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The Dynamics of Zooplankton in National Park of Lake Gala (Edirne-Turkey)

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Abstract: In this study, carried out at monthly intervals in four different stations between March 2004 and January 2005, it is aimed to have new knowledge on the dynamics of zooplankton communities and the effects of physical-chemical values of the Lake Gala. As a result of the study, a total of 76 species have been identified as 50 species belong to Rotifera, 15 species – to Cladocera, and 11 species – to Copepoda. Of these species *Proalides tentaculatus* de Beuchamp, 1907*, Itura myersi* Wulfert, 1935, *Asplanchnopus hyalinus* (Harring, 1913) are found only in Turkish Thrace. As a result of quantitative evaluation of zooplankton samples, while an average of 35 334 ind./m^3 Rotifera, 19 305 ind./m^3 Cladocera, 72 369 ind./m^3 Copepoda was found an average of 127 008 ind/m^3 zooplankton organisms have been determined in the lake. According to the results of PCA analysis, when looking at the seasonal distribution of zooplankton species**,** it is seen that species assembled to form three groups as species which appear in spring, summer and winter. According to the results of RDA analysis, correlation (for RDA axis1 0.956, for RDA axis 2 0.925) between zooplankton organisms and environmental variables being so high shows that Water tem, EC, SO4, Ca, pH, Chl-a, Secchi and PO_4 are significant ($p = 0.0020$) factors determining the distribution of zooplankton organisms in the Lake Gala.

Key words: Zooplankton community structure, biodiversity, physicochemical parameters

Introduction

Zooplankton is an inherent component of aquatic system. While feeding on phytoplankton and micro-organisms, they have also important role in the nutrient and substance circle in ecosystem as food for fish larvae and aquatic invertebrates. Abundance and species composition of zooplankton gives information on the trophic level in aquatic systems (Saler, Şen 2002). The abundance of zooplankton organisms in a water body is closely related with physical-chemical features and nutrient amounts in the water resources (Bozkurt, Sagat 2008). Especially, some physical-chemical variables affect the distribution and abundance of zooplankton in it. Also, these features affect the interactions of zooplankton species with each other (Duggan 2001). Zooplankton organisms are used as water quality indicator because of their sensitivity to any ecological change in the water body (Tasevska *et al*. 2004).

Ecosystems where mixed both fresh and brackish water are the most reproductive regions in the world. These environments host the various biological communities. There are lots of places like this in Turkey and one of them is Lake Gala in these environments. The lake is a lagoon formation and located in the region where they pour into Aegean Sea, after Meriç (Maritsa) and Tunca (Tundzha) Rivers from

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Bulgaria and Arda River from Greece meet. It is expected that the lake includes organisms that belong to aquatic fauna of three countries, owing to streams from Greece, Bulgaria and Turkey.

Besides, wetlands located in this region provide an area for resting and spending the night for birds that migrate from Europe to Asia or opposite way (Kaya, Kurtonur 2003). The region was declared as a Type A wetland and National Park in 2005, owing to the importance that it has. Numerous studies have been performed formerly for putting forward the biodiversity in the Lake Gala forming research area. As a result of the studies performed, 108 phytoplankton (Öterler *et al*. 2008), 72 macrophyte (Seçmen, Leblebici 1991), 71 Rotifera (Erdoğan, Güher 2005), 36 Cladocera, 24 Copepoda (Ortak, Kirgiz 1988, Güher 2000), 14 Oligochaeta (Kirgiz 1989), 22 Chironomidae (Özkan, Kirgiz 1995), 20 fish (Balik 1985), 3 frog, (Yilmaz 1988) and 163 bird (Kaya, Kurtonur 2003) species were ascertained.

Rice agriculture around the lake is rather dense and 25% of Turkey's rice production is supplied from the area. Sometimes water coming from these agricultural areas flows in the lake and sometimes water is obtained from the lake for these areas. So, having the knowledge of the dynamics of zooplankton of the lake is important from the point of view of following the alteration that will be able to take form in the lake too.

In this study, it is aimed to have new knowledge on the dynamics of zooplankton communities (Rotifera, Cladocera, Copepoda) and the effects of physical-chemical values of the Lake Gala. In addition, it is hoped that this study will provide valuable biological information for the National Park of Lake Gala.

Material and Methods

Study Area

Lake Gala is an alluvial dam lake located between Ipsala and Enez (40°46´11.37´´ N, 26°11´14.87´´ E) counties in Edirne city in Turkey, where Maritsa River that forms Turkey-Greece border, flows to Aegean Sea. It consists of two parts named Lake Big Gala and Lake Small Gala. It has 5.6 km^2 surface area and 2 m above the sea level (Fig. 1). The depth varies between 0.4-2.2 m. It is fed by IP-1 drainage canal (Basamaklar Stream), Kızkapan Stream, other small streams and rain. The lake is surrounded by wide reed areas (*Phragmites australis* and *Thypa* sp.). Apart from *Phragmites* sp., *Thypa* sp. and *Nymphea* sp. of floating vegetation *Lemna* sp. and *Salvinia* sp. species is found.

Sampling Protocol

This study was carried out at monthly intervals in four different stations between March 2004 and January 2005 (Fig. 1). Due to bad weather conditions, sampling could not be made in February 2005. Station 1 was chosen where the lake water is discharged into the sea; Station 2 was chosen in the center of the lake; Station 3 was chosen in the intensive macro vegetation zone; and Station 4 was chosen in the section of Small Gala.

Zooplankton samples were collected with a Hensen type plankton net (mesh size 55 µ, mouth diameter 15 cm, length 75 cm). They were brought to the laboratory in 250 mL plastic bottles containing 4% formaldehyde.

Identification of the zooplankton organisms was made according to Kolisko (1974), Koste (1978), Segers *et al*. (1995) for Rotifera; Flössner (1972), Smirnov (1974), Margaritora (1983), Korinek (1987) for Cladocera; Dussart (1967, 1969) and Kiefer (1978) for Copepoda.

Counting of the organisms was made according to Edmondson (1959) by using Olympus inverted microscope.

In Lake Gala, some physical-chemical parameters, such as water temperature (measured by ordinary thermometer), light permeability (by Secchi disc), depth (by ordinary meters), conductivity (by Lovibond CM 35 of conductivity meter), pH (by Lovibond mark CG 837 of pH meter), dissolved oxygen (by Lovibond 3040 of oxygen meter) were measured at sampling time. Moreover, dissolved oxygen was also measured by Winkler method in the laboratory. To determine other physical-chemical features of the water, sampling was made by a Ruttner water sampler. The values of magnesium, calcium, total hardness, chloride, nitrate, nitrite, phosphate, sulphate and chlorophyll-a were measured photometrically and titrimetrically in the laboratory. Analyses in pelagic zone were calculated by

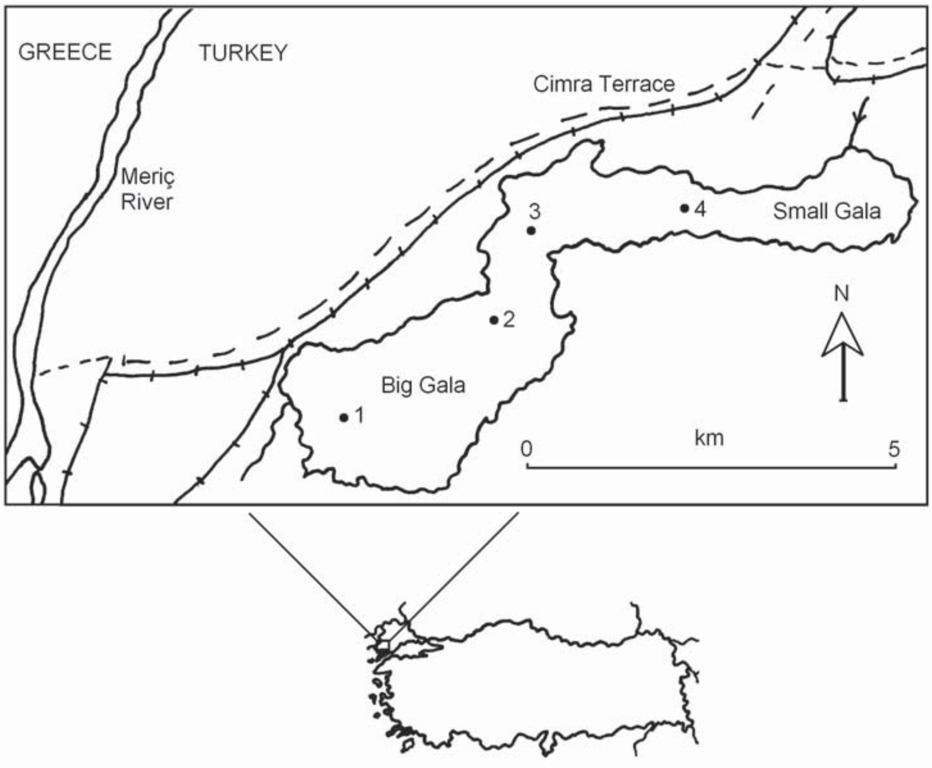

Fig. 1. Location of Lake Gala and the Sampling Stations (●1: Station 1; ●2: Station 2; ●3: Station 3; ●4: Station 4.).

measuring in Ceccil mark of spectrophotometer utilizing Nush (1980).

Statistical Analysis

While Jaccard Similarity Index was used to examine the similarities of sampling months according to diversity and abundance of zooplankton species, Margalef Index was used to determine the species richness (Jaccard 1912, Margalef 1958). Shannon-Weaver index was used to determine the species diversity of zooplankton organisms in Lake Gala, (Shannon, Weaver 1949). Detrended Correspondance Analysis (DCA) (Hill, Gauch 1980) was applied to the zooplankton data, and used to determine the appropriate response model (linear or unimodal).

An initial DCA showed that gradients on the first two axes within the data set were short (2.353 and 2.055 SD respectively), suggesting that a linear response model is appropriate (ter Braak, Prentice 1988). Principal Components Analysis (PCA), indirect linear gradient analysis, was used to determine the major patterns of variation in species composition data.

In addition, to determine the relative importance of environmental variables on the distribution of zooplankton species, Redundancy Analysis (RDA) was used (van den Wollenberg 1977). In addition, raw data were centered based on correlation matrix prior to linear gradient analyses.

Monte Carlo permutation test (with 499 permutations) with forward selection was used to assess statistical validity ($p \leq 0.05$) of the relationship between environmental variables and ordination values of samples, species.

Raw data were transformed log10 (x +1) prior to each analysis. In addition the taxa with two and less occurrences were excluded prior to analyses.

Ordination methods were applied to data by using CANOCO for Windows 4.5 Program (ter Braak, Simulauer 2002).

Results

Physical and Chemical Variables

It was found that the minimum and maximum values of the physical-chemical parameters measured in the lake vary as follows: pH 8.2-8.7, Conductivity 143-320 (µS/cm), water temperature 6.2-27.6 (^{o}C), chlorophyll-a 4.8-65.5 (µg/L), DO 8.6-17.8 (mg/L), depth 106.5-199 (cm), Secchi 24.0-91.5 (cm), Mg 41.4- 98.6 (mg/L), Ca 52.1-105.8 (mg/L), total hardness 40.1-62.9 (Fr°), NO_3 0-7.2 (mg/L), NO_2 0-0.242 (mg/L), SO_4 0.06-4.43 (mg/L), PO_4 0-0.06 (mg/L) (Fig. 2 and 3).

Zooplankton community structure

As a result of the examination of zooplankton samples a total of 50 species from Rotifera, 15 species from Cladocera and 11 species from Copepoda have been identified. The list of these species is given in Table 1.

As a result of quantitative evaluation of zooplankton samples, while an average of 35 334 ind./m^3 Rotifera, 19 305 ind./m^3 Cladocera, 72 369 ind./m^3 Copepoda was found an average of 127 008 ind/m^3 zooplankton organisms have been determined in the lake. Their distribution according to the months and sampling stations are given in Fig. 4 and 5.

Looking at the results of Jaccard similarity index, to compare the similarities of months according to abundance and diversity of zooplankton species identified in the lake, while the highest similarity was found (62%) between March and April, it was followed by the July and August that have 57% of similarity. Lowest similarity (20%) was observed between March and August (Fig. 6).

Monthly changes in species richness, diversity and maximum dominancy of zooplankton are seen in Table 2. According to the results of Margalef Index, while species richness is the maximum (9.144) in July, it has also the lowest value (4.051) in April.

According to Shannon diversity index, no significant differences in the species diversity between months were observed. While Shannon diversity is the highest (3.777) in July, it has lowest value (2.79) in April. While the month that maximum dominancy is the highest (8.8) in April, it is the lowest (3.6) in July.

PCA analysis was used to determine the major patterns of variation in species composition in Gala Lake. Rare taxa were eliminated prior to analysis, 62 zooplankton taxa were used in PCA analysis. The eigenvalues of the first two axes for PCA analysis are 0.198 and 0.121 respectively, explaining together 31.9% of the total variance.

As it can be seen in Fig. 7, the first group (Group 1) was assembled on the bottom left of the first PCA axis, related to March, April and May. The species seen intensely in October, November, December and January were assembled on the top left of the second PCA axis (Group 3) and the species seen densely in

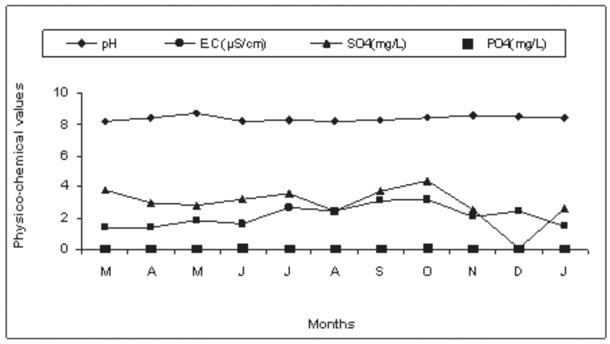

Fig. 2. pH, EC, SO_4 and PO_4 values of the lake Gala during the sampling period.

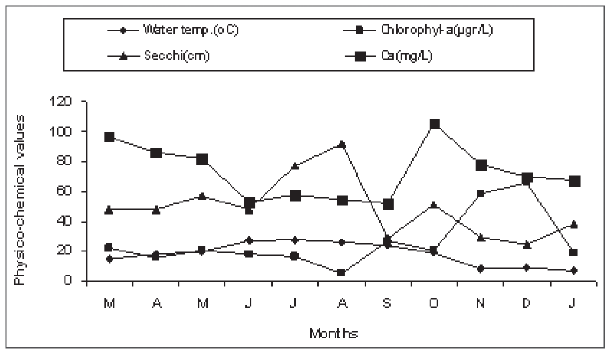

Fig. 3. Water temperature, Chlorophyll-a, Secchi and Ca values of Lake Gala during the sampling period.

June, July, August and September were assembled on the right side of the second PCA axis (Group 2).

Relationship between zooplankton and physical-chemical variables

The relationship between zooplankton organisms and physical-chemical variables in the Lake Gala were determined with RDA analysis. It started at 15 environmental variables and they were reduced to 8 in the final RDA, according to forward selection procedure. All variables together explained 62.8% of the total variance. According to Monte Carlo Permutation tests, first and all canonical axes are statistically significant (p: 0.002).

A final RDA with the reduced environmental data explained 50.5% of the variance in the species data. Monte Carlo Permutation tests of the axes found that first and all canonical axes are statistically significant (p: 0.002). The eigenvalues of the first two axes are 0.179 and 0.100 explained together 27.9% of the total inertia in the species data. Correlation between zooplankton taxa and environmental variable is very high for the first RDA axis (0.956) and

Table 1. Zooplankton species composition in Lake Gala.

ROTIFERA	Abbreviations for species	Station I	Station II	Station III	Station IV
Philodina megalotrocha Ehrenberg, 1832	*Phi mega*	+	+	+	+
Proalides tentaculatus de Beuchamp, 1907	*Pro tent*	+	+	+	-
Anuraeopsis fissa Gosse, 1851	*Anu fiss*	+	+	+	+
Brachionus angularis Gosse, 1851	*Bra angu*	+	+	+	+
Brachionus bidentatus Anderson, 1889	*Bra bide*	-	+	+	+
Brachionus budapestinensis Daday, 1885	*Bra buda*	+	-	+	+
Brachionus calyciflorus Pallas, 1766	*Bra caly*	+	+	+	+
Brachionus diversicornis (Daday, 1883)	Bra dive	+	-	-	-
Brachionus leydigi Cohn, 1862	*Bra leyd*	+	+	+	+
Brachionus plicatilis (O.F.Müller, 1786)	*Bra plic*	+	+	+	+
Brachionus quadridentatus Hermann, 1783	*Bra quad*	+	+	+	+
Brachionus urceolaris (O.F.Müller, 1773)	*Bra urce*	+	+	+	+
Keratella cochlearis (Gosse, 1851)	*Ker coch*	+	+	+	+
Keratella c. tecta (Lauterborn, 1900)	*Ker tect*	+	+	+	+
Keratella tropica (Apstein, 1907)	*Ker trop*	+	+	+	+
Keratella quadrata (O.F.Müller, 1786)	*Ker quad*	+	+	+	+
Notholca acuminata (Ehrenberg, 1832)	*Not acum*	+	+	+	+
Notholca squamula (O.F.Müller, 1786)	Not squa	+	+	+	+
Platyas quadricornis (Ehrenberg, 1832)	*Pla quad*	+	-	+	+
Euchlanis dilatata Ehrenberg, 1832	*Euc dila*	-	+	+	+
Trichotria pocillum (O.F.Müller, 1776)	*Tric poc*	+	+	+	+
Trichotria tetractis (Ehrenberg, 1830)	*Tric tet*	-	-	-	+
Lepadella patella (O.F.Müller, 1786)	*Lep pate*	-	-	-	+
Lepadella triptera (Ehrenberg, 1830)	*Lep trip*	-	-	-	+
Colurella adriatica Ehrenberg, 1831	*Col adri*	+	+	+	+
Colurella colurus (Ehrenberg, 1830)	*Col colu*	+	+	+	+
Colurella uncinata (O.F.Müller, 1773)	*Col unci*	-	-	-	+
Lecane bulla (Gosse, 1886)	Lec bull	+	+	+	+
Lecane closterocerca (Schmarda, 1859)	*Lec clos*	+	-	+	+
Lecane hamata (Stokes, 1896)	*Lec hama*	+	+	-	+
Lecane furcata (Murray, 1913)	*Lec furc*	+	+	-	+
Lecane luna (O.F.Müller, 1776)	*Lec luna*	-	+	+	+
Lecane quadridentata (Ehrenberg, 1832)	*Lec quad*	-	-	+	+
Lecane stenroosi (Meissner, 1908)	*Lec sten*	-	-	-	+
Monommata sp.	Monomm	-	+	-	-
Itura myersi Wulfert, 1935	*Itu myer*	-	+	+	+
Scaridium longicaudum (O.F.Müller, 1786)	*Sca long*	-	-	-	+
Trichocerca elongata (Gosse, 1886)	Tri elon	+	+	+	-
Trichocerca relicta (Donner, 1950)	*Tri reli*	+	+	+	+
Trichocerca rattus (O.F.Müller, 1776)	*Tri ratt*	-	-	-	+
Synchaeta pectinata Ehrenberg, 1832	*Syn pect*	+	+	+	+
Synchaeta oblonga Ehrenberg, 1831	*Syn oblo*	+	+	+	+
Asplanchnopus hyalinus (Harring, 1913)	*Asp hyal*	-	-	-	+
Dicranophorus grandis (Ehrenberg, 1832)	*Dic gran*	-	+	-	-

Table 1. Continued.

ROTIFERA	Abbreviations for species	Station I	Station II	Station III	Station IV
Paradicranophorus hudsoni (Glascott, 1893)	*Par huds*	+	+	+	+
Encentrum saundersiae (Hudson, 1885)	*Enc saun*	+	-	-	+
Testudinella patina (Hermann, 1783)	*Tes pati*	+	+	+	+
Filinia longiseta (Ehrenberg, 1834)	Fil long	+	+	+	+
Filina cornuta (Weisse, 1847)	*Fil corn*	+	+	+	-
Hexartra fennica (Levander, 1892)	*Hex fenn*	+	+	-	+
CLADOCERA					
Dapnia magna Straus, 1820	Dap magn	+	+	+	+
Daphnia similis Claus, 1876, emend. Brooks, 1957	*Dap simi*	+	-	+	-
Daphnia pulex Leydig, 1860, emend. Scourfield, 1942	*Dap pule*	+	-	-	+
Simocephalus vetulus O.F. Müller, 1776	*Sim vetu*	-	-	-	+
Moina brachiata Jurine, 1820, emend. Goulden, 1968	*Moi brac*	+	+	+	+
Moina micrura Kurz, 1874, emend. Goulden, 1968	*Moi micr*	+	-	-	-
Bosmina longirostris (O.F.Müller, 1785)	*Bos long*	+	+	+	+
Chydorus sphaerieus (O.F. Müller, 1776)	*Cyd spha*	+	+	+	+
Pleuroxus aduncus Baird, 1843	*Ple adun*	+	+	+	+
Alona guadrangularis (O.F. Müller, 1785)	*Alo quad*	+	+	-	+
Alona rectangula Sars, 1862	Alo rect	+	+	+	+
Alona costata Sars,1862	*Alo cost*	+	+	+	+
Macrothrix laticornis (Fischer, 1848)	*Mac lati*	+	-	-	-
Ilyocryptus sordidus (Liévin, 1848)	*Ily sord*	+	-	-	+
Diaphanosoma brachyurum (Liéven, 1848)	*Dia brac*	+	+	+	+
COPEPODA					
Cyclops vicinus Uljanin , 1875	*Cyv vici*	+	+	+	+
Cyclops abyosorum G.O. Sars, 1863	*Cyc abys*	-	+	-	-
Cyclops insignis Claus, 1857	*Cyc insi*	+	+	+	+
Achanthocyclops robustus (G.O. Sars, 1863)	*Aca robu*	+	+	+	+
Megacyclops viridis (Jurine,1820)	*Meg viri*	-	+	-	-
Thermocyclops crassus (Fischer, 1853)	*The cras*	-	+	-	-
Eucyclops serrulatus (Fischer, 1851)	*Euc serr*	+	+	+	+
Calanipeda aquae-dulcus Kritschagın, 1873	*Cla aqua*	+	+	+	+
Archtodiapotomus wierzejskii Richard, 1888	Arc weri	+	+	+	-
Onychocamptus mohammed (Blanchard, Richard, 1891)	*Ony moha*	+	+	+	+
Nitocra hibernica (G.S. Brady, 1880)	*Nit hibe*	+	+	+	+

Table 2. Maximum dominancy, species diversity and species richness values of zooplankton according to months.

	Mar	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**
Max. Dom (lim. betw. 0-100)	6.200	8.800	5.000	5.000	3.600	4.300	3.900	5.500	5.900	5.900	4.500
Shannon (H') (lim. betw. 0-5)	3.184	2.790	3.498	3.461	3.777	3.663	3.615	3.267	3.379	3.355	3.512
Margaleff (M) (unlimited)	5.585	4.051	7.285	7.069	9.144	8.470	7.872	5.845	6.785	6.532	7.345

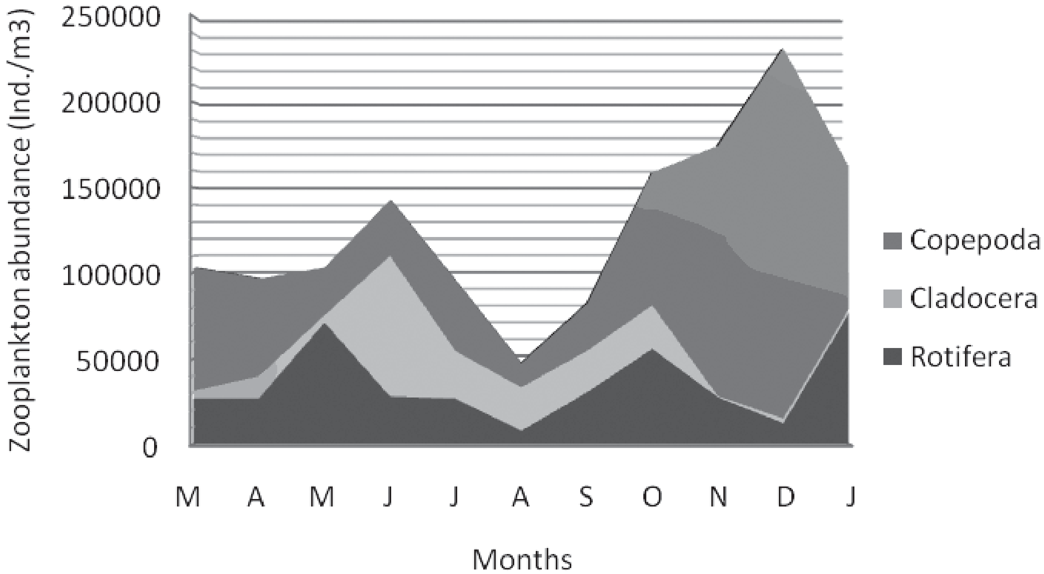

Fig. 4. Distribution of zooplankton organism groups identified in Lake Gala by months.

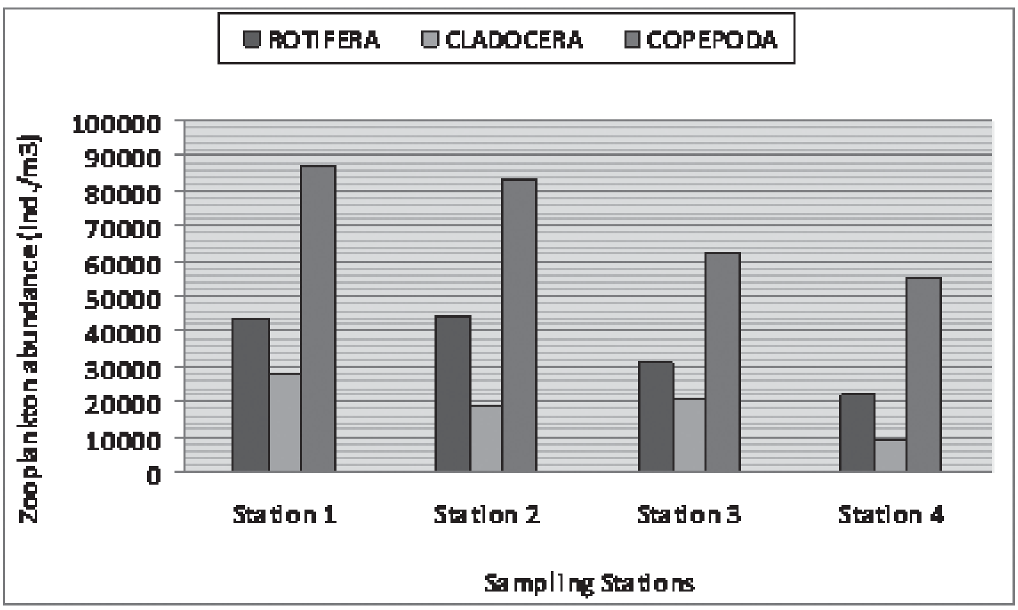

Fig. 5. Distribution of zooplankton organism groups identified in Lake Gala according to sampling stations.

the second RDA axis (0.925) and 55.1% of the explainable variance of species-environment relation. These correlation values show that there is a strong relationship between taxa distribution and environmental variables. These also indicated that the whole data is consisting of two dominant gradients.

According to Monte Carlo Permutation tests, Water tem, EC, SO_4, Ca, pH, Chl-a, Secchi and PO_4 are significant ($p = 0.0020$). Forward selection procedure indicated that water temperature, SO_4 and EC are the most important environmental variables affecting the quantitative structural spatial-seasonal changes of zooplankton. Water temperature explained 17% of the total zooplankton variance, while SO_4 – 8% and EC – 7%. These three environmental variables totally captured 32% of the total variance while the other five environmental variables constituted 18.5%.

According to Fig. 8, The first RDA axis mostly related to water temperature, SO_4, PO_4, EC and Secchi, while second RDA axis EC, SO_4 and Ca.

According to Fig. 8, Calcium is the most important environmental variable affecting the zooplank-

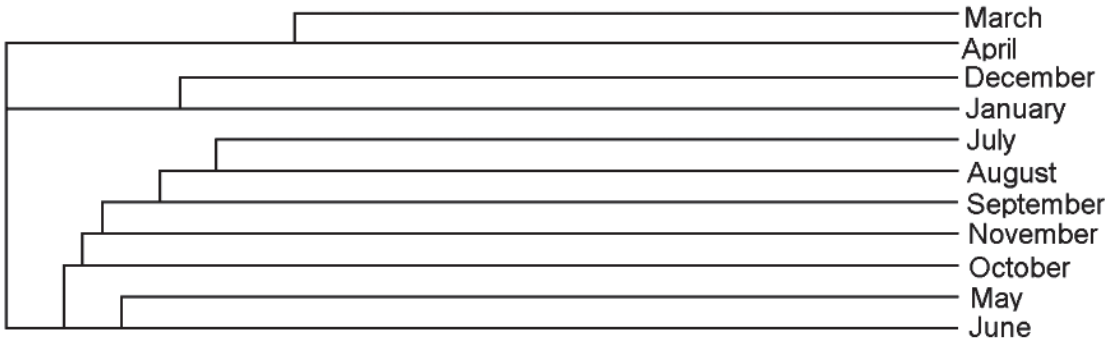

Fig. 6. Jaccard similarity of zooplankton according to months.

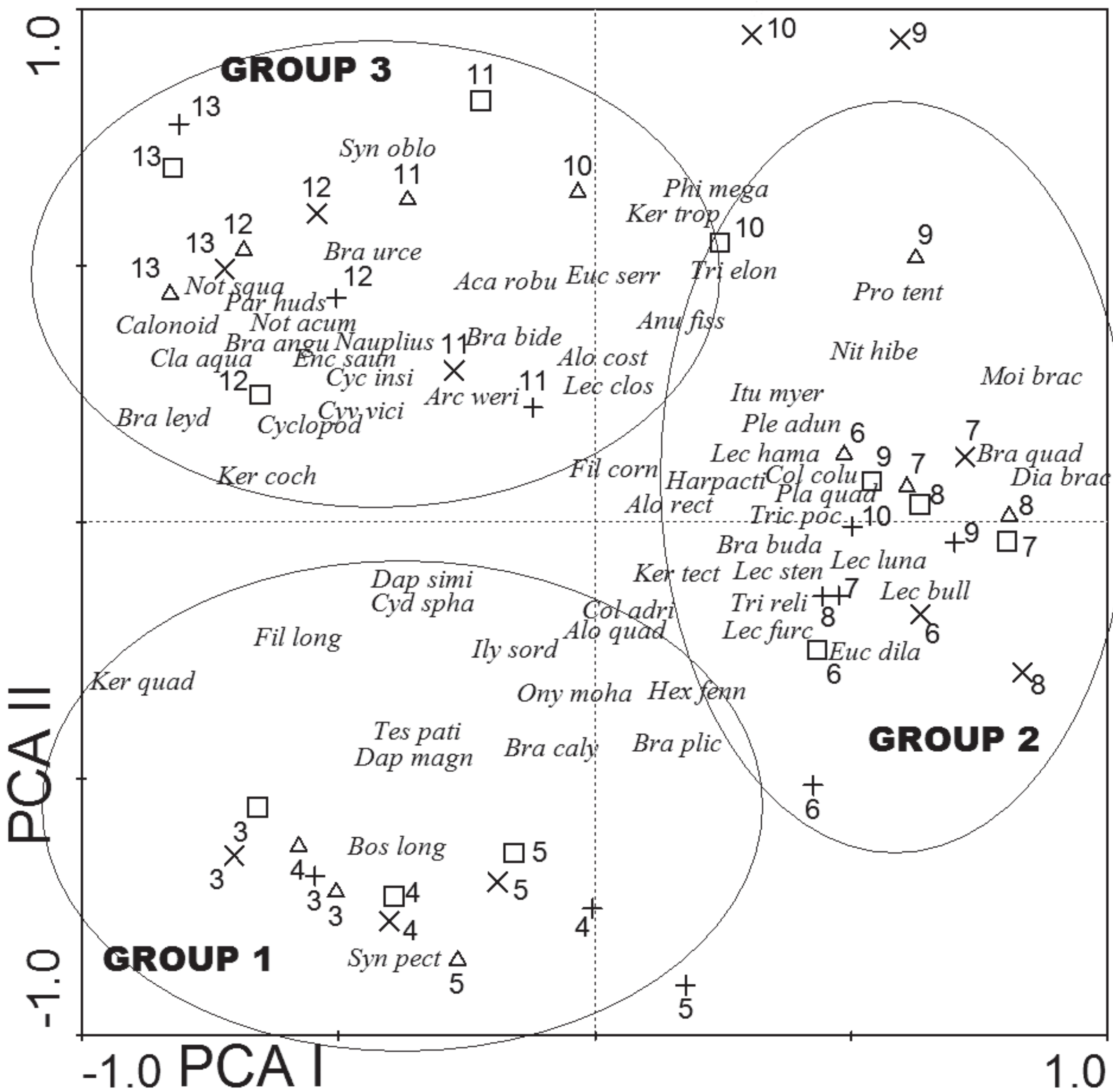

Fig. 7. Principal component analysis (PCA) ordination graphic of 62 species. Trick Marks indicate 0.5 units along both axes.

(△: Station 1; ×: Station 2; □: Station 3; +: Station 4)

(**3**: March; **4**: April; **5**: May; **6**: June; **7**: July; **8**: August; **9**: September; **10**: October; **11**: November; **12**: December; **13**: January.

ton in March, April and May (Fig. 9). The most affected species from this variable are the *F. longiseta*, *K. quadrata*, *I. sordidus*, *D. similis*, *D. magna* and *B. angularis* assembled on the top right of the second RDA axis (Fig. 8).

Of the most important environmental variables affecting zooplankton in June, July and August, water temperature, sulphate (SO_4) and Secchi affect predominantly the species (*H. fennica*, *L. furcata*, *T. relicta*, *K. tecta*, *B. plicatilis*, *C. adriatica*, *O. mohammed*) assembled on the top left of the second RDA axis.

The most important environmental variables affecting zooplankton in September and October are electrical conductivity and phosphate (Fig. 9). These variables affect predominantly the species (*L. bulla*, *E. dilatata*, *L. hamata*, *P. tentaculatus*, *P. megalotrocha*) assembled on the bottom left of the second RDA axis too) (Fig. 8).

It was observed that the most important environmental variables affecting zooplankton in the months November, December and January respectively was chlorophyll-a and pH affecting trophic level (Fig. 9). The most affected species from these variables are the ones on the bottom right of the second RDA axis. The most important ones from these species are the *A. werijieski*, *C. sphaericus*, *C. vicinus*, *A. robustus*, *E. saundersiae*, *Nauplius*, *B. urceolaris*, *N. acuminata*, *C. aqua-dulcus*, *B. leydigi* (Fig. 8). It was seen that the negative correlation between these species and the water temperature.

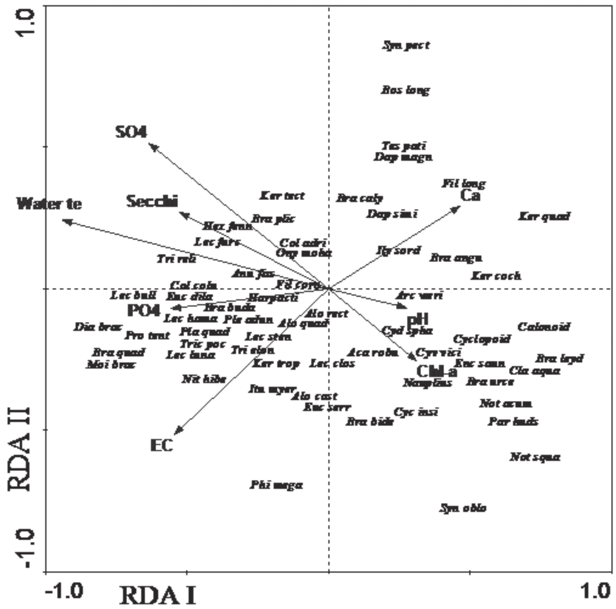

Fig. 8. RDA biplot ordination diagram of species. Arrows show physical-chemical variables.

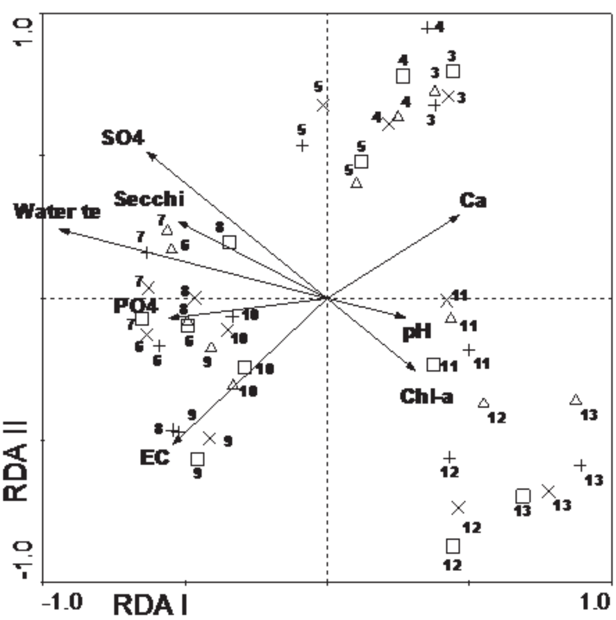

Fig. 9. RDA biplot ordination diagram of samples. Arrows show physical-chemical variables.
(△: Station 1; ×: Station 2; □: Station 3; +: Station 4)
(**3**: March; **4**: April; **5**: May; **6**: June; **7**: July; **8**: August; **9**: September; **10**: October; **11**: November; **12**: December; **13**: January.

Discussion

In the study which was performed for one-year period in the Lake Gala, a total of 76 species have been identified as 50 species belong to Rotifera, 15 species belong to Cladocera and 11 species belong to Copepoda. While a large number of these species show distribution all over Turkey, *Proalides tentaculatus* De Beuchamp, 1907*, Itura myersi* Wulfert, 1935, *Asplanchnopus hyalinus* (Harring, 1913) are found only in Turkish Thrace.

Lake Gala is under the influence of Arda River from Greece and Maritsa River from Bulgaria and since these regions are close to each other, zooplankton fauna of them is also similar (Zarfdjian, Economidis 1989, Zarfdjian *et al*. 1990, Zarfdjian *et al*. 2000, Michaloudi, Kostecka 2004, Kozuharov *et al*. 2009). The species found in the Lake Gala are seen in Greece and in Bulgaria too.

When the mean values of each environmental factor measured in the Lake Gala were evaluated according to Water Pollution Control Regulations, it can be concluded that they are within the normal range.

Phosphate, Sulphate, Nitrite and Nitrate used in agriculture are expected to be high in the wetlands, such as Lake Gala, that are surrounded by intensive agricultural areas.

However, entrance of sulphate and phosphate ions into the lake is partially limited by the dense reed fields between agricultural lands and the lake and also small channels separating it from agricultural areas.

But, this case causes the lake surface to dwindle allowing the reed areas to develop more rapidly.

If some physical-chemical parameters like pH, EC and Ca values measured in Lake Gala were compared with similar lakes in Thrace region, it is seen that these values are similar to the lagoon lakes (Güher 2003, Çamur-Elipek 2003, Koşal-Şahin 2006) while they are higher than the lakes of Hamam and Pedina located entirely within forest (Güher 2003).

The cause of increasing Chlorophyll-a in a lake is the increase in the number of phytoplankton organisms. Chlorophyll-a values have increased in Lake Gala in the late summer and autumn. They were higher depending on increase in the number of pytoplankton organisms in September and October and due to the enrichment of organic matter in autumn.

In the freshwater ecosystems, depending on environmental factors, the abundance and species composition of zooplankton organisms in the temperate zone lakes is like Rotifera > Cladocera > Copepoda. In Lake Gala, while species composition is like Rotifera > Cladocera > Copepoda, abundance of zooplankton organisms is also like Copepoda > Rotifera > Cladocera.

Rotifera is represented by highest number of individuals within the zooplankton organisms in the lake. This can be connected with that Rotifera include species showing wide spread in shallow lakes and ponds and being cosmopolite majority of them, in addition to, that these species can tolerate very different environmental conditions (Kolisko 1974, Koste 1978). Moreover, containing of a large number of species also supports the numerical abundance. The reason for the increase in numerical is the numerical excess of *Brachionus* spp. commonly found in eutrophic lakes.

The reason for Copepoda to be high in number stems from *Nauplius* larvae especially in November and December. Decrease in Copepoda in January shows that a major part of *Nauplius* larva is died by depending on biotic or abiotic factors.

Considering the geographical region where Turkey is located, zooplankton organisms are expected to increase twice in spring and summer during a year. But, in Lake Gala, while Rotifera reaches the maximum in spring, Cladocera in summer and Copepoda in winter, Rotifera becomes minimum in summer, Cladocera in winter and Copepoda in summer. Increase in Rotifera in spring stems from *Brachionus calyciflorus.* This is a species that is tolerant to oxygen and pH 7-9, commonly found in lakes eutroph and hipereutroph and can be observed throughout the year.

As it can be understood from the results of Jaccard similarity index, according to the diversity and abundance of zooplankton species, similarities of months is associated with seasons. It is particularly affected by water temperature. Consecutive months have similar environmental conditions. Likewise, the species that can also tolerate these environmental conditions are available together in these months.

Margelef index results show that species richness of zooplankton is higher during summer months. Then the increase in water temperature and the increase in aquatic macrophytes forming very specific habitats within the water body support species richness.

Looking at the results of Shannon diversity index, no significant differences in species diversity of zooplankton by months is observed. Species diversity and species richness increase and decrease in the same months and are affected by similar conditions. The reason is that the zooplankton species showing wide spread in shallow lakes and ponds and being cosmopolite majority of them is common in the lake and that these species can tolerate very different environmental conditions.

That maximum dominance increase in parallel with increase in phytoplankton organisms in spring can be explained by the abundance of zooplankton species fed on them.

According to the results of PCA analysis, when looking at the seasonal distribution of zooplankton species, it is seen that species form three groups (Fig.

7). This case shows that species found in the same group occur in the water body at the same time and are affected by similar environmental conditions

According to the results of RDA analysis, correlation (for RDA axis 1: 0.956, for RDA axis 2: 0.925) between zooplankton organisms and environmental variables being so high shows that water temperature, EC, SO_4, Ca, pH, Chl-a, Secchi and PO_4, are the significant ($p = 0.0020$) factors determining the distribution of zooplankton organisms.

As it can be seen in Fig. 8 and 9, the amount of Ca ions in the lake being high in March, April and May positively influenced the development of species such as *F. longiseta*, *K. quadrata*, *I. sordidus*, *D. similis* and *B. angularis*. Calcium is an important component for the carapax development of Cladocera and Copepoda. If lack of this element growth slows and deaths occur (Bozkurt, Sagat 2008 and references there in).

It was found that in June, July and August water temperature, sulphate and light permeability are the most important environmental parameters positively affecting the development of species (Fig. 9). In these months, an increase in water temperature and Secchi depth increases the abundance of species living in temperate conditions, such as *K. tecta* (6-26 ^oC), *H. fennica* (19.3-22.8 ^oC), *B. plicatilis* (19.3-26 ^oC), *C. adriarica* (23.5 ^oC) (De Manuel Barrabin 2000).

EC and Phosphate (PO_4) are the other most important environmental variables affecting zooplankton especially in September and October (Fig. 9). EC has measured at the highest value in these months. *B. quadridentatus* (197.2-765.5 pS cm), *K. tropica* (262-1065 pS cm) and *P. quadricornis* (305-765 pS cm) are species that can tolerate high salinity (De Manuel Barrabin 2000).

Again, species such as *L. bulla*, *L. hamata*, *L. luna*, *L. stenroosi*, A. *rectangula* and *A. quadrangularis* affected by these values are littoral and periphytic and generally feed on the substrate on the macrophytes (Koste 1978, Hahn 1995, Kuczynska-Kippen, Nagengast 2006). The increasing of phosphate concentration in water is a factor supporting macrophyte development and this affects the abundance of zooplankton species.

In November, December and January, the most important environmental variables affecting zooplankton are pH and Chlorophyll-a affecting the trophic level (Fig. 9). The most important species affected by these parameters are also *S. oblonga*, *N. squamula*. While these species are positively affected from increase in Chlorophyll-a and pH, they have shown negative correlation with water temperature. Chlorophyll-a values were found at higher values in autumn and in September and October increase in the number of phytoplankton organisms, due to the fact that depending on the lake grow rich in organic matter. This situation led to abundance of the species fed as herbivour and found in zooplankton such as *N. acuminata*, *N. squamula*, *B. urceolaris*, *B. bidentata* and *S. oblonga* (De Manuel Barrabin 2000 and references there in, Kolisko 1974). Also, these months include cyclopoid and calanoid copepod species affected from the same chemical parameters. Cyclopoid and Calanoid copepoda are effective predator of Rotifera (Brandl 2005). The abundance of herbivore rotifers positively influenced the development of copepod through the food chain.

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References

Balik S. 1985. Trakya Bölgesi İçsu Balıklarının Bugünkü Durumu ve Taksonomik Revizyonu.– *Doğa Bilim Dergisi,* A2,9,2.

Brandl Z. 2005. Freshwater copepods and Rotiferas: predators and their prey. –*Hydrobiologia,* **546**: 475-489.

Bozkurt A., Y. Sagat 2008. Birecik Baraj Gölü Zooplaktonunun Vertikal Dağılımı. –*Journal of FisheriesSciences.com*, **2** (3): 332-342.

Çamur Elipek B. 2003. The Dinamics of Bentic Macroinvertebrates in a mesotrophic lake: Terkos (Turkey). – *Ekologia,* **38** (1-2): 31-40.

De Manuel Barrabin J. 2000. The Rotifers of Spanish Reservoirs: Ecological, Systematical and Zoogeographical Remarks. – *Limnetica*, **19**: 91-167.

Duggan I. C. 2001. The Ecology of Periphytic Rotifers. – *Hydrobiologia,* **446/447**: 139-148.

Dussart B. 1967. Les Copepodes des Eaux Continentales d' Europe Occidentale, Tome I, Calanoides et Harpacticoides. – *Editions N. Boubee, et cie*, Paris, 499.

Dussart B. 1969. Les Copepodes des Eaux Continentales d' Europe Occidentale Tome II, Cyclopoides et Biyology. – *Editions N. Boubee et cie*, Paris, 285.

Edmondson W. T. 1959. Methods and Equiment in Freshwater biology 2nd ed. John Willey and Sons. Inc., NewYork, 420-1202.

Erdoğan S., H. Güher 2005. The Rotifera Fauna of Gala Lake. – *Pakistan Journal of Biological Sciences,* **8** (11): 1579-1583, ISSN 1028-8880.

Flössner D. 1972. Krebstiere Crustacea Kiemen und Blattfussar Brachiopoda Fischlause, Branchiura. – Tierwelt-Deusch. 60 Veb. Gustav Fischer Verlag, Jena, 105-161.

Güher H. 2003. Mert, Erikli, Hamam ve Pedina Göllerinin (İğneada/Kırklareli) Zooplanktonik Organizmalarının Kommunite Yapısı. – *E.U.Journal of Fisheries & Aquatic Sciences,* Vol. 20, **1-2**: 51-62.

Hann B. J. 1995. Invertebrate associations with submersed aquatic plantsin a Prairie Wetland. – UFS (Delta Marsh) Annual Raport, **3**: 78-84.

Hill M. O. and H. G. Gauch 1980. Detrended Correspondence Analysis: An Improved Ordination Technigue. Vegetatio, **42**: 47-58.

Jaccard P. 1912. The distribution of the flora of the alpine zone. – *New Phytologist*, **11**: 37-50.

Kaya M., C. Kurtonur 2003. Gala Gölü ve Çevresinin (Edirne) Ornitho Faunası Üzerine Araştırmalar. – *Trakya Üniversity Journal of Science,* **4** (2): 169-179.

Kirgiz T. 1989. Gala Gölü Bentik Faunası. – *Anadolu Üniversitesi Fen-Edebiyat Fakültesi Dergisi*, cilt 1, **2**: 67-87.

Kiefer F. 1978. Das Zooplankton der, Binnengewasser. -2. Teil Stuttgart, 343 pp.

Kolisko R. A. 1974. Plankton Rotiferas biology and taxonomy. Biological station lunz of the Austrian Academy of Sciences, Stuttgart, pp: 145.

Korinek V. 1987. Revision of three species of the genus Diaphanosoma Ficher 1850. -*Hydrobiologia*, 145: 35-45.

Koste W. 1978. Die Radertiere Mitteleuropas I, II Textband, (Rotiferas of Middle Europea Vol. I, II). Berlin Stuttgart, 235-670.

Koşal-Şahin S. 2006. Büyükçekmece Gölü (İstanbul) Bentik Makroomurgasızlarının Nitel ve Nicel Dağılımları, İstanbul Üniversitesi Fen-Bilimleri Enstitüsü, Temel Bilimler Anabilim Dalı İç Sular Biyolojisi Programı, 64 p. (Doktora Tezi).

Kozuharov D., T. Trichkova, P. Borisova and M. Stanachkova 2009. The zooplankton Composition in two reservoirs in the North-west Bulgaria in relation to Dreissena spp., occurence. – *Biotechnology&Biotechnological Equipment*, **23**, Se special edition, On-line.

Kuczyńska-Kippen N. M., B. Nagengast 2006. The Influence of the spatial structure of hydromacrophytes and differentiating habitat on the structure of rotifer and Cladoceran communities. – *Hydrobiologia,* **559**: 203-212.

Margalef R.1958. Information theory in ecology. – *General Systems,* **3:** 36-71.

Margaritora F. 1983. Cladoceri (Crustacea: Cladocera). – *Instituto di Zoologia e Anatomia Comparata dell' Università di Roma*, 169 p.

Michaloudi E., M. Kostecka 2004. Zooplankton of Lake Koroneia (FYRMacedonia, Greece). – *Biologia, Bratislava,* **59/2**: 165-172.

Ortak R., T. Kirgiz 1988. Gala Gölü Cladocera ve Copepoda (Crustacea) Türleri. – IX. Ulusal Biyoloji Kongresi, Cumhuriyet Üniversitesi Fen Edebiyat Fakültesi Sivas, 21-23 Eylül, 377-385

Öterler B., T. Kirgiz and M. Albay 2008. Gala Gölü (Edirne)'nün Epifitik Algleri ve Su Kimyasıyla Olan İlişkilerinin İncelenmesi. Ulusal Limnoloji Sempozyumu, 27-29 Ağustos, Urla-İzmir.

Özkan N., T. Kirgiz 1995. Chironomidae (Diptera) Larvae of Edirne Province and Their Distribution (in Turkish). – *Doğa Turkish Journal of Zoology*, **19**: 51–58.

Piepenburg D., U. Piatkowski 1992. A program for computer-aided analyses of ecological field data. – *CABIOS,* **8**: 597-590.

Saler S., D. Şen 2002. Seasonal Variation of Rotifera Fauna of Cip Dam Lake (Elazığ-Turkey). – *Pakistan Journal of Biological Sciences,* **5**(11): 1274-1276.

Seçmen Ö., E. Leblebici 1991. Aquatic Flora of Thrace (Turkey). – *Willdenowia,* **20**: 53-66. ISSN 0511-6918.

Segers H. 1995. Guides to the Identification of the Microinvertebrates of the Continental waters of the World; The Lecanidae (Monogononta). -SPB Academic Publishing bv., Vol. 2, ISSN 0928-2440.

Shannon C. E., W. Weaver 1949. The Mathematical Theory of Communication. University of Illinois Press, Urbana, 117 p.

Smirnov N. N. 1974. Fauna of USSR Crustacea Chydoridae. – *English Translation Israel Program Scientific,* Vol. 1, **2**: 238-629.

Tasevska O., G. Kostoski and D. Guseska 2004. Compozition and Dynamic of Rotifera Fauna from Eastern Littoral Zone of Lake Ohrid as Parameter of Water quality, Ohrid. FYRepublic of Macedonia, 25-29 May 2004, – *BALWOIS.*

Ter Braak C. J. F., I. C. Prentice 1988. A theory of gradient analysis. – *Advances in Ecological Research,* **18**: 271–317.

Ter Braak C. J. F., P. Smilauer 2002. Reference manual and user's guide to CANOCO for Windows. Software for canonical community ordination, version 4.5. Centre for Biometry., Wageningen, The Netherlands.

Van Den Wollenberg A. L. 1977. Redundancy analysis, an alternative for canonical correlation analysis. – *Psychometrika,* **42**: 207-219.

Yilmaz İ. 1988. Edirne İli Sınırlarında Yaşayan Amfibi Faunası ve Ekonomik Önemi, Gala Gölü ve Sorunları Sempozyumu, 27. Mayıs.1988. Enez.Bildiriler. Doğal Hayatı Koruma Derneği Bilimsel Yayın Serisi. Kıral Matbaası.

Zarfdjian M. H., P. S. Economidis 1989. Listes Provisoires Des Rotiferes, Cladocéres & Copépodes Des Eaux Continentales Grecques. – *Biologia Gallo-Hellenica,* **15**: 129-146.

Zarfdjian M., M. Vranovský and P.S. Economidis 1990. Les Invertébrés Planctoniques du Lac Volvi (Macédoine, Gréce). – *Int. Revueges, Hydrobiologia,* **75** (3): 403-412.

Zarfdjian M. H., B. C. Evangelia Dimitra and M. M. Spiros 2000. Zooplankton Abundance in the Aliakmon River. Greece. – *Belgian Journal of Zoology,* **130** (Supplement 1): 29-33.

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