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Effects of limnoecological changes on the Ostracoda (Crustacea) community in a shallow lake (Lake Çubuk, Turkey)

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A B S T R A C T

We sampled Lake Çubuk, a shallow lake in Bolu (Turkey), for 26 months to investigate the effect of limnoecological changes on the composition of ostracod species. Seventeen ostracod species were identified from the six stations sampled between 2008 and 2010. Numbers of species and individuals were both significantly reduced during 2010, which corresponded to a 3 m water level increase. Ostracod Watch Model (OWM) displayed distinct seasonal occurrences of five species (*Candona neglecta*, *Cypria ophtalmica*, *Cypridopsis vidua*, *Limnocythere inopinata*, *Fabaeformiscandona* cf. *japonica*) when *Physocypria kraepelini* was the only species encountered all year round. Approximately 77.2% of the relationship between species and environmental variables was expressed by the first two axes of Canonical Correspondence Analysis (CCA). Electrical conductivity and water temperature ($P = 0.002$) were the most influential variables on species. There was a significant negative correlation of seven species to conductivity. Of those (*F.* cf. *japonica* and *C. vidua*) showed a significant positive correlation to water temperature, while *C. candida* was negatively correlated to water temperature ($P < 0.05$). *C. neglecta* was the only species to show a positive correlation to dissolved oxygen. Tolerance limits for the most common species were higher than the mean water temperatures, but lower than mean levels of electrical conductivity. Finding the ratio of noncosmopolitan to cosmopolitan species "pseudorichness" as 1.13 suggested significant role of cosmopolitan species to species diversity.

Introduction

Ostracods are microscopic invertebrates widely distributed in almost all continents (Martens and Savatenalinton 2011) and found in almost every kind of natural and artificial aquatic habitat ranging from springs, creeks, and lakes to troughs and wells. Each species shows species-specific tolerance and optimum levels to different ecological variables (Külköylüoğlu 1999) that can be seen in their distribution among habitats. If ecological characteristics (e.g., seasonal occurrence, ecological tolerance and optimum levels, geographic distribution) of living ostracods are known, they can be used as indicator species to estimate past, present and future aquatic conditions (Delorme 1969; De Deckker and Forester 1988; Külköylüoğlu 2003; Külköylüoğlu and Yılmaz 2006). Previous studies (e.g., see Hull 1997; Külköylüoğlu 2005a) showed that changes in species occurrences will eventually alter species diversity, abundance and composition. However, long-term seasonal studies on the relationship between ecological changes and ostracod species diversity are limited (Mezquita et al. 1999; Coma et al. 2000; Ramdani et al. 2001) and scarce in natural lakes (Külköylüoğlu et al., 2007, 2010; Dügel et al. 2008). The occurrence of ostracods is affected by factors external (e.g., climate, anthropogenic factors) and internal (e.g., changes in water structure and quality) to the body of water in which they are found. Accordingly, species can have eurychronal (occurring almost continually throughout the year) and/or stenochronal (occurring with seasonality) occurrences in marine (Hull 1997) and freshwater habitats (Külköylüoğlu and Dügel 2004; Akdemir 2008; Akdemir and Külköylüoğlu 2011). Külköylüoğlu (2004) introduced the concept of "pseudorichness" to explain the relationship between water quality and the presence of cosmopolitan versus noncosmopolitan species. For example, when the ratio of noncosmopolitan/cosmopolitan species is <1, cosmopolitan species are dominant within relatively low water conditions. Thus, descriptions of the ratios of groups of species to each other can be used to make predictions about aquatic habitat

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quality and species composition in the future. The main objectives of this study were to: (1) establish a detailed spatio-temporal record of groups of species and physicochemical characteristics of Lake Çubuk, and (2) to identify the importance of limnoecological factors effecting seasonal species composition and estimate the ecological tolerance and optimum values of individual species for this lake.

Materials and methods

Site description

Lake Çubuk (Göynük, Bolu, Turkey) is a natural landslide lake (40°28′91″ N 30°50′09″ E) located at about 1032 m above sea level (a.s.l.) (Fig. 1). Surrounded by mountain ranges, it is fed by springs, rainfall and snow-melt. The lake was formed in the basin bordered by branches of North Anatolian Fault Zone (Lahn 1948). The lake has approximately 16 ha of surface area with the maximum depth of 8.5 m, mean depth of 6 m, length of 780 m, width of 430 m and volume of 461,788 m^3 (this study). Mean annual precipitation and air temperature of the nearby town of Göynük is approximately 617.4 mm and 10.6 °C, respectively (Türkeş 1999).

Sampling and measurements

One sampling station was established in the approximate geographic middle of the lake to sample the pelagic zone, and 5 were established to sample the littoral zone) were randomly selected and visited monthly from 19 July 2008 to 14 November 2010. Ice cover prohibited sampling in January and February of 2008 and January of 2009. All sampling was done between 06:00 a.m. and 13:00 p.m. Ostracods were collected from the littoral zone with a handmade net (0.2 mm mesh) from water up to 100 cm in depth, while samples from the pelagic zone at the lake bottom were collected with an Ekman Grab. Water samples (ca. 100 ml) for chemical analyses were also taken from each station in the littoral zone and at every meter in the pelagic zone from the water surface to the lake bottom. Approximately 200 ml of samples were fixed with 70% ethyl alcohol in 250 mL jars *in situ* and were brought to laboratory where they were washed through standardized sieves (0.25, 0.50, 1.00 mm mesh). Specimens were separated from the sediment under a stereomicroscope and stored in 70% alcohol for further analyses. Dissected species were stored in a lactophenol solution, while carapace and valves of each species identified were retained in micropaleontological slides. Only initially living adults were included in the analyses while broken carapaces, juveniles and subfossils were excluded. Taxonomic identification of ostracods was done using Meisch (2000), but also some related systematic keys (e.g., Bronshtein 1947). To reduce a possible effect of pseudoreplication (Hurlbert 1984) and Type I and Type II errors, field measurements were taken before sampling collection.

We used bathymetric maps to calculate lake volume, surface area and its bottom morphological structure with the aid of Skipper 603 EchoSounder. A geographical positioning system (GARMIN GPS 45 XL) was used to associate geographical data (altitude and coordinates) for each sampling site. Nine environmental variables (Secchi depth, water temperature, air temperature, percent oxygen saturation, dissolved oxygen (DO), electrical conductivity, salinity, pH and redox potential) were measured at each time sampling occurred. Secchi depth was measured with Secchi disk. A Hanna model HI-98150 pH/ORP meter was used to measure redox potential and pH. Air temperature, wind speed and moisture were measured with Anemometer (Testo- 410). Turbidity (NTU) and biological oxygen demand (BOD_5) ($mg\,L^{-1}$) were measured with a turbidity meter from water samples *in vitro*. Measurement of BOD_5 was done following APHA (1989). All other variables (unless otherwise indicated) were measured with a YSI-85 model oxygen-temperature meter. Nitrate, nitrite, ammonium, chlorophyll-a, and total dissolved solids in the water samples were measured in the laboratory. Total dissolved solids (TDS) were calculated by multiplying the value of electrical conductivity by 0.65 (Forester and Brouwers 1985). Analyses of other chemicals, heavy metals and radioactive elements were achieved with the aid of HPIC in the Water Chemistry and Environmental Tritium Laboratory of Hacettepe University, Ankara. SEM photographs of the species were taken in TÜBİTAK-MAM Institute (İstanbul, Turkey). All materials are kept at the Limnology Laboratory of the Department of Biology (Abant İzzet Baysal University) and are available upon request.

Statistical analyses

The mean values of all the water quality variables were used for statistical analyses. The seasonal distribution of adult species was represented with graphical Ostracod Watch Model (OWM) (Külköylüoğlu 1998). Analysis of Variance (ANOVA) with unequal variance along with the *F*-test and *t*-tests in Excel were used to test differences between water quality and species abundance among water stations. Later correlations between species and environmental variables were analyzed with a nonparametric Spearman Rank Correlation analysis along with two-tailed tests at 0.01 or 0.05 significant levels (Magurran 1988). Canonical Correspondence Analysis (CCA) applied with Monte Carlo (499 permutations) tests was used to determine the most effective variable(s) on 11 species occurring at least three times over the study. We used five major environmental variables (water temperature, electrical conductivity, redox potential, pH and turbidity) after the data were log-transformed and tested with a detrended correspondence analysis (DCA) (Ter Braak and Barendregt 1986; Ter Braak 1987; Birks et al. 1990). The gradient length of DCA was found as 4.290 and supported the use of CCA. We also calculated optimum (uk) and ecological tolerance (tk) values for individual species to the variables by means of using C2 program (Juggins 2003) in which weighted averaging of the species and environmental variables were applied for the calculations. CCA outcomes were obtained from the CALIBRATE program, version 1.0 (Juggins 2001) when UPGMA was done in MVSP program, version 3.1 (Kovach 1998).

Results

Physicochemical characteristics of Lake Çubuk

During the study, the water of Lake Çubuk was generally alkaline (mean pH = 7.97) with a mean water temperature of (Tw = 15.66 °C), low levels of dissolved oxygen (DO = 5.65 $mg\,L^{-1}$) and electrical conductivity (240 $\mu S\,cm^{-1}$) (Table 1). Some environmental variables showed similar monthly patterns for both years of sampling (Fig. 2). The only negative significant correlation was found between water temperature and electrical conductivity ($P = 0.015$, $r = -0.47$) (Table 2). BOD_5 values ranged between 0.37 and 5.31 $mg\,L^{-1}$ with the average of 2.94 $mg\,L^{-1}$ while turbidity changed from 1.3 to 9.6 NTU. The upper (220 cm) and lower (50 cm) levels of Secchi depth were measured in May and October 2010, respectively. There were no significant measurements of phosphorus (PO_4), ammonium (NH_4) and nitrite ($N{-}NO_2$) levels during this study that almost all measurements were about the standard levels (but see Table 1). Additionally, lake water depth changed from 4.7 to 8.5 m during this study. Because of seasonal changes, lake water depth began to drop down end of summer and remained at lower levels until the middle of winter (February).

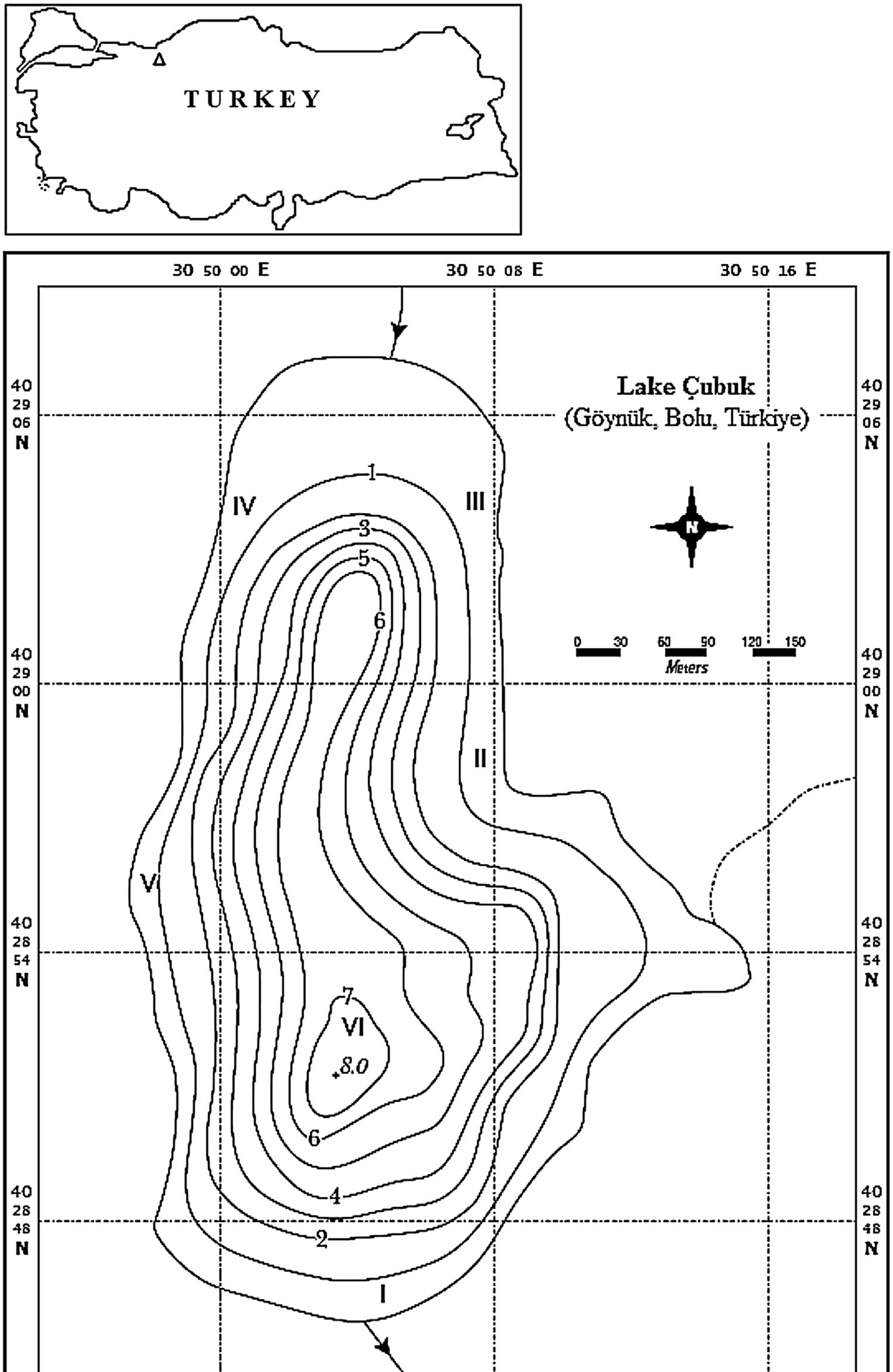

Fig. 1. Bathymetric map of Lake Çubuk and six (I–VI) sampling points and depth lines (1–8+). Triangle shows lake's location.

Species assemblages

Seventeen ostracod species (*Candona neglecta*, *C. candida*, *C. sanociensis*, *C. weltneri*, *Pseudocandona sucki*, *P. albicans*, *P. semicognita*, *P.* cf. *eremita*, *Fabaeformiscandona brevicornis*, *F.* cf. *japonica*, *Physocypria kraepelini*, *Cypria ophtalmica*, *Cypridopsis vidua*, *Limnocythere inopinata*, *Ilyocypris gibba*, *Trajancypris serrata*, *Prionocypris zenkeri*) were collected from Lake Çubuk (Table 3, Plates 1 and 2). *F.* cf. *japonica* is a new report for Turkish ostracod fauna. The mean numbers of individuals per species (31.2) was low. The numbers of individual ostracods collected in 2010 was almost 50% lower than that collected in 2009 ($P < 0.01$, F-test 4.41). Additionally, the number of species collected in 2010 (8 species) was half of that collected in 2009 (16 species). Such reduction in the numbers of individuals and species corresponds with the high water levels in the year 2010 (see discussion). Five of the most commonly

Table 1
Monthly means of 15 different variables measured in Lake Çubuk from 19 July 2008 to 14 November 2010.

Date	pH	SHE	EC	TDS	DO	Sal.	%S	Tw	Ta	BOD$_5$	Tur	N-NO$_2$	NH$_4$	Chl-a	Secchi
07/19/2008	7.91	149.63	198.00	128.70	7.20	0.11	83.03	22.22	na	4.41	4.4	0.001	0.069	7.91	140
08/21/2008	8.13	131.87	204.00	132.60	6.26	0.11	75.41	23.89	na	3.46	3.3	0.002	0.060	na	120
09/20/2008	7.46	157.78	183.00	118.95	5.74	0.10	61.30	18.98	20.6	2.75	6	0.000	0.101	19.12	120
10/18/2008	8.20	135.82	208.00	135.20	7.70	0.10	77.75	15.22	21	4.34	2.2	0.008	0.097	20.94	90
11/22/2008	7.85	164.33	212.00	137.80	8.60	0.11	74.80	8.73	11.3	7.14	9.6	0.043	0.229	15.18	120
12/20/2008	7.93	164.06	255.00	165.75	9.22	0.10	77.65	6.02	9.3	7.28	2.3	0.043	0.238	14.66	180
03/28/2009	8.93	273.84	348.76	226.70	7.10	0.20	58.52	7.14	2.2	1.45	1.7	0.007	0.424	14.58	125
04/25/2009	8.01	155.66	334.25	217.27	7.74	0.19	73.68	12.11	16.4	3.35	3.9	0.010	0.072	36.34	130
05/23/2009	8.05	148.10	291.49	189.47	7.24	0.15	77.05	17.88	22	2.51	2.8	0.120	0.021	96.07	150
06/20/2009	8.30	187.57	233.82	151.98	5.61	0.11	64.07	22.06	23.8	3.59	3.3	0.000	0.187	23.28	145
07/18/2009	7.98	197.70	198.18	128.82	4.87	0.10	55.87	22.18	25.1	2.73	2.6	0.004	0.136	12.92	200
08/22/2009	7.88	157.86	199.31	129.55	3.53	0.10	39.88	21.17	19.6	1.03	2.9	0.002	0.222	7.126	70
09/26/2009	8.13	146.41	183.98	119.59	4.32	0.10	46.04	17.55	15.1	0.83	5.3	0.055	0.201	30.08	110
10/24/2009	7.99	154.43	200.37	130.24	3.68	0.10	37.76	16.60	22.3	0.91	5	0.000	0.018	17.90	50
11/21/2009	7.91	162.13	200.98	130.64	3.61	0.10	31.63	9.37	11.2	1.73	5	0.004	0.365	47.93	110
12/19/2009	8.07	162.19	219.87	142.92	3.22	0.10	25.06	4.75	4.10	1.77	4.4	0.019	0.042	50.10	115
02/20/2010	7.72	177.38	333.86	217.01	3.68	0.18	30.34	7.17	14.6	2.17	6	0.003	0.394	31.72	110
03/20/2010	7.81	166.81	347.97	226.18	4.61	0.18	39.20	8.52	12.5	2.52	5.4	0.015	0.395	24.10	130
04/17/2010	7.89	161.44	338.70	220.16	3.94	0.18	37.83	13.55	20.6	1.43	3.4	0.011	0.029	19.72	160
05/22/2010	7.91	161.91	308.50	200.53	3.11	0.16	30.69	15.60	17.2	0.28	2.7	0.005	0.132	19.83	220
06/19/2010	7.27	188.75	254.43	165.38	1.07	0.12	12.38	21.16	24.8	0.37	2.8	0.019	0.128	15.15	210
07/24/2010	7.96	268.89	175.00	113.75	6.75	0.08	79.85	23.61	22.1	2.53	1.3	0.006	0.144	14.20	140
08/21/2010	7.85	197.67	195.08	126.80	5.44	0.09	63.84	23.22	24.1	1.33	3.5	0.012	0.029	21.08	150
09/18/2010	7.82	200.28	183.27	119.13	6.06	0.09	66.95	19.88	26.6	5.33	2.9	0.045	0.137	22.09	130
10/24/2010	8.29	204.29	194.20	126.23	11.0	0.09	103.0	13.01	12.4	na	na	na	na	na	na
11/14/2010	7.76	195.08	190.40	123.76	6.08	0.09	83.70	11.62	22.7	na	na	na	na	na	na
Min.	7.27	131.87	175.00	113.75	1.07	0.08	12.38	4.75	2.20	0.37	1.3	0.000	0.018	7.12	50
Max.	8.93	273.84	348.76	226.70	10.9	0.20	102.9	23.89	26.6	5.31	9.6	0.120	0.424	96.07	220
Mean	7.97	175.07	240.08	156.05	5.65	0.12	56.94	15.66	17.3	2.94	3.9	0.018	0.161	25.31	134.38

Abbreviations: SHE (redox potential, mV), EC (electrical conductivity, μS cm^{-1}), TDS (total dissolved solids, ppt), DO (dissolved oxygen, mg L^{-1}), Sal (salinity, ppt), %S (percent dissolved oxygen), Tw (water temperature, °C), Ta (air temperature, °C), BOD$_5$ (biological oxygen demand, mg L^{-1}), Tur (turbidity, NTU), N-NO$_2$ (mg L^{-1}), NH$_4$ (mg L^{-1}), Chl-a (chlorophyll a, μg L^{-1}), Secchi (Secchi depth, cm), na (not available).

occurring species in the lake (*C. neglecta*, *L. inopinata*, *C. ophtalmica*, *F.* cf. *japonica*, *C. vidua*) showed clear seasonal occurrences while *P. kraepelini* was seen throughout the year (Fig. 3). According to the CCA diagram (Fig. 4), approximately 77.2% of the variance was explained between 11 species and five environmental variables (Table 4). Electrical conductivity and water temperature were the most influential ($P = 0.002$) variables associated with species collected. A negative correlation was found between seven species (*C. neglecta*, *P. semicognata*, *P.* cf. *eremita*, *F.* cf. *japonica*, *C. ophtalmica*, *L. inopinata*, *C. vidua*) and electrical conductivity. Two (*F.* cf. *japonica* and *C. vidua*) and one (*C. candida*) species had a positive ($P < 0.05$, $r = 0.488$, $r = 0.433$) and negative ($P < 0.05$, $r = -0.572$) correlations to water temperature, respectively. A significant correlation was found between *C. neglecta* and dissolved oxygen.

The most common species could tolerate levels of most or all environmental variables that were higher than the mean levels measured (e.g., water temperature) except for electrical conductivity (Table 5). Individual species tolerance to environmental variables and optimum level seems to be species-specific. The ratio of pseudorichness (9 noncosmopolitan/8 cosmopolitan = 1.13) suggested that cosmopolitan species occurred more frequently than the noncosmopolitan species. Thus, cosmopolitans seemed to be better adapted to seasonal changes in physicochemical fluctuations of Lake Çubuk and played a significant role in shaping species diversity.

Discussion

Lake Çubuk has a relatively high diversity of ostracod species (i.e., 17) than compared to many lakes in Turkey (e.g., 13.2 species) (Külköylüoğlu 2005b). However, the mean numbers of individuals per species (31.2 individuals) was not very high. The reductions in species richness and abundance of individuals were associated with an increased water level (up to 3.5 m) in 2010 where the flood zone was covered by an intrusion of more than five meters, especially on stations 3 and 4. We assume that water flow direction may be important for the numbers of species in the stations 3 and 4 since each is located on the northern parts of the lake, from which water flows to opposite direction down to southern parts. Eventually, affect of flow from north to southern parts of the lake may bring more individuals to these areas. Külköylüoğlu et al. (2010) reported similar results (see Table 1) in Lake Sünnet (Turkey) that they sampled 56 and 31 individuals of various ostracod species at 7.75–8.75 m and 9.0–12.8 m of depth, respectively. Külköylüoğlu et al. (2010) did not report living species when

Table 2
Significant results of Spearman correlation analysis for 11 species (Spp) and 6 variables (Var) measured in Lake Çubuk from 19 July 2008 to 14 November 2010.

Var/Spp	Cn	Cc	Cs	Pm	Pe	Fj	Pk	Co	Cv	Li	Ig
pH			0.405*								
SHE						−0.501*	−0.435*				
EC	−0.536**			−0.451*	−0.451*	−0.476*		−0.512**	−0.520**	−0.572**	
DO	0.421*										
Tw		−0.489*				0.488*			0.433*		
Tur							0.427*			0.510*	0.437*

Abbreviations are given in Tables 1 and 3. *0.05 and **0.01 significant levels follow negative or positive coefficient values.

Table 3
Monthly distribution of 17 species and total numbers of adult individuals collected from six stations in Lake Çubuk during this study.

Date	Cn	Cc	Cs	Cw	Ps	Pa	Pm	Pe	Fb	Fj	Pk	Co	Cv	Li	Ig	Ts	Pz	Total
07/19/2008	2									5	3							10
08/21/2008	1									3	7	6	5	6				28
09/20/2008	2						3	3		11	27	9	8	6				69
10/18/2008	3		4			4				9	4	5						29
11/22/2008	2	3				2			2		13	18	4	2	34			80
12/20/2008						14					23	2	1			2		42
03/28/2009		2															3	5
04/25/2009											2							2
05/23/2009	1			2	2						5							10
06/20/2009					2	3						19	4			2		30
07/18/2009			2							4		9	3					18
08/22/2009										7	3		3					13
09/26/2009	5						1	2		4	13	7	1	4				37
10/24/2009											24	3		2	6			35
11/21/2009	1										8			14	3			26
12/19/2009		2	1	2							20	1		1				27
02/20/2010											2							2
03/20/2010											5							5
04/17/2010						2					2							4
05/22/2010					2						6							8
06/19/2010						5					4							9
07/24/2010																		0
08/21/2010	2										9	4	1	1				17
09/18/2010												8	3	2				13
10/24/2010	2		1			2					4	3						12
11/14/2010	1										2		2	1				6

Abbreviations: Cn, *Candona neglecta*; Cc, *C. candida*; Cs, *C. sanociensis*; Cw, *C. weltneri*; Ps, *Pseudocandona sucki*; Pa, *P. albicans*; Pm, *P. semicognita*; Pe, *P.* cf. *eremita*; Fb, *Fabaeformiscandona brevicornis*; Fj, *F.* cf. *japonica*; Pk, *Physocypria kraepelini*; Co, *Cypria ophtalmica*; Cv, *Cypridopsis vidua*; Li, *Limnocythere inopinata*; Ig, *Ilyocypris gibba*; Ts, *Trajancypris serrata*; Pz, *Prionocypris zenkeri*.

Table 4
Summary table of CCA results for five variables with 11 species occurred at least 3 or more times.

Axes	1	2	3	4	Total inertia
Lengths of gradient[a]	4.290	2.511	1.761	2.087	
Eigen values	0.263	0.166	0.071	0.056	1.744
Species-environment correlations	0.881	0.740	0.576	0.587	
Cumulative percentage variance					
of species data	15.1	24.6	28.7	31.9	
of species-environment relation	47.3	77.2	89.9	100.0	
Sum of all eigenvalues					1.744
Sum of all canonical eigenvalues					0.556

Data is Log-transformed and rare species were downweighted. Most effective variables are as follow: EC ($P = 0.002$, $f = 3.660$), Tw ($P = 0.002$, $f = 2.469$), Turbidity ($P = 0.086$, $f = 1.625$), pH ($P = 0.432$, $f = 0.994$), DO ($P = 0.702$, $f = 0.700$).

[a] DCA value.

Table 5
Tolerance (Tol) and optimum (Opt) estimates of 11 species (Code) occurred (Max: numbers of individuals) at least 3 or more times (Count) for the six environmental variables during this study.

Code	Count	Max	N_2	pH		SHE		EC		DO		Tw		Tur	
				Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
Cn	11	5	8.34	7.99	0.24	160.19	24.76	199.79	23.77	6.53	2.16	16.75	4.84	4.15	2.68
Cc	3	3	2.88	8.22	0.57	195.00	61.71	253.33	74.8	6.63	2.78	7.14	2.04	5.87	4.21
Cs	4	4	2.91	8.14	0.13	163.14	36.69	205.31	9.422	6.84	2.78	15.38	6.34	2.33	1.39
Ps	3	2	3.00	8.09	0.20	165.86	20.03	277.94	39.14	5.32	2.08	18.52	3.28	2.96	0.3
Pa	7	14	3.97	7.91	0.36	168.96	20.82	245.79	36.89	7.16	3.58	12.12	7.35	2.83	2.19
Fj	7	11	5.83	7.89	0.31	153.10	18.83	195.6	10.64	5.78	1.6	19.43	3.03	3.94	1.65
Pk	21	27	11.8	7.89	0.24	161.21	15.32	221.58	45.28	5.6	2.41	13.87	6.44	4.5	2.11
Co	13	19	8.34	7.99	0.26	172.08	23.97	206.4	20.33	6.37	1.83	17.52	5.95	4.7	2.87
Cv	11	8	7.90	7.87	0.29	168.43	24.16	200.7	19.7	5.96	1.45	18.69	5.48	4.35	2.61
Li	10	14	5.09	7.89	0.24	158.63	19.16	196.62	10.99	4.9	1.57	15.09	6.57	4.86	1.81
Ig	3	34	1.54	7.87	0.08	162.79	5.765	209.61	7.855	7.57	3.4	9.87	4.58	8.64	3.15
Mean	8.46	12.8	5.6	7.98	0.27	166.31	24.66	219.33	27.17	6.24	2.33	14.94	5.08	4.47	2.27
Stdev	5.54	10.3	3.15	0.12	0.13	10.89	14.36	27.499	20.42	0.81	0.73	3.91	1.7	1.72	1.02

Abbreviations: SHE (redox potential), EC (electrical conductivity), DO (dissolved oxygen), Tw (water temperature), Tur (turbidity), Mean (mean of data), Stdev (standard deviation), N2 (Hill's coefficient). Species codes (Code): Cn (*Candona neglecta*), Cc (*Candona candida*), Cs (*Candona sanociensis*), Ps (*Pseudocandona sucki*), Pa (*Pseudocandona albicans*), Fj (*Fabaeformiscandona* cf. *japonica*), Pk (*Physocypria kraepelini*), Co (*Cypria ophtalmica*), Cv (*Cypridopsis vidua*), Li (*Limnocythere inopinata*), Ig (*Ilyocypris gibba*).

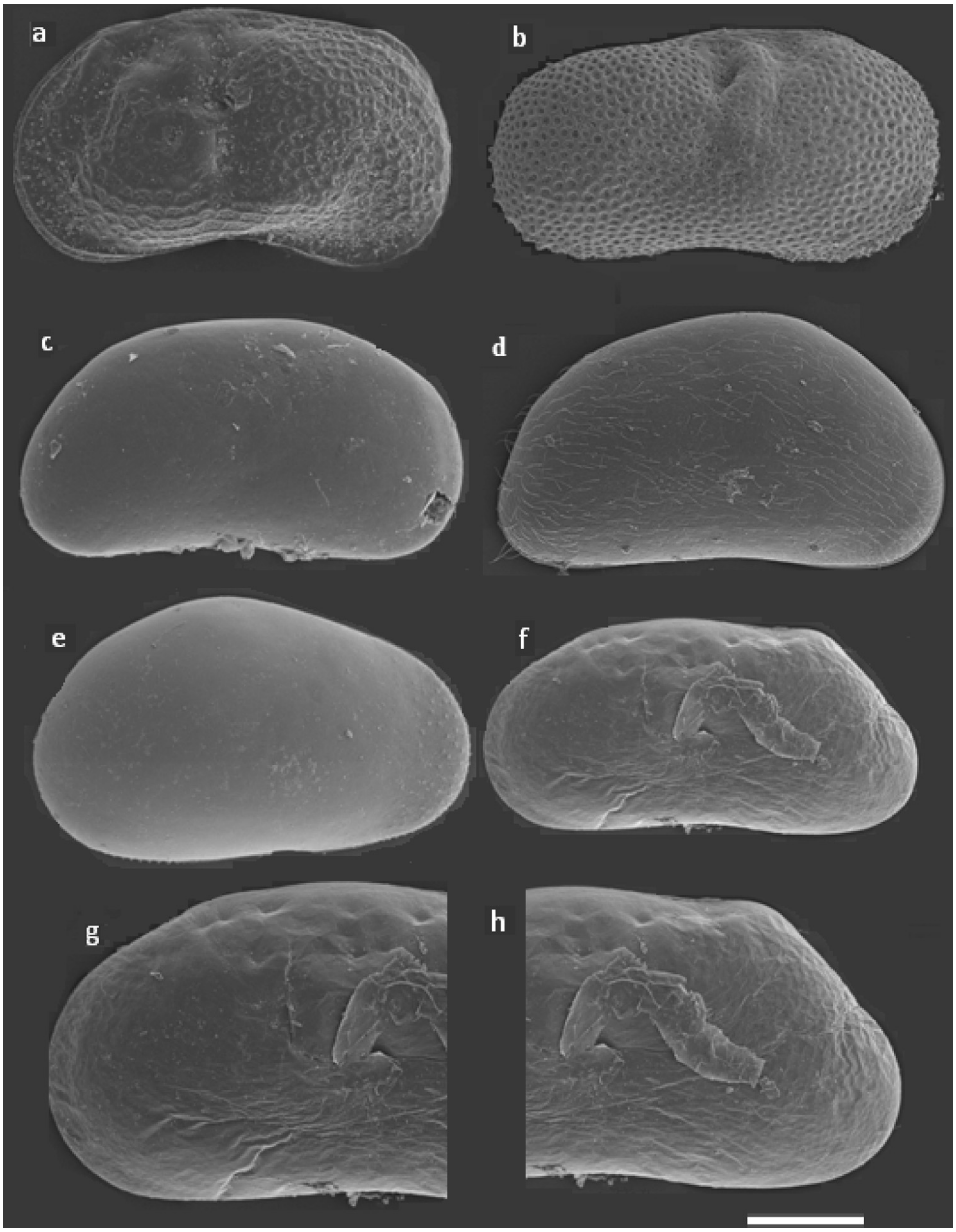

Plate 1. (a) *Limnocythere inopinata* (Baird, 1843), (b) *Ilyocypris gibba* (Ramdohr, 1808), (c) *Fabaeformiscandona brevicornis* (Klie, 1925), (d) *Potamocypris similis* G.W. Müller, 1912, (e) *Trajancypris serrata* (G.W. Müller, 1900), (f) *Fabaeformiscandona* cf. *japonica* (Okuba, 1990), (g) *F.* cf. *japonica* (anterior margin, external view), (h) *F.* cf. *japonica* (posterior margin, external view). Note to the anomalies on the carapace of *F.* cf. *japonica*. Scale: a: 168 μm; b: 202 μm; c: 200 μm; d: 190 μm; e: 360 μm; f: 258 μm; 190 μm for g and h.

water level was increased with 13 m. A flood which increases water levels can happen within several hours or a few days. During which, only some species can migrate out of the flooded zone. For example, in the present study, *L. inopinata* was not found below 9 m of water depth while *I. gibba* and *P. kraepelini* were even common after flood. Indeed, Szlauer-Łukaszewska (2008) reported that after about 24 h of intrusion, the flood zone was dominated by swimming forms (e.g., *C. vidua*, *P. kraepelini*, *C. ophtalmica*) while bottom-dependent (or crawling species with short or totally reduced swimming setae on the second antennae) species (e.g., *L. inopinata*, *Ilyocypris* spp.) were better successive in the river bed and medial zones of a River Odra in Poland. We did not observe a significant difference between swimming and crawling forms among the most frequently occurring five species common in all stations.

Electrical conductivity and water temperature influenced ostracod species (Fig. 4; Table 4). Increased temperatures increase the rate of evaporation and electrical conductivity of water. In such situation, species can survive if they can tolerate the changes or can move to other places. Although tolerance levels of the most common species were higher than the mean water temperature they were lower than mean electrical conductivity (Table 5). Tolerance and optimum levels seem to be species-specific and which affected the seasonal occurrence of species in our samples. For example, we detected a distinct increase in seasonal occurrence for five species (*C. neglecta*, *L. inopinata*, *C. ophtalmica*, *C. vidua*, *F.* cf. *japonica*,) while one species (*P. kraepelini*) was encountered all year around (Fig. 3). All these species (except *F.* cf. *japonica*) that showed clear seasonal patterns during this study have a widespread geographical distribution with relatively high tolerance levels to different

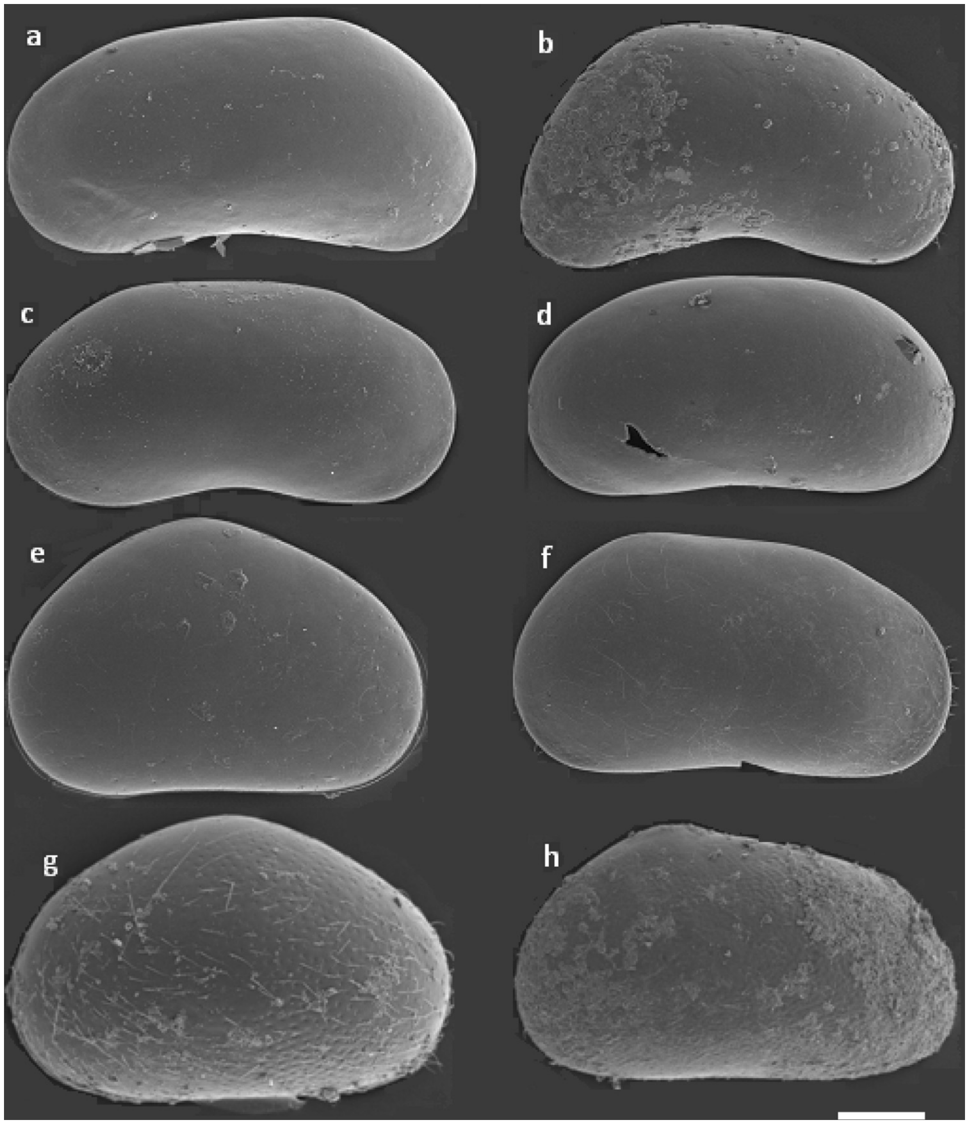

Plate 2. (a) *Candona neglecta* Sars, 1887, (b) *C. candida* (O.F. Müller, 1776), (c) *C. sanociensis* Sywula, 1971, (d) *Candona* sp. (e) *Cypria ophtalmica* (Jurine, 1920), (f) *Pseudocandona semicognita* (Schäfer, 1934), (g) *Cypridopsis vidua* (O.F. Müller, 1776), (h) *Prionocypris zenkeri* (Chyzer and Toth, 1858). Scale: a: 172 μm; b: 228 μm; c: 160 μm; d: 218 μm; e: 130 μm; f: 157 μm; g: 105 μm; h: 203 μm.

ecological variables (Külköylüoğlu 2014). Because of scant ecological knowledge and taxonomic problems (Escrivá et al. 2012), a detailed discussion is not provided for *F.* cf. *japonica.*

Physocyria kraepelini was the most frequently occurring species with eurychronal distribution in all stations. Earlier studies (Külköylüoğlu 1998; Yılmaz and Külköylüoğlu 2006; Külköylüoğlu et al. 2007) indicated similar patterns of seasonality. This species is known to have a high tolerance to different environmental variables (Külköylüoğlu 2005a) including eutrophic conditions (Shornikov and Trebukhova 2001; Külköylüoğlu et al. 2007; Yu et al. 2007, 2008, 2009) with rich ionic content (Rossetti et al. 2004). Meisch (2000) described the species as meso- to polytitanophilic due to its tolerance to calcium levels in waters (>72 mg Ca L^{-1}). In the Odra River, Poland, this swimming species was one of the most common species found in the flood zone (Szlauer-Łukaszewska 2008). In the present study, the CCA diagram suggests a close relationship between the species and electrical conductivity (Fig. 4). Indeed, the species showed the highest tolerance to electrical conductivity (tk = 45.28) among the other most common species (Table 5). According to Külköylüoğlu (2014), “cosmoecious species” are those cosmopolitan species with wide ranges of tolerance to various environmental variables. Such species seems to have a better chance for surviving or adapting in changing conditions. Hence, as shown previously (Meisch 2000), *P. kraepelini* can be called as cosmoecious species because it has a wide geographical distribution and high tolerances to different ecological variables.

We found adults of a crawling species, *C. neglecta*, from April to November (Fig. 3) while juveniles were rarely observed from May to November. Such occurrence patterns correspond with earlier studies in Germany (Hiller 1972) and Turkey (Külköylüoğlu 2005a; Külköylüoğlu and Dügel 2004; Dügel et al. 2008). Meisch (2000) emphasized that reproduction and larval development of *C. neglecta* are mainly affected by fluctuations in environmental conditions. *C. neglecta* was found in a newly developing spring water with low levels of oxygen (e.g., 0.32 mg L^{-1}, Külköylüoğlu 2009). The species was the last one to disappear from Lake Mondee, Australia undergoing eutrophication (Danielopol et al. 1993), indicating its tolerance to increasing pollution levels in the lake. It has also been reported to occur within a wide range of temperatures (2.2 to ca. 28 °C) (Külköylüoğlu 2005a). In another study, Külköylüoğlu and Yılmaz (2006) found not only a strong negative correlation between *C. neglecta* and water temperature, but

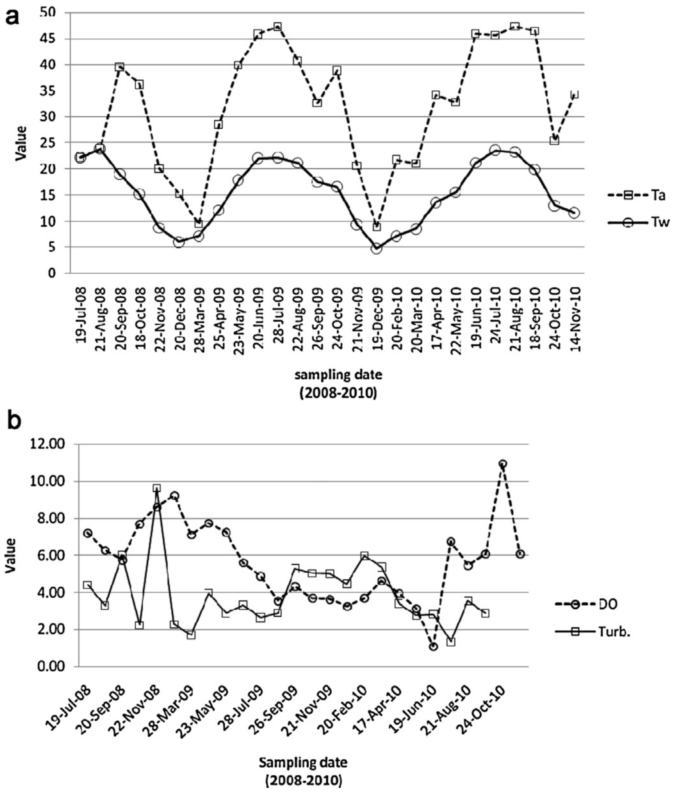

Fig. 2. (a) Mean monthly temperature fluctuations of air (Ta) and water (Tw) at Lake Çubuk between 19 July 2008 and 14 November 2010. The squares and circles reflect a mean Ta and Tw at all six stations. (b) Monthly distribution of dissolved oxygen (DO) and turbidity in Lake Çubuk between 19 July 2008 and 14 November 2010. The squares and circles reflect a mean turbidity and DO at all six stations.

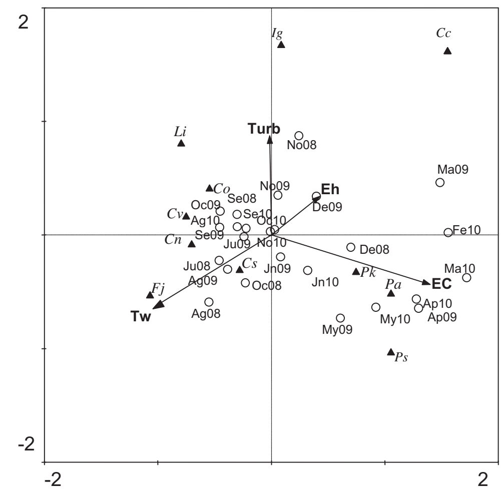

Fig. 4. CCA diagram shows distribution of 11 species (Cn, *Candona neglecta*; Cc, *C. candida*; Cs, *C. sanociensis*; Ps, *Pseudocandona sucki*; Pa, *P. albicans*; Fj, *F.* cf. *japonica*; Pk, *Physocypria kraepelini*; Co, *Cypria ophtalmica*; Cv, *Cypridopsis vidua*; Li, *Limnocythere inopinata*; Ig, *Ilyocypris gibba*) occurred at least three times with 4 environmental variables (EC (electrical conductivity), Eh (redox potential), Tw (water temperature), Turb (turbidity)). Months without species were not shown here.

the high tolerance to water temperature (tk = 3.8 °C) and optimum estimates to dissolved oxygen (uk = 9.08 mg L^{-1}) of all the ostracod species sampled a cold helocrene spring. Recent studies from Germany (Viehberg 2005), the Iberian Peninsula (Mezquita et al. 2005), and Turkey (Yavuzatmaca et al. 2012) revealed similar results about the high tolerance levels of some ostracod species to environmental variables. Our results confirmed that *C. neglecta*

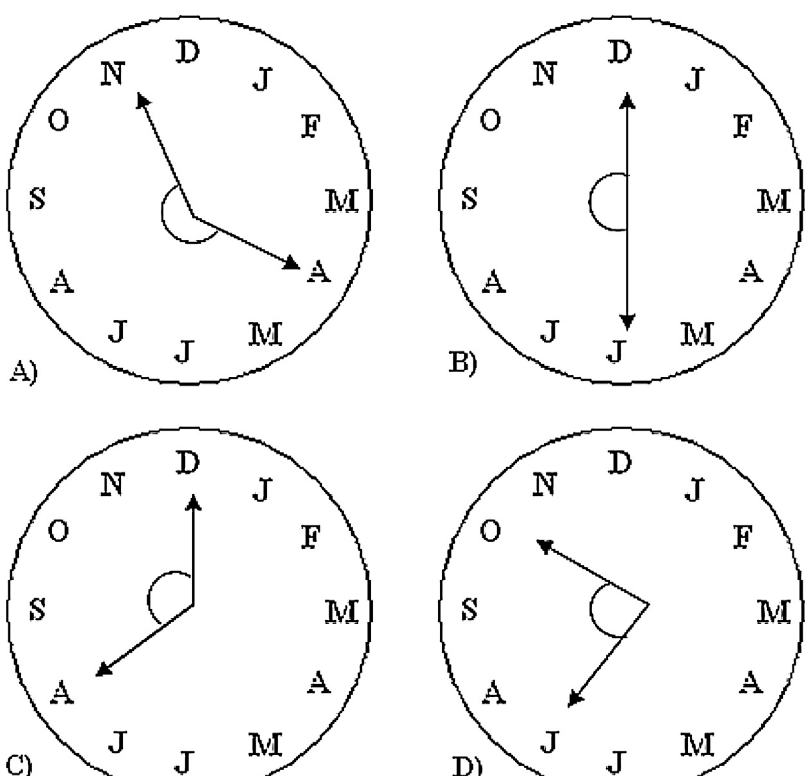

Fig. 3. Ostracod Watch Model (OWM) for five species shows seasonal species occurrences of five adult species from Lake Çubuk: (A) *Candona neglecta*, (B) *Cypria ophtalmica* and *Cypridopsis vidua*, (C) *Limnocythere inopinata*, (D) *Fabaeformiscandona* cf. *japonica*. Capital letters (J, F, M, . . .D) represent 12 months (January, February, March, . . .December) of the year. Occurrence of adult individuals is shown with arc between arrows. Note that *C. vidua* was not found in October while *Physocypria kraepelini* was encountered all year around (not shown here).

which are often found in lentic habitats can also be found in almost all types of water bodies in across a wide geographical range, and can be called cosmoecious species (Külköylüoğlu 2014).

Limnocythere inopinata is another crawling species that was found at stations 1, 2 and 5 (Fig. 1) when water level was shallower than 6 m. This species was absent in the flooded zone. It is bottom dependent and during flood, may not have had enough time to migrate to the flood zone. Supporting evidence comes from a study on a land slide Lake Sünnet in Turkey by Külköylüoğlu et al. (2010) who reported finding the species when water level was their lowest between 7.75 and 8.75 m. In contrast, *L. inopinata* was absent in the littoral zone when water level was about nine meters (or shallower) in depth. In this study, the species was collected from late August to December but absent during the rest of the season. According to Cohen et al. (1983), *L. inopinata* can be used as an indicator of moderate to high salinity and alkalinity. Supporting evidence for this conclusion come from previous studies which showed that *L. inopinata* was common in streams, lakes and reservoirs with eutrophic conditions (Scharf 1993; Kılıç 2001; Mezquita et al. 2001; Külköylüoğlu and Dügel 2004). Our results supporting the model showed that *L. inopinata* can be called cosmoecious species (Külköylüoğlu 2014) because it has a wide geographical distribution and tolerates a relatively wide range of environmental variables.

Two of the other most common species *C. vidua* and *C. ophtalmica* showed similar occurrence in almost all station from late June to December in Lake Çubuk. Such occurrence was also reported in earlier studies in Turkey (Külköylüoğlu, 1998, 2005a,b). *Cypridopsis vidua*, a cosmopolitan species, can be found in fresh to saline aquatic bodies and from sea level to 2175 m of altitude (Saldarriaga and Martínez 2010). Ganning (1967, 1971) showed that *C. vidua* was able to tolerate salinity ranges from 1 ppt to 20 ppt, and could be described as a mesohalophilic species (Meisch 2000). This was supported with previous studies in Canary and Cape Verde islands in which *C. vidua* was found in waters with low (37 mS cm^{-1}) to very high values of conductivity (7410 mS cm^{-1}) (Meisch and Broodbakker 1993; Meisch et al. 2007). According to Külköylüoğlu (2003), *C. vidua* can tolerate environmental variables (e.g., dissolved oxygen and electrical conductivity) across a wide range. Recent studies conducted in Portugal showed that the species survived in low oxygenated waters (Martins et al. 2010). In a study across 150 sampling sites of the Bolu region in Turkey, *C. vidua* displayed high optimum and tolerance values to water temperature (uk = 28.33 °C, tk = 5.96 °C), pH (uk = 9.29, tk = 1.21) and altitude (uk = 1378.23 m, tk = 478.17 m) (Külköylüoğlu and Sarı 2012). This species was located on the left side of CCA diagram (Fig. 4), indicating possible correlation to water temperature and turbidity. Indeed, *C. vidua* showed relatively high tolerance (tk = 5.48 °C) and optimum estimates (uk = 18.69 °C) to water temperature compared to the mean values reported for the ~~of~~ other species (Table 5). Overall, our results support describing *C. vidua* as a cosmoecius species.

Cypria ophtalmica, a swimming cosmopolitan species, is a typical species found in most of the stagnant water bodies in Turkey. Meisch (2000) documented its occurrence in different types of waters throughout the year where it shows a remarkable tolerance to a wide range of environmental variables. In northern Italy, the species was among the most frequently occurring species from a variety of water bodies (Rossetti et al. 2006) sampled from May to December. During the present study, we found *C. ophtalmica* from late April to the end of October in Lake Çubuk, similar to Lake Abant in Turkey (see Dügel et al. 2008). However the species was collected in a highly eutrophic Lake Yeniçağa from April to October, except in June and September (Külköylüoğlu et al. 2007). One of the most recent studies from Portugal revealed that *C. ophtalmica* was also common in ponds from December to April, and it was among the common species found after inundation (Martins et al. 2010). This supports the idea that the seasonal occurrence of *C. ophtalmica* may be much broader than previously known. In this study, this species showed the highest tolerance and optimum values for five environmental variables for the most frequently occurring species we sampled. Our finding of a negative correlation between *C. ophtalmica* and the electrical conductivity of lake water is also supported by the CCA diagram where the species was located on the left upper corner opposite to the arrow of electrical conductivity (Fig. 4). These finding correspond with earlier results by Delorme (1991), Bellavere et al. (1999), and Külköylüoğlu (2000, 2004) who reported this species from a wide range of temperature (3.5–33.0 °C), dissolved oxygen (0.00–20.00 mg L^{-1}) (Delorme 1991), conductivity (87–5260 μS cm^{-1}) and pH (5.0–13.0). Compared to other species (e.g., *C. vidua*), the altitudinal range of the species is narrower than many other species we collected (e.g., 36–1347 m a.s.l.) (Külköylüoğlu 2004; Rossetti et al. 2005). Our results suggest that *C. ophtalmica* is cosmoecious because it is tolerant to a wide range of different environmental variables, and has a wide geographical distribution.

According to our findings, several species differ seasonally in their occurrence in Lake Çubuk and in their tolerance to different environmental variables. Although it is argued that cosmopolitanism is not common among nonmarine ostracod species (Martens et al. 2008), our results suggest that several ostracod species are cosmopolitan with a much wider geographical distribution and wide tolerances to environmental variables than was previously known. Being a cosmopolitan species with a wide tolerance to environmental variables may suggest adaptive capacity in nonstable habitats such as bodies of water impacted by global climate change. Overall, these results suggest that the trophic state of this shallow lake (Lake Çubuk) shows typical oligo-mesotrophic freshwater characteristics. Because of high ostracod diversity, Lake Çubuk deserves protection and should be put under conservation rules.

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