Biologia, Bratislava, **59**/2: 165—172, 2004

Zooplankton of Lake Koroneia (Macedonia, Greece)

Evangelia Michaloudi[1] & Marta Kostecka[2]

[1] *Aristotle University of Thessaloniki, School of Biology, Laboratory of Ichthyology, Box 134, GR-54124, Thessaloniki, Greece; e-mail: tholi@bio.auth.gr*
[2] *Ul. Politechniczna 3, PL-32020 Wieliczka, Poland*

Michaloudi, E. & Kostecka, M., Zooplankton of Lake Koroneia (Macedonia, Greece). Biologia, Bratislava, **59:** 165—172, 2004; ISSN 0006-3088.

Twenty four species (19 Rotifera, 4 Cladocera, 1 Copepoda) were recorded in the zooplankton of Lake Koroneia from June 1999 to June 2000. The dominant species were the Cladocera *Daphnia magna* and the rotifers *Brachionus dimidiatus* and *B. rubens*. Total abundance ranged from 13 to 32,426 ind. L^{-1} and its seasonal dynamics resembled those of hypertrophic lakes, but attaining much higher numbers due to the absence of predation pressure from fish. Rotifers prevailed (up to 100%) during the warm months (June–October) and their seasonal dynamics were governed by temperature and the presence of large *Daphnia* individuals. Cladocera were absent during the summer due to high pH values (9.32–11.10) and/or the composition of the phytoplankton community where *Anabaenopsis milleri* prevailed.

Key words: lake, hypertrophic, fishless, zooplankton, Greece.

Introduction

Lake Koroneia (23°04′–23°14′ E, 40°7′–40°43′ N) (Fig. 1) is located near the city of Thessaloniki in N Greece, at an altitude of 75 m a.s.l. It is a highly eutrophic lake, characterised by low transparency (0.20–0.60 m) and high phytoplanktonic biomass (max. dry weight 5.6 gm^{-3}), dominated by blue-green algae and diatoms (Kilikidis et al., 1984). It receives water from small streams and torrents within a drainage area of about 780 km^2. The lake and the areas around it are protected by the RAMSAR convention and have been proposed to be included in the protected areas of NATURA 2000. However, water quality of the lake has been declining due to negative water balance and huge amounts of pollutants received from point and diffuse sources.

In the 1970's the lake occupied an area of about 46.2 km^2 with a maximum depth of 8.5 m (Psilovikos, 1977), while it used to be one of the most productive lakes in Greece concerning fisheries production. During recent decades its water volume has decreased dramatically, due to the overexploitation of water for agricultural and industrial purposes and changes in climatic conditions (in particular lack of rain). In August 1995, an acute change in environmental parameters in combination with the low water volume (depth 1 m, area 30 km^2) killed all the fish in the lake, while any efforts since then to re-establish fish populations have failed. Currently the lake has a maximum depth < 1 m, has no macrophytes, no fish and is under a restoration program (which has not started yet) for an increase in its water volume and improvement of water quality, although it still receives agricultural and industrial effluents as well as domestic sewage from the surrounding area. The changes in water quality of the lake can be seen in Table 1, where some of the main physicochemical parameters are presented.

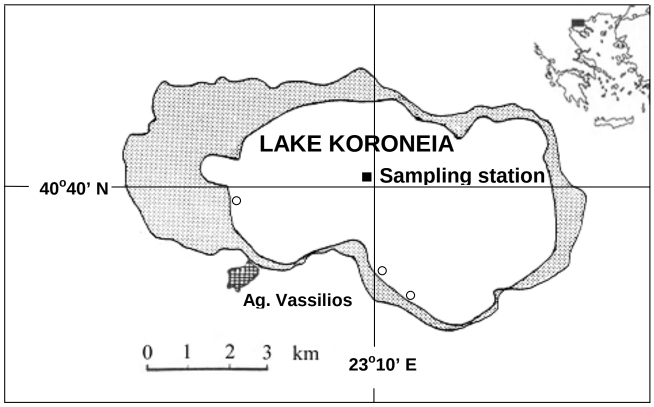

Fig. 1. Map of Lake Koroneia showing the location of the sampling station. Grey area: the extent of lake surface in 1970, white area: lake surface in 1995, open circles indicate stations where only qualitative samples were collected (modified from Hellenic Ministry for the Environment, 1996).

Table 1. Physicochemical parameters of Lake Koroneia.

	Temperature (°C)		pH		Conductivity (μS cm^{-1})		O_2 (mg L^{-1})		Secchi (cm)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1983–1989[1]	2	32	7.8	9.4	1200	1760	3.2	13.2		
1990–1997[1]	0	34	7.9	10.1	1630	6750	4.1	13.8		
1999–2000[2]	0.10	25	8.8	11.1			2.9	16.3	10	49

Key: [1] Data from the Ministry of Agriculture, [2] unpublished data from the present study.

Although several studies exist concerning the period prior to 1995 the current state of the lake is unknown, while for the zooplankton community practically no information is available except for a few qualitative studies (Ananiadis, 1951; Christomanos, 1972; Kilikidis et al., 1984). Thus, in 1999–2000 a one-year sampling program was carried out and the results presented here concern the zooplankton community and aim to provide information on the lake's current status.

Material and methods

Samples were collected monthly, from June 1999 to June 2000, at the deepest point of the lake (1.5 m), using a 2-L Niskin sampler. At least 30 L of the water column were filtered each time, through a net of 50 μm mesh size, preserved in 4% formalin and analysed in the laboratory. In addition, samples were collected with vertical and horizontal hauls, in the pelagic area of the lake and along the shore, using plankton nets (50 and 100 μm mesh size), for qualitative analysis. All sampling was performed between 9:00 a.m. and 1:00 p.m.

Diversity was calculated using the Shannon-Wiener index H, and evenness using Pielou's J (Magurran, 1988).

Pearson's correlation coefficient was applied in order to establish the relationships between abundance data and physicochemical parameters (unpublished data) and was performed on log-transformed data (Zar, 1984).

Results

Species composition

During this study a total of 24 zooplankton species were identified (Tab. 2). The Rotifera community consisted of 19 species (three were undetermined). *Brachionus calyciflorus* was recorded in three forms that were present together in the zooplankton community: *B. c.* f. *amphiceros* (Ehrenberg, 1838), *B. c.* f. *anuraeiformis* (Brehm, 1909) and *B. c.* f. *dorcas* (Gosse, 1851). *Brachionus dimidiatus* was found in two forms: *B. d.* f. *inernis* (Schmarda, 1854) and *B. d.* f. *quartarius* De Beauchamp, 1932 which was dominant, while the typical species and the other form were only recorded once. *Filinia longiseta* and its variatio *F. l.* v. *passa* (O. F. Müller, 1786) were recorded together, as well as *Keratella cochlearis* and its variatio *K. c.* v. *tecta* (Lauterborn, 1900). The crustacean community was comprised of four Clado-

Table 2. Occurrence time of the zooplanktonic species of Lake Koroneia and the min-max values of abundance (ind. L^{-1}) for species with regular appearance. Species for which values are not noted were found only occasionally.

Species	Months													Min.	Max.
	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI		
Asplanchnella brithwelli (Gosse, 1850)	+				+										
Brachionus calyciflorus Pallas, 1766	+	+	+		+		+						+	6.67	106.67
B. dimidiatus (Bryce, 1931)	+	+	+	+	+		+				+	+	+	0.03	31413.33
B. diversicornis (Daday, 1883)	+														
B. plicatilis (O.F. Müller, 1786)		+	+	+	+								+	4.44	826.67
B. rotundiformis Tschugunoff, 1921												+			
B. rubens (Ehrenberg, 1833)	+	+	+	+	+		+				+	+		0.67	653.33
B. urceolaris Müller, 1773	+	+	+	+										2.22	106.67
Brachionus sp.	+														
Collotheca sp.			+												
Epiphanes macrourus (Barrois et Daday, 1834)					+										
Filinia longiseta (Ehrenberg, 1834)	+	+												53.33	253.33
Keratella cochlearis (Gosse, 1851)	+	+	+		+										
Lecane luna (Müller, 1776)	+														
Trichocerca cylindrica (Imhof, 1891)	+														
T. similis (Wierzejski, 1893)	+				+										
Polyarthra sp.	+												+		
Pompholyx complanata Gosse, 1851	+														
Proalides tentaculatus De Beauchamp, 1907	+														
Ceriodaphnia pulchella Sars, 1862					+										
Daphnia magna Straus, 1820				+	+	+	+	+	+	+	+	+		5.37	106.67
D. similis Claus, 1876						+	+	+	+	+	+	+		0.23	16.67
Moina brachiata (Jurine, 1820)	+				+										
Acanthocyclops robustus (Sars, 1863)	+	+				+	+	+	+	+	+	+	+		

cera and one Copepoda: [*Acanthocyclops robustus* which was formerly determined as *A. vernalis* (Michaloudi et al., 2000)].

From the recorded species only six (*A. brithwelli, F. longiseta, K. cochlearis, C. pulchella, M. brachiata, A. robustus*) have been previously found in the lake. Clearly, the lack of previous data as well as the enormous changes that took place in the lake's environment do not allow any certainty about which of the species are really new for the lake.

As for the seasonal structure of the zooplankton community, it was well divided (Tab. 2). Thus, all rotifers were present from April to October, Cladocera from September to May, while the copepod species were absent during August–October.

Seasonal dynamics

Total abundance ranged from 13 to 32,427 ind. L^{-1}, exhibiting a major peak in October and a smaller one during the summer (Fig. 2). Rotifers comprised 100% of the zooplankton community from June to October (high abundance period), while the rest of the year Cladocera dominated (80–100%), apart from December and May when Copepoda contributed 75% to the total zooplankton community (Fig. 2).

The seasonal variations of abundance of the zooplankton groups and the percentage contribution of the main species are shown in Fig. 3. Rotifers abundance ranged from 0.7 to 32,320 ind. L^{-1}. During the period of their high abundance (June–October) the rotifer community was comprised almost totally (up to 95%) of *Brachionus dimitiatus*, whilst during the remainder of the year *B. rubens* dominated. Cladocera were absent during the entire summer. For the rest of the year their abundance ranged from 0.89 to 107 ind. L^{-1} and their community was dominated by *Daphnia magna* (79–100%), whose population consisted mainly of individuals > 1100 μm in length (Tab. 3). *Daphnia similis* had a smaller contribution (2–21%), except for February (59%) and its population was comprised mainly of individuals 900–1300 μm in length (Tab. 3). The copepod community was represented only by one species,

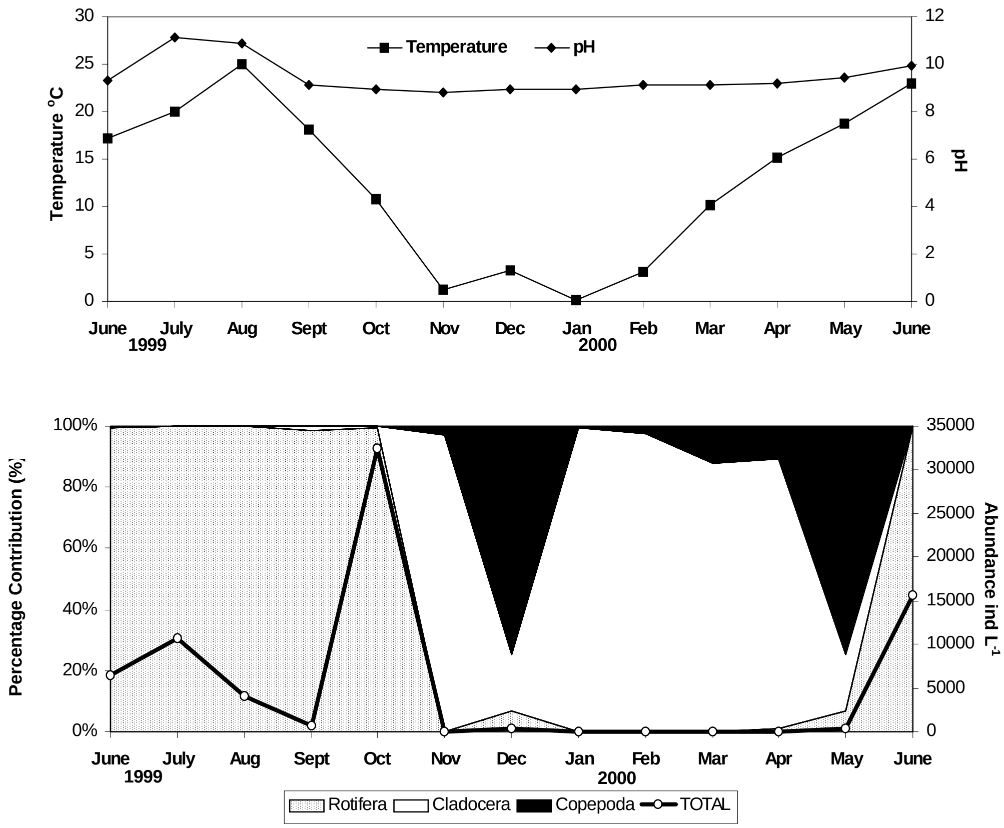

Fig. 2. Seasonal variations of temperature (℃) and pH (top panel) and the percentage contribution of zooplankton groups to the total abundance and the seasonal dynamics of the total abundance (ind. L^{-1}) in lake Koroneia during the period 1999–2000.

Table 3. Percentage contribution of the size classes (in μm) to the mean total abundance (ind. L^{-1}) of the cladocera species in Lake Koroneia during the period 1999–2000.

Daphnia magna mean total abundance: 29.13 ind. L^{-1}					
Size (μm)	300–1100 3%	1100–1900 69%	1900–2700 18%	2700–3500 9%	3500–4300 1%
Daphnia similis mean total abundance: 3.92 ind. L^{-1}					
Size (μm)	300–500 1%	500–700 2%	700–900 24%	900–1100 34%	1100–1300 39%

the cyclopoid *Acanthocyclops robustus.* The developmental stages (nauplius + copepodites) made up 80–100% of the population and abundance ranged from 1.10 to 227 ind. L^{-1}.

Diversity

Diversity H ranged from 0.2 to 1.2 and evenness J from 0.1 to 0.7 and their variations did not exhibit a seasonal pattern.

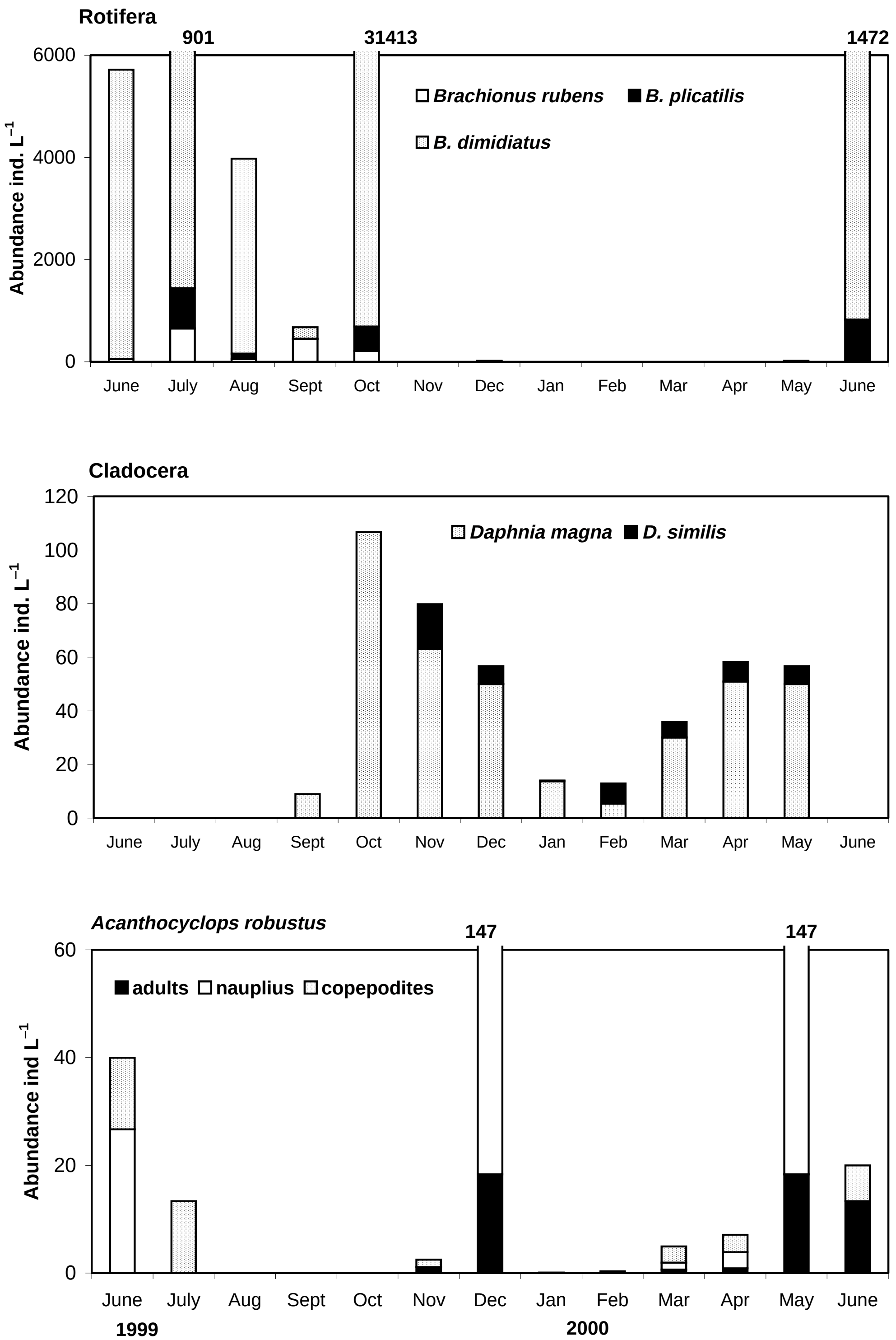

Fig. 3. Seasonal variations of the percentage contribution of the dominant rotifer and cladocera species and the copepod developmental stages to their total abundance (ind. L^{-1}) in lake Koroneia during the period 1999–2000.

Discussion

Lake Koroneia was characterised by a very simple zooplankton community. Although, 24 species were identified (Tab. 2) the whole community was actually comprised of only six (three rotifers of the genus *Brachionus*, two Cladocera of the genus *Daphnia* and one cyclopoid copepod) (Fig. 3). This community structure with few dominating species is characteristic of hypertrophic conditions in general (OLTRA & MIRACLE, 1992; JEPPESEN et al., 1998), while the presence of the rotifer species *Brachionus rotundiformis*, *B. rubens* and *B. plicatilis* which are brackish water species (VOIGT & KOSTE, 1978) indicates increased levels of salinity in Koroneia. In addition, it is interesting to note that the zooplankton community of lake Koroneia (Tab. 2), resembled the one found in a biological wastewater treatment system in Greece with *Daphnia magna* and *Brachionus* spp. dominating (KOUMI, 2000).

The seasonal dynamics of zooplankton abundance (Fig. 2) resembled that of hypertrophic lakes with rotifers reaching numbers of some thousands and crustaceans of some hundreds. Total abundance was highest in autumn, which is the seasonal pattern recorded in other hypertrophic lakes in Greece: Lake Pamvotis (ROMERO et al., 2002), Lake Kastoria (MICHALOUDI, 2000), while the lack of a strong spring maximum characterizes hypertrophic lakes in general [Lake Zwemlust, the Netherlands (VAN DONK et al., 1990), Lake Alte Donau, Austria (MAYER et al., 1997)].

Rotifers (Figs 2, 3) were the group that determined the seasonal variations of total abundance due to their high numbers. In that sense they are dominating the zooplankton community in hypertrophic lakes (VAN DONK et al., 1990; OLTRA & MIRACLE, 1992; NASELLI-FLORES & BARONE, 1997; JEPPESEN et al., 1998; MICHALOUDI, 2000; ROMERO et al., 2002), although, the values recorded in the present study were much higher probably due to the lack of predation pressure from fish. The main regulating factors for rotifers were found to be temperature (r = 0.708, P = 0.0067, n = 13) and the presence of large sized Cladocera (r = −0.604, P = 0.0287, n = 13). Temperature is well known to be one of the most important factors favouring rotifers increase in combination with food availability (ALLAN, 1976). *Daphnia* species (especially large sized individuals), however, having higher filtering rates are able to exploit more effectively the available food resources compared to rotifers, while in addition to exploitative competition there is also mechanical interference between *Daphnia* and rotifers (GILBERT, 1988). In Koroneia the absence of fish allowed the dominance of large sized *Daphnia* (Tab. 3), which consequently, during their presence outcompeted rotifers (Fig. 2). Thus, although rotifers as highly opportunistic species (ALLAN, 1976) started to increase immediately following winter due to the temperature increase, they followed in time Cladocera. Their first peak was in summer when, taking advantage of the absence of their competitors and lack of predation pressure to control them, they dominated the community. The species that dominated were *Brachionus dimidiatus* and *B. rubens* (Fig. 3) that are able to tolerate the high pH values (VOIGHT & KOSTE, 1978; LINCOLN & EARLE, 1990) recorded in Koroneia during summer (Fig. 2).

The Cladocera community was characterised by the dominance of the large sized *Daphnia magna* and their complete absence during the summer (Tab. 3, Figs 2, 3). The size structure of the Cladocera populations and the presence of *D. magna* were to be expected due to the absence of fish. Generally, in hypertrophic lakes *D. magna* builds a population right after massive fish kills or fish removal (VAN DONK et al., 1990; NASELLI-FLORES & BARONE, 1997). Its seasonal dynamics in Koroneia, however, were quite different from those reported in ecosystems where it is significantly participating in the zooplankton community. Thus, in a fishless lake (CARVALHO & CRISP, 1987), a lake with fish (LAMPERT, 1991) and an aerated sewage lagoon (CAUCHIE et al., 1995) *D. magna* is present throughout the year, while in Little Mere U.K. (BEKLIOGLU et al., 1999) and three ponds in Sweden (LEONARDSON & RIPL, 1980) it is present during the summer. In all cases pH values (< 10) were lower compared to the summer values in Koroneia (Fig. 2), while values above 10.5 can eliminate *Daphnia* species from the zooplankton community (JEPPESEN et al., 1998). Therefore, in Koroneia pH could be the controlling factor for *Daphnia,* something that is also reinforced by the correlation analyses ($r = -0.754$, P = 0.0029, n = 13). Nevertheless, the phytoplankton community should be considered too, since it is well established that Cyanobacteria in general as well as toxic ones can greatly affect several aspects of the life cycle of *Daphnia* species (PORTER & ORCUT, 1980; GLIWICZ, 1990). Although, there are no available current data concerning the phytoplankton community, in summer 1999 the Cyanobacteria *Anabaenopsis milleri,* which is toxic (LANARAS et al., 1989), was present in high numbers (VARDAKA, pers. comm.). Furthermore, in Lake Balaton when *Anabaenopsis* was in bloom *Daphnia* species practically disappeared (ZANKAI & PONYI, 1986). Thus, the phytoplankton community in combination with the high pH seems to be the controlling factors for the Cladocera community in Koroneia.

As for the population of *Acanthocyclops robustus*, its seasonal dynamics are quite variable. Mostly, it is present in the pelagic zone for a limited period of 5–7 months from April/May until December (MAIER, 1998), but it can also be perennial with peaks in spring, summer and autumn (LACROIX et al., 1989; OLTRA & MIRACLE, 1992). In the present study it was totally absent during three months (August–October) and abundance showed two peaks in winter and spring, while no parameter was found to affect its seasonal variations.

Finally, the community structure of zooplankton in Lake Koroneia was clearly depicted with the diversity indices. Shallow productive waters have low diversity and high population densities, which was clearly the case in Koroneia. It is well known that diversity decreases with the presence of a few highly predominant species and that it is controlled and determined by predation and/or competition (ODUM, 1975; KERFOOT & PASTOROK, 1978). Consequently, in Koroneia since there were no fish, the zooplankton community was regulated by competition, which is the determining factor in the absence of predation leading to the dominance of a few species, i.e. the decrease of diversity. Following ODUM'S (1975) classification, Koroneia may be classified as a very unstable ecosystem subjected to severe stress, since evenness J was generally very low with values lying mainly between 0.0 and 0.5.

In conclusion, we could say that the structure and dynamics of the zooplankton community in Lake Koroneia was governed by the absence of fish and the extreme summer conditions.

Acknowledgements

The authors would like to thank I. HUDEC for his helpful remarks on the manuscript.

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Received January 16, 2003
Accepted April 10, 2003