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# Species diversity and community structure of zooplankton in three different types of water body within the Sakarya River Basin, Turkey

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**Abstract:** The aim of this study was to identify differences between different types of water body within the same river basin by comparing the composition of the zooplankton community. The study was conducted in three types of water body in the Sakarya Basin in northwestern Turkey: an alluvial barrier lake (Lake Poyrazlar), a pond (Sorgun Pond), and a reservoir (Çubuk II Reservoir). The spatiotemporal changes of these three types of aquatic habitats were investigated in terms of the zooplankton organisms by examining their diversity, evenness, and differences in the abundance of species. A total of 81 species were identified. Thirty-eight species were observed in one water body only, while 15 species were observed in all the water bodies. Two of the 15 species belonged to the group Cladocera, while the rest belonged to the phylum Rotifera. The water bodies were different in terms of all the zooplankton species and cladocerans, even though they were located within the same basin. In addition, the size of the lake area and its electrical conductivity may affect species diversity and richness depending on the amount and quality of water inflow.

**Key words:** Zooplankton, species richness, diversity, different freshwater ecosystems, community structure

## 1. Introduction

Zooplankton is a very important component of the ecological quality of lakes (Moss et al., 2003), being a critical link between phytoplankton and higher consumers (Chalkia and Kehayias, 2013). Some biotic and abiotic parameters, such as temperature, habitat differences, and the presence or absence of fish and macrophytes, may affect the richness and composition of zooplankton species (Jeppesen et al., 2000; Muirhead et al., 2006; Kaya et al., 2010). Additionally, species richness is a key variable for ecological studies (Siqueira et al., 2015).

Beta diversity was defined by Whittaker (1972) as the variation in species composition among sites in a geographic area; it is a key concept for understanding the functioning of ecosystems, for the conservation of biodiversity, and for ecosystem management (Legendre et al., 2005). In the Mediterranean region, shallow lakes will be more saline in the future (Beklioğlu et al., 2007). Kaya et al. (2010) argued that rotifers' species richness increases with salinity up to a subsaline limit, contrary to other literature. Bonecker et al. (2013) showed that zooplankton diversity followed temporal dynamics in response to local and regional factors, but the groups (microcrustaceans, rotifers, etc.) showed different responses. Temporal turnover is negatively affected by ecosystem size (Adler et al., 2005), but is faster for small organisms (Korhonen et al., 2010). Fontenato and Ricci (2006) suggested that differences in body size should be carefully taken into account and that the geographical distribution of animals may be strongly influenced by animal size. Indeed, geographical distance between aquatic habitats is found to be important for zooplankton distribution (Florencio et al., 2015; Santos et al., 2016).

Protecting aquatic biodiversity at the landscape scale requires good knowledge of different types of lakes (De Bie et al., 2007) and also knowledge about the requirements of zooplankton species. Zooplankton differences in freshwater ecosystems can provide an insight about future diversity and richness, leading to a better understanding of the ecosystem structure.

Considering the "everything is everywhere" (Baas Becking, 1934) hypothesis, microorganisms should be everywhere; however, it also follows that "…but, the environment selects". It is known that the zooplankton composition is affected by environmental parameters and biotic interactions (Wetzel, 2001), and for this reason

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the aim of this study was to determine how zooplankton diversity can change with different types of aquatic habitats within the same river basin, using as examples three water bodies in the Sakarya Basin in northwestern Turkey. Therefore, the following questions were investigated: how are zooplankton species diversity and ecologic variables related? Do different aquatic habitats affect this relationship?

## 2. Materials and methods

### 2.1. Studied sites and sample analysis

This study was conducted in three types of aquatic habitats between May 2012 and February 2013: an alluvial barrier lake, a pond, and a reservoir. All the lakes studied are located in the Sakarya Basin in northwestern Turkey (Table 1). In previous studies, Çakıroğlu et al. (2014) have reported that the characteristics of the area are warm and

**Table 1.** Sampling localities, water parameters, and indices of studied sites.

| | Poyrazlar | Sorgun | Çubuk II |
|---|---|---|---|
| Elevation (m a.s.l.) | 25 | 1260 | 1110 |
| Geographical coordinates (lat/long) | 40°50′12″N<br>30°28′15″E | 40°19′50″N<br>32°13′80″E | 40°17′50″N<br>33°01′08″E |
| Lake surface area (km$^2$) | 0.6 | 0.35 | 0.9 |
| Lake type | Alluvial barrier | Pond | Reservoir |
| Catchment geology (rock–peat) | Rock | Rock | Rock |
| Max depth | <6 m | <6 m | >6 m |
| Chl a µg L$^{-1}$ (min–max) | 1.39–5.22 | 0.57–7.71 | 0.61–7.3 |
| Hardness mg L$^{-1}$ °f (min–max) | 55–162 | 22–58.5 | 43–168 |
| $PO_4^{-3}$-P µg L$^{-1}$ (min–max) | 0.01–1.89 | 0.03–1.31 | 0.02–1.68 |
| DIN µg L$^{-1}$ (min–max) | 0.266–5.657 | 0.625–1.094 | 0.516–4.584 |
| pH (min–max) | 7.7–10.2 | 8.53–9.83 | 7.95–9.45 |
| EC µs (min–max) | 312–1125 | 68–455 | 185–1280 |
| DO mg L$^{-1}$ (min–max) | 3.21–9.4 | 3.4–6.26 | 4.2–10.13 |
| T °C (min–max) | 8.3–31.5 | 11.9–26.5 | 7.2–24.7 |
| H' (min–max) | 0.76–2.66 | 1.51–2.10 | 1.43–2.35 |
| 1-D (min–max) | 0.30–0.89 | 0.57–0.85 | 0.63–0.86 |
| J' (min–max) | 0.26–0.93 | 0.50–0.80 | 0.56–0.85 |
| d (min–max) | 0.46–5.64 | 2.24–3.27 | 1.65–4.21 |
| SRot | 46 | 35 | 30 |
| SCla | 9 | 5 | 9 |
| SCop | 2 | 1 | 2 |
| $N_{(large\ cla/tot\ cla)}$ | 0.11 | 0 | 0.12 |

Lat: latitude, Lon: longitude, Chl *a*: chlorophyll *a*, $PO_4^{-3}$-P: orthophosphate, EC: electrical conductivity, DO: dissolved oxygen, DIN: dissolved inorganic nitrogen (sum of nitrites, nitrates and ammonia), H': Shannon–Weaver diversity, 1-D: Simpson's diversity index, J': Pielou's evenness, d: Margalef richness, SRot: total rotifer species number, SCla: total Cladocera species number, SCop: total copepod species number, $N_{(large\ cla/tot\ cla)}$: the ratio of the numbers of large-bodied Cladocera species to the total number of Cladocera species (all others).

temperate, arid cold steppe, while Peel et al. (2007) have stated that it has a Mediterranean climate. The maximum distance between sites is from Lake Poyrazlar to the Çubuk II Reservoir (about 225 km), and the minimum distance is from the Çubuk II Reservoir and Sorgun Pond (about 67 km). All lakes are fed mainly by rainfall, and only Lake Poyrazlar has no outlet. Lake Poyrazlar is an alluvial barrier lake that is also fed by underground sources and the Sakarya River when it is flooding (OSİB, 2013). Sorgun Pond is fed by a very small stream and has only one outflow during spring. The Çubuk II Reservoir is fed by two streams, but in summer this drops to one. Sorgun Pond's bed is partly covered with submerged plants, and Poyrazlar's northeastern shores are covered with marsh vegetation (Demirsoy et al., 2001). Lake Poyrazlar and Sorgun Pond are also used for recreational purposes.

Samples were collected seasonally, between May 2012 and February 2013, except for at Sorgun Pond in winter, because of ice cover. There are three sampling stations at Poyrazlar; the others have two because of their smaller surface areas. Two samples were collected at each point for the zooplankton analysis. Twelve samples from Lake Poyrazlar, eight samples from Çubuk II Reservoir, and six samples from Sorgun Pond were collected. Zooplankton samples were collected with vertical hauls in the pelagic zone using a Hydro-Bios plankton net (25 cm in diameter, 100 cm in length, with a 55-µm mesh size) and immediately fixed with a 4% solution of formalin. Counting of zooplankton was done according to Botrell et al. (1976). To identify zooplankton species, various resources were used: Ward and Whipple (1945), Kolisko (1974), Koste (1978), Edmonson (1959), Harding and Smith (1974), Nogrady and Pourriot (1995), Segers (1995), De Smet (1996), and Smirnov (1996).

For the physicochemical parameters of aquatic ecosystems, temperature (T), pH, dissolved oxygen, and electrical conductivity were measured in situ. T, pH, DO, and EC were measured using a multiparameter WTW 340i set. For the analysis of water samples, three bottles (volume 1 L) of water were taken from under the surface layer for each zooplankton sampling station. Nitrites, nitrates, ammonia, orthophosphates, and hardness were analyzed according to APHA (1975), and chlorophyll *a* was analyzed according to the Youngman (1978) principle in the laboratory. Before analysis in the laboratory, water samples were filtered through Whatman GF/C filters. All of the analyses were completed in 48 h.

### 2.2. Data analysis

Mean values of water quality parameters measured over the seasons were used for statistical analysis. All data (except pH) were $\log_{10}(x + 1)$ transformed for processing using Spearman's rank correlation, and the results were used to identify relationships between water quality and biological parameters. Statistical analysis was performed using SPSS v.21 (IBM Corp., Armonk, NY, USA, 2012). The Hellinger transformation (Legendre and Gallagher, 2001; Legendre, 2005) was used to process the zooplankton abundance data for use in multivariate analysis. The CANOCO 4.5 software package (Ter Braak, 1986) was used to determine relationships between ecological parameters and species abundance. The length of the gradient of the first axis of the detrended correspondence analysis (DCA) was found to be higher than three standard deviation (SD) units; consequently, the data showed unimodal behavior, and canonical correspondence analysis (CCA) was chosen for multivariate analysis (Leps and Similaur, 2003). To assess statistical differences between aquatic habitats, a random Monte Carlo permutation ($n = 499$) test was used. The PRIMER5 software package (Clarke and Warwick, 2001) was used to identify zooplankton species similarities/dissimilarities between water bodies with nonmetric multidimensional scaling (nMDS), analysis of similarity (ANOSIM), and similarity percentages (SIMPER) according to the Bray–Curtis similarity principle (Bray and Curtis, 1957). PRIMER5 was also used for analysis using the Shannon–Weaver species diversity index (Shannon and Weaver, 1949) and Simpson's index of diversity (Simpson, 1949), the Margalef species richness index (Margalef, 1951), and Pielou's evenness index (Pielou, 1975).

## 3. Results

### 3.1. Species composition

In the three different types of lake studied, a total of 81 species were identified. Of these, 63 belonged to Rotifera, 15 to Cladocera, and three to Copepoda. While 38 species were observed in one lake only, 15 species were observed in all lakes (*Asplanchna priodonta*, *Cephalodella gibba*, *Colurella adriatica*, *Euchlanis incisa*, *Filinia limnetica*, *Filinia terminalis*, *Keratella cochlearis*, *Keratella quadrata*, *Lecane closterocerca*, *Lecane luna*, *Lecane lunaris*, *Lepadella patella*, *Polyarthra vulgaris*, *Bosmina longirostris*, and *Chydorus sphaericus*); two of the 15 belonged to Cladocera and the others to phylum Rotifera. Lake Poyrazlar has 57 zooplankton species, while Sorgun Pond and the Çubuk II Reservoir both have 41 zooplankton species (Table 2).

The dominance percentages of zooplankton species, with the highest values first, are as follows:

in Poyrazlar: *Keratella quadrata* (56.5%,), *Polyarthra dolichoptera* (5%), *Colurella uncinata* (4.7%), *Chydorus sphaericus* (0.7 %), and *Mesocyclops leuckarti* (4.2%);

in Sorgun: *Collotheca pelagica* (21.8%), *Polyarthra dolichoptera* (18%), *Synchaeta pectinata* (16.2%), *Keratella cochlearis* (16%), and *Alona costata* (0.5%);

in Çubuk II: *P. vulgaris* (20.3%), *Keratella quadrata* (17.8%), *Kellicottia longispina* (15.7%), *Ceriodaphnia quadrangula* (4.2%), and *Eudiaptomus vulgaris* (5%).

**Table 2.** The list of species samples. Occurrence of zooplankton abundances (individuals per liter) in 3 water bodies throughout different seasons.

| Rotifera | Abbr. | Lake Poyrazlar | | | | Sorgun Pond | | | Çubuk II Reservoir | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spr. | Sum. | Fall | Win. | Spr. | Sum. | Fall | Spr. | Sum. | Fall | Win. |
| *Anuraeopsis fissa* (Gosse, 1851) | ANFI | | 1222 | | | 815 | | | | | | |
| *Asplanchna priodonta* (Gosse, 1850) | ASPR | 204 | | | | 2240 | | | 102 | 1629 | | |
| *Brachionus angularis* (Gosse, 1851) | BRAN | | | | | | | | | | 1222 | |
| *Brachionus plicatilis* (Müller, 1786) | BRPL | | | | | | | | 102 | | 509 | |
| *Brachionus quadridentatus* (Hermann, 1783) | BRQU | 305 | | | | | | | | | | |
| *Brachionus urceolaris* (Müller, 1773) | BRUR | | 204 | | | | | | | | | |
| *Cephalodella catellina* (Müller, 1786) | CECA | | | | | | 407 | | | | | |
| *Cephalodella gibba* (Ehrenberg, 1830) | CEGI | | | 1018 | | | | 1425 | | | 2546 | |
| *Cephalodella ventripes* (Dixon-Nuttall, 1901) | CEVE | | | | 1425 | | | | | | | |
| *Collotheca pelagica* (Rousselet, 1893) | COPE | | | | | 15,680 | 29,426 | | | | | |
| *Colurella adriatica* (Ehrenberg, 1831) | COAD | | 305 | | | 204 | | | | | 815 | |
| *Colurella colurus* (Ehrenberg, 1830) | COCO | | | 3360 | | | | | | | | |
| *Colurella obtusa* (Gosse, 1886) | COOB | | 204 | | | | | | | | 204 | |
| *Colurella uncinata* (Müller, 1773) | COUN | | 20,873 | | | | | | 815 | | | |
| *Dicranophorus epicharis* (Harring and Myers, 1928) | DISP | | | | | | 509 | | | | | |
| *Euchlanis dilatata* (Ehrenberg, 1830) | EUDI | | 1935 | | | | | 1018 | | | | |
| *Euchlanis incisa* (Carlin, 1939) | EUIN | | 9775 | 916 | | 204 | | | 407 | | 204 | |
| *Filinia limnetica* (Zacharias, 1893) | FILI | | 407 | | | | | 815 | 204 | | 204 | |
| *Filinia longiseta* (Ehrenberg, 1834) | FILO | | | | | 204 | | | | | | |
| *Filinia opoliensis* (Zacharias, 1898) | FIOP | | 15,884 | | | | | | | | | |
| *Filinia terminalis* (Plate, 1886) | FITE | | 1222 | | | 12,218 | | | | | 204 | |
| *Gastropus hyptopus* (Ehrenberg, 1838) | GAHY | | | | | | | | 611 | 204 | | |
| *Hexarthra fennica* (Levander, 1892) | HEFE | | | | | | | | 611 | | | 1018 |
| *Hexarthra intermedia* (Wiszniewski, 1929) | HEIN | | 2749 | | | 204 | | | | | | |
| *Kellicottia longispina* (Kellicott, 1879) | KELO | | | | | | | | 17,411 | | | 204 |
| *Keratella cochlearis* (Gosse, 1851) | KECO | | | 13,135 | | 27,899 | 1120 | 4175 | | | 204 | 815 |
| *Keratella quadrata* (Müller, 1786) | KEQU | 244,979 | 2851 | | 3666 | | 204 | | 18,124 | | 204 | 1731 |
| *Keratella tecta* (Gosse, 1851) | KETE | | 204 | | | 102 | | | | | | |
| *Lecane bulla* (Gosse, 1851) | LEBU | | 305 | | | | | | | | 204 | |
| *Lecane closterocerca* (Schmarda, 1859) | LECL | 509 | 1222 | 1731 | | | 713 | | 204 | 407 | | |
| *Lecane flexilis* (Gosse, 1886) | LEFL | | | 611 | | 1425 | | | | | | |
| *Lecane furcata* (Murray, 1913) | LEFU | | | | | | 204 | | | | | |
| *Lecane hamata* (Stokes, 1896) | LEHA | | 102 | | | | 204 | | | | | |
| *Lecane luna* (Müller, 1776) | LELU | | 7942 | | | | 305 | 2342 | 1222 | | | |
| *Lecane lunaris* (Ehrenberg, 1832) | LELN | | 1527 | | | | | 1324 | 204 | | 204 | |
| *Lecane quadridentata* (Ehrenberg, 1830) | LEQA | 204 | | | | | | | | | | |
| *Lepadella acuminata* (Ehrenberg, 1834) | LEAC | | | | | 611 | | | 509 | | | |
| *Lepadella ehrenbergii* (Perty, 1850) | LEEH | | 2647 | | | | | | | | | |
| *Lepadella patella* (Müller, 1773) | LEPA | | 611 | | | | | 204 | | | 204 | |
| *Lepadella quadricarinata* (Stenroos, 1898) | LEQU | | | | | | | | | | 204 | 407 |
| *Lophocharis salpina* (Ehrenberg, 1834) | LOSA | | 305 | | | | | | | | | |

**Table 2.** (Continued).

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Mytilina mucronata* (Müller, 1773) | MYMU | | | | | | 407 | | | | | |
| *Mytilina ventralis* (Ehrenberg, 1830) | MYVE | | 305 | | | | | | 916 | | 204 | |
| *Notholca squamula* (Müller, 1786) | NOSQ | | | 916 | | | | | 11,200 | | 204 | |
| *Philodina megalotrocha* (Ehrenberg, 1832) | PHME | | 916 | | | | 102 | | | | | |
| *Polyarthra dolichoptera* (Idelson, 1925) | PODO | | 16,800 | 5498 | | 26,270 | 6109 | 4684 | | | | |
| *Polyarthra vulgaris* (Carlin, 1943) | POVU | 2444 | | | | 6924 | | | | 20,568 | | 2240 |
| *Pompholyx sulcata* (Hudson, 1885) | POSU | 8553 | | | | | | | | | | |
| *Rotaria rotatoria* (Pallas, 1766) | RORO | 305 | | | | 204 | 204 | 204 | | | | |
| *Scaridium longicaudum* (Müller, 1786) | SCLO | 204 | | | | 916 | 509 | | | | | |
| *Squatinella lamellaris* (Müller, 1786) | SQMU | | | | | | 1120 | | | | | |
| *Synchaeta oblonga* (Ehrenberg, 1832) | SYOB | | 305 | 5702 | 2138 | | | | 2342 | 204 | | |
| *Synchaeta pectinata* (Ehrenberg, 1832) | SYPE | | | | | 28,510 | | 4887 | | | 204 | |
| *Testudinella emarginula* (Stenroos, 1898) | TEEM | 3666 | | | | | | | | | | |
| *Testudinella patina* (Hermann, 1783) | TEPA | 1120 | 1018 | | | | | | 102 | 204 | | |
| *Trichocerca bidens* (Lucks, 1912) | TRBI | | 305 | | | | | | | | | |
| *Trichocerca iernis* (Gosse, 1887) | TRIE | | 305 | | | | | | | | | |
| *Trichocerca longiseta* (Schrank, 1802) | TRLO | 305 | 1222 | | | 204 | | | | | | |
| *Trichocerca pusilla* (Jennings, 1903) | TRPU | | | | | 2036 | | | | | | |
| *Trichocerca rattus* (Müller, 1776) | TRRA | | 305 | | | | | | | | | |
| *Trichocerca similis* (Wierzejski, 1893) | TRSI | 13,440 | 2036 | | | 11,404 | 1833 | | | | | |
| *Trichotria pocillum* (Müller, 1776) | TRPO | | 305 | 102 | | | | | 916 | | | |
| *Trichotria tetractis* (Ehrenberg, 1830) | TRTE | | | | | | | | 204 | | 102 | |
| Cladocera | | | | | | | | | | | | |
| *Acroperus harpae* (Baird, 1843) | ACHA | | 407 | | | | | | | | | |
| *Alona costata* (Sars, 1862) | ALCO | | | | | | 1120 | | 611 | | | |
| *Alonella nana* (Baird, 1850) | ALNA | | | | | | 407 | | | | | |
| *Alona rectangula* (Sars, 1861) | ALRE | | 305 | 305 | | | | | | | | |
| *Bosmina longirostris* (O. F. Müller, 1776) | BOLO | | | 3666 | | | 611 | 204 | 2546 | 1833 | | |
| *Ceriodaphnia quadrangula* (O. F. Müller, 1785) | CEQU | 611 | 305 | 1018 | | | | | 204 | 4480 | | |
| *Ceriodaphnia reticulata* (Jurine, 1820) | CERE | | 305 | 305 | | | | | 204 | 102 | | |
| *Chydorus sphaericus* (O. F. Mueller, 1785) | CHSP | 204 | 1731 | 1425 | | | 305 | 204 | | 611 | | |
| *Daphnia cucullata* (Sars, 1862) | DACU | 509 | | 305 | | | | | | | | |
| *Daphnia galeata* (G. O. Sars, 1863) | DAGA | | | | | | | | 102 | | | |
| *Daphnia hyalina* (Leydig, 1860) | DAHY | | | | | | | | 204 | | | |
| *Daphnia longispina* (O. F. Müller, 1776) | DALO | | | | | | | | | 204 | | 204 |
| *Diaphanosoma brachyurum* (Liévin, 1848) | DIBR | 509 | | | | | | | 713 | | | |
| *Pleuroxus aduncus* (Jurine, 1820) | PLAD | | 407 | | | | | | | | | |
| *Moina brachiata* (Jurine, 1820) | MOBR | | | | | | 407 | | | | | |
| Copepoda | | | | | | | | | | | | |
| *Canthocamptus microstaphylinus* (Wolf, 1905) | CAMI | | 815 | | | | | | | | | |
| *Eudiaptomus vulgaris* (Schmeil, 1896) | EUVU | | | | | | | 204 | 204 | 4989 | | 407 |
| *Mesocyclops leuckarti* (Claus, 1857) | MELE | 16,800 | 1527 | 611 | | | | | 611 | 204 | | |
| *Nauplius* | NAUP | 305 | 305 | | | | | | | 204 | | |

Abbr: Abbreviation, Spr.: Spring, Sum.: Summer, Win.: Winter.

*Bosmina longirostris* (BOLO) occurred in all lakes as the most abundant cladoceran species, with percentages of 0.8%, 0.4%, and 3.9%, respectively.

According to the Shannon–Weaver and Simpson diversity indices (Table 1), the highest values occur in the Lake Poyrazlar summer sample, and the highest values of Margalef richness support that result. Pielou's evenness (J') for the Lake Poyrazlar spring sample has the lowest value, and the other indices show comparable results (Figure 1).

**3.2. Environmental variables and relationships between biological parameters**

In the studied aquatic habitats, summer surface temperature values ranged from 24.7 °C to 31.5 °C; according to Moss et al. (2003), these lakes can be classified as warm lakes. With respect to pH, the water bodies showed alkaline characteristics. Conductivity values ranged from 68 µS cm$^{-1}$ to 286 µS cm$^{-1}$ in Sorgun Pond, 185 µS cm$^{-1}$ to 1280 µS cm$^{-1}$ in Çubuk II Reservoir, and 312 µS cm$^{-1}$ to 1125 µS cm$^{-1}$ in Lake Poyrazlar; these values correlate only with dissolved oxygen (Table 3).

Spearman's correlation coefficient was calculated for physicochemical parameters, biological variables, and indices (Table 3). The pH was observed to be significantly and positively correlated with temperature. Dissolved inorganic nitrogen has a strong positive correlation with evenness but correlates negatively with temperature and dissolved oxygen.

Surprisingly, there is also a significant negative relationship between chlorophyll *a* and temperature. Spearman's rank correlation analysis showed that the ratio of the number of large Cladocera species (represented here by Daphnia and Diaphanosoma species numbers) to the total number of Cladocera (all others) are positively affected by dissolved oxygen; additionally, dissolved oxygen and electrical conductivity are negatively correlated with each other.

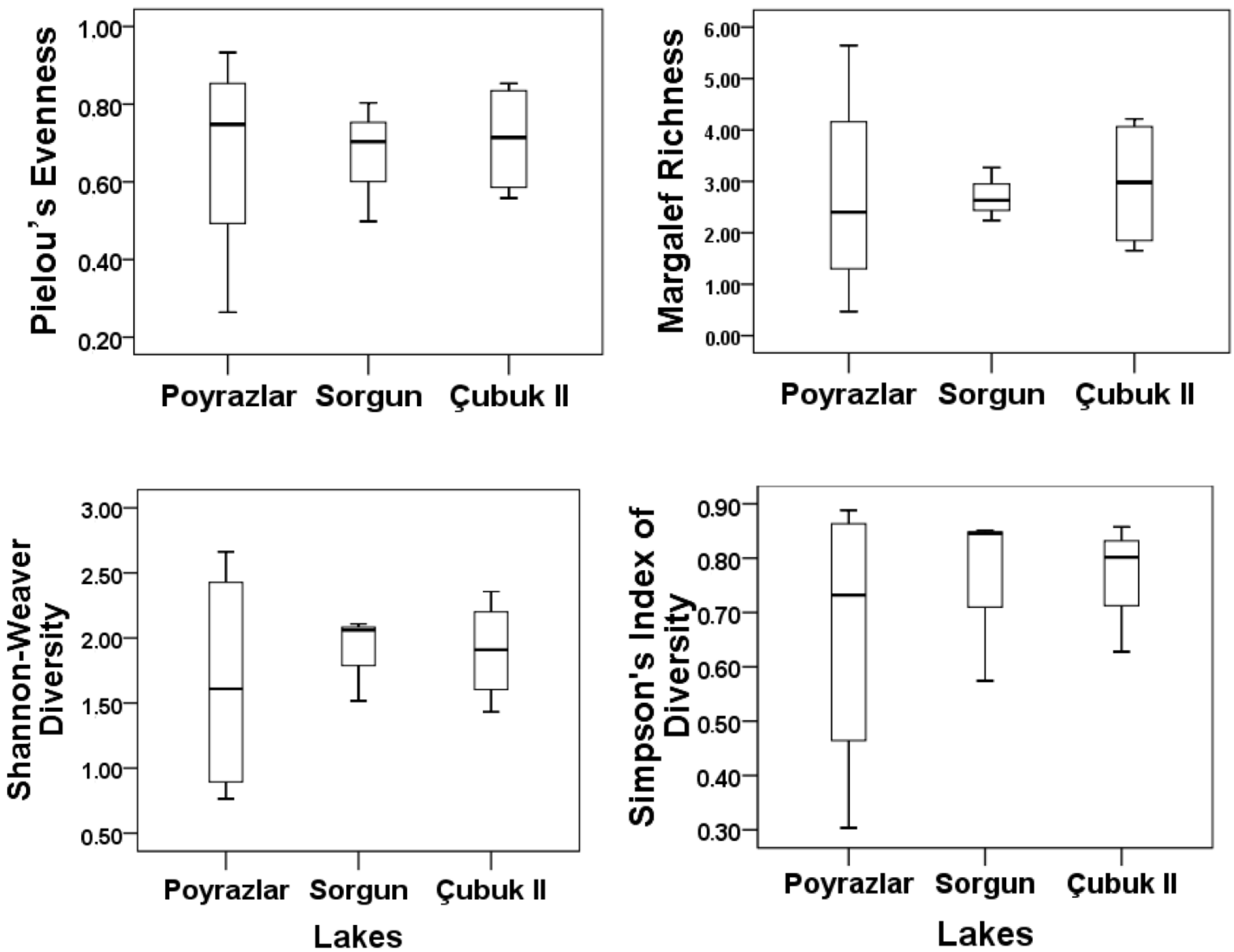


**Figure 1.** Species richness, evenness, and diversity boxplots in each lake. The horizontal thick black band represents the median value, and the boxplot margins indicate first and third quartiles.

**Table 3.** Spearman correlation analysis with environmental parameters and biodiversity indices (for abbreviations, see Table 1).

| | Chl *a* μg $L^{-1}$ | Hardness | DIN | EC μS | pH | DO mg $L^{-1}$ | T °C | d | J' | H' |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | ns | −0.442* | ns | ns | | | | | | |
| DO mg $L^{-1}$ | ns | ns | −0.480* | −0.470* | ns | | | | | |
| T °C | −0.519** | ns | −0.625** | ns | 0.504** | ns | | | | |
| D | ns | ns | ns | ns | 0.747** | ns | 0.440* | | | |
| J' | ns | ns | 0.547** | ns | ns | −0.462* | −0.738** | ns | | |
| H' | ns | ns | ns | ns | 0.619** | ns | ns | 0.891** | ns | |
| 1-D | ns | ns | ns | ns | 0.539** | ns | ns | 0.775** | 0.398* | 0.951** |
| $N_{(large\ cla/tot\ cla)}$ | ns | ns | ns | ns | −0.522** | 0.500** | ns | ns | ns | ns |

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
ns = nonsignificant.

When examining the similarity/dissimilarity within and between lakes for all zooplankton species (Figure 2), the similarity proportion was low according to the SIMPER result (similarity in all seasons and zooplankton groups: Lake Poyrazlar = 31.13%; Çubuk II Reservoir = 32.44%; Sorgun Pond = 44.40%). In addition, the goodness-of-fit of the nMDS stress factor had relatively good ordination (Kruskal, 1964) and so this result verified the SIMPER data. It was seen that dissimilarity was high between zooplankton groups, and similarity within zooplankton groups was lower than similarity between zooplankton groups. It appears that within the lakes, differences are associated with seasonal changes.

The differences between all three water bodies—Lake Poyrazlar, Sorgun Pond, and Çubuk II Reservoir—were not very significant in terms of the abundance and composition of all zooplankton species, according to ANOSIM (R = 0.361; P = 0.001). The results of SIMPER supported ANOSIM, and the average dissimilarity between groups was higher (Sorgun and Çubuk II = 84.23%; Poyrazlar and Sorgun = 81.90%, Poyrazlar and Çubuk II = 79.63%) than within groups.

When examining the differences between water bodies using the SIMPER and ANOSIM analysis for Rotifera fauna only, no similarity in the nMDS plot was seen (Figure 2a). The results of ANOSIM (R = 0.307; P = 0.002) and SIMPER dissimilarity for rotifers only (Sorgun and Çubuk II = 88.71%; Poyrazlar and Sorgun = 83.25%, Poyrazlar and Çubuk II = 82.96%) were higher than the results of the analysis that contained all groups; therefore, intragroup similarity is higher than intergroup similarity when all groups are considered. However, when only cladocerans are considered, ANOSIM (R = 0.422; P = 0.001) is higher than that of all groups and rotifers, while SIMPER is lower than the others (Poyrazlar and Çubuk II = 73.54%; Sorgun and Çubuk II = 73.34 %; Poyrazlar and Sorgun = 69.80%), and the differences between groups is seen on the nMDS plot (Figure 2).

In the CCA biplots of samples of environmental variables and species compositions, (Figure 3a and 3b), it can be seen that each water bodies sample (with seasonal and sampling stations) constitutes an own cluster. A Monte Carlo permutation done with regard to environmental variables (499 permutations under the full model) showed hardness and a chlorophyll *a* P-value <0.05, while the other variables were below 0.01. The pH, temperature, and orthophosphates were shown to be highly significant in explaining species composition.

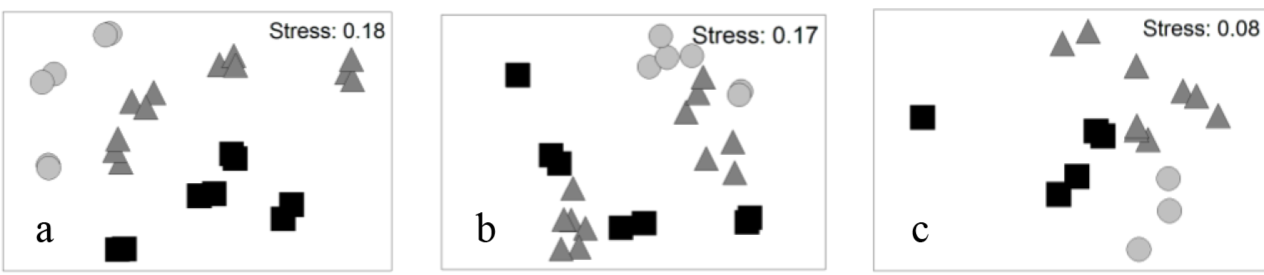


**Figure 2.** nMDS plots between lakes in terms of zooplankton species composition and abundance (a: all zooplankton species, b: rotifers, c: cladocerans.), Triangle: Lake Poyrazlar, Square: Çubuk II Reservoir, Circle: Sorgun Pond.

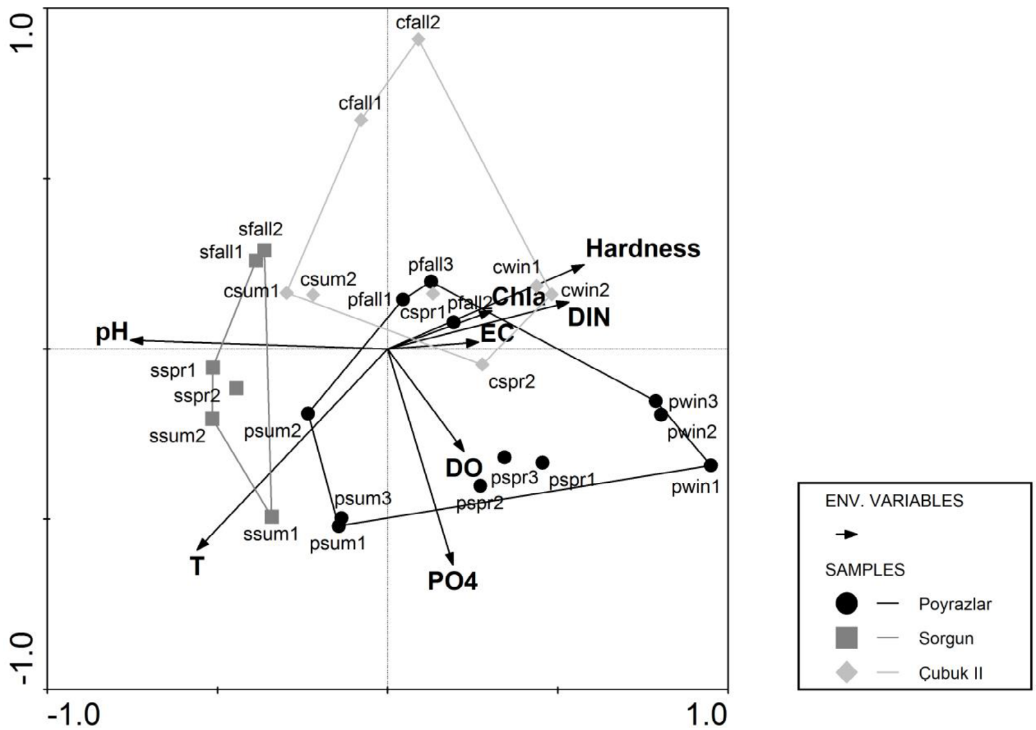


**Figure 3a.** CCA biplot diagram with three lakes (all seasons and stations), and eight environmental variables. For sample abbreviations, first letter indicates water body; s: Sorgun, p: Poyrazlar, c: Çubuk II; letters between 2 and 4 indicate the seasons: spr: spring, sum: summer, win: winter; numerical variables indicate sampling stations.

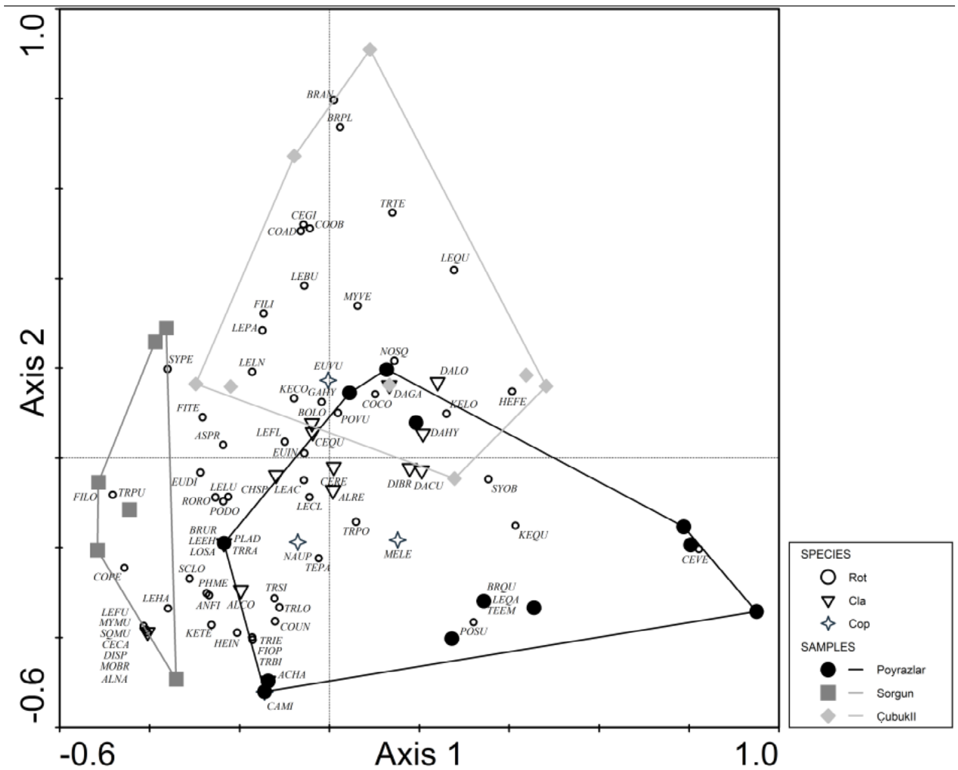


**Figure 3b.** CCA biplot diagram with three lakes (all seasons and stations) and 81 species (Rot: Rotifera, Cla: Cladocera, Cop: Copepoda, species abbreviations are listed in Table 2).

Canonical ordination was found to be much stronger, compared to other methods, when analyzing beta diversity (Legendre, 2005). Lakes closer together have communities more similar to one another. According to the biplot diagrams (Figures 3a and 3b), Sorgun Pond covers a more contrasting area compared to the other aquatic ecosystems. The CCA analysis shows that while large-bodied cladocerans (Daphnia and Diaphanosoma species) have a negative correlation with temperature, small-bodied cladocerans (Acroperus, Alonella, Bosmina, Ceriodaphnia, Chydorus, Pleuroxus, Moina species) have a positive correlation.

**4. Discussion**

There are an increasing number of studies comparing community composition among lakes with different groups like microcrustaceans and rotifers (Dodson et al., 2009; Merrix-Jones et al., 2013; Santos et al., 2016), but in the Mediterranean region, and especially in Turkey, there is a lack of such studies.

Conductivity values ranged from 68 $\mu S\,cm^{-1}$ to 1280 $\mu S\,cm^{-1}$ in all sampled water bodies and salinity can be predicted using conductivity: bodies of water with conductivity lower than 1000 $\mu S\,cm^{-1}$ are freshwater, and those that range from 1000 to 6000 $\mu S\,cm^{-1}$ are subsaline (Hammer et al., 1983). The salinities of Lake Poyrazlar and Çubuk II Reservoir varied depending on the seasons. While Çubuk II Reservoir showed subsaline characteristics in summer and autumn, Lake Poyrazlar was found to be subsaline in winter in addition to summer and autumn. As expected, species richness increased with salinity in rotifers (Kaya et al., 2010) and small-bodied cladocerans, but decreased in large-bodied cladocerans (Tavsanoglu et al., 2015). Additionally, salinity is known to be affected by long drought times in shallow Mediterranean lakes (Beklioğlu et al., 2007; 2011). Lake Poyrazlar's surface area is the largest of the studied aquatic ecosystems; it is also known that it is partially covered with macrophytes. It is possible that the macrophytes provide refuge for cladocerans against fish predation and seasonal salinity changes. In light of these results, cladoceran distribution does not depend only on their size but also on prey–predator interactions. On the other hand, the lakes studied have uncertain fish populations; according to a report of the Ministry of Forestry and Water Affairs (Republic of Turkey, OSİB, 2013), only in Lake Poyrazlar is there reliable data on the species and abundance of fish populations (Boll et al., 2016).

According to Spearman's correlation results, the expected positive relationship between chlorophyll *a* and temperature was, instead, negative. It is thought that this result stems from the declining linear relationship between temperature and chlorophyll *a* in nongrowing seasons.

Due to their small catchment area, physicochemical characteristics of ponds can easily change with water input from their environment. Although Sorgun is a pond, it has no large-bodied cladocerans. This can be explained as follows: in the absence of a refuge (provided by macrophytes), large-bodied crustaceans cannot avoid their predators easily or find shelter when conditions deteriorate. In addition, the mean body size of cladocerans declines with increasing temperature (Havens et al., 2015). The samples of Sorgun Pond positively correlated with pH and temperature and were located on the left side of the CCA biplot. Dissolved oxygen is affected by temperature, and the amount of dissolved oxygen decreases with increasing temperature. Havens and Beaver (2011) indicated that a more detailed analysis of how crustacean zooplankton species respond to changes is a better indicator of water quality than size–structure characterizations.

The *Daphnia galeata–hyalina–cucullata* species complex is commonly found in permanent lakes (Spaak and Hoekstra, 1995; Schewenk and Spaak, 1997), and their abundance fluctuates with the changing environment (Keller et al., 2008). *D. hyalina* is mainly seen in oligotrophic and mesotrophic lakes, while *D. cucullata* prefers mesotrophic to eutrophic lakes (Flosner and Kraus, 1986). *D. galeata* is an oligotrophy indicator (Pejler, 1983). In Çubuk II, *D. galeata* and *D. hyalina* were observed together during spring, when there is increased chlorophyll *a* and dissolved inorganic nitrogen. *D. cucullata* was observed only in Poyrazlar during the spring and fall, in addition to other eutrophic indicator species such as *B. longirostris* (Jaramillo and Pinto, 2010) and *C. sphaericus* (Pejler, 1983). Both *B. longirostris* and *C. sphaericus* are eutrophy indicators, but their abundance is important. Therefore, Lake Poyrazlar changes between oligotrophic and mesotrophic conditions according to the cladoceran species present.

It is known that the amount and variety of dissolved inorganic solid matter found in an aquatic environment affects the fauna present (Tanyolaç, 2009). The increase in dissolved inorganic solid matter decreases the dissolved oxygen level, which is a key parameter for aquatic organisms. All of the studied water bodies are surrounded by agricultural areas. These areas pollute the lakes with toxic contaminants such as fertilizers and pesticides (Atay and Pulatsü, 2000). This situation means that nutrient input to the lakes is high during the rainy season. Additionally, there is periodic floodwater flowing into Lake Poyrazlar from the Sakarya River during the flood season, and this explains the resultant periodic nutrient increase.

In recent years, many studies (Buyurgan et al., 2010; Kaya et al., 2010; Apaydın Yağcı and Ustaoğlu, 2012) showed that rotifers are the dominant species in both lakes and reservoirs. The reason is that rotifers are less affected than other groups by the deterioration of water quality and display better adaptation to these conditions. The importance of rotifers increases in comparison to cladocerans when the abundance of the latter is low (Wallace et al., 2006). Furthermore, rotifers are known as an opportunistic species in extreme conditions (Gannon and Stremberger, 1978). Within the last decade, because of the degradation of water quality of many wetlands for a variety of reasons (pollution, eutrophication, etc., and the effects of global warming), rotifers have become dominant species in many lakes in Turkey (Kaya and Altındağ, 2009). In line with that finding, this study identified that most of the zooplankton species belonged to phylum Rotifera.

It was observed that seasonal changes are important factors affecting seasonal distribution of zooplanktonic groups at Lake Poyrazlar. It is worth noting that both the minimums and maximums of Margalef richness, Pielou's evenness, and species diversities (Shannon–Weaver and Simpson) indices were found at this lake. These changes can be attributed to one or several of the following: presence of fish in the lake, discharging of the lake to Sakarya River in winter months, and errors in analysis arising from sampling procedures.

Water inflow was lower in Sorgun Pond compared to the other lakes, and the evaporation rate was relatively high. The lack of large-bodied cladocerans and the presence of eutrophic species in Sorgun Pond support mesotrophic conditions.

In Lake Poyrazlar, *K. quadrata* abundance comprises 83% of all zooplankton in spring. *K. quadrata* is a thermophilous species and its distribution is highly influenced by pH (Inaotombi et al., 2016). During the study period (May 2012), the regional temperature at Lake Poyrazlar remained +2 °C above the seasonal norm, according to the Turkish State Meteorological Service (MGM, 2013); it is thought that this seasonal anomaly caused *K. quadrata* to bloom (J' = 0.26, and the number of zooplankton is approximately $2.45 \times 10^5$ ind $L^{-1}$).

Although ANOSIM and SIMPER results suggest no differences in species composition of the water bodies, difference in species composition was observed according to CCA. Nevertheless, according to Legendre et al. (2005), the test of canonical ordination is more powerful than the test of significance, and the canonical result showed that each grouping of zooplankton samples belonged to a different lake. While no grouping was observed in the nMDS ordination of rotifers, the nMDS ordination of all zooplankton and cladocerans showed a grouping that signifies that the lakes are different when comparing all the zooplankton species and cladocerans. This may be caused by the ability of cladocerans to respond better to ecological conditions. In addition, the large-bodied cladocerans' position in the CCA biplot is nearly opposite the temperature and is on the side of dissolved oxygen. Analysis of the Spearman correlation and the CCA biplots show that pH and temperature affect nearly all zooplankton organisms.

Results showed us that the composition of the zooplankton community is influenced by structurally different aquatic ecosystem types. In Mediterranean basin lakes, water resources have an influence upon the composition of the zooplankton community. Similarly, the size of the lake area and its electrical conductivity may affect species diversity and richness, depending on the amount and quality of water inflow.

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