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Assessment of a Mediterranean shallow lentic ecosystem (Lake Pamvotis, Greece) using benthic community diversity: Response to environmental parameters

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Abstract

Macroinvertebrates play a key role in freshwater lentic and lotic ecosystems. The macroinvertebrate benthic community of a shallow Mediterranean lake (Lake Pamvotis, NW Greece) was studied. The benthic assemblage was sampled monthly at five sites during a period of 1 year (Apr. 1998–Mar. 1999). In addition hypolimnetic water quality variables were monitored over the same period at each site.

The aim of the study was (a) to describe the intra-annual and spatial variability in benthic communities, (b) to relate possible community changes to environmental conditions and (c) to evaluate the responses of the lake's ecological status on community indices.

The benthic fauna of Lake Pamvotis was found to be very limited with a total of 10 species belonging to five taxonomic groups. The oligochaete community comprised 80% of the total benthic fauna with *Potamothrix bavaricus* as a new record for the Lake Pamvotis and *Potamothrix hammoniensis*, being the dominant benthic species represented more than 61% of the total benthic fauna. *Chironomus plumosus* was the most abundant chironomid species contributing with about 6% of the total benthic fauna, and *Chaoborus flavicans* with 19% was the important dipteran. Almost all benthic species showed the same intra-annual seasonal pattern, with peak population densities during spring and early summer except *P. hammoniensis* which predominated during the whole sampling period. Dissolved oxygen and temperature seemed to be the main environmental factors affecting community indices.

Benthic communities are affected by human disturbances in Lake Pamvotis shifting their composition to more tolerant taxa, reflecting also the eutrophic to hypertophic character of the lake.

Keywords: Lentic ecosystems; Macroinvertebrates; Diversity; Shallow lake

Introduction

Freshwater benthic communities have long been used as bioindicators for monitoring pollution and anthropogenic influences (Garcia-Criado, Becares, & Fernadez-Alaez 2005; Lazaridou-Dimitriadou 2002).

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Human-induced impacts on freshwater ecosystems have been increasing worldwide. Their assessment and monitoring are usually based on long-term and/or inter-annual monitoring data and analyses of abiotic and biotic indices.

Macroinvertebrates play a key role in freshwater ecosystems in linking primary production, allochthonous input and top predators in freshwater ecosystems. They are usually diverse, are represented by many phyla and have different requirements for feeding, growth and reproduction. This often results in an extremely heterogeneous distribution of the macroinvertebrate community (Lazaridou-Dimitriadou 2002; Wetzel 2001). Benthic communities' composition is closely linked to habitat conditions (Weatherhead & James 2001). Moreover, environmental factors (physical or/and chemical) can have direct effects on the macroinvertebrate community through physical disturbance and indirect effects, which are mediated through the distribution of macrophytes (Varga 2003). Understanding of long-term and inter-annual variation in species composition and abundance is still relatively poor. While there is an increasing body of literature on persistence and stability of lotic invertebrate communities in relation to environmental variation, much less is known of lentic waters (Hamalainen, Luotonen, Koskenniemi, & Liljaniem 2003; Lazaridou-Dimitriadou 2002; Scarsbrook 2002). Use of macroinvertebrates as biotic indicators has been applied mostly to deep lake ecosystems and may provide a reliable indicator of eutrophication. According to Garcia-Criado et al. (2005), their use in shallow lakes is not clear.

Lake Pamvotis is an ancient Mediterranean shallow lake ecosystem situated in a topographically diverse landscape on the western flank of the Pindus mountain range, NW Greece (Tzedakis, Lawson, Frogley, Hewitt, & Preece 2002). In terms of global biodiversity, Lake Pamvotis is of global significance (Krystufex & Reed 2004). As suggested by the paleoclimate simulations the high topographic variability provided a range of sheltered habitats, such that populations could migrate and survive within the Pamvotis region (Tzedakis et al. 2002). The conservation value of the lake is also enhanced by Frogley and Preece (2004) and recently has been proposed as an internationally important conservation site under European Community legislation (Natura 2000 network). Under the European Community Council Directive on the conservation of natural habitats and of wild fauna and flora (the Habitats Directive, EC, 92/43). Lake Pamvotis is included to the Natura Special Conservation areas as "natural" eutrophic lake with *Magnopotamion* or *Hydrocharition* type vegetation. The characterization of the ecological status of lakes has become a legal imperative after the approval of the EC Water Framework Directive (European Commission 2000). This includes the use of macroinvertebrate communities for lake classification. For this to be effective, there is a need to assess the degree of natural variability of biota used in monitoring.

Data on the trophic state, phytoplankton, zooplankton assemblages, floristic features and pollution levels in Lake Pamvotis have been available since 1980s (Albanis, Pomonis, & Sdoukos 1986; Kagalou, Papastergiadou, Tsimarakis, & Petridis 2003; Kagalou, Petridis, & Tsimarakis 2003; Romero et al. 2002; Sarika-Hatzinikolaou 1994). To date there has been one attempt to study the benthic macroinvertebrates in Pamvotis (Economidis 1999).

The aims of the present study are to:

- describe the macroinvertebrate fauna of Lake Pamvotis and their contribution to nature conservation,
- analyze spatial and intra-annual variability in macrobenthic community structure in relation to environmental conditions and
- assess the responses of "natural" or anthropogenous influence on benthic communities in this nutrient-rich shallow ecosystem.

Methods

Description of study area

Lake Pamvotis, NW Greece (20°53′E, 39°40′N) is shallow (mean depth, 4.3 m, maximum depth of 7.5 m), occupies an area of 22.8 km^2 and is situated at 470 m above sea level. The lake formed during the late Miocene to the Pliocene period (Tzedakis et al. 2002). From a hydrological viewpoint, the lake basin is effectively closed, since there are no outflowing streams nor a major basin drainage. The basin has a sub-Mediterranean climate with high annual precipitation (Tzedakis et al. 2002). During recent decades, irrigation, discharge of domestic sewages and sediment deposit have impacted the lake's trophic state (Kagalou, Papastergiadou, et al. 2003; Kotti, Vlessidis, & Evmiridis 2000). Lake Pamvotis is a shallow eutrophic to hypertrophic lake according to the OECD classification (OECD 1982). The environmental parameters showed large intra-annual variations (Kagalou, Papastergiadou, et al. 2003). Eutrophication is causing frequent algal blooms, depletion of dissolved oxygen (DO) together with the rapid sediment accumulation, which decreases depth and enlarges the littoral macrophyte zone (Kagalou, Papastergiadou, et al. 2003). The sediments themselves are typical of profundal sediments from eutrophic, mid-latitude, hard-water lakes (Tzedakis et al. 2003). Lake Pamvotis does not maintain seasonal thermal stratification, but rather undergoes frequent periods of complete vertical mixing the lake's stratification regime is considered polymictic (Romero et al. 2002). A weak, unstable thermal stratification occurs during the summer period (Kagalou, Papastergiadou, et al. 2003) while hypoxic conditions are often present. The low oxygen level is induced by the high amount of organic matter in the sediment as a consequence of the high eutrophic state. The terrestrial input of organic nitrogen compounds, mainly as land runoff, results in elevated nitrates and ammonia concentrations during the wet period. DIN/SRP ratio is greater than the Redfield ratio of 16 (Redfield 1958) suggesting a P-limitation, but during the warm period nitrogen limitation occurs (Kagalou, Papastergiadou, et al. 2003).

Five sampling sites were surveyed in Lake Pamvotis. Sites were chosen to represent different hydrodynamic environments, depths and distances from pollution sources. All sites represented the sublittoral (S1) and the profundal zone (S2, S3, S4, S5). The littoral zone of the Lake Pamvotis, consisting mostly of reed beds (*Phragmites australis*) has deteriorated from various human activities. Periodic burning is widely practised in reed beds in order to promote new plant growth for grazing animals. Harvesting and derooting by machines is common. The construction of dikes along the northern shoreline (at 1970s) of the lake caused high water level fluctuations affecting mostly the littoral zone. The water level falls to approximately 1.5 m below the full supply level (470 m a.s.l.) between winter and summer period because of high evaporation, irrigation and no surface inflows with impacts on the littoral benthic fauna. Given these impacts Hamalainen et al. (2003) suggested that monitoring should be focused on the profundal benthos only.

Station S1 (depth of 4.3 m) was chosen near the confluence of the smaller northwestern basin to the much larger southeastern basin (Fig. 1). Station S2 (depth of 6.5 m) was considered to be a representative station near the center of the lake. S3 (depth of 5.0 m), situated near the lake's outflow, is representative of the shallow northwestern basin. S4 (depth of 5.5 m) is located near the two main inflows (Fig. 1) entering the lake. The first inflow predominately drains an agricultural area whereas the second one drains a watershed with mixed land uses (urban, rural, agriculture and industry). Station S5 (depth of 6.6 m) is situated at the northeastern part of the lake near a smaller inflow channel. Sediments in all sampling stations are slightly alkaline. pH values varied between 7.48 and 7.78. Sediment analysis (Romero & Imberger 1999) is shown in Table 1.

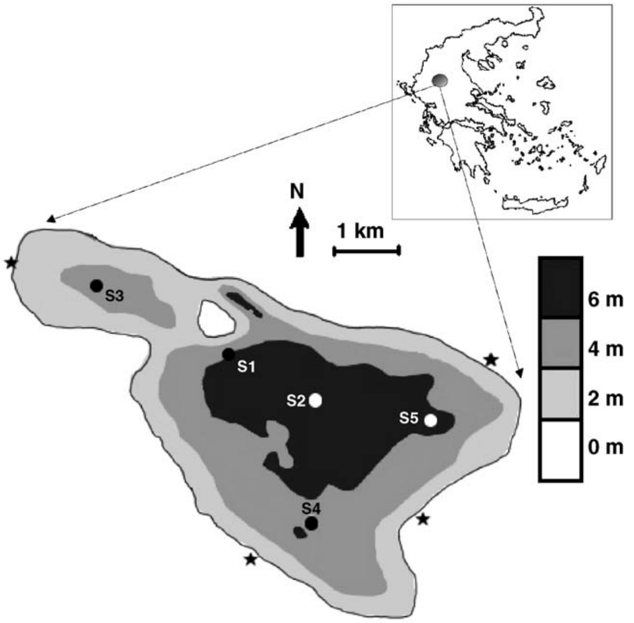

Fig. 1. Bathymetric map of the Pamvotis Lake. Dots show the sampling stations, asterisks show the inflows. Scale bar shows the different depths of the lake.

Table 1. Sediment analysis of Lake Pamvotis at the five sampling stations (Romero & Imberger 1999)

Sampling station	% silt	% clay	% organic content
S1	95.5	4.5	10.1
S2	95	5	10.7
S3	93	7	14.5
S4	92	8	11.3
S5	93.1	7.5	10.4

Submerged macrophytes in Lake Pamvotis are affected by serious deterioration of water quality, high chlorophyll-*a* values (mean value: 21.21 mg m^{-3}, max. value: 45.9 mg m^{-3}) and low transparency (Secchi depth: 0.4–0.9 m) through the whole year (Kagalou, Papastergiadou, et al. 2003; Sarika-Hatzinikolaou 1994). Well-developed vegetation was recorded only close to stations S1 and S2 comprised from *Nympaea alba*, *Nuphar lutea* and *Nympoides peltata* (Kagalou, Papastergiadou, et al. 2003).

Sampling

Monthly samples (in duplicates) were taken from April 1998 to March 1999 using an Ekman grab sampler (225 cm^2). All samples were sieved (mesh size 0.5 mm) and preserved in 6% formalin. Macroinvertebrates were sorted to the lowest practicable taxonomic level.

Water samples were collected bi-weekly using a HydroBios water sampler (2-l- capacity) from the same stations at the bottom zone (0.5 m above bottom). Limnological measurements included temperature (°C), pH, DO (mg L^{-1}), total phosphorus (mg L^{-1}), nitrates (mg L^{-1}) and ammonium (mg L^{-1}). Temperature and pH were monitored using a WTW meter. Analytical procedures used for the chemical analysis followed APHA (1989). DO was measured according to the Winkler method. Nitrates were determined spectrophotometrically by reduction to nitrite and following the method of diazotation and condensation with salicylate (RSD = 10%). Ammonium content was measured spectrophotometrically by the Nessler method (RDS = 10%). Total phosphorous was determined by converting to orthophosphates and determination of orthophosphates by the molybdenum blue method (RDS = 2%).

Data analysis

The Mann–Whitney test was used to analyze differences in the distribution of taxa and density among stations (over all months) and among months (over all stations).

As diversity indices are increasingly used to assess the well-being/health of the habitats, univariate measures included abundance (N), and number of benthic species (S), Shannon–Wiener (Shannon & Weaver 1963) diversity index ($H' = -\Sigma(\pi \log 2\pi)$, Pielou (1969) evenness index ($E = H'/\log 2S$), Margalef (1958) richness index ($R = (S-1)/\log 2(N)$) and the Simpson domination index ($D = \Sigma(\pi)^2$) were calculated. (where π is the proportion of abundance ith species from total abundance of benthic species; S is total number of benthic species).

Multivariate analysis of variance (MANOVA) was performed to study the possible effect of sampling station and/or month of sampling on univariate (ecological) indices. F-values reported from MANOVA were determined using Wilks' λ. Following a significant MANOVA, analysis of variance (ANOVA) tested, whether univariate indices differed among sampling stations and months.

Species data, excluding those with count less than 2% of total benthic abundance, were used. Prior to analysis biological data were fourth root transformed (Zar 1996) to reduce the effect of very abundant species and presence–absence transformation was used for colonial species data and combinations of count and colonial data. The above analyses were applied to both total and seasonal biological data. Spearman's rank correlation coefficient (r) was used to identify any significant correlation between the univariate measures of the benthic community (number of taxa, density, mean percentage of the most abundant taxa) and the environmental variables over all stations and sampling periods.

Following estimation of Bray–Curtis similarity measure (Bray & Curtis 1957) non-metric multidimensional scaling (MDS) was used to display a two-dimensional plot of the inter-relationships between samples based on the relative abundance. Stress coefficients <0.1 indicate a good portrayal of data with no real prospect of misleading interpretation (Clarke & Warwick 1994). Analysis of similarities (ANOSIM) identified significant differences of sampling months and stations in the MDS ordinations. The R statistic is a measure of group separation and ranges between 0 (indistinguishable) and 1 (well separated) (Clarke & Gorley 2001). The software package PRIMER (Plymouth Routines In Multivariate Ecological Research) was used for data analysis (Clarke & Gorley 2001).

Results

Abiotic data

Variations, of environmental variables, among sites and dates indicate some distinct temporal and spatial trends (Fig. 2). Temperature varied from 5.6 °C in January to 26.3 °C in August, showing the expected seasonal pattern with no differences between the sampling stations (Fig. 2a). Hypolimnetic DO fluctuated between 2.1 mg L^{-1}, observed in July at S2, and 12.5 mg L^{-1}, with minimum values through the warm period. The maximum concentration was recorded in January at S5. The horizontal variation of DO across stations was quite substantial with higher DO values recorded at S1 and S5, while S2 had lower DO concentrations than the other sites. The values of pH ranged between 6.8 at station S2 in July and 8.9 in August at station S1. Lower pH values were observed in late spring and summer. Concentrations of total phosphorus (TP) had a seasonal range of 0.03–1.19 mg P L^{-1}, with highest values during the warm period. Maximum values were recorded in July at S1. High phosphorus values were also recorded during winter at S3. Nitrate-nitrogen in the hypolimnion varied over the monitoring period with highest concentrations during spring and winter. The higher values in the wet period varied between 0.22 and 1.16 mg L^{-1}, and may be attributed to the nitrogen inputs from the inflows. During summer, lower concentrations, ranging from 0.34 to 0.71 mg L^{-1}, were probably the result of biological utilization. Horizontal variability was greater in the spring and winter than during the summer. The highest value of ammonia-nitrogen recorded in August (0.52 mg L^{-1}) was probably caused by the decomposition of organic matter at the sediment–water interface. Horizontal variability was high. Two minima occurred in May (0.04 mg L^{-1}) and October–November (0.13 mg L^{-1}).

Composition and distribution of the benthic macrofauna

The benthic fauna of Lake Pamvotis during the sampling period was almost exclusively comprised of five

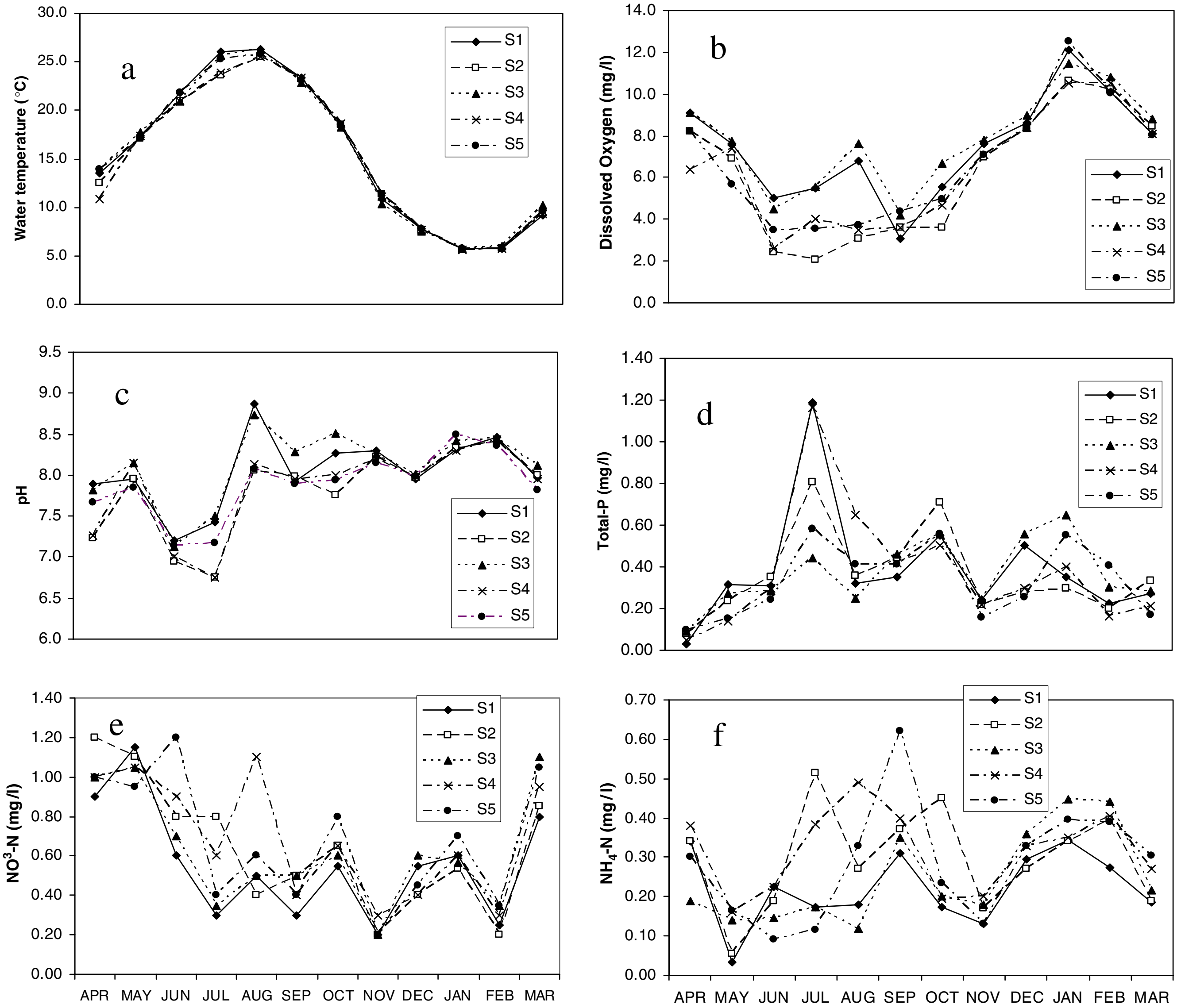

Fig. 2. Monthly variation of some water physicochemical parameters of the Lake Pamvotis (water temperature, dissolved oxygen, pH, NO_3-N, NH_4-N, total P).

oligochaetes species, *Limnodrilus hoffmeisteri* (Claparede, 1862) *Potamothrix hammoniensis* (Michaelsen, 1901), *Potamothrix bavaricus* (Oschmann, 1913) *Psammoryctides* sp. (Grube, 1861) *Tubifex tubifex* (Mullet, 1774) and of two chironomid species, *Chironomus plumosus* (L) and *Procladius choreus* (Meigen, 1804). *Chaoborus flavicans* (Meigen) was also abundant and common. Species of Culicidae and Nematoda were found sporadically in low abundances. Oligochaetes comprised 80% of the total abundance of the benthic fauna, with *Potamothrix hammoniensis* representing more than 61%. *Potamothrix bavaricus* was recorded for the first time in the lake. The density of *Potamothrix hammoniensis* showed two dinstict peaks, the highest in May (5342 indiv. m^{-2}) and a somewhat lower one in November (3377 indiv. m^{-2}) (Fig. 3). Lowest numbers were recorded during the summer. Highest densities of *Tubifex tubifex* were found in October (969 indiv. m^{-2}) and February (1547 indiv. m^{-2}), with lowest values recorded during the summer months. *Psammoryctides* sp. had highest population densities during February (329 indiv. m^{-2}) and March (116 indiv. m^{-2}); during the other months densities varied from 0 to 18 indiv. m^{-2}. Overall densities of Oligochaetae species were maximal during the end of the winter and minimal during the summer.

Chironomus plumosus the most abundant chironomid species comprised about 6% of the total benthic fauna and *Chaoborus flavicans* about 19%. Two peaks in the seasonal pattern of *C. flavicans*, were found first during May (1580 indiv. m^{-2}) and the second during July

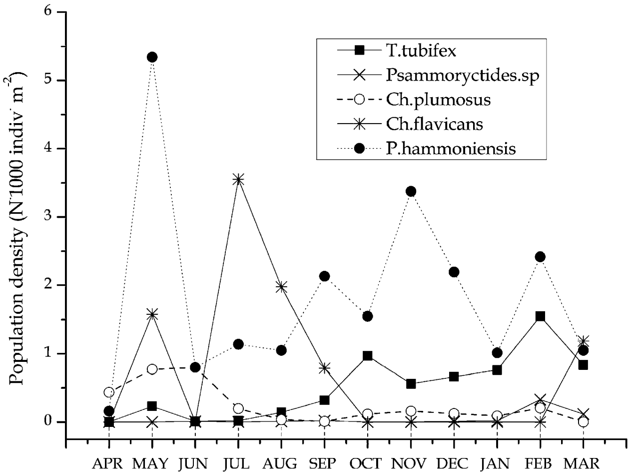

Fig. 3. Monthly population densities (as average values) of the most abundant benthic species in the Lake Pamvotis.

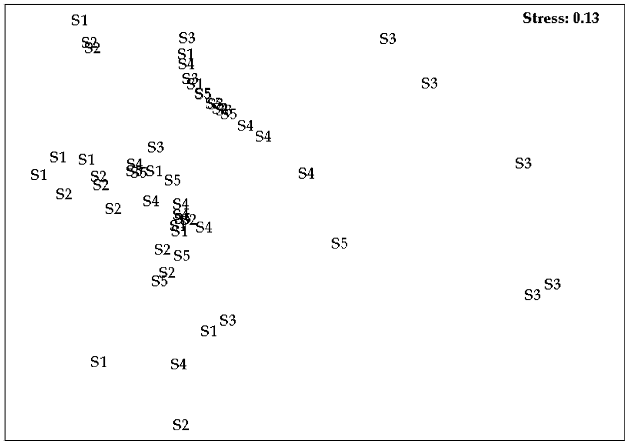

Fig. 4. MDS plot (stress = 0.13) showing similarities among the macrobenthic fauna (densities in individuals per m^2) from Pamvotis lake. S*i* corresponds to sampling station.

(3555 indiv. m^{-2}). During late autumn and winter no *C. flavicans* larvae were found.

Potamothrix hammoniensis was dominant at S1, S2, S4 and S5 with frequencies of 64, 76 and 77% respectively; while at station S3 the frequency was 29%. Highest abundance of *T. tubifex* was found at station S4, while chironomids were common at stations S2 and S4. No chironomids species were found at station S3. The dominant species at the shallower station S3 was *C. flavicans* with relative abundance of 60% while the overall abundance was 19%. In April no organisms were found in samples from stations S3 and S4 and in January at station S5.

Structural analysis

Mann–Whitney test indicated no spatial trends for richness of the benthic community of Lake Pamvotis. Moreover, it was found that there were no temporal trends for number of taxa ($P<0.05$).

Shannon diversity index (H') values differed among stations (MANOVA: $F_{4,41} = 4.51$, $P = 0.004$) and months (MANOVA: $F_{11,41} = 3.57$, $P = 0.001$). H' values ranged from 0.014 at S4, to 1.28 at S1. The lowest benthic diversity was recorded during July when DO values declined to very low levels (2.1–5.5 mg L^{-1}). Strong Spearman rank correlation at S1 was found between diversity index (H') and DO ($P<0.001$) and water temperature ($P<0.001$).

Simpson values (D) differed among stations (MANOVA: $F_{4,41} = 3.64$, $P = 0.013$) and months (MANOVA: $F_{11,41} = 3.41$, $P = 0.002$) and ranged between 0.021 (during April at station S2) and 0.7 (during February at S1). At station S1, there was also a significant correlation between Simpson diversity index and water temperature ($P = 0.01$). At station S3, significant correlations were found between Simpson diversity index and both water temperature ($P = 0.021$) and DO ($P = 0.026$). At station S4, a significant correlation was found between the Simpson diversity index and water temperature ($P = 0.032$).

Evenness (E) differed among months (MANOVA: $F_{11,41} = 3.25$, $P = 0.003$) but not among stations (MANOVA: $F_{4,41} = 2.27$, $P = 0.08$). (E) values ranged between 0.013 at S4 and 0.985 at S1. The highest E value was recorded during March and the lowest during July. Strong Spearman rank correlations were found between evenness and the two environmental parameters, temperature and DO.

Taxa richness differed among stations (MANOVA: $F_{4,41} = 6.53$, $P<0.001$) and months (MANOVA: $F_{11,41} = 2.42$, $P = 0.02$). Values fluctuated between 0.142 at S4 and 0.503 at S2, with lowest value also in July.

MDS discriminated the five sampling stations in to three groups (Fig. 4). The first group includes S1 and S2, the second group stations S4 and S5 and the remaining group station S3. The third sampling station (S3) was ordinated to the right of the plot, while the sampling stations S1, S2 were found in close proximity to the left of the plot and the sampling stations S4 and S5 were ordinated mainly in the center. No significant differences were found between stations S1 and S2 (ANOSIM: $r = 0.008$, $P>0.1$), such as S4 and S5 (ANOSIM: $r = 0.006$, $P>0.1$).

Discussion

The trophic state

The trophic state of Lake Pamvotis has been presented previously (Kagalou, Papastergiadou, et al.

2003; Kagalou, Petridis, et al. 2003; Romero et al. 2002). Our data showed that during the warm period, DO and pH conditions in the sediment–water interface enhance the internal loading process, enriching the water column with phosphorus from the sediment. This fact, in relation to the low water level, results in high concentrations of total phosphorus (TP). Winter phosphorous concentrations were greatly affected by the inflows, which were substantially greater than the outlet through the same monitoring year (Romero et al. 2002). Hence, the lake is a phosphorus sink for the catchment. Horizontal variability of abiotic factors across the sampling stations was high. This happens in the majority of shallow lake systems because the linkage between the shear at the sediment–water interface and the wind forcing at the surface is quite strong because of the lack of seasonal thermal stratification.

Benthic community diversity

Previous data on the composition and distribution of the benthic macrofauna of Lake Pamvotis are rare (Economidis 1999). In this study, we could show that benthic macrofauna of Lake Pamvotis was dominated by oligochaetes and chironomids. The dipteran larva, *Chaoborus flavicans*, had a high abundance while other organisms were less common. As a result of increased phytoplankton production (Kagalou, Papastergiadou, et al. 2003) the species diversity of benthic fauna was poorly dominated by chironomids, with low oxygen thresholds and the tubificid species *P. hammoniensis* and *T. tubifex* known for their resistance in hypoxic conditions. The dominant species among oligochaetes were *P. hammoniensis* and *T. tubifex* while *C. plumosus* was the dominant chironomid. *P. hammoniensis* is known to be a ubiquitous species, generally a dominant species in water bodies with mud and clay bottom (Risnoveanu & Vadineanu 2002) and common in hypertrophic conditions. Chironomidae are considered as a good indicator of various types of pollution, both in running waters and lake systems (Garcia-Criado et al. 2005; Reynoldson & Metcalfe-Smith 1992). Recent studies showed that the percentage of chironomids or Chironominae are probably not good indicators (Garcia-Criado et al. 2005; Kashian & Burton 2000) and the response to pollution varies among chironomid species with the most pollution-tolerant species within the sub-family of Chironominae. The dominance by *Chironomus plumosus* (Chironominae) as found in Lake Pamvotis may reflect its high tolerance in a Mediterranean shallow eutrophic lake.

The seasonal abundance of macroinvertebrates can be highly variable affected by a lot of environmental, biological and anthropogenic factors (Garcia-Criado et al. 2005; Reizopoulou & Nicolaidou 2004). Taking into consideration that smaller developmental stages (e.g., than 500 μm) did not included to the structural analysis, generally, the abundances of oligochaetes in Lake Pamvotis increased during spring because of favorable temperature and DO conditions. During this period sunlight is able to reach the bottom and to increase primary production. This was the reason of maximum hypolimnetic algal biomass, comprising mostly diatoms (Romero & Imberger 1999) which was expected to stimulate growth of oligochaete and chironomid communities. Similar results were reported by Risnoveanu and Vadineanu (2002) who studied the oligochaete dynamics in Lake Isacova in the Danube Delta. Brinkhurst (1964) demonstrated that many tubificid species in temperate regions have one reproductive period per year, often from May to July. Other authors (Risnoveanu & Vadineanu 2003) have reported that tubificid species reproduce more than once a year, irrespective of local differences in water temperature, food supply and oxygen concentration at the sediment/water interface. In Lake Pamvotis, tubificids appear to have two population maxima in their abundances: the first one between February and May and the second between September and November.

The literature (Devai 1990; Specziar & Biro 1998) suggests more than one (at least two or three) generations of chironomids when environmental conditions are suitable. The highest chironomid abundance in Lake Pamvotis was recorded in late spring. Temperature and DO conditions in the soft sediment of the lake are suitable for the large mud-dwelling chironomids. Moreover the organic matter of the sediment (10–14%) is quite higher than the critical limiting value of 1.2–1.5% suggested for *C. plumosus* (Devai 1990; Specziar & Biro 1998).

Chaoborous flavicans is one of the dominant species reflecting the eutrophic state of the lake since it is known as a common inhabitant of shallow and productive standing waters (Petridis & Sinis 1997). It seems to increase its abundance in late spring and summer but its absence during the winter may indicate that the larvae are mainly early instars, which are pelagic. The hypoxic hypolimnion, during the warm period, can be regarded as a predation refuge for *Chaoborous* from fish (Hanazato 1994).

During the warm period, sediment conditions (as expressed by higher temperatures and DO values in water–sediment interface) are not suitable to support high diversities and high numbers of benthic species. Almost all benthic species showed the same intra-annual seasonal pattern with peak population densities during spring and early summer with the exception of *P. hammoniensis* which predominates during the whole sampling period. This seasonal pattern has also been noticed in Lake Pamvotis during 1994–1995 (Economidis 1999) and in another Greek lake (M. Prespa), with a comparable benthic taxonomic composition (Petridis & Sinis 1997).

On the basis of faunal similarities, Lake Pamvotis presents one distinguishable area in the shallow north-western sub-basin (S3), characterized by the presence of *Chaoborous flavicans* larvae, and two other less distinct areas, namely the "central lake" (S1, S2) and the "inflows area" (S4, S5) located in the much larger eastern sub-basin.

Stations S4 and S5 appear to be species-poorer sites than S1 and S2. They are located near the two main inflows (Fig. 1). Inflow 1 predominately drains an agricultural catchment whereas inflow 2 drains a catchment with mixed land uses (urban, rural, agriculture and industry).

S1 followed by S2 are characterized by the most diversified benthic communities suggesting that the central part of the basin is the preferable habitat for macroinvertebrates since it is protected from the currents during high wind (Romero & Imberger 1999) and characterized by the presence of submerged vegetation (Garcia-Criado et al. 2005; Kagalou, Papastergiadou, et al. 2003).

Unfortunately, there are no previous data on benthic species richness in the area of S3. Practices such as frequent reed-bed harvesting and burning in the inshore littoral zone and the construction of dikes in the north-western shoreline, may be responsible for the low diversity. Moreover Kotti et al. (2000) found no differences in sediment nutrient concentrations among the same stations, except significantly higher ammonia concentration at S3 (mean value: $2.2\,\mathrm{mg\,L^{-1}}$, max. value: $7.5\,\mathrm{mg\,L^{-1}}$).

Spearman rank correlation between benthic community indices and water quality variables showed that DO and water temperature may affect community diversity. Previous studies showed no correlation between numerical abundance or taxa richness and the environmental variables in either different depth zones or sampling areas (Hamalainen et al. 2003). Scarsbrook (2002) suggests that variation in invertebrate communities is stochastic, or driven by biotic interactions rather than by the water quality. From the present work it is clear that within lake habitats, macrobenthic fauna cannot be explained by a single factor. As most of the environmental parameters are closely related to each other, it is difficult to segregate the effect of each one on the distribution of macroinvertebrates, especially in a highly eutrophic ecosystem. Low diversity may be a result of the very variable environmental conditions characterizing shallow Mediterranean lentic systems. Because of the shallowness, benthic species are more exposed to environmental variation and therefore macrofaunal community patterns may reflect species adaptations to those environmental conditions. Lake Pamvotis is considered as an urban heavy polluted system. Recent ecotoxicological studies showed that pesticides exert a significant pressure on the aquatic system of Lake Pamvotis, especially for the chronic-effect level (Hela, Lambropoulou, Konstantinou, & Albanis 2005). Point and non-point pollution sources affect macrobenthos communities shifting their composition to more tolerant taxa.

Benthic diversity as regards the requirements of the EU-Water Framework Directive

Many studies (Beklioglu, Romo, Kagalou, Quintana, & Becares 2006; Romo et al. 2005) have shown that in Mediterranean shallow lake systems the water quality becomes worse during the warm period greatly affecting the distribution and the composition of macrobenthos. The identification and the application of the most reliable indicators for shallow lakes still remain a difficult task because of the differences in geographic regions and different life traits.

The use of indicator species for water quality assessment is well developed for streams and deep lake ecosystems (Rosenberg & Resh 1992; Wright, Sutcliffe, & Furse 2000). On the other hand, the assessment of the ecological status in shallow Mediterranean lakes is scarce. However, new fast tools for assessments of water quality and conservation status have been successfully developed at a regional scale in northeast Spain, including the use of aquatic invertebrates as water quality indicators (Boix et al. 2005). Further investigation is necessary in order to develop and apply the appropriate indicators for shallow Mediterranean lakes. Besides the diversity indices based on abundance of different groups, an alternative methodology approach based on indicator species or genera may be rather effective. More attention needs to be focused on which taxa provide useful informations in assessing the ecological status of the lake. From the present work it could be supported that a sampling protocol including more and clearly defined sampling sites could be helpful not only to obtain a better assessment but also to understand the "natural" and perturbation-induced variability. The challenge for Mediterranean shallow lakes is to determine the ecological status according to EU-WFD since this directive sets out a wide range of parameters, including macroinvertebrates. The information of this particular site can contribute to the national licensing polices or to European legislative requirements relating to conservation regulations. However, since there are no guidance on methodology neither determination of reference conditions, much more research is needed to realize the directive and furthermore to achieve a favorable conservation status.

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