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Research Article

Limnoecological relationships between water level fluctuations and Ostracoda (Crustacea) species composition in Lake Sünnet (Bolu, Turkey)

Okan KÜLKÖYLÜOĞLU[1,*], Muzaffer DÜGEL[1], Muharrem BALCI[2],
Aziz DEVECİ[1], Derya AVUKA[1], Mustafa KILIÇ[2]

[1]Abant İzzet Baysal University, Faculty of Arts and Science, Department of Biology, Gölköy, 14280 Bolu - TURKEY

[2]İstanbul University, Department of Biology, Vezneciler, İstanbul - TURKEY

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Abstract: The ecological characteristics of ostracods in Lake Sünnet were monitored monthly between May 2005 and September 2007; 9 living and 5 subfossil ostracod taxa were recorded. Among the species, *Ilyocypris getica* was reported in Turkey for the first time, while *Stenocypria fischeri* was found for the second time in the country in 55 years. The most abundant species, *Limnocythere inopinata*, was collected in dry and wet months, while *I. bradyi* was the only species found in only the wet months. The 9 species clustered into 3 groups based on their ecological preference. Species composition and occurrences were closely related to the lake water level fluctuation, from 7 to 13 m within a year. These fluctuations played a significant role in changes in the physicochemical characteristics of the lake, along with ostracod species composition ($P < 0.01$). A strong negative correlation ($P < 0.05$) between precipitation and both ambient temperature and SO_4 was also interpreted as the outcome of such fluctuations. The number of species corresponded with salinity changes. Most of the ostracod species appearing in Lake Sünnet were tolerant to the large water level fluctuation. These results correspond with the idea of 'pseudorichness,' when species composition is dominated by cosmopolitans over noncosmopolitans, an indication of low water quality in a lake. Changes in the lake have been accelerated by anthropogenic activities such as water diversions for chicken farms and agricultural fields during dry climatic conditions. The occurrence of these activities appears to have produced seasonal differences in the lake's water quality and species composition.

Key words: Ostracoda, Lake Sünnet, water level fluctuations, ecological tolerance, pseudorichness

Sünnet Gölü'nde (Bolu, Türkiye) su seviyesi değişimleri ve Ostrakoda (Crustacea) tür kompozisyonu arasındaki limnoekolojik ilişkiler

Özet: Sünnet Gölündeki ostrakotların ekolojik özellikleri Mayıs 2005-Eylül 2007 tarihleri arasında izlenmiştir. Dokuz adet canlı, beş adet subfosil ostracoda türü teşhis edilmiştir. Bu türler arasında *Ilyocypris getica* Türkiye için ilk kayıt, *Stenocypria fischeri* ise 55 yıl içinde ikinci kayıttır. En yoğun olarak bulunan tür, *Limnocythere inopinata* kuru ve yağışlı aylarda bulunurken, *I. bradyi* ise yağışlı ayalarda bulunan tek türdür. Dokuz tür ekolojik özelliklerine göre üç gruba ayrılmıştır. Türlerin varlığı ve kompozisyonu yıl içinde görülen 7-13 m'lik su çekilmesiyle yakından ilgilidir. Suyun

* E-mail: kulkoyluoglu_o@ibu.edu.tr

çekilmesi, Ostrakoda tür kompozisyonuyla birlikte gölün fizikokimyasal özelliklerinin değişmesinde önemli bir rol oynar ($P < 0{,}01$). Yağış ile hem SO_4 miktarı hem de çevre sıcaklığı arasında ortaya çıkan güçlü bir negatif korelasyon ($P < 0{,}05$) bu tip çekilmeleri açıklamaktadır. Tür sayısı tuzluluk değişimleriyle uyumludur. Sünnet Gölü'nde bulunan çoğu ostrakoda türü geniş su çekilmelerine toleranslıdır. Bu sonuçlar bir göldeki düşük su kalitesinin göstergesi olan, kozmopolit olan türlerin kozmopolit olmayanlardan fazla olmasıyla ortaya çıkan 'yalancı zenginlik' görüşünü desteklemektedir. Kurak aylarda tavuk çiftliklerine ve tarımsal alanlara suyun alınmasıyla göldeki değişimler insan etkisiyle artırılmaktadır. Bu tip aktiviteler, gölün su kalitesindeki ve tür kompozisyonundaki mevsimsel değişikliği etkilediği görülmektedir.

Anahtar sözcükler: Ostrakoda, Sünnet Gölü, su seviye azalmaları, ekolojik tolerans, sahte zenginlik

Introduction

Water level fluctuation (WLF) not only changes the physical characteristics of lakes (e.g. water level changes), but also alters their chemical and biological structure. These changes may be natural (e.g. precipitation or evaporation), anthropogenic (e.g. water drainage or waste water input), or both. Studies show that anthropogenic activities, which have been the main factors in habitat destruction and species loss for the last couple of centuries (Fritz, 1990; White et al., 2008), have also had the fastest and most irreversible impacts on the hydrology and ecology of lakes. Factors causing WLFs eventually change the water quality (Chen et al., 2001) and can play a major role in biological disturbances. For example, changes in water levels can influence whether or not species occupy particular microhabitats. Therefore, it is possible that if the relationship between changes in lake levels and environmental variables (e.g. salinity or temperature) are known, species' responses to future hydrological conditions can be predicted. For example, Noe-Nygaard and Heiberg (2001) investigated climate and base-flow changes as possible reasons for the rising water level of a lake in Denmark. Using sediment cores, they were able to create a historical record of the lake and found that recent climate change also contributed to increasing sedimentation and groundwater levels.

In the long term, only those species adapted to water level changes can survive in lakes with WLFs. Other species may occur in the short term when local conditions are most suitable for them. Specifically, cosmopolitan species with high levels of tolerance to environmental changes have a better chance of surviving in fluctuating aquatic habitats than noncosmopolitan species (Külköylüoğlu, 2003a; Külköylüoğlu and Dügel, 2004; Dügel et al., 2008). The concept of 'pseudorichness' (Külköylüoğlu, 2004) was introduced to interpret water conditions by using the ratio of the number of noncosmopolitan to cosmopolitan species in aquatic habitats. Accordingly, the concept assumes that the ratio will be higher in the habitats with high levels of fluctuations than the habitats with no or low fluctuations. Consequently, the concept can provide an early assessment of the characteristics of aquatic habitat quality. Although preliminary results on ostracods in different habitats correspond with the assumptions of the concept, the idea should also be tested with different organisms in a variety of habitats to evaluate its generality.

Ostracod is a class of microscopic invertebrate crustaceans that inhabit a variety of aquatic habitats. Their worldwide distribution and long historical record suggest their use as indicators of habitat quality. Because each species has different tolerance levels to the changes in a variety of environmental variables, they are useful organisms for understanding past and present and estimating future conditions (De Deckker and Forester, 1988; Külköylüoğlu, 1998, 2005a; Mezquita et. al., 2005; Külköylüoğlu and Yılmaz, 2006). However, Külköylüoğlu (2003a) and Külköylüoğlu and Dügel (2004) also argued that past environmental conditions can be interpreted better if the ecological requirements of living ostracods are known. Applying the concept of pseudorichness depends on correctly identifying the taxonomic characteristics of each species along with its habitat preferences and tolerance levels. Once such levels are estimated, future possibilities can be predicted.

The main objectives of this study were to: (1) establish a detailed temporal record of physicochemical characteristics of Lake Sünnet, (2) identify the ostracod species composition of the lake, (3) evaluate the relationship between WLF and species distribution in the lake, and (4) report the ecology, microhabitat distribution, ecological tolerances, and optimum values of individual species.

Materials and methods

Study site description

Lake Sünnet (40°25′20″N, 30°57′25″E) is located about 100 km west of the city Bolu at an altitude of about 1050 m. It is a Y-shaped lake with 2 arms, extending to the southeast and southwest. This natural landslide lake (Figure 1) was probably created after the vertical sides of Gökdere valley, from Sarıkaya Hill (1450 m) to Göldağ (1442 m), slid to the ford of Gökdere Creek (Abdüsselamoğlu, 1959; Hoşgören and Ekinci, 2004). The north, west, and east sides of the lake basin are steeper than the sides of the arms, which are the only shallow zones. There are different historical reports of the size and volume of the lake, which may be partially attributed to seasonal fluctuations of the water level. Danışman (1938) reported that the lake surface was about 400 m^2, but this was before additional soil material was added to the northern coast of the lake in early 1998. Most recently, Hoşgören and Ekinci (2004) reported that the surface area was 186,000 m^2 (18.6 ha).

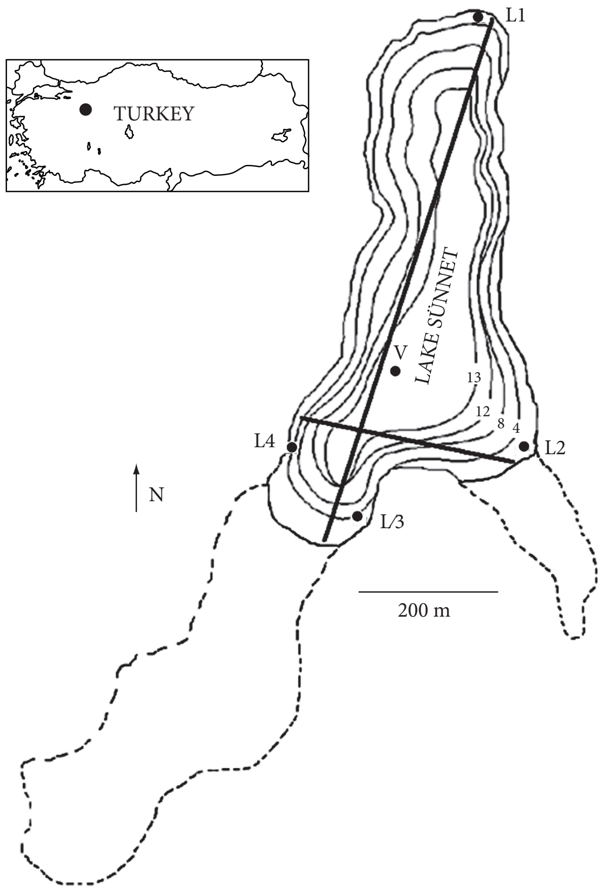

Figure 1. Contour lines of Lake Sünnet (4, 8, 12, and 13 m) with 1 vertical (V) and 4 littoral (L1-L4) sampling stations. The dotted area represents the area of maximum extension of the lake reported early in the 1950s. Bold lines represent the maximum length and width of the lake measured during this study.

Lake Sünnet is mainly fed by rainfall and snowmelt. Until about 20 years ago, it was also fed by at least 3 small creeks (Kuru, Karaköy, and Gölbaşı creeks), but only Karaköy Creek temporarily delivers a small amount of water to the southern part of the lake until the middle of summer. The surface is almost completely covered by ice for about 3 months, from January until the end of March. When the lake reaches a certain level between late spring and early fall, a private hotel nearby the lake manually elevates the gates located on the lake's northern corner, and water is released to Gökdere Creek via underground canals. There is also a weak underground leak at approximately the same site. Generally, the lake water level decreases until the end of summer and the middle of fall. Besides the hotel's activities since 1998, development around the lake includes a small village, Sünnet, on the southeast, and a private home on the southwest. There is also occasional and limited fishing. There are more than 200 different species of plants in the basin, of which 30 are endemic to Turkey (Nursel İkinci, personal communication, unreferenced). The common pine tree (*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe) is the dominant terrestrial species in the basin, while *Myriophyllum spicatum* L. is the most common aquatic species in the lake.

Methodology

We sampled monthly at 4 randomly selected littoral (<1 m) stations and at 1 pelagic (middle of the lake) station from May 2005 to September 2007. Ice cover prevented us from sampling during 3 months (December-February) in 2005, and in 2 months (February and December) in 2006. Vertical water samples were collected from the bottom to the lake surface at each meter of the pelagic layer; sediment samples from the bottom were taken with an Ekman Grab. Light penetration was measured using a Secchi disk. We used a bathymetric map to calculate the physical characteristics of the lake (e.g. surface area, depth, and volume) and presented it for the first time here (Figure 2). Chemical analyses were accomplished

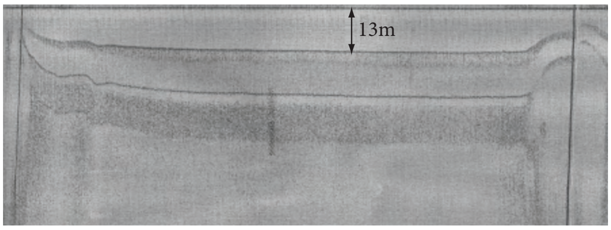

Figure 2. Bathymetric echograph of Lake Sünnet (in this study) taken at the maximum length from south to north (consulting from Figure 1).

by spectrophotometry according to standard methods (APHA, 1989).

We measured 9 environmental variables. Seven of them (dissolved oxygen [mg/L], percent oxygen saturation, salinity [ppt], water temperature [°C], electrical conductivity [µS/cm], redox potential [mV], and pH) were measured in situ with YSI-85 oxygen/temperature and HI-98150 pH/ORP meters. Turbidity (NTU) was measured with a turbidity meter and biological oxygen demand (BOD5) (mg/L) was measured from water samples in vitro. Monthly mean air temperature (°C) and precipitation rates (mm/m^2) were obtained from the meteorological station in Bolu. We used the Standardized Precipitation Index (SPI) from the Turkish Meteorological Service in Ankara to describe the distribution of precipitation during the study period and classify each month as a dry or wet month. Bathymetric photographs were taken with a Skipper 603 Echo Sounder to calculate the lake's total volume and surface area and to see the morphological structure of the bottom. Geographical data (e.g. altitude and coordinates) were recorded with a geographical positioning system (GARMIN GPS 45).

Materials, including ostracods, were collected with a plankton net (0.2 mm mesh) from the littoral zone at depths of up to 100 cm and fixed with 70% alcohol in 250 mL jars. In the laboratory, the samples were filtered under tap water with standardized sieves (0.25, 0.50, 1.00, and 2.00 mm mesh). We separated individuals from the sediment under a stereomicroscope and stored them in 70% alcohol. Species identification was done according to Broodbakker and Danielopol's (1982) and Meisch's (2000) systematic keys. Microbiological analyses (total coliform and *E. coli* bacteria) were also done in the laboratory following standard APHA methods (1989).

Statistical analyses

We used nonparametric Spearman correlation analyses to compare the relationship between species and physicochemical environmental variables. Differences between the stations in the abundance of each species were analyzed with one-way ANOVA with unequal variance, along with the F-test. Also, the unweighted pair group mean average (UPGMA), applied with the Jaccard coefficient after loge transformation, was used to show a possible clustering relationship among the 9 living ostracod species. This method is actually based on a set of pairwise distances between distance matrixes, in which we used binary data of species presence/absence. We compared the dry/wet conditions of our study area with the SPI data obtained from the 2 nearest meteorological stations (Sakarya-Geyve and Ankara-Nallıhan). We compared the values at each station using one-way ANOVA with the F-test and t-test, with equal variances at 0.05 critical levels. Accordingly, we did not find significant differences (P = 0.15) between these 2 stations, and we used the SPI values from the Ankara-Nallıhan meteorological station because of its closer distance and similar elevation and geography to the study area.

We calculated the environmental tolerance index (ETI), ecological tolerance (tk), and optima (uk) values of the 6 most dominant species with 7 different variables. High ETI values were assigned for the highest environmental tolerance range of the individual species (Curry, 1999), while optima (uk) and tolerance (tk) estimates were used to understand the tolerance and optimum ranges of species (Ter Braak and Barendregt, 1986; Külköylüoğlu and Dügel, 2004). A C2 computer program was used to find the tolerance and optimum estimates of individual species (Juggins, 2003), in which biological factors (e.g. competition and predation) were not included where weighted averaging of the species and environmental variables was applied for the calculations. Unless otherwise indicated, all statistical analyses were achieved using the MultiVariate Statistical Package (MVSP), version 3.1 (Kovach, 1998), and SPSS version 6.0.

Results

Meteorological conditions

According to the SPI index results for meteorological conditions during 4 seasons, there were more dry (16 months) than wet months (5 months: October and November 2005, March and September 2006, and January 2007) (Tables 1 and 2). Rainfall data values were lowest (1 mm) in September 2007 and highest (143 mm) in January 2007. The highest mean monthly atmospheric temperature (23 °C) was recorded in September 2006 and the end of August, while the lowest (2.4 °C) was recorded in March 2007. The average water temperature measured during the study (14.6 °C) was slightly but not significantly ($P > 0.05$) warmer than the average air temperature (14.3 °C) (Figure 3), and fluctuations in water temperature closely followed those of air temperature.

Hydrological fluctuations

Mean lake depth throughout the study was 9.61 m (SD 2.00) and was typically highest during the spring. Water levels fluctuated almost 6 m, with maximum (13.30 m) and minimum (7.75 m) lake levels in April 2006 and October-November 2005, respectively (Table 1). The maximum length of the lake ranged between 800 and 1100 m, and the maximum width ranged between 117 and 220 m during this study. Such fluctuations also changed the perimeter of the lake, approximately 2260 m in this study, compared to the earlier reports of 3200 m (Hoşgören and Ekinci, 2004). Water recessed more in the southeastern arm (about 400 m) than the southwestern arm of the lake. The amount of shoreline development (SLD) (Wetzel and Likens, 2000), an index of the regularity of the shoreline, measured as 1.51, was directly affected by these fluctuations, especially in the shallow zone of the arms (also see Discussion).

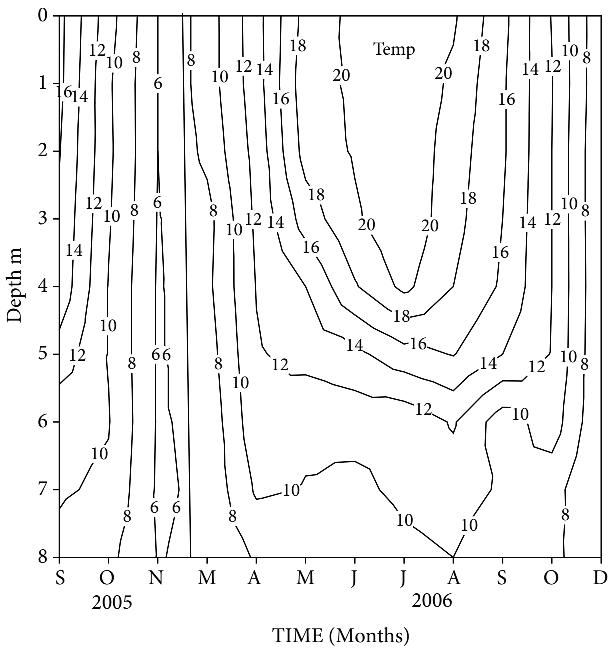

Figure 3. Seasonal development of water temperature (°C) in Lake Sünnet (Göynük, Bolu) from 2005 to 2006. The lake surface was covered by ice from December to the onset of March, for about 3 months.

Physicochemical characteristics

Changes in the water depth appeared to affect the physicochemical variables of the lake. The water was slightly alkaline (pH = 7.74) with relatively low levels of dissolved oxygen (mean = 6.4 mg/L) and medium to high conductivity (about 440 µS/cm) (Tables 1 and 2).

Dissolved oxygen, electrical conductivity, and the amount of total dissolved solids (ranging between approximately 212 and 525 mg/L) displayed discrete monthly fluctuations depending on the water temperature (Figure 4). There was a positive significant correlation between Secchi depth and electrical conductivity ($P < 0.05$).

The amount of precipitation was negatively correlated with the air temperature and sulfate ($P < 0.05$), but air temperature revealed a significantly negative and positive correlation to NO_3 ($P < 0.01$) and turbidity ($P < 0.05$), respectively (Table 3). Turbidity was also positively correlated to both water temperature and sulfate ($P < 0.01$), but it was negatively correlated to NO_3, salinity ($P < 0.05$), and electrical conductivity ($P < 0.01$). Similarly, there was a negative correlation of NO_2 to both BOD ($P < 0.01$) and total coliform bacteria ($P < 0.05$). BOD values were highest in the summer (June-August) and fall (September-November) seasons of 2006. During the study period, total coliform bacteria and E. coli bacteria values reached 4250 and 400 CFU/mL, respectively. A significant negative correlation was found between total coliform bacteria and NO_2 ($P < 0.05$).

Table 1. The mean, minimum, and maximum monthly measured physicochemical variables of all 5 stations and all species of Lake Sünnet from May 2005 to September 2007. The scientific abbreviations shown are dissolved oxygen (DO, mg/L), water temperature (Temp, °C), oxygen saturation (Sat, %), standard hydrogen electrode (SHE, mV), electrical conductivity (EC, µS/cm), total dissolved solids (TDS, mg/L), pH, salinity (Sal, ppt), biological oxygen demand (BOD, mg/L), lake water depth (Depth, m), Secchi depth (Secchi, cm), and "Not Available" (Na). Species codes include Pseudocandona albicans (PA), *Limnocythere inopinata* (LI), *Candona neglecta* (CN), *Pseudocandona* cf. *eremita* (PE), *Ilyocypris getica* (IG), *Ilyocypris inermis* (II), *Ilyocypris bradyi* (IB), *Physocypria kraepelini* (PK), *Stenocypria fischeri* (SF), *Potamocypris* sp. (POT), *Prionocypris zenkeri* (PZ), *Cypridopsis vidua* (CV), *Pseudocandona* sp. (PSC), and *Ilyocypris* sp. (ILS). Subfossils are shown in parentheses.

Sampling Date	DO	Temp	Sat	SHE	EC	TDS	pH	Sal	Turb	BOD	Depth	Secchi	Species
15.05.2005	9.38	17.6	99.6	187.74	316.7	212.19	7.45	0.2	5.8	4.38	Na	Na	5 PA
30.06.2005	4.63	20.93	53.18	195.95	433.7	290.58	7.25	0.23	8.17	1.09	Na	Na	1 LI
26.07.2005	5.2	26.03	62.6	206.33	391.38	262.22	7.46	0.2	9.57	2.79	Na	Na	(PZ, CC)
26.08.2005	7.69	20.12	85.13	150.75	400.47	268.32	8.02	0.21	6.12	5.37	8.5	100	1 LI (PZ, CV)
30.09.2005	4.58	14.76	46.11	213.66	415.07	278.1	7.94	0.22	8.44	2.14	8.75	110	(PZ, CV)
24.10.2005	9.35	10.37	84.85	216.51	415.36	278.29	7.95	0.21	4.94	5.86	7.75	120	3 LI (PZ, CV, CC)
26.11.2005	6.69	5.95	53.87	219.38	411.85	275.94	8.05	0.2	6.15	3.07	7.75	95	(PZ, CV, PSC)
30.03.2006	4.05	7.59	34.77	218.31	471.96	316.21	8.21	0.29	4.23	2.03	13	150	--
28.04.2006	2.84	11.06	26.46	216.06	502.04	336.37	7.98	0.24	2.39	1.27	13.3	110	--
28.05.2006	2.75	14.14	28.52	214.06	473.76	317.42	7.85	0.24	3.68	1.34	12.8	140	2 PA, 3 CN, 8 IG, 1PE, (PZ)
24.06.2006	7.01	15.71	83.76	213.04	453.09	303.57	7.78	0.24	2.61	7.4	11	210	5 CN, 1 IG, 7 II, 3 PK, 1 SF
29.07.2006	6.68	17.94	73.09	211.59	438.28	293.65	7.81	0.24	3.83	Na	9.2	115	(PZ, CV, POT, PSC)
04.09.2006	6.65	17.31	72.88	212	415.45	278.35	7.77	0.22	Na	4.7	8.5	80	(POT, PSC, ILS)
30.09.2006	6.57	14.54	66.88	213.8	403.44	270.3	7.72	0.22	6.33	5.09	8.75	80	21 LI, 2 IB, (POT)
31.10.2006	6.48	11.44	60.82	179.47	418.19	280.18	7.61	0.22	4.85	6.64	8.5	80	9 LI, 1 II, (CV, POT, ILS)
02.12.2006	7.48	6.46	62.09	178.4	418.19	280.19	7.72	0.2	5.17	2.69	8.3	80	14 LI, 3 IG, 2 PK, (POT)
26.01.2007	6.52	4.3	50.3	197.09	420.3	281.6	7.38	0.2	3.61	3.94	Na	Na	--
03.03.2007	6.74	5.15	54.17	198.52	784.47	525.59	7.3	0.2	5.7	2.38	8.5	120	(PZ, CV)
25.07.2007	6.93	23.9	66.82	207.98	410.84	275.86	7.59	0.2	8.36	3.01	Na	Na	--
26.08.2007	8.29	22.77	68.29	185	429.18	287.57	7.76	0.2	7.84	3.16	Na	Na	--
28.09.2007	8.1	18.7	69.22	205.32	413.47	277.03	7.95	0.2	6.93	4.38	Na	Na	--
Mean	6.4	14.6	62.06	201.95	439.86	294.73	7.74	0.22	5.39	3.66	9.61	113.57	
Minimum	2.75	4.3	26.45	150.74	316.7	212.18	7.25	0.2	2.39	1.09	7.75	80	
Maximum	9.38	26.02	99.6	219.38	784.46	525.59	8.21	0.29	9.57	7.4	13.3	210	

Table 2. The mean, minimum, and maximum values of some other chemical and microbiological data from Lake Sünnet. The scientific units of variables were E. coli, total coliform bacteria (T.Col., CFU/mL), ammonia (N-NH_4, mg/L), nitrate (N-NO_3, mg/L), nitrite (N-NO_2, mg/L), phosphate (P-PO_4, mg/L), sulfate (SO_4, mg/L), rainfall (Raif, mm/m^2), air temperature (Tair, °C), Standardized Precipitation Index value (SPI), and "Not Available" (Na).

Sampling Date	E. coli	T. Col.	N-NH_4	N-NO_3	N-NO_2	P-PO_4	SO_4	Raif	Tair	SPI
15-05-05	Na	1	Na	Na	Na	Na	Na	42.8	14.4	0.22
30-06-05	5	110.625	0.05	0.0194	0.014	0.003	Na	59.1	16.3	0.39
26-07-05	Na	41.25	0.059	0	0.007	0.014	Na	58.1	20.9	1.29
26-08-05	Na	Na	0.002	0.008	0.002	0.010	0.004	8.6	21.7	-0.43
30-09-05	Na	4250	0.071	0	0.005	0.022	Na	25.9	16.6	0.01
24-10-05	Na	322.5	0.065	Na	Na	0.001	0.003	52.1	10.3	-0.53
26-11-05	Na	275	0.317	Na	Na	0.011	Na	63.7	6.6	1.23
30-03-06	Na	37.5	0.008	0.161	0.021	0.003	0.003	49.5	6.7	1.06
28-04-06	400	100	0.005	0.038	0.010	0.012	0.003	13.7	10.5	-1.48
28-05-06	Na	35	0.004	0.018	0.008	0.002	0.004	37.0	14.0	-0.70
24-06-06	170	2330	0.008	0.015	0.003	0.002	0.003	22.6	18.2	-0.47
29-07-06	Na	Na	0.005	0.002	0.003	0.001	0.004	12.6	19.4	0.80
04-09-06	Na	150	Na	Na	Na	Na	Na	1.8	23.2	-1.77
30-09-06	150	337.5	0.002	0.008	0.006	0.005	0.004	71.9	16.0	2.44
31-10-06	Na	160	0.004	0.012	0.004	0.011	Na	23.7	13.0	1.04
02-12-06	Na	2.5	0.030	0.009	0.009	0.012	Na	37.5	5.6	-0.64
26-01-07	110	87	0.019	0.290	0.007	0.015	0.002	143.0	2.6	0.55
03-03-07	Na	1	0.053	0.805	0.008	0.018	0.005	8.8	2.4	-0.52
25-07-07	Na	Na	0.009	0.010	0.008	0.011	0.005	6.3	22.1	-1.02
26-08-07	Na	Na	0.008	0.009	0.004	0.011	0.005	25.9	22.0	0.31
28-09-07	Na	Na	0.007	0.008	0.003	0.010	0.006	1.0	17.3	-1.28
Mean	167	515	0.038	0.083	0.007	0.01	0.004	36.45	14.27	
Minimum	5.0	1.0	0.002	0.000	0.001	0.001	0.002	1.0	2.4	
Maximum	400	4250	0.317	0.806	0.021	0.022	0.006	143	23.2	

Species composition

The Lake Sünnet ostracod species assemblage comprised 9 living (*Candona neglecta, Ilyocypris bradyi, I. getica, I. inermis*, *Limnocythere inopinata*, *Physocypria kraepelini*, *Stenocypria fischeri*, *Pseudocandona eremita*, and *P. albicans*) and 5 subfossil (*Ilyocypris* sp., *Cypridopsis* sp., *Eucypris* sp., *Potamocypris* sp., and *Prionocypris zenkeri*) taxa (Table 3). This is the first report of I. getica in Turkey. The number of species (9 living species) was lower than the average number of species (13.2) reported for other lakes in Turkey (see Discussion). The most frequent and abundant species, *L. inopinata*, was collected in both dry and wet months, while *I. bradyi* was found only in the wet months. The other species were all reported in dry months. Three species (*S. fischeri*, *I. bradyi*, and *P. eremita*) were encountered only once during the study, while this was the second report of *S. fischeri* in Turkey in 55 years. The number of recorded species per station was significantly different among the stations ($P < 0.05$). Species abundance was higher at the second, third, and fourth stations. *P. kraepelini* was collected from the fifth station in the pelagic zone.

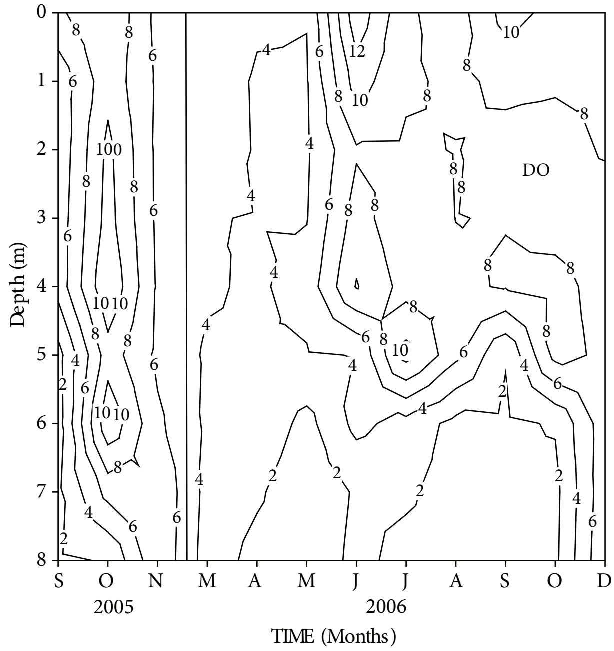

Figure 4. Seasonal oxygen stratification (DO = dissolved oxygen) in Lake Sünnet.

Based on binary species data, the 9 living species clustered into 3 main groups, shown in UPGMA dendrogram (Figure 5). The first group (A) contained only *L. inopinata*, the second group (B) contained *P. albicans*, and the third group (C) consisted of 2 subgroups with 7 species: *C. candida, I. bradyi, I. getica, I. gibba, P. kraepelini, S. fischeri,* and *P. eremita*. The species within each group had similar habitat preferences.

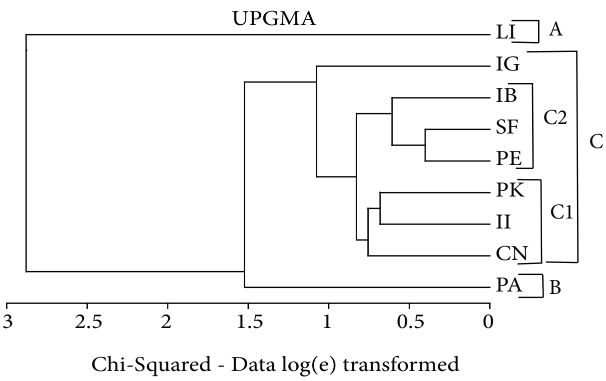

Figure 5. Unweighted pair group mean averages (UPGMA) illustrate the relationships among 9 Ostracod species from Lake Sünnet. This figure shows 3 main clustering groups (A, B, C).

Among the species, *P. kraepelini* had a higher tolerance (tk) to water temperature while *P. albicans* showed a higher ETI and tolerance (tk) to dissolved oxygen (2.99) and salinity (7.27) during this study. Of all the species collected, *L. inopinata* was the most tolerant to redox-potential and pH (18.49 and 0.11, respectively), as well as demonstrating high ETI values (0.80) for pH (Table 4). The number of ostracod species at a site was significantly correlated to electrical conductivity ($P < 0.01$). All results suggest that Lake Sünnet has a mesotrophic-eutrophic range of water quality.

Discussion and conclusion

Recent studies have reported that *I. bradyi*, with an almost cosmopolitan distribution, can be found in different aquatic conditions in mesotrophic (Külköylüoğlu et al., 2007) and eutrophic lakes (Anadón et al., 1986; Dügel et al., 2008) and springs and peat bogs (Külköylüoğlu, 1999; Pieri et al., 2007). Unlike its common occurrence in a variety of aquatic habitats due to a wide range of tolerance to environmental variables (Külköylüoğlu, 1999), this bottom-dependent species was one of the least frequently occurring species in Lake Sünnet. Indeed, earlier studies (Meisch, 2000; Dügel et al., 2008) pinpointed that *I. bradyi* was a euryhaline and polythermophilic species with wide tolerance to salinity and temperature. In contrast, except for tolerances to pH and alkalinity, the species did not show a wide tolerance to measured environmental variables in the Iberian Peninsula (Mezquita et al., 2005). Compared to these studies, the physical and chemical conditions we reported here were found to be within the range of minimum and maximum values that this species is known to inhabit (Tables 1 and 4).

There is not much published ecological information available for 2 other species, *S. fischeri* and *P. eremita*, of which *P. eremita* is a bottom-dependent species while *S. fischeri* is a swimming form. Such morphological characteristics can be important for species distribution and transportation during WLFs (see details below). Because of scarcity in numbers and occurrence of these species (Table 4), we could not determine their tolerances to environmental conditions in the lake.

Table 3. Spearman correlation analyses show a comparison of 15 different variables and total numbers of species (SPP) collected from Lake Sünnet between May 2005 and September 2007. Abbreviations are given in Tables 1 and 2.

	DO	Temp	EC	pH	Turb	BOD	Secchi	NH_4	NO_3	NO_2	PO_4	SO_4	Raif	Tair	SPP	SHE
DO	1.00															
Temp	0.187	1.00														
EC	-0.409	-0.413	1.00													
pH	-0.053	-0.156	0.050	1.00												
Turb	0.174	0.589**	-0.624**	-0.220	1.00											
BOD	0.610**	0.086	-0.429	0.064	-0.112	1.00										
Secchi	-0.069	-0.062	0.562*	0.334	-0.537	-0.212	1.00									
NH_4	0.102	-0.177	-0.100	-0.149	0.405	-0.265	0.222	1.00								
NO_3	-0.317	-0.642**	0.678**	-0.211	-0.582*	-0.318	0.488	-0.022	1.00							
NO_2	-0.441	-0.272	0.372	-0.245	-0.125	-0.697**	0.143	0.186	0.625**	1.00						
PO_4	-0.032	-0.207	-0.147	-0.277	0.312	-0.170	-0.443	0.447	-0.012	-0.010	1.00					
SO_4	0.495	0.676*	-0.352	-0.308	0.835**	0.091	-0.494	-0.038	-0.581*	-0.266	0.143	1.00				
Raif	-0.229	-0.329	-0.129	-0.187	0.035	-0.140	0.020	0.332	0.160	0.347	0.036	-0.632*	1.00			
Tair	0.170	0.889**	-0.361	0.016	0.484*	0.256	-0.096	-0.267	-0.686**	-0.466	-0.242	0.549	-0.486*	1.00		
SPP	-0.638	-0.224	0.849**	-0.052	-0.535	-0.052	0.396	0.052	0.486	0.185	-0.479	-0.410	-0.207	-0.035	1.00	
SHE	-0.394	-0.316	0.197	0.555**	-0.208	-0.203	0.361	0.168	0.112	0.206	-0.270	-0.440	0.202	-0.174	0.173	1.00

* $P < 0.05$
** $P < 0.01$

Table 4. Descriptive statistics of 6 species for 6 environmental variables, including environmental tolerance index (ETI), estimated optima (OPT), and tolerance (TOL) values. Due to the low frequency of occurrence and small numbers of individuals reported herein, values for 3 species, *I. bradyi, P. eremita*, and *S. fischeri*, are not shown in the table. SPP stands for species code. For all other abbreviations, see Tables 1 and 2.

SPP	DO ETI/OPT/TOL	Temp ETI/OPT/TOL	Sal ETI/OPT/TOL	SHE ETI/OPT/TOL	EC ETI/OPT/TOL	pH ETI/OPT/TOL
PA	1.0/7.49/2.99	0.16/16.61/1.57	0.44/0.21/7.27	0.55/195.3/11.9	0.34/361.6/70.90	0.42/7.57/0.18
CN	0.64/5.41/2.06	0.07/15.12/0.76	0.00/0.24/5.18	0.02/213.4/0.49	0.04/460.84/10.0	0.07/7.81/0.03
IG	0.71/4.29/2.18	0.43/12.35/3.43	0.44/0.23/4.06	0.75/205.1/15.4	0.12/458.14/23.7	0.14/7.81/0.06
LI	0.71/6.97/0.81	0.67/11.65/3.82	0.33/0.22/6.75	1.38/195.9/18.5	0.07/411.65/7.89	0.80/7.71/0.11
PK	0.07/7.20/0.23	0.43/12.01/4.53	0.44/0.22/6.98	0.73/199.2/16.9	0.07/439.13/17.1	0.06/7.76/0.03
II	0.08/6.94/0.18	0.20/15.17/1.41	0.22/0.24/6.71	0.70/208.8/11.1	0.07/448.72/11.54	0.18/7.76/0.06

Some interpretable ecological data about the 3 species clustered in the second subgroup of the UPGMA dendrogram (*C. neglecta, P. kraepelini,* and *I. inermis*) are available. *Candona neglecta* is one of the most common bottom-dependent species in the aquatic habitats of Turkey, with an almost cosmopolitan distribution (Karakaş-Sarı and Külköylüoğlu, 2007). Previous studies showed that *C. neglecta* has a wide tolerance to pH levels and DO concentrations (Roca and Baltanás, 1993; Külköylüoğlu, 1999, 2003b, 2005a, 2005c; Dügel et al., 2008). In the present study, this species showed high levels of optimum values for pH, conductivity, and redox potential. Results support that its tolerance to different environmental variables can be much broader than is currently known (Dügel et al., 2008). We support that *C. neglecta* can be called a "cosmoecious" species (Külköylüoğlu, 2007) due to its worldwide geographical distribution and wide tolerance to environmental conditions.

The second species of this group, *P. kraepelini*, is usually found in large aquatic ecosystems such as lakes, ponds, and reservoirs (Külköylüoğlu, 1998; Kiss, 2002). The species can move in water due to its long swimming setae on the second antenna. Therefore, it can increase its distributional range actively. It is reported to tolerate heavily polluted bodies of water (Shornikov and Trebukhova, 2001; Külköylüoğlu et al., 2007) and a wide range of temperatures (i.e. it is eurythermal) in waters with calcium levels greater than 72 mg Ca/L (i.e. meso- to polytitanophilic) (Meisch, 2000). It was also described in a reservoir with low alkalinity but moderate to high water temperatures (Yılmaz and Külköylüoğlu, 2006) and in springs where its occurrence was reported to be negatively correlated to water temperature (Külköylüoğlu and Yılmaz, 2006). We found *P. kraepelini* in water with an ionic content associated with higher trophic conditions, similar to the results of Rossetti et al. (2004) in Italy. Thus, various studies indicate that *P. kraepelini* has broader ecological tolerance levels than previously known.

The third species of this group, *I. inermis*, has been commonly reported from European countries, though with limited ecological data. Although the species is known from different habitats such as wells (Löffler, 1964), rice fields (Rossi et al., 2003), and springs, its occurrence in lakes is rare. According to Nüchterlein (1969, in Meisch, 2000) this bottom-dependent species has a narrow tolerance to temperature in spring or spring-related ecosystems (i.e. cold stenothermal and mesorheophilic). In Spain, Mezquita et al. (1996) collected the species from a spring and river and reported data for conductivity (485.1-749.8 µS/cm), pH (7.38-8.55), dissolved oxygen (6.6-8.0 mg/L), and water temperature (12.8-18 °C). Most recently, *I. inermis* was collected from a limnocrene spring, where it showed a positive relationship to redox potential and temperature (Külköylüoğlu and Yılmaz, 2006). It seems that the species may occur predominantly in cold waters, as well as warm waters with low oxygen and salinities

(Meisch, 2000). For example, one individual was reported from a small lake (Lake Sazlı, Bolu, Turkey) where the water temperature was 19.3 °C (Külköylüoğlu, 2004). Recent studies showed that *I. inermis* could have broader tolerance ranges not only to temperature but also to other environmental variables. For example, the species occurred only once in the Due Grande spring in the Trecasali district of Northern Italy, where conductivity and nitrate and chloride levels were high (Rossetti et al., 2005). Additionally, Külköylüoğlu and Yılmaz (2006) tracked this frequently occurring species in a shallow limnocrene spring almost year round. During that time, the spring's water temperature ranged from 5.70 to 17.60 °C. In the present study, we found *I. inermis* when minimum and maximum temperature values of the lake were 11.44 and 15.71 °C, respectively. As a result, we think that *I. inermis* prefers relatively cold waters but can tolerate a much broader range of temperature.

Another species of the third group of the UPGMA dendrogram, *I. getica*, is a new report for Turkish ostracod fauna. This bottom-dependent species' geographical distribution covers the Palaearctic zone from Britain to China (Mischke, 2001). It has been found in shallow bodies of water and slow-flowing streams (Meisch, 2000). We collected the species from the third station, at which the water temperature ranged between 6.46 and 15.71 °C and there was a weak inflow of water into the lake. These values are higher than those of the earlier reports. For example, Meisch (2000) indicated that *I. getica* can tolerate slightly increased salinity at temperatures between 10 and 15 °C. Among the species reported in this study, *I. getica* displayed medium tolerance and optimum values for almost all environmental variables measured (Table 4).

The second group of the UPGMA dendrogram carries a single Holarctic species, *P. albicans*. Although it frequently occurs in a variety of European water bodies, it is not common in Turkey. In Spain, Mezquita et al. (1996) found the species in a river (R. Guadiela, Vadillos) with a gravel substrate and relatively high values of pH (8.44), conductivity (542.8 µg/L), water temperature (18.4 °C), and dissolved oxygen (7.9 mg/L). Meisch (2000) related its occurrence in springs with sulfuric water to its tolerance to salt (e.g. 5.5‰; Hiller, 1972). The species was collected from a lowland spring in Northern Italy with a high nitrite concentration (577 µg/L) (Rossetti et al., 2005). In the present study, *P. albicans* showed the highest optima (7.49) and tolerance (2.99) values to dissolved oxygen within very narrow temperature (14.14-17.60 °C) and pH ranges (7.45-7.85). Although we do not have detailed ecological data about this species, preliminary findings support the idea that the species is mesohalophilic (Meisch, 2000) and mesothermophilic and titanoeuryplastic (Hartmann and Hiller, 1977).

Limnocythere inopinata, the dominant bottom-dependent species in the lake, is thought to have an almost worldwide cosmopolitan distribution (Yılmaz and Külköylüoğlu, 2006). The species has been reported from eutrophic reservoirs (Külköylüoğlu, 2005b), rivers (Mezquita et al., 2001), and lakes (Hiller, 1972) in Europe. Not only does it tolerate a wide range of salinity, ranging from 0.5‰ (Usskilat, 1975) to 9‰ (Kempf, 1986), but also high levels of chloride (Löffler, 1959). Cohen et al. (1983) indicated that *L. inopinata* can be used an indicator species for high levels of salinity and alkalinity, but its tolerance ranges are not limited (Külköylüoğlu, 1998; Scharf, 1998; Griffiths et al., 2002). For example, Mezquita et al. (2005) described the species with relatively high optimum values for flow (2.32), pH (8.49), conductivity (3.39 µS/cm), and dissolved oxygen (10.2 mg/L), but low to moderate tolerances. Most recently, in Serbia, the species was frequently found in conditions with wide ranges of variables, such as pH ranging from 7.2 to 8.2 and water temperatures from 21.5 to 35 °C (Karan-Žnidaršič and Petrov, 2007). In contrast, we calculated low optimum values for dissolved oxygen (6.97), pH (7.71), conductivity (411.65 µS/cm), and temperature (11.65 °C) with high tolerance values. Such discrepancies also point out a wide range of ecological preference of the species and an explanation for its cosmopolitan distribution. Thus, the species can be ecologically characterized as polythermophilic, rheoeuryplastic, and mesohalophilic (Vesper, 1975; Meisch, 2000).

In addition to these 9 living ostracod species, 2 other species (*Cypria ophthalmica* and *Darwinula stevensoni*) had been previously reported from Lake Sünnet (Külköylüoğlu, 2003b). However, during the present study, we did not observe these 2 cosmopolitan species in the lake. It is possible that climatic changes can cause decline of water level at a rapid rate due to the precipitation to evaporation ratio, which can affect the disappearance of species (Jones et al., 2001). For example, Wiche (1998) showed how the habitat around the edge of Devils Lake changed after erosion affected the water quality. Similar problems exist in Lake Sünnet, where the steep coastal zones on the north, northeast, and southeast sides are likely to erode. In such cases, bottom-dependent species (e.g. *D. stevensoni*) cannot survive during the rise and fall of water, because they cannot move and actively leave the site in a short period of time. Actually, *C. ophthalmica* prefers mostly acidic water, but when a sudden change in water level increases the alkalinity, it cannot disperse to a more suitable part of the lake. Another reason why we did not find these 2 species after the lake level changed could be the occurrence of aquatic plants. Martin-Rubio et al. (2005) reported the presence of *C. ophthalmica* in up to 10 m of water because the species' occurrence was also dependent on the major substrate of charophytes. There are no rooted aquatic plants along the eroded part of the Lake Sünnet shoreline. Thus, even if the species is carried to the deeper parts of the lake when the level decreases, it probably cannot survive because of the almost anoxic conditions at those sites.

Compared to other Turkish lakes with about 13 living species per lake (Külköylüoğlu, 2005a), Lake Sünnet has low species richness. In many lakes, changes in climate and precipitation have been thought to be major contributors to WLFs (Christensen and Bergman, 2005). Although Lake Sünnet has been affected by such factors, the changes we observed suggest that in the last 50 years, human activities have had more impact on the lake's water budget than natural causes. For example, the lake level has showed tremendous fluctuation since the Bolu Department of the National Parks Service installed 2 gates on the northern end of the lake in 1998. There is extensive water discharge from the gates when the lake level reaches the gates, and approximately 100 tons of water is diverted from the lake for chicken farms and agricultural fields each month. Such anthropogenic activities have a direct influence on the occurrence of ostracods, especially on the 7 bottom-dependent species reported in this study.

Like many other natural aquatic bodies, Lake Sünnet is under heavy anthropogenic pressure while also being exposed to the seasonal effects of hydrological changes. We recommend developing emergency outlets or using precipitation levels to adjust the amount of water that is diverted from Lake Sünnet so that changes to the water level and therefore quality are minimized.

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