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Macro Zoobenthos of Lake Uluabat, Turkey, related to some physical and chemical parameters

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Abstract. Lake Uluabat, Bursa, Turkey, was sampled monthly between December 2001 and November 2002 at four stations for the purpose of evaluating the spatial and seasonal variations in the diversity and abundance of benthic macroinvertebrates in relation to the dynamics of water temperature, conductivity, water transparency, pH, dissolved oxygen, phosphate, nitrate and chlorophyll-a concentrations. A total of 24 taxa and 9281 individuals were identified. Insecta and oligochaete were the most abundant groups in the lake. Benthic macroinvertebrates of Lake Uluabat were dominated by species characteristic to nutrient rich waters, including *Pristina aequiseta* Bourne, 1891, *Nais communis* Piguet, 1906, *Tubifex tubifex* Mueller, 1774, *Limnodrilus hoffmeisteri* Claparede, 1862, *Potamothrix hammoniensis* Michaelsen, 1901 and *Tanypus punctipennis* Meigen, 1818. Most of the variance (63.5%) in relationships between species and environmental variables were explained by the first two axes of a canonical correspondence analysis (CCA). CCA placed most Oligochaete and Chironomidae near the vectors of high nutrients and chlorophyll-a concentrations, while the sensitive Crustacea and some Oligochaete (Lumbricidae) species were placed on sectors of the plot with the smallest weight of those variables.

Key Words: Canonical correspondence analysis, diversity, eutrophication, macrobenthos

Resumen. Macrozoobentos del Lago Uluabat, Turquía, y su relación con parámetros ambientales físicos y químicos. El Lago Uluabat, Bursa, Turkía, fue muestreado mensualmente en cuatro sitios entre diciembre de 2001 y noviembre de 2002 para evaluar la variabilidad temporal y espacial en la diversidad y abundancia de macroinvertebrados bentónicos, y su relación con la temperatura del agua, la conductividad, transparencia, pH, oxígeno disuelto, y concentración de fosfato, nitrato y clorofila-a. Se identificaron un total de 24 taxones. Insecta y Oligochaeta fueron los grupos más abundantes del conjunto de macroinvertebrados bentónicos, el cual estuvo dominado por especies características de aguas ricas en nutrientes, incluyendo *Pristina aequiseta* Bourne, 1891, *Nais communis* Piguet, 1906, *Tubifex tubifex* Mueller, 1774, *Limnodrilus hoffmeisteri* Claparede, 1862, *Potamothrix hammoniensis* Michaelsen, 1901 y *Tanypus punctipennis* Meigen, 1818. La mayor parte de la varianza (63.5 %) en la relación entre especies y variables ambientales fue explicada por los dos primeros ejes de un análisis de correspondencia canónica (CCA). El CCA ubicó a la mayoría de los Oligochaeta y Chironomidae cerca de los vectores de alta concentración de nutrientes y clorofila-a, mientras que los grupos de Crustacea (más sensibles a condiciones ambientales) y algunas especies de Oligochaete (Lumbricidae) fueron ubicados en regiones del gráfico correspondientes a los menores pesos de dichas variables.

Palabras clave: Análisis de correspondencia canónica, diversidad, eutrofización, macrobentos

Introduction

It is widely accepted that benthic macroinvertebrates play a major role in the evaluation of environmental quality of aquatic ecosystems (Stewart *et al*. 2000). They reflect the combined effects of various stresses influencing water quality in time and space (Timms 2006).

In lakes, habitat-scale characteristics such as differences of substrate and different levels of nutrients are considered critical in determining the density and species composition of the macroinvertebrates (Johnson *et al*. 2004). Seasonal variability of environmental factors is another important source of variations in macroinvertebrate communities (Tolonen *et al*. 2001).

Relationships between environmental factors and benthic invertebrate communities are essential to understand how communities are structured by the physical and chemical properties of their environment (Timm *et al*. 2001). Bazzanti & Seminara (2004) state that differences in abundance and species composition of benthic organisms are due to differences in physical and chemical characteristics of individual aquatic systems.

Despite the fact that many factors impact benthic macroinvertebrate communities, the relative contributions of such factors have rarely been quantified (Bazzanti & Seminara 2004). In a few studies, the canonical correspondence analysis (CCA) (ter Braak and Smilauer 2002) method has been successfully applied to quantify the contribution of environmental factors on the structure of macroinvertebrate communities (Peeters *et al*. 2001).

There is an extensive literature on benthic macroinvertebrate taxa association with lake trophic state (Stoffels *et al*. 2005, Tolonen *et al*. 2001). The understanding of community patterns of macroinvertebrates to nutrient or chlorophyll-a concentrations in lakes lag considerably behind.

In this study, CCA method was applied to data collected from December 2001 to November 2002 for determining the environmental factors structuring the macroinvertebrates community in Lake Uluabat. The specific purpose of this study was to determine the spatial and seasonal variations of the abundance and species diversity of benthic macroinvertebrates in relation to certain physical and chemical parameters in Lake Uluabat, Turkey.

Materials and Methods

Lake Uluabat is a shallow eutrophic lake located at 40° 10' N and 28° 35' E in the province of Bursa, Turkey (Fig. 1). The lake lies 9 m above sea level and has a muddy bottom. It has a mean depth of 2 m, a maximum depth of 6 m, a length of 23 km, a width of 12 km and a surface area of 156 km^2. The lake is mainly fed by Mustafakemalpaşa Stream. Kocasu Stream serves an outlet for the lake when the water level is high and it feeds the lake when the water level is low.

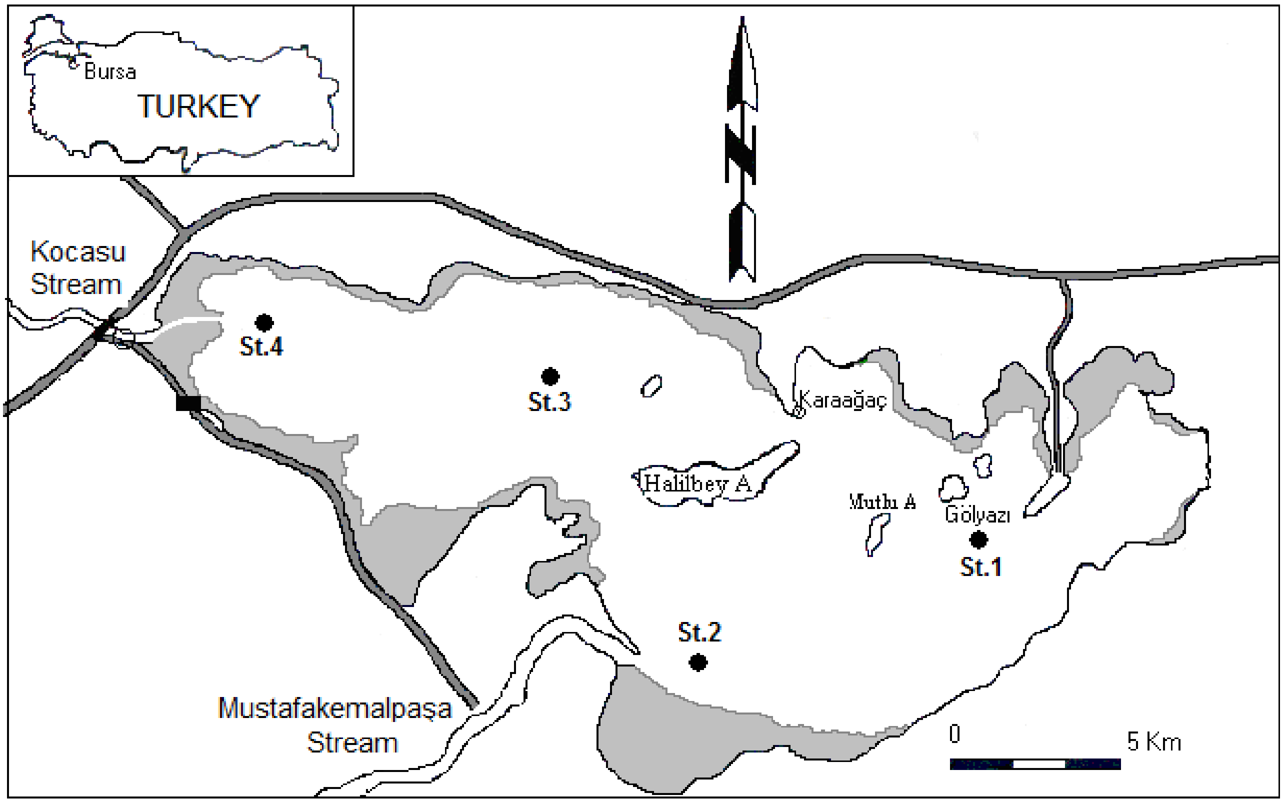

Figure 1. The map of Lake Uluabat and the locations of sampling stations.

There have been various studies on Lake Uluabat (Altınsaçlı & Griffiths 2004, Salihoglu & Karaer 2004, Barlas *et al*. 2006, Kökmen *et al*. 2007), but the number of studies on the benthic macroinvertebrates of the lake are far from complete. The lake was covered in the Ramsar Convention in 1998 (Kökmen *et al*., 2007).

Lake Uluabat was sampled monthly from December 2001 to November 2002 at four stations to evaluate the community structure of benthic macroinvertebrates in relation to the dynamics of water temperature, conductivity, transparency, pH, dissolved oxygen, phosphate, nitrate and chlorophyll-a concentrations.

Two replicate samples were collected with a Birge-Ekman grab (15 cm X 15 cm) at each station. Each sample was washed in a 250-µm-mesh sieve bucket and placed into plastic jars. Organisms were fixed with 10 percent formalin containing Rose Bengal stain. Samples were examined under a compound microscope. Nitrate (NO_3), phosphate (PO_4) and chlorophyll-a (Chla) concentrations were measured spectrophotometrically according to standard methods (APHA 1995). Water temperature, pH, dissolved oxygen and conductivity were measured using a WTW multiline probe. Water transparency was measured using a Secchi disk.

Commony used keys such as Dobrowolski (1994), Dusoge et al. (1999), Geldiay and Bilgin (1969), Brinkhurst & Wetzel (1984), Şahin (1984), Savage (1999) and Timm (1999) were used for species identification.

Shannon and Wiener (1964) diversity index was calculated for each sampling period and station to determine the spatial and seasonal dynamics of the macroinvertebrate species diversity. A one-way analysis of variance (ANOVA) test was used for determining the statistical differences in the density and species diversity among seasons and sampling stations using SAS software (SAS Institute 1990).

Detrended Correspondence Analysis (DCA) was used to detect the length of the environmental gradient. After DCA, Canonical Correspondence Analysis(CCA) was applied to the data. The Monte Carlo permutation test was used to reveal the effects of the environmental variables on the benthic species abundance. The results of the analyses were visualised in the ordination diagrams. The canonical correspondence analysis (CCA) was carried out using CANOCO software (ter Braak & Smilauer 2002). Only the taxa identified to species level were considered for the CCA.

Results

Conductivity ranged from 0.32 to 0.61 mS cm^{-1} at the first station, from 0.38 to 0.60 mS cm^{-1} at the second station, from 0.27 to 0.78 mS cm^{-1} at the third station and from 0.42 to 0.78 mS cm^{-1} at the fourth station, respectively. Average conductivity increased from first station to the fourth station. Secchi disk depth ranged from 0.1 to 1.5 m at the first and second stations, from 0.3 to 1.5 m at the third station and from 0.2 to 0.7 m at the fourth station, respectively. Secchi disk depth significantly decreased at the fourth station (Table 1).

Table 1- Summary statistics of conductivity (mS cm^{-1}), Secchi disk depth (Secchi) (m), pH, dissolved oxygen (DO) (mg L^{-1}), nitrate (NO_3) (mg L^{-1}), phosphate (PO_4) (mg L^{-1}) and chlorophyll-a (Chl-a) (µg L^{-1}) of Lake Uluabat from November 2001 to December 2002

	Station1			Station 2			Station3			Station4		
	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
Conductivity	0.61	0.32	0.42	0.60	0.38	0.44	0.78	0.27	0.51	0.78	0.42	0.55
Secchi	1.5	0.1	0.5	1.5	0.1	0.5	1.5	0.3	0.6	0.7	0.2	0.4
pH	8.9	8.1	8.3	8.8	8.1	8.2	8.8	8.3	8.0	8.6	8.1	8.2
DO	12.5	4.3	7.9	13.5	4.3	7.9	12.4	4.2	7.8	11.5	4.0	7.0
NO_3	1.48	0.08	0.98	1.84	0.06	1.13	2.30	0.37	1.40	2.50	0.47	1.50
PO_4	1.12	0.05	0.62	1.14	0.03	0.63	1.11	0.02	0.61	1.17	0.03	0.67
Chl-a	80	14	32	90	13	35	73	11	31	109	10	38

Nitrate ranged from 0.08 to 1.48 mg L^{-1} at the first station, from 0.06 to 1.84 mg L^{-1} at the second station, from 0.37 to 2.30 mg L^{-1} at the third station and from 0.47 to 2.50 mg L^{-1} at the fourth station, respectively. Nitrate concentrations showed an ascending gradient from the first station to the fourth station. Phosphate ranged from 0.05 to 1.12 mg L^{-1} at the first station, from 0.03 to 1.14 mg L^{-1} at the second station, from 0.02 to 1.11 mg L^{-1} at the third station and from 0.03 to 1.17 mg L^{-1} at the fourth station, respectively. pH ranged from 8.1 to 8.9 at the first station, from 8 to 8.8 at the second station, from 8.3 to 8.8 at third station and from 8.1 to 8.6 at the fourth station, respectively. No distinct trends could be identified in pH dynamics. Bottom dissolved oxygen concentrations ranged from 4.3 to 12.5 mg L^{-1} at the first station, from 4.2 to 13.4 mg L^{-1} at the second station, from 4.2 to 12.5 mg L^{-1} at third station and from 4 to 11.5 mg L^{-1} at the fourth station, respectively (Table 1).

Chlorophyll-a ranged from 14 to 80 µg L^{-1}at the first station, from 13 to 90 µg L^{-1} at the second station, from 11 to 73 µg L^{-1} at the third station and from 10 to 109 µg L^{-1} at the fourth station, respectively. No distinct trends could be identified in Chlorophyll-a concentrations (Table 1).

Twenty four macroinvertebrate taxa were identified, including 1 Gastropoda, 1 Bivalvia, 11 Oligochaeta, 1 Hirudinea, 1 Amphipoda, 1 Decapoda, 1 Ceratopogonidae, 6 Chironomidae and 1 Heteroptera. *Pristina aequiseta* Bourne, 1891 and *Nais communis* Piguet, 1906 in Naididae, *Tubifex tubifex* Mueller, 1774, *Limnodrilus hoffmeisteri* Claparede, 1862 and *Potamothrix hammoniensis* Michaelsen, 1818 in Tubificidae were the most common species at the first station; *Pristina aequiseta* and *Nais communis*, *Tubifex tubifex* and *Potamothrix hammoniensis* at the second station; *Pristina aequiseta* and *Nais communis*, *Limnodrilus hoffmeisteri* and *Tanypus punctipennis* Meigen, 1818 were the most common species at the third and fourth stations.

Pristina aequiseta Bourne, 1891 and *Nais communis* Piguet, 1906 in Naididae were the most common species in all stations, with the tubificids *Tubifex tubifex* Mueller, 1774, and *Potamothrix hammoniensis* Michaelsen, 1818 at stations 1 and 2, *Limnodrilus hoffmeisteri* Claparede, 1862 at stations 1 and 3, and *Tanypus punctipennis* Meigen, 1818 at the latter.

The seasonal average density of macroinvertebrates was about 4.5 ind. m^{-2} in winter and spring at the first station, 7 ind. m^{-2} in summer at the second station and 2.8 ind. m^{-2} in fall at the third station. At the fourth station, the seasonal average density was about 5 ind. m^{-2} in winter and spring, 7 ind. m^{-2} in summer and 5 ind. m^{-2} in fall. The average density of macroinvertebrates was the highest at the fourth station and the lowest at the first station (Fig. 2a). The density of macroinvertebrates was significantly different among seasons ($F=35$, $p<0.05$), but not among sampling stations ($F=0.5$, $p>0.05$).

Shannon-Wiener diversity was about 0.8 in winter and spring and about 0.9 in summer and fall at the first station. At the second station, diversity was about 0.6. At the third station, the highest diversity (0.8) was observed in December 2001 and the lowest (0.2) in April 2002. At the fourth station, species diversity was about 0.6. The species diversity was significantly higher at the first station then the other stations (Fig. 2b). The species diversity was significantly different among sampling stations ($F=31$, $p<0.05$), but not among seasons ($F=1.4$, $p>0.05$).

The first and second axes of CCA explained 63.5% of the variance in species-environment relationships (eigenvalues, 0.12 and 0.055). The third and fourth axes together explained 23.8% of the variance (eigenvalues, 0.043 and 0.028) (Table 2).

In the CCA diagram, *Tubifex tubifex* (Tubificidae), *Theodoxus pallasi* Lindholm, 1924 (Gastropoda) and *Chironomus plumosus* (Chironominae) occurred together at sites near NO_3, PO_4 and chlorophyll-a. *Nais communis* (Tubificidae), *Potamothrix hammoniensis* (Tubificidae), *Hirudo medicinalis* Linnaeus, 1758 (Hirudinea) and *Unio terminalis delicates* Lea, 1863 (Bivalvia) occurred together in the opposite site of the above species near dissolved oxygen concentration and water temperature vectors (Fig. 3).

Limnodrolis hoffmeisteri (Tubificidae), *Limnodrolis profundicola* (Tubificidae), *Nais barbata* (Naididae), *Nais variabilis* (Naididae), *Cryptotendipes holsatus* (Chironominae), *Gammarus pulex* Linnaeus, 1758 (Amphipoda) and *Astacus leptodactylus* Eschscholtz, 1823 (Decapoda) occurred together at sites near transparency vector in the CCA diagram. *Limnodrolis udekemianus* (Tubificidae), *Psammoryctides albicola* Michaelsen, 1901 (Tubificidae), *Cryptochironomus defectus* (Chironominae) and *Tanypus punctipennis* (Tanypodinae) occurred near pH vector (Fig. 3).

Discussion

The density of macroinvertebrates was higher during summer than during the other seasons at all stations. The observed seasonal patterns probably resulted from the fact that different families appeared only in certain season of the year (Sharma & Rawat 2009, Cui *et al*. 2008, Kagalou *et al*. 2006). The most abundant species, *Pristina aequiseta* (Naididae), had a density over 3.5 ind. m^{-2} from June to September throughout the study period at all stations.

Shannon's diversity values were low (about 0.6) in Lake Uluabat compared with species diversity in similar lakes (Prato *et al*. 2009), but it is

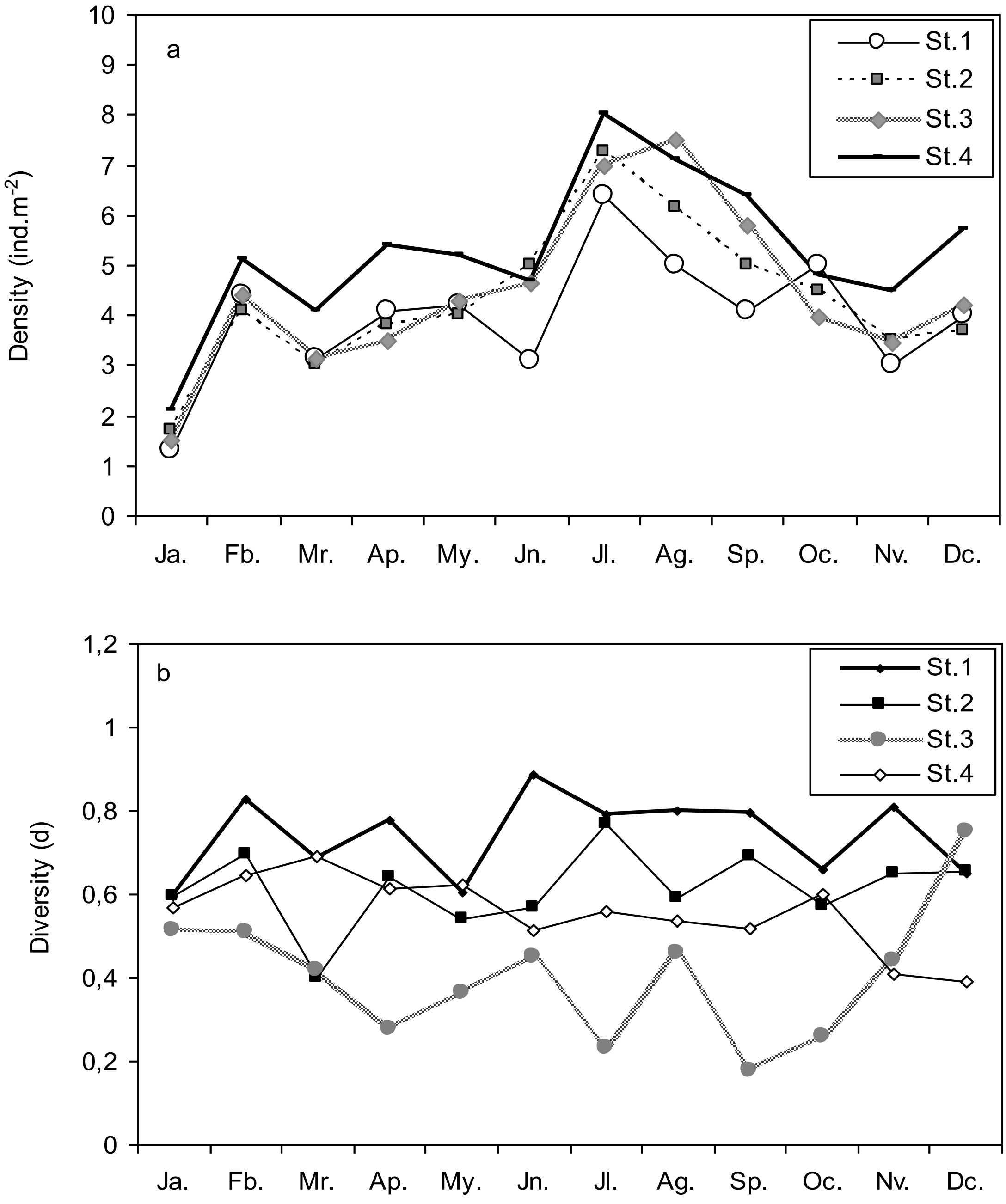

Figure 2. a) Density and b) diversity of benthic macro invertebrates of Lake Uluabat. Abbreviations: Ja.= January, Fb.= February, Mr.= March, Ap.= April, My.= May, Jn.= June, Jl.= July, Ag.= August, Sp.= September, Oc.= October, Nv.= November, Dc.= December.

difficult to distinguish if these low diversity values were natural or a result of anthropogenic stress. Ruellet & Dauvin (2007) state that low values of Shannon's diversity may not necessarily be a sign of degradation, they could be related to natural conditions.

Although CCA is multidimensional, only the first and second axes (eigenvalues, 0.12 and 0.055) were included in the analysis. Most of the variance in relationships between species and environmental variables were explained by the first two axes (63.5%). Axes three and four were less important, their eigenvalues were relatively low (0.043 and 0.028), and the added percentage of variance in species-environment relation was only 14.1% for axis three and 9.7 % for axis four.

Table 2- Summary statistics of CCA of macro zoobenthos and some physical and Chemical parameters in Lake Apolyont

Axes	1	2	3	4
Eigenvalues	0.121	0.055	0.043	0.028
Species-environment correlations	0.664	0.511	0.567	0.559
Cumulative percentage variance of species data	8.7	12.5	15.2	17.1
Cumulative percentage variance of species-environment relation	44.4	63.5	77.6	87.3
Sum of all eigenvalues	1.480			
Sum of all canonical eigenvalues	0.291			
Total inertia	1.480			

Among the eleven oligochaete species, CCA revealed that *Tubifex tubifex* (Tubificidae) was related to NO_3, PO_4 and chlorophyll-a, while *Nais communis* (Naididae) and *Potamothrix hammoniensis* (Tubificidae) were related to dissolved oxygen concentrations and water temperatures. *T. tubifex* is usually recognized as the member of macroinvertebrates typical of nutrient rich lakes (Milbrink *et al*. 2002). *N. communis* (Naididae) and *P. hammoniensis* (Tubificidae) are widely distributed in Turkey and across Europe occurring in eutrophic lakes with a wide range of nutrient concentrations (van Duinen *et al*. 2006, Yıldız *et al*. 2008).

CCA showed that *Limnodrouis hoffmeisteri* (Tubificidae), *Limnodrolus profundicola* (Tubificidae), *Nais barbata* (Naididae) and *Nais variabilis* (Naididae) occurred at sites with high transparency. Wolfram *et al.* (2002) state that these species prefer well oxygenated eutrophic waters. Lake Uluabat is eutrophic (Turkish Ministry of Environment and Forestry 2006) and never had oxygen deficiency during the study period being a suitable place for the occurrence of these species. *Limnodrolus udekemianus* (Tubificidae) and *Psammoryctides albicola* (Tubificidae) occurred in the sites with relatively low pH and transparency. Yıldız & Balık (2005) found that both *L. udekemianus* and *P. albicola* occurred in various lakes with low pH values in Lake District Area in Turkey.

The CCA revealed that among the four Chironomidae species, *Chironomus plumosus* (Chironominae) occurred in sites near NO_3, PO_4 and chlorophyll-a vectors. *C. plumosus* is one of the most common species in eutrophic water bodies worldwide (Kajak & Prus 2004). Rossaro *et al.* (2007) found that *C. plumosus* was highly tolerant to high nutrient concentrations in a study on 42 Italian lakes. *Cryptochironomus defectus* (Chironominae) occurred in the sites near pH and transparency vectors. This species is common in macroinvertebrates of eutrophic lakes (O'Toole *et al*. 2008). *Cryptotendipes holsatus* (Chironominae) was related to water transparency. *C. holsatus* is widely collected at the littoral parts of lakes and riffles of European and Turkish inland waters (Özkan 2006, Rossaro *et al*. 2007).

Two Crustacean species *Gammarus pulex* (Amphipoda) and *Astacus leptodactylus* (Decapoda) were related to water transparency. *G. pulex* is known as a member of macroinvertebrates typical of eutrophic lakes in Europe (Nuttall & Purves 2006, Arslan *et al*. 2007). *A. leptodactylus***,** known as cryfish, is the most common crustacean in Turkish inland waters with various degrees of nutient levels (Balık *et al*. 2005).

CCA placed *Tanypus punctipennis* (Tanypodinae) and *Eiseniella tetraedra neapolitana* Csuzdi and Pavlicek, 2005 (Lumbricidae) apart from all other species in the ordination diagram. Arslan et al. (2007) found that the abundance of *T. punctipennis* showed a positive correlation with dissolved oxygen concentrations and negative correlations with nutrient concentrations in a shallow reservoir in central part of Turkey. Smiljkov *et al.* (2005) found that *E. tetraedra neapolitana* was usually abundant in lakes with muddy bottoms. The bottom of Lake Uluabat is also muddy (Kökmen *et al*. 2007).

Although it is not shown in CCA diagram, *Pristina aequiseta* (Naididae) was the most dominant species in Lake Uluabat throughout the study period at all stations. This species is a member of macroinvertebrates typical to eutrophic lakes across Europe and Turkey (Collado *et al.* 2006, van Duinen *et al*. 2006, Arslan & Şahin 2004).

In conclusion, benthic macroinvertebrates of Lake Uluabat were dominated by species characteristic of nutrient rich waters including *P.*

aequiset, N. communis, and *P. hammoniensis*. CCA placed Oligochaete and Chironomidae near the vectors of high nutrients and chlorophyll-a. On the other hand, the sensitive organisms including Crustacea, Lumbricidae species and *T. punctipennis* were placed on sectors of the plot with the smallest weight of those variables. This study showed that phosphate, nitrate, Secchi disk depth (transparency) and chlorophyll-a were useful parameters for identifying relations of benthic macroinvertebrates to nutrients in a large shallow eutrophic lake.

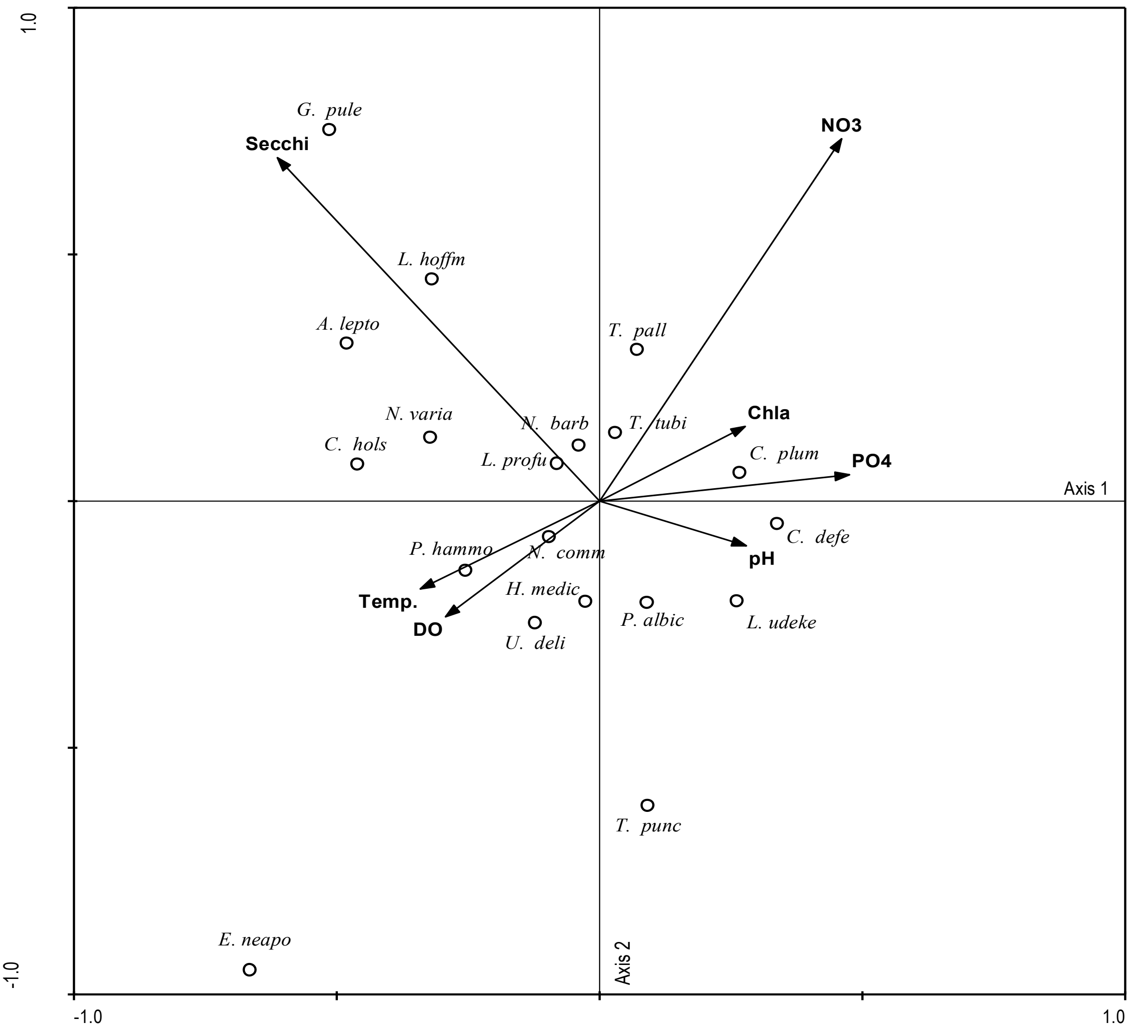

Figure 3. Diagram of canonical correspondence analysis (CCA) of physico-chemical variables (arrows) and benthic macroinvertebrate species (circlus) in Lake Uluabat. Abbreviations: *C. plum= Chironomus plumosus, T. tubi= Tubifex tubifex, T. pall= Theodoxus pallasi, N. barb= Nais barbata, L. profu= Limnodrolis profundicola, C. hols= Cryptotendipes holsatus, N. varia= Nais variabilis, A. lepto= Astacus leptodactylus, L. hoffm= Limnodrolis hoffmeisteri, G. pule= Gammarus pulex, P. hammo= Potamothrix hammoniensis, N. comm= Nais communis, H. medic= Hirudo medicinalis, U. deli= Unio terminalis delicates, E. neapo= Eiseniella tetraedra neapolitana, T. punc= Tanypus punctipennis, P. albic= Psammoryctides albicola, L. udeke= Limnodrilus udekemianus and C. defe= Cryptochironomus defectus.*

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