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Zooplankton and environmental factors of a recovering eutrophic lake (Lysimachia Lake, Western Greece)

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Abstract: The present study investigates the zooplankton community dynamics and the abiotic environment in the eutrophic Lake Lysimachia (western Greece). The lake is considered to be recovering from eutrophication after the termination of an urban sewage inflow in 2000, and its waters are replenished constantly from the nearby oligotrophic Lake Trichonis. The results show that, although a decrease in nutrient concentrations was observed compared to the past, the lake still has eutrophic characteristics. This was reflected in the zooplankton community which is typical of those found in eutrophic lakes where rotifers prevail. Similarities among this lake and other nearby lakes were found considering the zooplankton community composition and seasonal variation. However, Lake Lysimachia is inhabited also by a number of different and even unique species (e.g., *Moina micrura*), suggesting that this ecosystem may be an important biodiversity refuge. Most of the zooplankton species were correlated with water temperature and, to a lesser extent, eutrophication key-water quality variables. Although there are few available data on the zooplankton of the lake, the abundance and composition of the community presenting characteristics indicative of intermediate trophic conditions and suggesting that the lake is probably under a kind of "biological" recovery.

Key words: zooplankton; eutrophication; restoration; Lysimachia; Mediterranean lake

Introduction

Many lakes worldwide have become eutrophic by wastewater effluent, agricultural run-off and other nutrient sources. Wastewater treatment and diversion of nutrients from lake inflows are the foremost techniques used to reduce external nutrient loadings (Cooke et al. 1993). There are also a few cases where improvement in a lake's water quality has been achieved by hydrological management which involves replenishing of the lake with water from an extraneous source or from another lake with lower nutrient levels. Dilution as a restoration tool therefore, implies reducing the concentration of nutrients in lake water (Cooke et al. 1993).

Lake Lysimachia is a typical Mediterranean shallow lake which until the year 2000 received the untreated municipal wastewaters of the city of Agrinio, and thus became eutrophic. This was first reported by Overbeck et al. (1982) some thirty years ago and was verified by measurements of the Greek Ministry of Agriculture between 1980 and 1997 (www.minagric.gr) and Psilovikos et al. (1995), while the lake's condition after 2000 has not been estimated. A particular feature of the lake is that it is connected by a canal to the oligotrophic Lake Trichonis from which it receives large quantities of water, while there is also an outflow of water for irrigation purposes. In this sense, there has been a constant natural replenishing of the lake which, together with termination of the sewage inflow in 2000, may be considered processes leading to a possible recovery of this ecosystem.

Zooplankton organisms are important elements of the structure and function of freshwater lake ecosystems, as they occupy a critical position within the trophic web of a lake and are sensitive to anthropogenic impacts (Jeppesen et al. 2011). Although zooplankton is still not included as a biological quality indicator for aquatic ecosystems according to the implementation of the EU Water Framework Directive, there are several studies that have shown its usefulness as an indicator of changes in trophic dynamics and the ecological state of lakes related to changes in nutrient loading and climate (see Jeppesen et al. 2011). Considering that the recovery of a disturbed ecosystem is affected by interacting biotic and abiotic processes, irrespective of the importance of large-scale studies, it is interesting to determine how local conditions may determine zooplankton communities' composition (Kagalou et al. 2010).

Assuming that Lake Lysimachia is a recovering ecosystem, the aim of the present study is to describe the zooplankton community as a biological element relevant in the assessment of its ecological status and to explore relationships between community dynamics and environmental factors.

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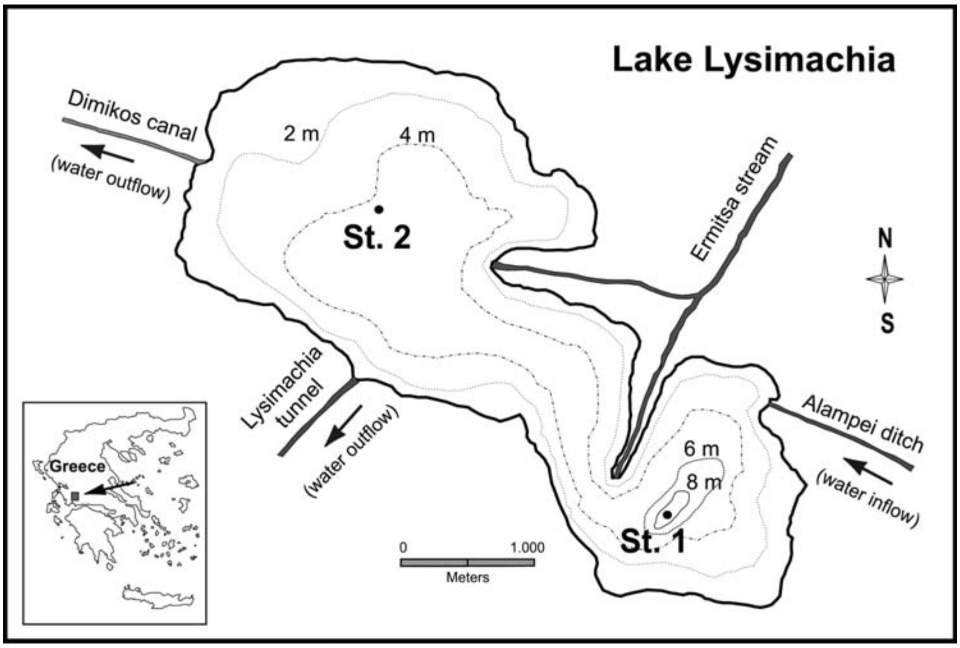

Fig. 1. Location of Lake Lysimachia and the sampling stations (1, 2).

Material and methods

Description of the study area

Lake Lysimachia (38°36′ N, 21°22′ E) is a shallow lake (maximum depth 8.1 m), located near the city of Agrinio (population 80,000) in western Greece (Fig. 1). It is a warm monomictic lake that belongs to the carbonate type (Overbeck et al. 1982). The lake is surrounded by alluvial deposits and has a surface area of 13.5 km^2 and a large drainage basin of 246 km^2. It has positive water balance due to seasonal inflow of water from Ermitsa stream and mainly from the nearby Lake Trichonis (Fig. 1), with which it is connected by a 6.5 km canal (Alampei ditch). A large amount of water outflows from the lake through a 6,450 m tunnel (Lysimachia tunnel) and is used for irrigation of agricultural areas, while the lake's surplus water outflows into the Acheloos River via Dimikos canal (Fig. 1). The lake has been listed among the Greek NATURA 2000 protected areas (Directive 92/43/EEC) and is important for wintering ducks and migrating waterbirds. Sixteen fish species have been recorded, some of which are endemic in the western Greece region. Extensive reed communities (mainly *Phragmites australis*) grow around the lake and these offer valuable refuge to wild fauna. After the establishment of the wastewater treatment plant of Agrinio in the year 2000, the lake presently receives only small amounts of wastewaters and fertilizers from the surrounding agricultural areas.

Field and laboratory operations

Zooplankton samples were taken monthly from June 2009 to May 2010 from two stations with depth variations between 8.1 and 5.4 m (station 1), and 6.8 to 4 m (station 2) (Fig. 1). The samples were collected with vertical hauls from near the lake bottom to the surface using a HYDROBIOS plankton net (20 cm in diameter, 100 cm in length, 50 µm mesh size). The net was towed at a speed of approximately 0.5 m s^{-1}. All samples were taken in the morning and were fixed in 4% buffered formalin. The zooplankton specimens were examined microscopically and were identified to the lowest taxonomic level possible using the keys of Rylov (1963), Ruttner-Kolisko (1974), Alonso (1996), and Benzie (2005). Copepod nauplii were not identified to species. For the abundance analysis, three counts of 1.5 ml subsamples were made on a Sedwick-Rafter cell from each sample having a total volume of 100 ml (Doulka & Kehayias 2008).

Measurements of water temperature, pH, conductivity and dissolved oxygen (DO) were taken at both stations and all depths using a TROLL 9500 water quality instrument. Water transparency was measured with a Secchi disc (SD). To estimate total phosphorus (TP), phosphates (PO_4), nitrates (NO_3), nitrites (NO_2), ammonia (NH_4) and silicates (SiO_2), water samples were collected at the deepest station 1 from 0 and 5 m, with a HYDROBIOS water sampler. Analyses of all chemical parameters were performed according to A.P.H.A., A.W.W.A. & W.P.C.F. (1998). To determine chlorophyll-*a* concentration (chl-*a*), a 1500 ml water sample was taken from the upper depths and filtered through a Whatman GF/A glass fibre filter shortly after collection. Pigment extraction was made in 90% acetone and concentrations were determined spectrophotometrically (A.P.H.A., A.W.W.A. & W.P.C.F. 1998). The trophic classification of the lake was estimated by the Trophic State Index (TSI) using Carlson's (1997) equations for TP, chl-*a*, and water transparency.

To ascertain the structural features of the zooplankton community the Shannon-Wiever diversity index H', was calculated for each sampling station and date. The Mann-Whitney (*U test*) was used to investigate differences in the environmental parameters and the abundance of zooplankton species and groups between the two stations. Multiple regression analysis was used to clarify the influence of the environmental factors on each zooplankton species using data from station 1 for the entire sampling period. The analysis was performed using forward stepwise selection to identify the significant factors. These factors were then correlated with each other (Pearson's r) to eliminate those having strong correlation. Finally, the explanatory factors were standardized so as to compare their relative importance. All data analyses were performed using SPSS 17.0 software (SPSS, Inc. 2008).

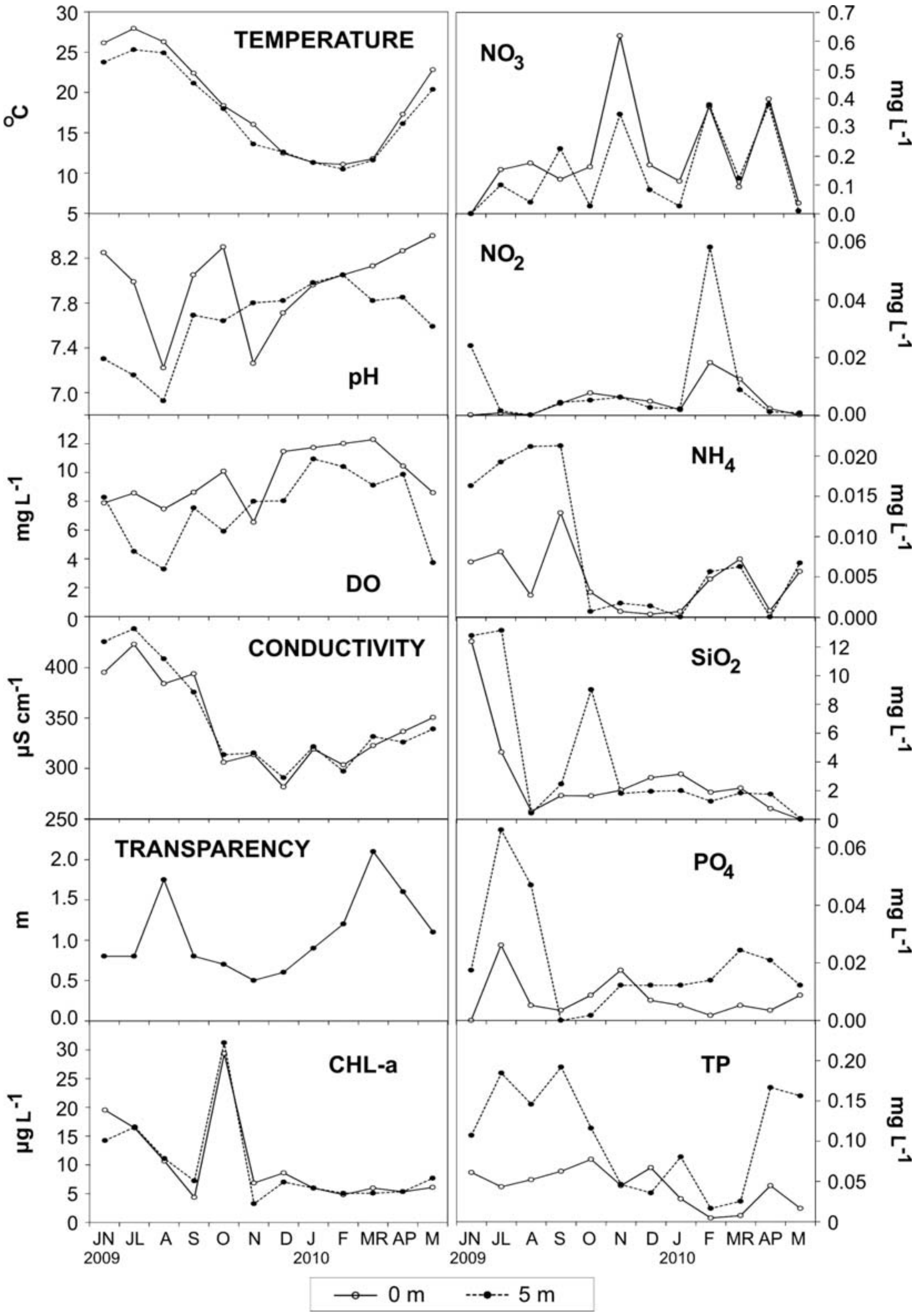

Fig. 2. Monthly variation of the physical and chemical parameters (temperature, dissolved oxygen, pH, conductivity, transparency, chl-*a*, NO_2, NO_3, NH_4, PO_4, TP, SiO_2) at 0 m and 5 m depth in the water column of station 1 during June 2009 to May 2010 in Lake Lysimachia.

Results

Physicochemical parameters

The water temperature of Lake Lysimachia fluctuated between 10.48 and 28.68℃ and, due to its shallow depth no thermal stratification was observed (Fig. 2). Generally, the lake presented high surface DO concentrations throughout most of the year, while considerably lower DO values were recorded close to the bottom of the deeper station 1, reaching 3.29 mg L^{-1} in August. The pH was alkaline throughout the sampling period having maximum values (8.4) in spring, while the lowest value was recorded in August (6.93) close to the bottom of station 1. Conductivity values fluctuated

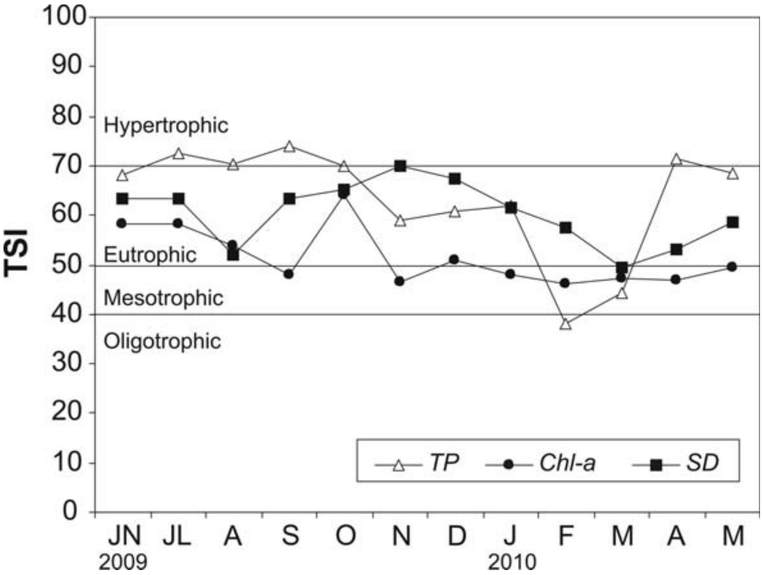

Fig. 3. Monthly variation of the values of TSI index for total phosphorus (TP), chlorophyll-a (chl-a) and transparency (SD) in Lake Lysimachia.

Table 1. List of the zooplankton species found in Lake Lysimachia.

ROTIFERA: *Asplanchna priodonta* (Gosse, 1850), *Brachionus angularis* (Gosse, 1851), *Brachionus calyciflorus* (Pallas, 1766), *Brachionus calyciflorus f. anuraeiformis* (Brehm, 1909), *Brachionus falcatus* (Zacharias, 1898), *Collotheca* sp., *Conochilus unicornis* (Rousselet, 1892), *Epiphanes* sp., *Filinia longiseta* (Ehrenberg, 1834), *Filinia opoliensis* (Zacharias, 1898), *Gastropus stylifer* (Imhof, 1891), *Hexarthra mira* (Hudson, 1871), *Hexarthra intermedia* (Wiszniewski, 1929), *Kellicottia longispina* (Kellicott, 1879), *Keratella cochlearis* (Gosse, 1851), *Keratella tecta* (Gosse, 1851), *Keratella tropica* (Apstsein, 1907), *Keratella quadrata* (Müller, 1786), *Lecane* sp., *Ploesoma hudsoni* (Imhof, 1891), *Polyarthra* sp., *Pompholyx sulcata* (Hudson, 1885), *Synchaeta* sp., *Trichocerca* sp., *Trichocerca similis* (Wierzejski, 1893), *Trichotria* sp.

COPEPODA: *Eudiaptomus drieschi* (Poppe & Mrázek, 1895), Harpacticoida sp., *Macrocyclops albidus* (Jurine, 1820)

CLADOCERA: *Bosmina longirostris* (O.F. Muller, 1785), *Ceriodaphnia pulchella* (Sars, 1862), *Daphnia cucullata* (G.O. Sars, 1862), *Diaphanosoma orghidani* (Negrea, 1982), *Leptodora kindtii* (Focke, 1844), *Moina micrura* (Kurz, 1874)

MOLLUSCA: *Dreissena blanci* (Westerlund, 1890)

between 281.5 and 438.1 μS cm^{-1}, being higher in the summer period and lower during winter (Fig. 2). The seasonal variation of water transparency ranged from 0.5 m in November, to 2.1 m in March (Fig. 2). There were no differences between the two sampling stations considering all the above parameters (U-test, $P > 0.05$).

At a depth of 5 m the chl-a concentration fluctuated between 3.24 and 31.23 μg L^{-1} in November and October, respectively (Fig. 2). The concentration of phosphates (PO_4) and total phosphorus (TP) presented highest values from summer to early autumn, reaching 0.066 mg L^{-1} in July and 0.192 mg L^{-1} in September, respectively (Fig. 2). Nitrites (NO_2) and nitrates (NO_3) fluctuated between undetected values to 0.058 mg L^{-1} in February and 0.618 mg L^{-1} in November, respectively. Ammonia (NH_4) presented high values in summer and early autumn close to the lake bottom, with a highest concentration of 0.021 mg L^{-1} recorded in September. Finally, the concentration of silicates (SiO_2) was greater during the summer period reaching 13.11 mg L^{-1} in July. Statistically significant differences were found for the concentrations of PO_4 and TP (U-test, $P < 0.05$), having their highest values at 5 m depth (Fig. 2).

The application of Carlson's index (TSI) for total phosphorus (TP), transparency (SD) and chl-a revealed values between 37.9–74.0, 49.3–69.9 and 46.2–64.1, respectively. These values clearly classify Lake Lysimachia as eutrophic (Fig. 3).

Zooplankton species composition and variability

The zooplankton sampling in Lake Lysimachia revealed 36 invertebrate species which comprised four groups; 26 rotifers, six cladocerans, three copepods and one mollusc larvae (Table 1). Shannon diversity index (H') ranged from 1.74 to 2.36 showing generally lower values during winter and higher values during warmer months, while no statistical differences were observed between the two stations (U-test, $P = 0.686$). The mean integrated abundance of the total zooplankton ranged between 147.9 and 4449.3 ind. L^{-1} in February and May, respectively (Fig. 4A). There were no statistically significant differences in the abundance of total zooplankton or for any of the species between the two stations

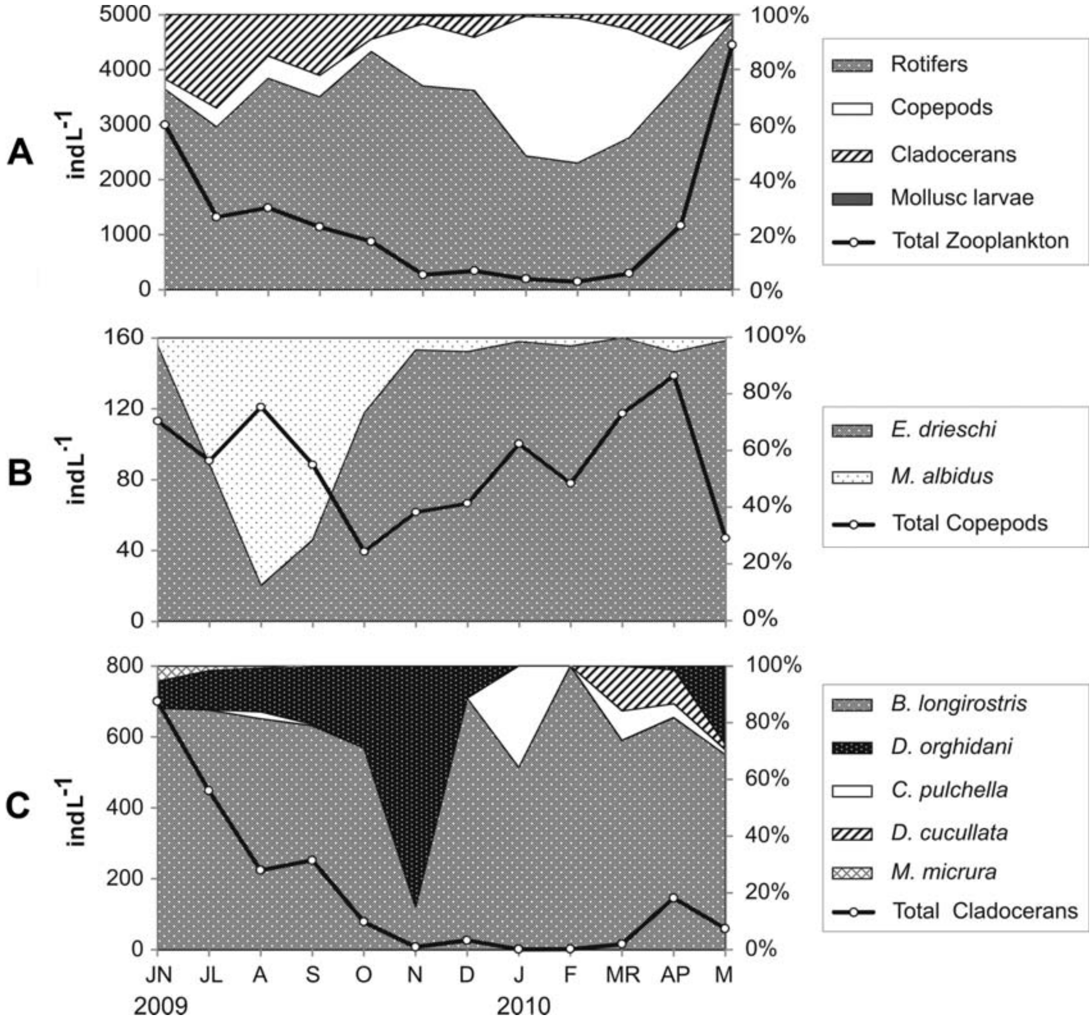

Fig. 4. A – Seasonal variation of the total zooplankton abundance (ind. L^{-1}) and percentage (%) contribution of the main zooplanktonic groups during June 2009 to May 2010 in Lake Lysimachia. B – Seasonal variation of the total copepods abundance (ind. L^{-1}) and percentage (%) contribution of the copepod species *Eudiaptomus drieschi* and *Macrocyclops albidus* to the abundance of the community. C – Seasonal variation of the total cladocerans abundance (ind. L^{-1}) and percentage (%) contribution of the cladoceran species *Bosmina longirostris*, *Diaphanosoma orghidani*, *Ceriodaphnia pulchella*, *Daphnia cucullata* and *Moina micrura* to the abundance of the community.

(U-test, $P > 0.05$). The seasonal variation of total zooplankton abundance presented a decrease after the summer period, remained low during autumn and winter and increased in the beginning of spring (Fig. 4A). The peak of abundance in May 2010 was the result of rotifer increase.

The group of rotifers dominated in the lake's zooplankton community accounting for 69.6%, followed by copepods (19.1%) and cladocerans (11.2%), while a few larvae of the mollusc *Dreissena blanci* (Westerlund, 1890) were found only in December (Fig. 4A). The abundance of rotifers ranged between 68.2 and 4343.0 ind. L^{-1} peaking in May. *Keratella cochlearis* (Gosse, 1851) and *Polyathra* sp. were the two numerically most important rotifer species accounting for 21.9 and 16.2% of the community, respectively. These were followed by *Synchaeta* sp., accounting for 10.8%, *Filinia longiseta* (Ehrenberg, 1834) with 9.9%, *Conochilus unicornis* (Rousselet, 1892) with 8.7%, and *Asplanchna priodonta* (Gosse, 1850) with 7.9%. Most of these species showed a distinct pattern of seasonal variation having higher abundances in spring and summer, while in late autumn and winter they were present in low numbers (Fig. 5).

The abundance of copepods ranged between 27.1 and 198.6 ind. L^{-1} (in October and April, respectively). The calanoid *Eudiaptomus drieschi* (Poppe & Mrazek, 1895) was the dominant species throughout the sampling period accounting on average for 35.7% of the copepod community (Fig. 4B), while the cyclopoid *Macrocyclops albidus* (Jurine, 1820) had considerably lower contribution (8.37%). The maximum abundance of *E. drieschi* was recorded in April, while the peak of abundance for the cyclopoid *M. albidus* species coincided with the lowest values of *E. drieschi*. Nauplii of all species were present in considerable numbers throughout the year and accounted on average for 45.2%. A few specimens of unidentified harpacticoid copepods were found sporadically in the samples.

The abundance of cladocerans ranged from 0.7 ind. L^{-1} in January to 888.3 ind. L^{-1} in June. The pattern of seasonal fluctuation of abundance pre-

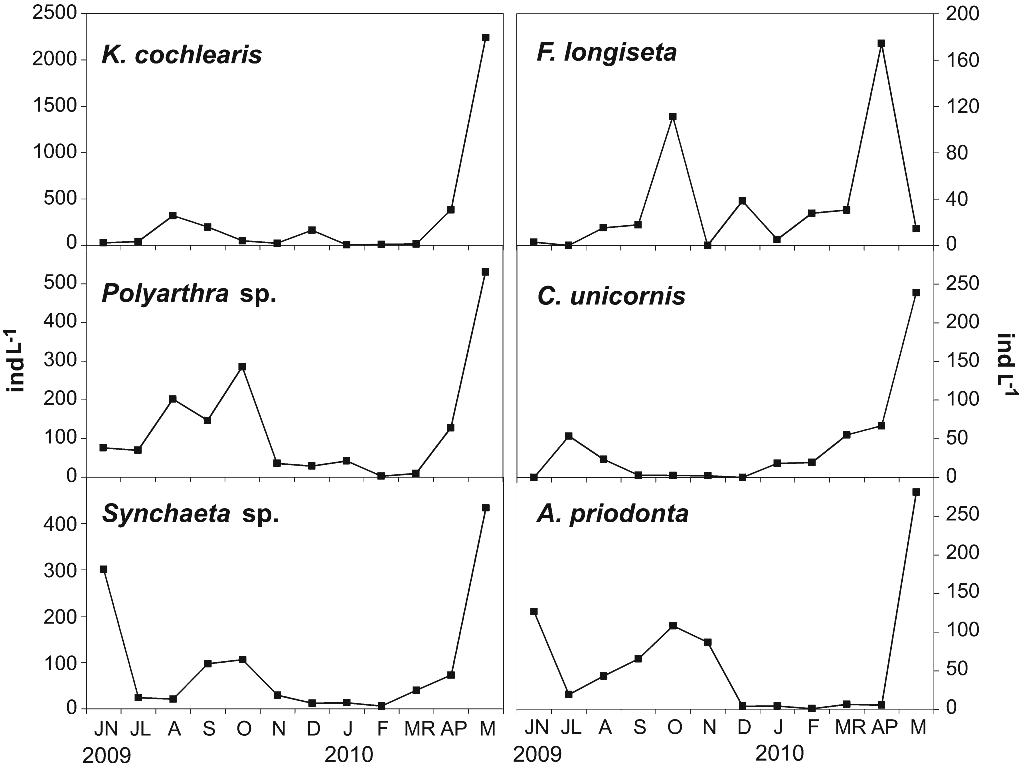

Fig. 5. Seasonal variation of the average abundance (ind. L^{-1}) of the six most important rotifer species (*Asplanchna priodonta*, *Conochilus unicornis*, *Filinia longiseta*, *Keratella cochlearis*, *Polyarthra* sp., *Synchaeta* sp.) during June 2009 to May 2010 in Lake Lysimachia.

sented higher values in summer and spring, and lower values in late autumn and winter (Fig. 4C). *Bosmina longirostris* (Müller, 1785) was the dominant species and accounted for an average of 74.5% of the cladocerans community, followed by*Diaphanosoma orghidani* (Negrea, 1982) which accounted for 17.8%. The former species was present throughout the entire study period having maximum abundance in June, while the latter was abundant mainly in the warmer period. *Ceriodaphnia pulchella* (Sars, 1862) accounted for 4.6% of the cladoceran community (Fig. 4c) and showed two peaks of abundance in August 2009 and April 2010. *Daphnia cucullata* (Sars, 1862) was found only in spring, while *Moina micrura* (Kurz, 1874) was found during the summer months (Fig. 4C). Finally, a few specimens of *Leptodora kindtii* (Focke, 1844) were recorded sporadically during the summer period.

Influence of physicochemical parameters

The results of multiple regression analysis showed that water temperature was among the main factors correlated with the abundance variation of the zooplankton community in Lake Lysimachia (Table 2). Specifically, temperature affected the rotifer group, especially *Keratella cochlearis*, *Hexarthra* sp. and *Trichocerca similis* (Wierzejski, 1893). Water temperature also greatly impacted the most important cladoceran species of *Bosmina longirostris* and *Diaphanosoma orghidani.* DO concentration has a negative effect on the rotifers *Filinia opoliensis* (Zacharias, 1898) and *Asplanchna priodonta*, and pH values appear to be crucial for the variation of the copepods *Eudiaptomus drieschi* and *Macrocyclops albidus* and the rotifers *Filinia longiseta* and *Synchaeta* sp. Conductivity did not seem to influence strongly the zooplankton species distribution, however, silicate concentration seems to affect different types of rotifer and cladoceran species. Ammonia seems to be associated with the presence of the cyclopoid *M. albidus*, while there is a positive correlation of phosphates with *E. drieschi.* Finally, the concentration of total phosphorus seems to play an important role in the variation of the rotifer *Polyarthra* sp. (Table 2).

Discussion

Physicochemical parameters

Lake Lysimachia is classified as eutrophic according to the TSI index (Carlson 1977). The eutrophic character of this ecosystem has also been identified in the research of Overbeck et al. (1982) and Psilovikos et al. (1995) and was attributed mainly to the chronic discharge of domestic sewage from the nearby city of Agrinio. For several decades this constant organic pollution produced high concentrations of total phosphorus, which in turn affected the productivity of the lake and chl-*a*, also resulting in low water transparency. However, this discharge terminated in the year 2000 when the city's wastewater treatment plant started operating. Considering that the present data on the physicochemical characteristics of the lake's water are the first collected after this intervention, comparisons with past conditions could provide a valuable

Table 2. Multiple regression analysis between the environmental factors (temperature, DO, pH, conductivity, NH_4, PO_4, SiO_2, TP) and the zooplankton species/groups.

Environmental parameters										
Species/Groups	TEMP	DO	PH	COND	NH_4	PO_4	SiO_2	TP	(r^2)	(d.f.)
Asplanchna priodonta		–0.751**							0.565	10
Conochilus unicornis				0.528*			–0.749**		0.597	9
Filinia opoliensis		–0.627**					0.562**		0.943	8
Filinia longiseta			0.743**						0.553	10
Hexarthra sp.	0.883**								0.779	10
Keratella cochlearis	0.747**						–0.656**		0.777	9
Polyarthra sp.								0.856**	0.732	10
Synchaeta sp.			0.682**				0.569**		0.741	9
Trichocerca similis	0.832**								0.692	10
ROTIFERS	0.909**								0.827	10
Eudiaptomus drieschi			1.006**			0.598**			0.658	9
Macrocyclops albidus			–0.584**		0.491**				0.824	9
COPEPODS				0.651*					0.424	10
Bosmina longirostris	0.919**								0.845	10
Diaphanosoma orghidani	0.940**								0.833	10
Moina micrura				0.528*			0.533*		0.735	9
CLADOCERANS	0.957**								0.915	10
TOT. ZOOPLANKTON	0.946**								0.894	10

Explanations: * $P < 0.05$, ** $P < 0.01$.

Table 3. Comparison of the range (minimum – maximum values) of the environmental parameters recorded in the present study with those of Overbeck et al. (1982) and the Greek Ministry of Agriculture (1980–1997).

	Present study	Overbeck et al. (1982)	Greek Ministry of Agriculture
Parameters/Period	(2009–2010)	(1978–1981)	(1980–1997)
Temperature (℃)	10.48–28.68	13.0–26.4	6.0–28.0
DO (mg L^{-1})	3.29–12.29	1.4–17.2	1.2–13.8
pH	6.93–8.4	7.3–8.5	6.4–8.6
Conductivity (μS cm^{-1})	282–438	312–390	240–550
Transparency (m)	0.5–2.1	0.6–2.5	–
Chl-α (μg L^{-1})	3.24–31.23	2.5–30.9	–
TP (μg L^{-1})	0.005–0.192	0.039–0.095	0.000–0.500
PO_4 (mg L^{-1})	0.000–0.066	0.017–0.065	–
NH_4 (mg L^{-1})	0.000–0.021	0.000–0.143	0.000–2.251
NO_2 (mg L^{-1})	0.000–0.058	0.005–0.012	0.001–5.310
NO_3 (mg L^{-1})	0.000–0.618	0.086–0.566	0.030–20.91
SiO_2 (mg L^{-1})	0.000–13.11	1.587–3.153	–

insight into the development of this ecosystem (Table 3).

The maximum nutrient and chl-a values observed in the present study were lower than those reported for the period 1980–1997 (www.minagric.gr; Psilovikos et al., 1995), but remain above levels documented in the late 1970s (Overbeck et al. 1982). In particular, during the intermediate period of 1980–1997 there was an increase of the maximum concentration of TP by 426.3%, while the present value remains 102.1% higher than that of Overbeck et al. (1982). The respective values for chl-a are 139.5% and 1.1%. For the same time period, the maximum concentrations of nitrates, nitrites and ammonia increased dramatically by 3594.3, 44150.0 and 1474.1%, respectively (Table 3), while the present value for ammonia remains considerably lower than that recorded by Overbeck et al. in 1982. The chronic variation of maximum conductivity and the lowest pH values also follow the same trend. The above figures show that there has been an unambiguous recovery of the ecosystem towards lower nutrient loads, and consequently lower productivity, since 1997 when the last measurements were conducted. Maximum water temperature showed an increase of 2.3 ℃ compared to thirty years ago, which may be associated with global warming and its effects on aquatic ecosystems (Adrian et al. 2009). The decrease of maximum DO values during the same period could be a possible side-effect of the increased water temperature leading to lower solubility of the oxygen in the water, than ought to the photosynthetic activity taking into account the chl-a variation previously mentioned.

One of the reasons for the ecosystem's recovery is most probably the termination of untreated sewage dumping into the lake and the operation of the wastewater treatment plant. In fact, after 2000 all the municipal wastewaters of Agrinio city are biologically treated and even the remnants of this process are not discharged into the lake. Thus, during the last decade the major source of organic pollution was confined to just small quantities of wastes from the surrounding agricultural areas. The second reason for the recovery is the particular hydrological characteristics of the lake itself. As mentioned previously, the lake has several water inflows and outflows which result in considerable renewal of its water volume. Thus, Lake Lysimachia receives considerable amounts of water from the oligotrophic Lake Trichonis, and from Ermitsa stream, which often overflows during the winter. On the other hand, a large volume of water outflows through the Lysimachia tunnel for irrigation purposes and surplus lake water drains into the Acheloos River through the Dimikos canal. Psilovikos et al. (1995) estimated that there could be a total water renewal of the lake thirteen times per year, while during the irrigation period the renewal rhythm is expected to be greater.

However, although there was a clear recovery due to the decrease of human impacts and the particular hydrology of the lake, the ecosystem still retains basic eutrophic characteristics, such as high concentrations of nutrients and phosphorus. Current literature provides examples of many lakes that were highly resistant to loading reductions and have shown only slight improvements after management plans were applied (van der Molen & Boers 1994). The internal phosphorus load may be very persistent and last ten years or more after a load reduction has been achieved. This resistance may be chemical (Søndergaard et al. 2002) and/or biological (Scheffer et al. 1993). The recovery period following a phosphorus load reduction depends on the loading history and the accumulation of phosphorus in the sediment (Søndergaard et al. 2003). No sediment analyses were performed in the present study, however, the increased values of total phosphorus and phosphates near the lake's bottom could suggest that large amounts of phosphorus have accumulated in the lake's sediments. These pollutants could return to their soluble states following sediment disturbance (Søndergaard et al. 2003).

The seasonal variation of total phosphorus is similar to that described in the nearby lakes Trichonis (Doulka 2010; Doulka & Kehayias 2011) and Amvrakia (Chalkia et al. 2012a) where elevated concentrations were recorded during warmer months, near to the bottom. High chl-a values were recorded in autumn as also reported by Overbeck et al. (1982) and the maximum concentrations were found to be similar. The alkaline pH values are considered a characteristic indicator of high photosynthetic activity that occurs mostly during the warm period. On the vertical axis, the distribution of DO was uniform in the water column and the high DO values recorded during the cold months are the result of increased oxygen solubility at lower temperatures. Despite the sharp decline of DO in the summer close to the lake's bottom, no hypoxic or anoxic conditions were recorded in any sampling occasion. Finally, there were no horizontal differences in transparency, temperature, DO, pH and conductivity, and this can be attributed to the small size of Lake Lysimachia and its prevailing water circulation (Psilovikos et al. 1995).

Zooplankton species composition and variability

The zooplankton community of Lake Lysimachia has not been studied extensively and the only existing data came from a survey conducted by Koussouris (1978) who reported the presence of just eight rotifer species. Our research adds 28 new records of zooplankton species, most of which have been recorded as present in the nearby lakes of western Greece such as Trichonis (Doulka & Kehayias 2008), Stratos Reservoir (Kehayias et al. 2008) and Amvrakia (Chalkia et al. 2012a). The general similarities in species composition between these aquatic ecosystems can be attributed to their common origin, as at the end of the Pliocene they belonged to a much larger lake created by the outflow of the Acheloos River (Verginis & Leontaris 1978). Moreover, lakes Lysimachia and Trichonis are still connected, thus similarities in their species composition are to be expected. Furthermore, as the zooplankton community composition is concerned, Lake Lysimachia presented various similarities with other lakes of the western Greece, like Lake Kalodiki (Kagalou et al. 2010) and Lake Pamvotis (Antonopoulos et al. 2008), while less similarities with the lakes of the northern Greece such as Lake Mikri Prespa (Michaloudi et al. 1997), Lake Volvi (Zarfdjian et al. 1990), Lake Koroneia (Michaloudi & Kostecka 2004). This could possibly be attributed to the geomorphological characteristics and evolution of the southern Balkans. Zogaris et al. (2009) using fish distributional patterns indicate that the Pindos Mountains create a prominent biogeographical discontinuity that separates distinct freshwater biogeographic "regions" west and east of Pindos. It is probable then, that the above mentioned lakes of western Greece, along with Lake Lysimachia, belong to the "Ionian" ecoregional unit (Zogaris et al. 2009), although this needs further verification.

On the other hand, Lake Lysimachia is inhabited by a number of species which have not been reported in the nearby lakes and especially in Lake Trichonis (e.g., the cladoceran*Moina micrura* and the rotifers *Brachionus angularis, B. falcatus*, *Epiphanes* sp., *Keratella tecta*, *K. tropica*, *Trichotria* sp.). This suggests the importance of Lake Lysimachia from a biodiversity aspect, as well as the existence of certain ecological differences between lakes Trichonis and Lysimachia. It should be noted here that communication between the two lakes is only one-way, meaning that water from Lysimachia does not enter Lake Trichonis and therefore it is unlikely that zooplankton species are actively transferred to the latter lake.

Moina micrura commonly regarded as a cosmopolitan cladoceran species which can be found in all types of limnetic habitats, almost all over the world except for arctic and cold-temperate regions. This species had been recorded only at the early ‘50s in lakes of the northern Greece (e.g., Koroneia) and in ponds of the Corfu Island (Zarfdjian & Economidis 1989), but it has not been found since in any of the above areas (Michaloudi & Kostecka 2004), as well as in the Greek territory. Thus, the presence of *M. micrura* in Lake Lysimachia is the first record of this species in the southern Greece and can be considered as the first recent record in the country. On the other hand, Petrusek et al. (2004) noted that there are certain taxonomic problems with the existence of sibling species within the *M. micrura* complex and, comparisons in a large number of geographically diverse populations from different continents, must be made to resolve the pattern of variation and the phylogenetic relationships of this species (Petrusek et al. 2004).

The seasonal dynamics of zooplankton abundance resembled that of eutrophic lakes in which rotifers prevail. Most of the rotifer species found in Lake Lysimachia are associated with high trophic state (Bērziņš & Pejler 1989). In more persistently eutrophic waters, certain species become numerically important constituents of the rotifer community, as in the cases of Lake Koroneia (Michaloudi & Kostecka 2004) and Lake Dojran (Tasevska et al. 2012), where the rotifer community dominated by the eutrophic *Brachionus* species. In contrast, the high abundance of a relatively diverse group of eurytopic rotifer species in Lake Lysimachia suggests that the lake may be experiencing an intermediate than a highly enriched trophic state.

The crustacean community of Lake Lysimachia was dominated by the calanoid copepod *E. drieschi*. This species was also the dominant crustacean in Lakes Trichonis and Amvrakia, while there were great similarities in its seasonal variation between the three lakes (Doulka & Kehayias 2008; Chalkia et al. 2012a). The cyclopoid copepod *M. albidus* was present in Lake Lysimachia but in low numbers, while its peak of abundance coincided with the lowest values of *E. drieschi* thus suggesting competitive interactions (Chalkia et al. 2012a). It is well-established that eutrophication in lakes leads to decreased proportions of calanoids, which promotes the development of cyclopoid copepods (Arora & Mehra 2009). However, in Lake Lysimachia, the continuous water inflow from the oligotrophic Lake Trichonis, where the calanoid *E. drieschi* is the predominant species, along with the water quality improvement, were probably responsible for the high abundance of this calanoid copepod.

The variation of the cladoceran community, which was dominated by small-bodied species whose abundance became highest in summer, is similar to the pattern described in other eutrophic lakes (Michaloudi et al. 1997). The high abundance of *B. longirostris*, *D. orghidani* and *M. micrura* in summer seemed to be controlled by the ability of each species to consume bacteria (Geller & Müller 1981). *Bosmina longirostris* was the predominant species in the cladoceran community and is considered an indicator of eutrophic lakes (Yildiz et al. 2007). *Diaphanosoma orghidani* is a highly efficient bacteriofeeder and its presence is to be expected during summer (Geller & Müller 1981). The high abundance of cyanobacteria during the summer period (Gkelis et al. 2005) is probably responsible for the decrease of *Daphnia cucullata* as cyanobacteria can greatly affect the growth and reproduction of this species (Michaloudi et al. 1997; Michaloudi & Kostecka 2004; Hansson et al. 2007). Low abundances of large-bodied cladocerans may also be due to size-selective fish predation, as planktivorous fish selectively consume large crustaceans and shift zooplankton communities toward dominance by smaller species (Gliwicz & Pijanowska 1989). Lake Lysimachia (as well as Lake Trichonis) is inhabited by a population of *Atherina boyeri* (Risso, 1810) which was proved to exercise great predation impact on large crustaceans (Doulka et al. 2012).

Larvae of the mollusc *D. blanci* have been recorded in considerable abundance in the zooplankton of other lakes and reservoirs in western Greece. Their near absence from Lake Lysimachia may be due to the lake’s muddy bottom substrate (Chalkia et al. 2012b).

Generally, the diversity of a zooplankton community tends to decrease as a water body becomes more eutrophic, while the common characteristic of such ecosystems is the presence of a few dominant species with high density (Michaloudi & Kostecka 2004; Tasevska et al. 2012). In Lake Lysimachia, however, the values and seasonal variation of the diversity index exhibited remarkable similarities with those recorded in the nearby oligotrophic Lake Trichonis (Doulka 2010) and the mesotrophic Lake Amvrakia (Chalkia et al. 2012a). Taking into account that increased zooplankton diversity could indicate the internal stability of an aquatic ecosystem (Michaloudi et al. 1997), communities structured in this manner are generally characteristic of stable environments (Ferrara et al. 2002).

Multiple regression analysis showed that certain environmental factors seem to be important for some taxa in structuring their communities. Thus, most zooplankton species are affected by water temperature and, to a lesser extent, by certain water quality variables. In the present study water temperature was significant for rotifer and cladoceran species. The strong influence of this parameter on several rotifer species (e.g., *Keratella cochlearis*, *Hexarthra* sp., *Trichocerca similis*) has been also demonstrated by Devetter (2011) and Chalkia et al. (2012a). It has been reported that temperature affects the metabolic rate of cladocerans and their occurrence and distribution, although the quality and quantity of food are also determinants for the density and biomass of these organisms (Abrantes et al. 2006). The positive correlation of *E. drieschi* with pH could possibly be associated with optimal lake conditions, since pH can be affected by several physicochemical factors, as well as biological production. The correlation of silicates with various zooplankton species could be explained by taking into account some indirect effects. Silica cycling in a freshwater system is what drives diatom dominance. A decrease in silica concentrations leads to a decline in diatom populations, which in turn affects indirectly the zooplankton density. Overbeck et al. (1982) reported high abundance of diatoms in Lake Lysimachia, however, more data on phytoplankton variation and the diet of the zooplanktonic species is necessary to assess these interrelations.

In conclusion, restoration practices such as the inflow of water from a nearby oligotrophic lake, along with the cessation of sewage inflow, appear to have affected the concentrations of nutrients in Lake Lysimachia leading to a state of "chemical" recovery. However, the lake remains eutrophic and this was reflected in the dynamics and composition of the zooplankton community. Although there are few available data on the zooplankton, the above restoration efforts appear to have affected its abundance and composition presenting characteristics that appear in ecosystems with lower trophic status, and suggesting that the lake is probably under a type of "biological" recovery. Continued monitoring of the biotic and abiotic characteristics of Lake Lysimachia is proposed to better appraise the specific restoration and management actions.

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