0.18 ± 0.07	0.15 ± 0.00	0.16 ± 0.01	0.22 ± 0.06	0.22 ± 0.02	0.31 ± 0.01	0.15 ± 0.05	0.16 ± 0.01	0.14 ± 0.01	.00
TN:TP		3.67 ± 1.25	7.17 ± 4.20	8.60 ± 0.88	9.26 ± 4.66	5.36 ± 2.20	9.17 ± 0.17	3.30 ± 1.86	0.60 ± 0.45	1.07 ± 0.25	5.63 ± 1.75	.00

All environmental parameters showed significant seasonal variation according to one-way ANOVA test.

Secchi depth varied between 45 cm and 300 cm, with an annual mean of 164 cm. Turbidity values ranged from 1.14 NTU to 59.75 NTU throughout the year, and it was determined that the lake was moderately turbid with a value of 8.19 NTU. The mean chlorophyll *a* value measured in the lake was 42.06 μg l^{-1}, the mean total nitrogen value was 0.98 mg l^{-1}, and the mean total phosphorus value was 0.18 mg l^{-1}. To determine which nutrient limits phytoplankton growth in the lake, the TN:TP ratio was calculated, yielding a mean ratio of 5.36. Lake Yeniçağa was classified as eutrophic according to Carlson's Trophic State Index (Carlson 1977), ranging from 57.23 to 77.10 throughout the year with an annual average of 65.65 (Fig. 2).

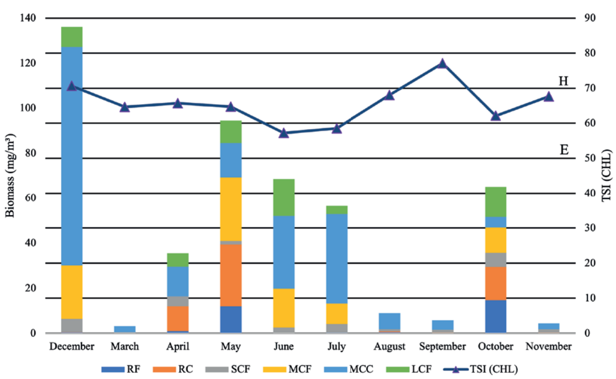

Figure 2

Monthly changes in biomass of Lake Yeniçağa zooplankton functional groups and TSI(CHL) index (abbreviations: H – hypertrophic state; E – eutrophic state).

3.2. Zooplankton functional groups

A total of 19 zooplankton taxa were identified, including 12 taxa of Rotifera, four taxa of Cladocera, three taxa of Copepoda, and larval stages of copepods (copepodites and nauplii). Significant seasonal fluctuations in species biomass were observed in the lake. *Acanthodiaptomus denticornis*, the only calanoid copepod in the lake, accounted for the largest contribution to the total zooplankton biomass, at 38.32%. Another copepod species, the cyclopoid copepod *Cyclops strenuus*, contributed 7.43% to the total biomass. *Daphnia pulex* and *Daphnia magna*, which have a significant impact on the total biomass, contributed 18.67% and 12.21%, respectively. The biomass of Rotifera in the lake showed lower values compared to other groups due to their small size. The species with the highest biomass value in this group was *Asplanchna priodonta*, and the biomass of this species accounted for 5.77% of the total biomass (Table 3).

The total biomass of zooplankton in the lake was distributed among six functional groups: the RF group accounted for 6.14% of the total biomass, the RC group for 11.22%, the SCF group for 5.98%, the MCF group for 18.67%, the MCC group for 45.74% and the LCF group for 12.21% (Fig. 3). The biomass of zooplankton functional groups showed significant variations throughout the year. In winter, the zooplankton community was dominated by the MCC group, which exhibited the highest biomass. However, this dominance was subsequently reduced in the spring as other groups emerged. By summer, the MCC group was again the most dominant group. The second most dominant group, MCF, also demonstrated seasonal fluctuations. Its biomass peaked in May, but then declined as the summer progressed. However, it increased again in October (Fig. 2). Figure 2 shows the relationship between Carlson's TSI, which is used to determine the trophic level, and the biomass of zooplankton functional groups (Carlson 1977).

Table 3

Results for zooplankton biomass dominance in Lake Yeniçağa.

Species	Functional Group	Dominance (%)
Asplanchna priodonta	RC	5.77
Polyarthra vulgaris	RC	0.4
Synchaeta pectinata	RC	1.98
Trichocerca pusilla	RC	4.53
Brachionus calyciflorus	RF	0.68
Brachionus urceolaris	RF	2.68
Filinia longiseta	RF	0.02
Keratella quadrata	RF	2.74
Lepadella patella	RF	0.01
Notholca acuminata	RF	0.01
Notholca squamula	RF	0.01
Testudinella patina	RF	0.01
Ceriodaphnia dubia	SCF	0.71
Diaphonosoma brachyurum	SCF	0.43
Eucyclops serrulatus	SCF	0.01
Copepodit	SCF	0.97
Nauplii	SCF	3.87
Daphnia pulex	MCF	18.67
Daphnia magna	LCF	12.21
Acanthodiaptomus denticornis	MCC	38.32
Cyclops strenuus	MCC	7.43

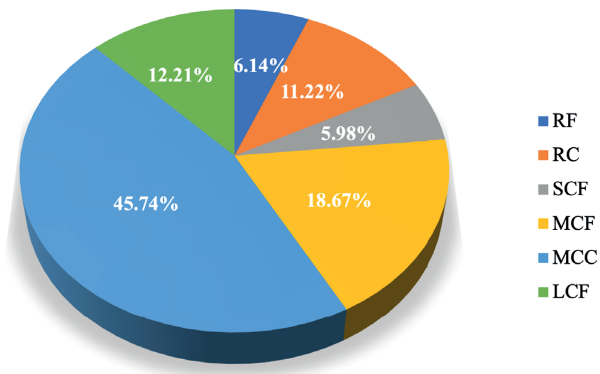

Figure 3

Distribution of zooplankton biomass among zooplankton functional groups in Lake Yeniçağa.

GR′ values showed significant fluctuations throughout the year, ranging from a minimum of −1 in July to a maximum of 0.736 in April (ANOVA, F = 2.902, $p < 0.05$). GR′ values were below zero in all months except April and May (Fig. 4).

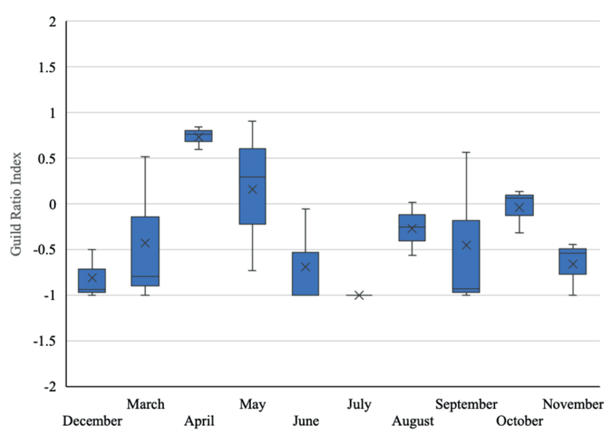

Figure 4

Guild ratio (mean ± SD) of the Rotifera group in Lake Yeniçağa.

3.3. Correlation analysis between environmental parameters and zooplankton functional groups

According to the correlation analysis between zooplankton functional groups and environmental parameters determined in the lake, pH was negatively correlated with MCF (r= −0.360), MCC (r = −0.330), and LCF (r = −0.389). Dissolved oxygen was positively correlated with RC (r = 0.364) and negatively correlated with MCF (r = −0.348). Electrical conductivity was positively correlated with MCF (r = 0.424). Secchi depth showed a positive correlation with MCF (r = 0.582) and LCF (r = 0.366), whereas turbidity and chlorophyll *a* showed a negative correlation with MCF (r = −0.591 and r = −0.470, respectively) and LCF (r = −0.389 and r = −0.386, respectively; Table 4).

Table 4

Pearson correlation analysis of zooplankton functional group biomass and environmental parameters in Lake Yeniçağa. Significant correlations ($p < 0.05$) are indicated in bold.

	RF	RC	SCF	MCF	MCC	LCF
Temperature	0.264	0.096	0.219	0.248	0.048	0.164
pH	0.131	0.177	−0.052	**−0.360**	**−0.330**	**−0.389**
Dissolved Oxygen	0.276	**0.364**	0.273	**−0.348**	−0.024	−0.122
Electrical Conductivity	0.028	−0.164	0.320	**0.424**	0.216	0.200
Secchi Depth	0.114	0.116	0.187	**0.582**	0.196	**0.366**
Turbidity	−0.113	−0.170	−0.131	**−0.591**	−0.130	**−0.389**
Chlorophyll *a*	−0.123	−0.184	−0.172	**−0.470**	−0.140	**−0.386**
Total Nitrogen	−0.211	−0.132	−0.139	0.088	0.220	0.082
Total Phosphorus	−0.230	−0.180	−0.206	−0.054	−0.541	0.001

Correlation analysis between different functional groups revealed a positive correlation between the RF group and the RC (r = 0.731) and SCF (r = 0.381) groups. Furthermore, the SCF group was positively correlated with all groups except the RC group. The MCF group was positively correlated with the SCF (r = 0.555), MCC (r = 0.469), and LCF (r = 0.617) groups. Similarly, the MCC group was positively correlated with SCF (r = 0.605), MCF, and LCF (r = 0.401), while the LCF group was positively correlated with SCF (r = 0.433), MCF, and MCC (Table 5).

Table 5

Pearson correlation analysis between the biomass of zooplankton functional groups. Significant correlations ($p < 0.05$) are indicated in bold.

	RF	RC	SCF	MCF	MCC	LCF
RF	1					
RC	**0.731**	1				
SCF	**0.381**	0.202	1			
MCF	0.312	0.130	**0.556**	1		
MCC	0.050	0.038	**0.605**	**0.470**	1	
LCF	0.314	0.163	**0.433**	**0.617**	**0.401**	1

3.4. RDA analysis of zooplankton functional groups with environmental parameters

The variables in the RDA analysis explained 58.45% of the total variability. In addition, a permutation test was applied to the correlations between species and environmental parameters, which revealed that pH, dissolved oxygen, Secchi depth, and chlorophyll *a* were significant ($p < 0.05$; Table 6). The analysis indicated that the SCF, MCF, MCC, and LCF groups were positively correlated with Secchi depth and negatively correlated with chlorophyll *a*, pH, and dissolved oxygen. However, the RF and RC groups showed no significant correlation with the determined parameters (Fig. 5).

Table 6

Permutation test results for environmental parameters used in redundancy analysis.

	F	*p* value
Temperature	1.598	0.191
pH	5.190	0.007**
Dissolved Oxygen	2.951	0.037*
Electrical Conductivity	2.162	0.107
Secchi Depth	5.835	0.001***
Turbidity	2.132	0.110
Chlorophyll *a*	3.733	0.015*
Total Nitrogen	1.554	0.206
Total Phosphorus	0.773	0.490

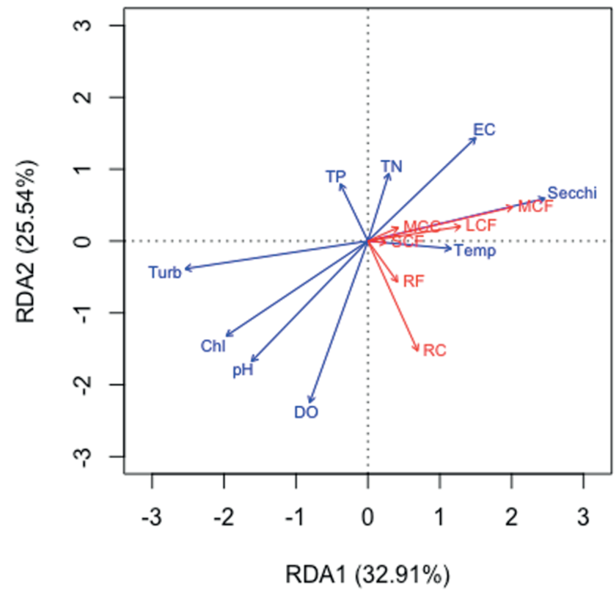

Figure 5

RDA results for biomass of zooplankton functional groups (Chl – Chlorophyll *a*; EC – Electrical Conductivity; DO – Dissolved Oxygen; Secchi – Secchi depth; Temp – temperature; TN – Total Nitrogen; TP – Total Phosphorus; Turb – turbidity; RF – rotifer filter feeders; RC – rotifer carnivorous feeders; SCF – small-sized cladoceran and copepod filter feeders; MCC – medium-sized cladoceran and copepod carnivorous feeders; MCF – medium-sized cladoceran and copepod filter feeders; LCF – large-sized cladoceran and copepod filter feeders).

The results of this study indicate that medium and large zooplankton functional groups generally dominated in the lake throughout the year. Statistical analyses for zooplankton functional groups and environmental parameters showed that MCF and LCF were positively correlated with Secchi depth and negatively correlated with chlorophyll *a*.

4. Discussion

Classification of zooplankton into groups based on functional traits allows researchers to gain a more comprehensive understanding of the relationship between zooplankton communities and the factors that shape their composition and function (Hébert et al. 2016; Krztoń, Kosiba 2020). This approach provides a more detailed explanation of how zooplankton communities function in freshwater ecosystems (Fintelman-Oliveira et al. 2023). In this study, zooplankton were classified into six functional groups (RF, RC, SCF, MCF, MCC, and LCF) and the relationship between these groups and environmental parameters in Lake Yeniçağa was evaluated.

The lake, which is under pressure from human activities, is threatened by domestic, urban and industrial waste throughout the year. To assess the trophic level of Lake Yeniçağa, Carlson's TSI was calculated based on the determined chlorophyll *a* concentrations. The index indicated that the lake exhibited hypertrophic characteristics in December and September, while it showed eutrophic status in the other months of the year (Fig. 2). Total nitrogen and total phosphorus concentrations are the primary factors affecting phytoplankton biomass in lakes, and these two nutrients are parameters that can be used to estimate trophic levels (Phillips et al. 2008). In lakes where nitrogen is the limiting nutrient, nitrogen is the more appropriate determinant of phytoplankton biomass, while in lakes where phosphorus is the limiting nutrient, phosphorus is the more appropriate determinant (Prairie et al. 1989). Consequently, in lakes where the ratio of total nitrogen to total phosphorus is greater than 17, phosphorus is the limiting nutrient.

In lakes where the ratio is between 10 and 17, both nitrogen and phosphorus act as limiting factors. In lakes where the ratio is below 10, nitrogen is the limiting nutrient (Sakamoto 1966). In Lake Yeniçağa, the mean annual TN:TP ratio was 5.36, indicating that nitrogen was the limiting nutrient in the lake. Lakes characterized by low TN:TP values tend to be dominated by cyanobacteria. This phenomenon can be attributed to the facilitation of nitrogen-fixing cyanobacteria growth under such conditions (Smith 1982; Vrede et al. 2009). Secchi depth values showed seasonal fluctuations, with low values observed in months with high chlorophyll *a* values. Cyanobacteria blooms were also observed in the lake during these months (unpublished data). Turbidity levels in Lake Yeniçağa indicated that the lake is moderately turbid with a mean annual value of 8.19 NTU (Table 2).

In eutrophic lakes, the zooplankton community is usually dominated by small cladocerans, copepods and rotifer species (Gliwicz, Lampert 1990; Gulati 1990; Ejsmont-Karabin 2012). In Lake Yeniçağa, however, medium- and large-sized groups such as MCC, MCF and LCF were the dominant groups in the total zooplankton biomass, while rotifers accounted for only 17.36% of the total zooplankton biomass (Fig. 3). In the presence of large filamentous algae, the lack of suitable nutrients for rotifers reduces the filtration rate and has a negative impact on their nutrition and life cycle (Karabin 1985; Gilbert, Durand 1990). Therefore, we concluded that the reason for the low biomass of rotifers is the dominance of large filamentous algae such as *Anabaena circinalis*, *Aulacoseira granulata* and *Aphanizomenon flos-aquae* (unpublished data). In lakes with higher trophic levels, there may be an increase in the proportion of species considered indicative of eutrophication, such as *Anuraeopsis fissa*, *Brachionus* spp, *Filinia longiseta*, *Keratella cochlearis*, *K. quadrata*, *Pompholyx sulcata*, *Trichocerca pusilla* (Ejsmont-Karabin 2012). In Lake Yeniçağa, *B. calyciflorus*, *B. urceolaris*, *F. longiseta, K. quadrata* and *T. pusilla* occurred among these species and accounted for 61.34% of the total rotifer biomass. Furthermore, the Rotifera group in the lake was dominated by the RF functional group, which consisted of microphagous species, except in April and May, and GR′ values were below zero (Fig. 4). Microphagous-feeding rotifers are generally more likely to thrive in environments with low nutrient quality and cyanobacterial blooms than raptorial-feeding species (Wen et al. 2017; Dorak et al. 2023). The negative GR′ values found in Lake Yeniçağa may be related to the trophic status of the lake. These results may indicate that although Rotifera biomass did not increase with eutrophication, the species composition and functional diversity of the group is directly related to the trophic status of the lake.

Significant seasonal fluctuations in the biomass of zooplankton functional groups were observed in Lake Yenicaga. Small size groups, including RF, RC and SCF, showed higher biomass values in spring and autumn and lower values in winter and summer. In contrast, the MCC group showed higher biomass values in winter and summer and lower values in spring and autumn. The MCF and LCF groups showed minimal changes between the summer and winter months. These groups peaked at different times throughout the year. Planktivorous fish typically prefer larger species over small crustaceans and rotifers as their primary food source. In lakes with a high abundance of planktivorous fish, the zooplankton community consists mainly of smaller species. Whereas, lakes lacking planktivorous fish tend to have a higher proportion of larger zooplankton species (Brooks, Dodson 1965; Henrikson et al. 1980; Wright, Shapiro 1984). In lakes, fish populations commonly face winter mortality due to various factors, such as thermal stress and starvation (Hurst 2007). A study conducted by Saygı et al. (2023) in parallel with this research revealed a decreased CPUE of bentho-planktivorous fish sampled in Lake Yeniçağa in winter and summer compared to spring and autumn. The decrease in predation pressure on zooplankton by fish in winter and summer seasons may have led to an increase in the abundance and biomass of the MCC group.

Pearson correlation analysis revealed that environmental parameters had the greatest impact on the MCF and LCF functional groups. They were affected by similar parameters, including pH, turbidity, chlorophyll *a*, and Secchi depth. However, dissolved oxygen and electrical conductivity only affected MCF. RF was not affected by any parameter, whereas the RC group was affected by dissolved oxygen, and MCC was only affected by pH. Of the environmental parameters, temperature, total nitrogen and total phosphorus were not correlated with any functional group ($p > 0.05$). These parameters, along with electrical conductivity and turbidity, were also found to be insignificant in the ordination analysis ($p > 0.05$; Table 6). In this study, temperature, which is typically one of the most important parameters affecting zooplankton functional groups, showed no significant correlation with any of the functional groups (Zhao et al. 2020; Dorak et al. 2023). This can be attributed to the heterogeneous nature of the zooplankton functional groups identified in Lake Yeniçağa, which are based on different species. These results indicate that MCF and LCF are more sensitive to environmental parameters than other groups.

The trophic state of Lake Yeniçağa, which exhibits characteristics between eutrophic and hypertrophic levels, is another factor affecting zooplankton functional groups (Duré et al. 2021; Goździejewska et al. 2021). Pearson correlation analysis showed that the functional groups MCF and LCF, consisting of *Daphnia* species, were significantly negatively correlated with chlorophyll *a* levels (Table 4). The RDA, conducted to examine the relationship between the functional groups and environmental parameters, showed that MCF and LCF were positively correlated with Secchi depth in the lake. Conversely, these groups were negatively correlated with chlorophyll *a*, pH, and dissolved oxygen, which were identified as significant parameters in the permutation test (Fig. 5). Phytoplankton, particularly cyanobacteria, form large colonies and produce toxins that can make it difficult for medium and large cladocerans, such as *Daphnia*, to consume food. These toxins can also reduce reproduction and growth parameters, causing stress in these organisms (Lampert 1987; Gliwicz 1990). Smaller filter-feeding cladocerans and copepods are less affected by these factors and are more common in ecosystems characterized by high trophic levels and dominance of cyanobacteria (Haney 1987; Kirk, Gilbert 1992; Tõnno et al. 2016). The ordination analysis revealed that MCF and LCF are significantly correlated with chlorophyll *a* and Secchi depth, parameters that, according to the existing literature, are used to determine the trophic level of lakes. SCF, consisting of smaller cladocerans and copepods, and MCC, consisting of copepods that have raptorial-feeding habits, did not show a strong relationship with these environmental parameters.

The correlation analysis for the zooplankton functional groups aimed to determine food competition and predation between zooplankton functional groups. The results show a positive correlation between all groups (Table 5). The high correlation between the RF and RC groups ($r = 0.731$) indicates that these groups are affected by the availability of the same food resources (Ma et al. 2019). It is known that the species in the RC group (*A. priodonta*, *P. vulgaris*, *S. pectinata*, *T. pusilla*) can also feed on bacteria and phytoplankton, in addition to rotifers and protozoans. These species can be considered macrophagous algivores (Stemberger 1979; Bogdan, Gilbert 1984; May et al. 2001; Gilbert 2022). It was found that the SCF group, 80.80% of which consisted of nauplii and copepodite stages of the copepod group, was significantly correlated with all functional groups except RC. Among the groups comprising medium to large organisms, the MCC, MCF, and LCF groups were correlated with each other. The positive correlation between SCF, MCC, MCF, and LCF indicates that species in these groups are affected by the availability of the same food resources (bottom-up effect of phytoplankton; Sommer et al. 2001; Ma et al. 2019). MCF and LCF groups, which consist of two different species from the same genus (*Daphnia pulex* and *Daphnia magna*), were expected to be affected by the availability of the same food resources (Lürling, Van Donk 1997; Yin et al. 2010). The species *Acanthodiaptomus denticornis* and *Cyclops strenuus*, which make up the MCC group, are not exclusively carnivorous and are known to feed on phytoplankton and bacteria. They can be considered as omnivorous species (Lair 1992; Makino, Ban 1998).

5. Conclusions

This study employed functional traits to classify zooplankton into functional groups, subsequently investigating the relationship between these groups and environmental parameters in eutrophic Lake Yeniçağa.

A total of 19 zooplankton taxa were identified, including 12 Rotifera, four Cladocera and three Copepoda, with *Acanthodiaptomus denticornis, Daphnia pulex, Daphnia magna,* and *Cyclops strenuus* being the dominant species. Zooplankton were classified into six functional groups: rotifer filter feeders (RF), rotifer carnivorous feeders (RC), small-sized cladoceran and copepod filter feeders (SCF), medium-sized cladoceran and copepod filter feeders (MCF), medium-sized cladoceran and copepod carnivorous feeders (MCC), and large-sized cladoceran and copepod filter feeder (LCF).

Environmental parameters in the lake showed significant monthly variations. The lake was found to be hypertrophic in December and September, and eutrophic for the rest of the year. Compared to other groups, the MCF and LCF groups were most affected by environmental parameters. Both Pearson correlation and ordination analyses showed that these groups were negatively correlated with chlorophyll *a* ($p < 0.05$). In addition, the negative GR′ values observed in all months except April and May may be a consequence of the eutrophic status of the lake.

Seasonal biomass patterns differed between the functional groups. The RF, RC, and SCF groups showed peaks in spring and autumn, with lower biomass in winter and summer. On the other hand, the MCC group showed higher biomass in winter and summer, and lower in spring and autumn. The MCF and LCF groups showed minimal variation in biomass between summer and winter.

The observed seasonal variations in the biomass of zooplankton functional groups may be due to different factors. The higher winter and summer biomass of the MCC group suggests a potential link to top-down control by fish predation, which may be less intense during these seasons. The MCF and LCF groups, on the other hand, may be affected primarily by environmental parameters and the trophic status of the lake. Finally, seasonal peaks of the RF, RC, and SCF groups could be driven by the availability of food resources.

Statements & Declarations

Funding: This study was conducted with financial support from the Hacettepe University Scientific Research Project Commission (Project No. FHD-2021-19615).

Competing Interests: The authors declare no competing interests.

References

Anderson, D. M., Glibert, P. M., & Burkholder, J. M. (2002). Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. *Estuaries, 25*, 704–726. https://doi.org/10.1007/BF02804901

APHA. (1992). Standard Methods for the Examination of Waters and Wastewaters (18th ed.). American Public Health Association.

Barnett, A. J., Finlay, K., & Beisner, B. E. (2007). Functional diversity of crustacean zooplankton communities: Towards a trait-based classification. *Freshwater Biology, 52*(5), 796–813. https://doi.org/10.1111/j.1365-2427.2007.01733.x

Bennett, E. M., Carpenter, S. R., & Caraco, N. F. (2001). Human impact on erodable phosphorus and eutrophication: A global perspective: Increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication. *Bioscience, 51*(3), 227–234. https://doi.org/10.1641/0006-3568(2001)051[0227:HIOEPA]2.0.CO;2

Błędzki, L. A., & Rybak, J. I. (2016). Freshwater Crustacean Zooplankton of Europe: Cladocera & Copepoda (Calanoida, Cyclopoida). Key to Species Identification, with Notes on Ecology, Distribution, Methods and Introduction to Data Analysis. Springer International Publishing. https://doi.org/10.1007/978-3-319-29871-9

Bogdan, K. G., & Gilbert, J. J. (1984). Body size and food size in freshwater zooplankton. *Proceedings of the National Academy of Sciences of the United States of America, 81*(20), 6427–6431. https://doi.org/10.1073/pnas.81.20.6427 PMID:16593521

Bottrell, H. H., Duncan, A., Gliwicz, Z., Grygierek, E., Herzig, A., Hilbricht-Ilkowska, A., Kurasawa, H., Larsson, P., & Weglenska, T. (1976). Review of some problems in zooplankton production studies. *Norwegian Journal of Zoology, 21*, 477–483.

Bradshaw, E. G., Rasmussen, P., & Odgaard, B. V. (2005). Mid-to late-Holocene land-use change and lake development at Dallund S0, Denmark: Synthesis of multiproxy data, linking land and lake. *The Holocene, 15*(8), 1152–1162. https://doi.org/10.1191/0959683605hl887rp

Brooks, J. L., & Dodson, S. I. (1965). Predation, body size, and composition of plankton. *Science, 150*(3692), 28–35. https://doi.org/10.1126/science.150.3692.28 PMID:17829740

Carlson, R. E. (1977). A trophic state index for lakes 1. *Limnology and Oceanography, 22*(2), 361–369. https://doi.org/10.4319/lo.1977.22.2.0361

Chislock, M. F., Doster, E., Zitomer, R. A., & Wilson, A. E. (2013). Eutrophication: Causes, consequences, and controls in aquatic ecosystems. *Nature Education Knowledge, 4*(4), 10.

Dorak, Z., Köker, L., Gürevin, C., & Saç, G. (2023). How do environmental variables affect the temporal dynamics of zooplankton functional groups in a hyper-eutrophic wetland? *Environmental Science and Pollution Research International, 30*(43), 97115–97127. https://doi.org/10.1007/s11356-023-29252-8 PMID:37587395

Dumont, H. J., Van de Velde, I., & Dumont, S. (1975). The dry weight estimate of biomass in a selection of Cladocera, Copepoda and Rotifera from the plankton, periphyton and benthos of continental waters. *Oecologia, 19*(1), 75–97. https://doi.org/10.1007/BF00377592 PMID:28308833

Duré, G. A. V., Simões, N. R., Braghin, L. D. S. M., & Ribeiro, S. M. M. S. (2021). Effect of eutrophication on the functional diversity of zooplankton in shallow ponds in Northeast Brazil. *Journal of Plankton Research, 43*(6), 894–907. https://doi.org/10.1093/plankt/fbab064

Dussart, B. H., & Defaye, D. (2001). Introduction to the Copepoda. Backhuys, Winschoten.

Ejsmont-Karabin, J. (1998). Empirical equations for biomass calculation of planktonic rotifers. *Polskie Archiwum Hydrobiologii*. *Polskie Archiwum Hydrobiologii, 45*(4), 513–522.

Evrendilek, F., Berberoglu, S., Karakaya, N., Cilek, A., Aslan, G., & Gungor, K. (2011). Historical spatiotemporal analysis of land-use/land-cover changes and carbon budget in a temperate peatland (Turkey) using remotely sensed data. *Applied Geography (Sevenoaks, England), 31*(3), 1166–1172. https://doi.org/10.1016/j.apgeog.2011.03.007

Fintelman-Oliveira, E., Kruk, C., Lacerot, G., Klippel, G., & Branco, C. W. C. (2023). Zooplankton functional groups in tropical reservoirs: Discriminating traits and environmental drivers. *Hydrobiologia, 850*(2), 365–384. https://doi.org/10.1007/s10750-022-05074-6

Ger, K. A., Hansson, L. A., & Lürling, M. (2014). Understanding cyanobacteria-zooplankton interactions in a more eutrophic world. *Freshwater Biology, 59*(9), 1783–1798. https://doi.org/10.1111/fwb.12393

Gilbert, J. J. (2022). Food niches of planktonic rotifers: Diversification and implications. *Limnology and Oceanography, 67*(10), 2218–2251. https://doi.org/10.1002/lno.12199

Gilbert, J. J., & Durand, M. W. (1990). Effect of *Anabaena flos-aquae* on the abilities of *Daphnia* and *Keratella* to feed and reproduce on unicellular algae. *Freshwater Biology, 24*(3), 577–596. https://doi.org/10.1111/j.1365-2427.1990.tb00734.x

Gliwicz, Z. M. (1990). Food thresholds and body size in cladocerans. *Nature, 343*(6259), 638–640. https://doi.org/10.1038/343638a0

Gliwicz, Z. M., & Lampert, W. (1990). Food thresholds in *Daphnia* species in the absence and presence of blue-green filaments. *Ecology, 71*(2), 691–702. https://doi.org/10.2307/1940323

Goździejewska, A. M., Koszałka, J., Tandyrak, R., Grochowska, J., & Parszuto, K. (2021). Functional responses of zooplankton communities to depth, trophic status, and ion content in mine pit lakes. *Hydrobiologia, 848*(11), 2699–2719. https://doi.org/10.1007/s10750-021-04590-1

Gulati, R. D. (1990). Structural and grazing responses of zooplankton community to biomanipulation of some Dutch water bodies. *Hydrobiologia, 200/201*, 99–118. https://doi.org/10.1007/BF02530332

Hairston, N. G., Jr., & Hairston, N. G., Sr. (1993). Cause-effect relationships in energy flow, trophic structure, and interspecific interactions. *American Naturalist, 142*(3), 379–411. https://doi.org/10.1086/285546

Hanazato, T. (2001). Pesticide effects on freshwater zooplankton: An ecological perspective. *Environmental Pollution, 112*(1), 1–10. https://doi.org/10.1016/S0269-7491(00)00110-X PMID:11202648

Haney, J. F. (1987). Field studies on zooplankton-cyanobacteria interactions. *New Zealand Journal of Marine and Freshwater Research, 21*(3), 467–475. https://doi.org/10.1080/00288330.1987.9516242

Hébert, M. P., Beisner, B. E., & Maranger, R. (2016). A meta-analysis of zooplankton functional traits influencing ecosystem function. *Ecology, 97*(4), 1069–1080. https://doi.org/10.1890/15-1084.1 PMID:27220222

Henrikson, L., Nyman, H. G., Oscarson, H. G., & Stenson, J. A. (1980). Trophic changes, without changes in the external nutrient loading. *Hydrobiologia, 68*(3), 257–263. https://doi.org/10.1007/BF00018835

Hurst, T. P. (2007). Causes and consequences of winter mortality in fishes. *Journal of Fish Biology, 71*(2), 315–345. https://doi.org/10.1111/j.1095-8649.2007.01596.x

Jeppesen, E., Kronvang, B., Olesen, J. E., Audet, J., Søndergaard, M., Hoffmann, C. C., Andersen, H. E., Lauridsen, T. L., Liboriussen, L., Larsen, S. E., Beklioglu, M., Meerhoff, M., Özen, A., & Özkan, K. (2011). Climate change effects on nitrogen loading from cultivated catchments in Europe: Implications for nitrogen retention, ecological state of lakes and adaptation. *Hydrobiologia, 663*(1), 1–21. https://doi.org/10.1007/s10750-010-0547-6

John, E. H., Batten, S. D., Harris, R. P., & Hays, G. C. (2001). Comparison between zooplankton data collected by the Continuous Plankton Recorder survey in the English Channel and by WP-2 nets at station L4, Plymouth (UK). *Journal of Sea Research, 46*(3-4), 223–232. https://doi.org/10.1016/S1385-1101(01)00085-5

Jongman, R. G. H., Braak, C. J. F., & Tongeren, O. F. R. (1995). Data Analysis in Community and Landscape Ecology. Cambridge University Press. https://doi.org/10.1017/CBO9780511525575

Karabin, A. (1985). Pelagic zooplankton (Rotatoria + Cladocera) variation in the process of lake eutrophication. I. Structural and quantitative features. *Ekologia Polska, 33*, 567–616.

Kılınç, S. (2003). The phytoplankton community of Yeniçaga Lake (Bolu, Turkey). *Nova Hedwigia, 76*(3-4), 429–442. https://doi.org/10.1127/0029-5035/2003/0076-0429

Kirk, K. L., & Gilbert, J. J. (1992). Variation in herbivore response to chemical defenses: Zooplankton foraging on toxic cyanobacteria. *Ecology, 73*(6), 2208–2217. https://doi.org/10.2307/1941468

Koste, W. (1978). *Rotatoria, die Rädertiere Mitteleuropas* (2nd ed.). Gebruder Borntraeger.

Krztoń, W., & Kosiba, J. (2020). Variations in zooplankton functional groups density in freshwater ecosystems exposed to cyanobacterial blooms. *The Science of the Total Environment, 730*, 139044. https://doi.org/10.1016/j.scitotenv.2020.139044 PMID:32402967

Lair, N. (1992). Daytime grazing and assimilation rates of planktonic copepods *Acanthodiaptomus denticornis* and *Cyclops vicinus vicinus*. Comparison of spatial and resource utilisation by rotifers and cladoceran communities in a eutrophic lake. *Hydrobiologia, 231*, 107–117. https://doi.org/10.1007/BF00006503

Lampert, W. (1987). Laboratory studies on zooplankton-cyanobacteria interactions. *New Zealand Journal of Marine and Freshwater Research, 21*(3), 483–490. https://doi.org/10.1080/00288330.1987.9516244

Lewis, W. M., Jr., & Wurtsbaugh, W. A. (2008). Control of lacustrine phytoplankton by nutrients: Erosion of the phosphorus paradigm. *International Review of Hydrobiology, 93*(4-5), 446–465. https://doi.org/10.1002/iroh.200811065

Litchman, E., Ohman, M. D., & Kiørboe, T. (2013). Trait-based approaches to zooplankton communities. *Journal of Plankton Research, 35*(3), 473–484. https://doi.org/10.1093/plankt/fbt019

Lürling, M., & Van Donk, E. (1997). Morphological changes in *Scenedesmus* induced by infochemicals released in situ from zooplankton grazers. *Limnology and Oceanography, 42*(4), 783–788. https://doi.org/10.4319/lo.1997.42.4.0783

Ma, C., Mwagona, P. C., Yu, H., Sun, X., Liang, L., Mahboob, S., & Al-Ghanim, K. A. (2019). Seasonal dynamics of zooplankton functional group and its relationship with physico-chemical variables in high turbid nutrient-rich Small Xingkai Wetland Lake, Northeast China. *Journal of Freshwater Ecology, 34*(1), 65–79. https://doi.org/10.1080/02705060.2018.1443847

Makino, W., & Ban, S. (1998). Diel changes in vertical overlap between *Cyclops strenuus* (Copepoda; Cyclopoida) and its prey in oligotrophic Lake Toya, Hokkaido, Japan. *Journal of Marine Systems, 15*(1-4), 139–148. https://doi.org/10.1016/S0924-7963(97)00073-0

Marker, A. F. H. (1994). Chlorophyll *a* SCA method revision (1st ed.). National Rivers Authority.

May, L., Bailey-Watts, A., & Kirika, A. (2001). The relationship between *Trichocerca pusilla* (Jennings), *Aulacoseira* spp. and water temperature in Loch Leven, Scotland, UK. *Hydrobiologia, 446/447*, 29–34. https://doi.org/10.1023/A:1017508719110

McCauley, E., & Kalff, J. (1981). Empirical relationships between phytoplankton and zooplankton biomass in lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 38*(4), 458–463. https://doi.org/10.1139/f81-063

Negrea, S. (1983). Cladocera. In Fauna R.S. *Romania, Academiei Bucuresti*, *4*(12), 399.

Obertegger, U., Smith, H. A., Flaim, G., & Wallace, R. L. (2011). Using the guild ratio to characterize pelagic rotifer communities. *Hydrobiologia, 662*(1), 157–162. https://doi.org/10.1007/s10750-010-0491-5

Ochocka, A., & Pasztaleniec, A. (2016). Sensitivity of plankton indices to lake trophic conditions. *Environmental Monitoring and Assessment, 188*(11), 1–16. https://doi.org/10.1007/s10661-016-5634-3 PMID:27752916

Oksanen, J., Simpson, G., Blanchet, F., Kindt, R., Legendre, P., Minchin, P., O'Hara, R., Solymos, P., Stevens, M., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., De Caceres, M., Durand, S., Evangelista, H., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., Hill, M., Lahti, L., McGlinn, D., Ouellette, M., Ribeiro Cunha, E., Smith, T., Stier, A., Ter Braak, C., & Weedon, J. (2024). Vegan: Community Ecology Package. R package version 2.6-7 [computer software].

Paturej, E., Gutkowska, A., Koszalka, J., & Bowszys, M. (2017). Effect of physicochemical parameters on zooplankton in the brackish, coastal Vistula Lagoon. *Oceanologia, 59*(1), 49–56. https://doi.org/10.1016/j.oceano.2016.08.001

Phillips, G., Pietiläinen, O. P., Carvalho, L., Solimini, A., Lyche Solheim, A., & Cardoso, A. C. (2008). Chlorophyll–nutrient relationships of different lake types using a large European dataset. *Aquatic Ecology, 42*(2), 213–226. https://doi.org/10.1007/s10452-008-9180-0

Pomerleau, C., Sastri, A. R., & Beisner, B. E. (2015). Evaluation of functional trait diversity for marine zooplankton communities in the Northeast subarctic Pacific Ocean. *Journal of Plankton Research, 37*(4), 712–726. https://doi.org/10.1093/plankt/fbv045

Prairie, Y. T., Duarte, C. M., & Kalff, J. (1989). Unifying nutrient–chlorophyll relationships in lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 46*(7), 1176–1182. https://doi.org/10.1139/f89-153

Sakamoto, M. (1966). Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. *Archiv für Hydrobiologie, 62*, 1–28.

Saygı Başbuğ, Y. (2005). Seasonal succession and distribution of zooplankton in Yeniçağa Lake in Northwestern Turkey. *Zoology in the Middle East, 34*(1), 93–100. https://doi.org/10.1080/09397140.2005.10638088

Saygı, Y. (2023). *Yeniçağa Gölündeki (Bolu) Zooplankton Biyokütlesinin Zamana Bağlı Değişimi*. Hacettepe University Scientific Research Project Commission, Ankara, Turkey (Report No. 19615).

Saygı, Y., & Demirkalp, F. Y. (2004). Trophic status of shallow Yeniçağa Lake (Bolu, Turkey) in relation to physical and chemical environment. *Fresenius Environmental Bulletin, 13*(5), 385–393.

Saygı, Y., & Yiğit, S. (2005). Rotifera community structure of Lake Yeniçağa, Turkey. *Journal of Freshwater Ecology, 20*(1), 197–199. https://doi.org/10.1080/02705060.2005.9664954

Saygı, Y., & Yiğit, S. A. (2012). Heavy metals in Yeniçağa Lake and its potential sources: Soil, water, sediment, and plankton. *Environmental Monitoring and Assessment, 184*(3), 1379–1389. https://doi.org/10.1007/s10661-011-2048-0 PMID:21494824

Schindler, D. W. (1977). Evolution of phosphorus limitation in lakes. *Science, 195*(4275), 260–262. https://doi.org/10.1126/science.195.4275.260 PMID:17787798

Schindler, D. W., Hecky, R. E., Findlay, D. L., Stainton, M. P., Parker, B. R., Paterson, M. J., Beaty, K. G., Lyng, M., & Kasian, S. E. M. (2008). Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. *Proceedings of the National Academy of Sciences of the United States of America, 105*(32), 11254–11258. https://doi.org/10.1073/pnas.0805108105 PMID:18667696

Smith, V. H. (1982). The nitrogen and phosphorus dependence of algal biomass in lakes: An empirical and theoretical analysis. *Limnology and Oceanography, 27*(6), 1101–1111. https://doi.org/10.4319/lo.1982.27.6.1101

Sommer, U., Sommer, F., Santer, B., Jamieson, C., Boersma, M., Becker, C., & Hansen, T. (2001). Complementary impact of copepods and cladocerans on phytoplankton. *Ecology Letters, 4*(6), 545–550. https://doi.org/10.1046/j.1461-0248.2001.00263.x

Søndergaard, M., & Jeppesen, E. (2007). Anthropogenic impacts on lake and stream ecosystems, and approaches to restoration. *Journal of Applied Ecology, 44*(6), 1089–1094. https://doi.org/10.1111/j.1365-2664.2007.01426.x

Stemberger, R. S. (1979). A guide to the rotifers of the Laurentian Great Lakes. Environmental Monitoring and Support Laboratory.

Sun, S., Huo, Y., & Yang, B. (2010). Zooplankton functional groups on the continental shelf of the yellow sea. *Deep-sea Research. Part II, Topical Studies in Oceanography, 57*(11-12), 1006–1016. https://doi.org/10.1016/j.dsr2.2010.02.002

Tavsanoglu, U. N., & Akbulut, N. E. (2019). Seasonal dynamics of riverine zooplankton functional groups in Turkey: Kocaçay Delta as a case study. *Turkish Journal of Fisheries and Aquatic Sciences, 20*(1), 69–77. https://doi.org/10.4194/1303-2712-v20_1_07

Telesh, I., Postel, L., Heerkloss, R., Mironova, E., & Skarlato, S. (2009). Zooplankton of the Open Baltic Sea: Extended Atlas. Meereswissenschaftliche Berichte.

Tõnno, I., Agasild, H., Kõiv, T., Freiberg, R., Nõges, P., & Nõges, T. (2016). Algal diet of small-bodied crustacean zooplankton in a cyanobacteria-dominated eutrophic lake. *PLoS One, 11*(4), e0154526. https://doi.org/10.1371/journal.pone.0154526 PMID:27124652

Vrede, T., Ballantyne, A., Mille-Lindblom, C., Algesten, G., Gudasz, C., Lindahl, S., & Brunberg, A. K. (2009). Effects of N:P loading ratios on phytoplankton community composition, primary production and N fixation in a eutrophic lake. *Freshwater Biology, 54*(2), 331–344. https://doi.org/10.1111/j.1365-2427.2008.02118.x

Wang, H., Huo, T., Du, X., Wang, L., Song, D., Huang, X., & Zhao, C. (2022). Zooplankton community and its environmental driving factors in Ulungur Lake, China. *Journal of Freshwater Ecology, 37*(1), 387–403. https://doi.org/10.1080/02705060.2022.2093279

Wen, X., Zhai, P., Feng, R., Yang, R., & Xi, Y. (2017). Comparative analysis of the spatio-temporal dynamics of rotifer community structure based on taxonomic indices and functional groups in two subtropical lakes. *Scientific Reports, 7*(1), 578. https://doi.org/10.1038/s41598-017-00666-y PMID:28373702

Wright, D. I., & Shapiro, J. (1984). Nutrient reduction by biomanipulation: An unexpected phenomenon and its possible cause. *Internationale Vereinigung für theoretische und angewandte Limnologie. Verhandlungen - Internationale Vereinigung für Theoretische und Angewandte Limnologie, 22*(1), 518–524. https://doi.org/10.1080/03680770.1983.11897338

Yin, X. W., Liu, P. F., Zhu, S. S., & Chen, X. X. (2010). Food selectivity of the herbivore *Daphnia magna* (Cladocera) and its impact on competition outcome between two freshwater green algae. *Hydrobiologia, 655*(1), 15–23. https://doi.org/10.1007/s10750-010-0399-0

Zar, J. H. (2010). Biostatistical analysis. Prentice-Hall.

Zengin, M., İlhan, S., Küçükkara, R., Güler, M., & Oktay, Ç. (2021). An evaluation of fisheries management on the Lake Yeniçağa, Bolu, Turkey. *Acta Aquatica Turcica*, *17*(4), 489-504. (In Turkish). https://doi.org/10.22392/actaquatr.867466

Zhao, F., Yu, H. X., Ma, C. X., Sun, X., Liu, D., Shang, L. D., Liu, J. M., Li, X. Y., Li, S., Li, X. C., Li, T. Y., Yu, Shabani, I. E., Wang, Y. Z., Su, L. J., Zhang, L. M., Mu, Y. Y., Xiao, L., Tian, Z., Pan, C., Sun, B., Pan, H. F., Shang, G. Y. Q., Chai, Y., Meng, Y. (2020). Characteristics of zooplankton functional groups and their environmental factors in the Harbin Section of the Songhua River. China. *Applied Ecology and Environmental Research, 18*(5), 7457–7471. https://doi.org/10.15666/aeer/1805_74577471