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Selçuk Altınsaçlı
Merdivenköy Mahallesi Ortabahar, Daire, Özdin Apt. Kadıköy İstanbul, Turkey

Songül Altınsaçlı
Istanbul University, Department of Biology, Faculty of Science, Vezneciler, Istanbul, Turkey

Ferda Perçin-Paçal
Istanbul University, Institute of Experimental Medicine Research, Department of Genetics, Vakıf Gureba Street, Şehremini, Istanbul, Turkey

Correspondence
Selçuk Altınsaçlı
Merdivenköy Mahallesi Ortabahar, Daire, Özdin Apt. Kadıköy İstanbul, Turkey

Spatial and temporal distribution of non-marine ostracods in a small crater lake: Lake Karagöl (Dikili, İzmir, Turkey)

Selçuk Altınsaçlı, Songül Altınsaçlı and Ferda Perçin-Paçal

Abstract
The Ostracoda fauna of a volcanic Mediterranean lake (Lake Karagöl, Dikili, İzmir, Turkey) was studied in order to determine the annual and spatial variability of Ostracoda assemblage according to environmental conditions. We investigated the distributional patterns and habitat preferences of ostracods in Lake Karagöl, recording 10 taxa from the lake. The Ostracoda assemblage was sampled seasonally during May, June, September, and November in 2009 and water quality variables were monitored over the same period. The Ostracoda fauna of Lake Karagöl was found to be very limited with only 10 species. *Potamocypris arcuata* and *Heterocypris salina* were the dominant ostracod species, comprising 28.1% of the ostracod population. Salinity, pH, salinity conductivity, and water temperature seemed to be the main environmental factors affecting the Ostracoda community.

Keywords: Ostracoda, Crustacea, ecology, Crater Lake, Lake Karagöl

1. Introduction

Ostracods (class Ostracoda) are one of the most diverse groups of living crustaceans. There are close to 2,000 subjective species and about 200 genera of recent non-marine Ostracoda [1]. The zoogeographical region with the highest specific diversity is the Palearctic, with more than 700 species [1]. Much published ecological data on ostracod species living in western and central Europe was summarized by Meisch [2]. All recent freshwater ostracods belong to the order Podocopida [2]. Meisch [2] summarized new and already published ecological data of western and central-European species. Ostracods, which are bivalved crustaceans, can be found in all types of water bodies. They are very common in most inland waters, where they abound in the benthic zone, but they also occur in marine, interstitial, and subterranean environments. These small bivalved microcrustaceans have been the subject of numerous monographs and articles on taxonomy, systematics, and ecology. Ostracods are used widely in paleoclimatic and paleolimnological studies due to their well-calcified shells, high abundance, and wide distribution. The distribution and habitat preferences of ostracods are affected by one or more factors, such as temperature, salinity, pH, dissolved oxygen, sediment type, depth, vegetation, elevation, and the transparency of the water [3, 4]. Each ostracod species has different morphological and ecological characteristics. Therefore ostracods are valuable indicator species for estimating past and present environmental changes. A distribution list of non-marine Ostracoda in Turkey was given by Altınsaçlı [5] and an Ostracoda species list belonging to 63 major wetlands (many with international significance) in Turkey was given by Altınsaçlı & Griffiths [6]. Recent freshwater ostracod fauna in Turkey has been studied in detail. An updated checklist of the marine and coastal waters ostracod species in Turkey was presented by Perçin-Paçal *et al*. [7].

Stratovolcanoes (such as Mt. Ağrı, Mt. Erciyes, Mt. Nemrud, Mt. Karadağ (Konya), Mt. Tendürek, Mt. Hasan, Mt. Süphan, and Mt. Göllü) and cone-shaped volcanic rock formations (such as Kula, Meke) were formed as a result of volcanic activity in different geological periods in many regions of Turkey. While most of these volcanic formations do not feature a crater lake, Karadağ, a volcanic mountain at an altitude of 772 meters (in the Dikili district of Izmir), does. This Crater Lake called "Karagöl" (meaning "Black Lake" in Turkish) is located near the summit of Karadağ Mount. Radiometric dating on intermediate lavas represented by pyroclastic deposits and andesitic-dacitic lavas from Dikili volcanic activity show them to be from the early-to-middle Miocene epoch (16.7–18.5 Ma [8, 9]; 15.2 ± 0.40–15.5 ± 0.30 Ma [10]). This study presents the results of the first extensive study on Lake Karagöl ostracods.

The main objectives of the present study were: a) to determine the spatial and temporal distribution of ostracod species in Lake Karagöl, b) to discuss the relationship between habitat suitability and ostracod species diversity, and c) to clarify the most important environmental factors affecting species distribution in the habitats.

2. Materials and Methods

2.1 Site description

The Crater Lake Karagöl (38° 57' 30.8''N, 26° 50' 55.6''E) is located on Mount Karadağ (Dikili region, İzmir province) in the northern-Aegean region of Turkey (Fig. 1). The water surface area is small (~3.35 ha) and the maximum water depth is ~8-10 m. Its altitude reaches 430 m above sea level [11]. It is an alkaline, oligotrophic, and endorheic lake [11]. As shown in Fig. 1, the bottom of Lake Karagöl is covered with sandy sediment, the lake has no outlet, and it is mainly fed by winter and spring rainfall [11]. There is very little human activity around the lake. Some dunes surrounding the lake are mainly covered by oak (*Quercus*) species and also sparsely covered with maquis vegetation. Aegean and Mediterranean coasts have typical Mediterranean climates with hot summers and mild, wet winters.

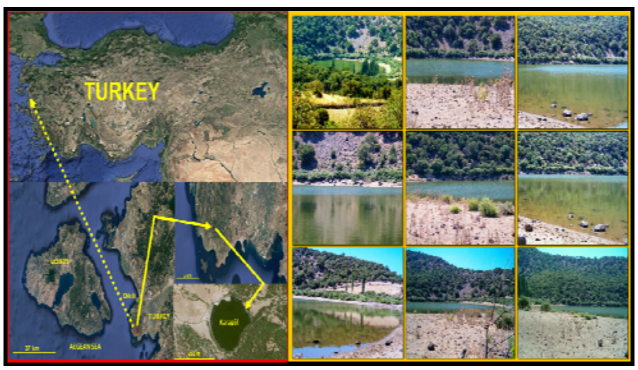

Fig 1: Geographic location and pictures of Lake Karagöl.

2.2 Sampling and measurements

Samples were collected with a hand net (mesh size 200 µm) from shallow water not exceeding 50 cm in depth. At each site, we collected about 200 g of surface sediment, which was fixed in 4% ethanol in situ. The collected samples were kept in polyethylene jars (250 ml bottles) and then taken to the laboratory, where they were washed with pressurized tap water and separated from the sediment using four standardized sieves (2.0, 1.5, 0.5, and 0.25 mm mesh size). Ostracod samples and other invertebrates were separated from each other under a stereomicroscope and fixed again in 70% alcohol. Subsequently, specimens were preserved in 70% ethanol and glycerine (1:1 ratio) and the retained material transferred to a petri dish. Subsequently, the ostracods were sorted from sediment under a stereomicroscope and their soft body parts were dissected in lactophenol solution for taxonomic identification. Species identification was done using a light microscope. The number of adult individuals belonging to each identified ostracod species was counted under a stereomicroscope. Juvenile stages of each ostracod species were observed at the sampling site. The taxonomic key provided by Meisch [2] was primarily used for taxonomic classification and species identification, although additional taxonomic keys (e.g., Bronshtein [12]; Karanovic [13]) were used when necessary.

Seven physicochemical variables and some ionic components commonly used in studies using freshwater were measured in May, June, September, and November in 2009. Eight environmental variables (dissolved oxygen (DO, mg L^{-1}), percent oxygen saturation (% S), water temperature (Tw, ◦C), electrical conductivity (EC, µS cm^{-1}), total dissolved solids (TDS, mg L^{-1}), salinity (Sal, ppt), oxidation reduction potential (ORP, mV) and pH) were measured in situ using electronic probes (WTW 340i multimeter) at the Lake Karagöl. Determined species with seasonal individual numbers and measurement results of the seven physicochemical variables are given in Table 1.

2.3 Statistical analyses

The relationships between species and environmental variables (salinity, electrical conductivity, water temperature, dissolved oxygen, percent oxygen saturation, and pH) were examined by Canonical Correspondence Analysis (CCA) [14]. CCA was performed using MVSP 3.22 to assess the influence of the physicochemical variables on the ostracod species

Spearman rank correlations were used to test for relationships between five independent environmental variables (water temperature, salinity, electrical conductivity, pH, and dissolved oxygen) and ostracod species.

The species diversity for each season was calculated using the Shannon-Weaver diversity index (H'). The total number of species and the total number of individuals determined in each of the seasons for all ostracod species were used to calculate the Shannon-Weaver diversity values. The dominance (%) values were calculated for each species as the mean density of species divided by the mean total density of ostracods and multiplied by 100. Average values were used for all variables.

Table 1: Measurement result of the seven physicochemical variables (dissolved oxygen (DO, mg L^{-1}), percentage of oxygen saturation (% S), water temperature (Tw, ◦C), electrical conductivity (EC, µS cm^{-1}), total dissolved solids (TDS, mg L^{-1}), salinity (Sal, ‰), oxidation reduction potential (ORP, mV), and pH) ostracod species (abbreviations: CN: *Candona neglecta*, FF: *Fabaeformiscandona fabaeformis*, IB: *Ilyocypris bradyi*, HS: *Heterocypris salina*, CV: *Cypridopsis vidua*, PA: *Potamocypris arcuata*, PP: *Potamocypris producta*, PV: *Potamocypris variegata*, PN: *Plesiocypridopsis newtoni*, LI: *Limnocythere inopinata*) and their seasonal individual numbers.

	Tw	Sal	EC	pH	ORP	DO	%S	PN	PA	PP	PV	CV	CN	LI	HS	IB	FF
May 09	17	0,1	783	8,2	-120	7,1	86,4	13	25	19	17	21	12	10	15	18	7
July 2009	27	0,2	802	9,1	-156	6,2	71,2	43	58	44	51	61	20	48	62	25	11
September 2009	21	0,2	756	8,6	-90	7,1	83,2	24	35	32	29	23	18	28	27	12	6
November 2009	12	0,1	450	7,9	-84	7,3	89,7	2	5	3	2	2	12	4	18	7	5
Total number of individuals								82	123	98	99	107	62	90	122	62	29
Min.	12	0,1	450	7,9	-156	6,2	71,2	2	5	3	2	2	12	4	15	7	5
Max.	27	0,2	802	9,1	-84	7,3	89,7	43	58	44	51	61	20	48	62	25	11
Mean	19,25	0,15	697,75	8,45	-112,5	6,925	82,625	20,5	30,75	24,5	24,75	26,75	15,5	22,5	30,5	15,5	7,25

3. Results

A total of 874 specimens of 10 ostracod taxa (*Candona neglecta* (Sars 1887), *Fabaeformiscandona fabaeformis* (Fischer 1851), *Ilyocypris bradyi* (Sars 1890) *Potamocypris producta* (Sars 1924), *Potamocypris arcuata* (Sars 1903), *Potamocypris variegata* (Brady & Norman 1889), *Plesiocypridopsis newtoni* (Brady & Robertson 1870), *Cypridopsis vidua* (O.F. Muller 1776), *Limnocythere inopinata* (Baird 1843), *Heterocypris salina* (Ramdohr 1868)) were collected from Lake Karagöl. Eight of these species (*C. neglecta*, *P. producta*, *P. arcuata*, *P. variegata*, *P. newtoni*, *C. vidua*, *L. inopinata*, *H. salina*) were reported in a preliminary study on this lake by Altınsaçlı & Altınsaçlı [11].

Ostracod species, the total individual numbers of species, and the percentage of these specimens found in Lake Karagöl are given in Table 2.

In the lake, a total of 874 ostracod specimens of 10 taxa were recorded across all of the seasons. *Heterocypris salina* was the most dominant species in terms of numbers of individuals in the summer (62 individuals) and winter (18 individuals) periods, whereas *Potamocypris arcuata* was the most dominant species in the spring (25 individuals) and autumn (35 individuals) periods. Overall, *Potamocypris arcuata* (123 individuals) and *Heterocypris salina* (122 individuals) were the dominant ostracod species, comprising 28.1% of the ostracod population (see Table 2).

The results of the Spearman rank correlation coefficient are presented in Table 3.

Table 2: Ostracod species, total individual numbers per species, and percentage of these specimens found in Lake Karagöl (Species abbreviations are the same as in Table 1)

Species	Total number of individuals	Frequency (%)
PA	123	14.1
HS	122	14.0
CV	107	12.3
PV	99	11.3
PP	98	11.3
LI	90	10.3
PN	82	9.4
CN	62	7.0
IB	62	7.0
FF	29	3.3
Total	874	100

Table 3: Spearman rank correlation matrix for the studied ostracod species and some environmental variables (Species and environmental variables abbreviations are the same as in Table 1) (** Correlation is significant at the 0.01 level.)

	Tw	Sal.	Con.	pH	DO	PN	PA	PP	PV	CV	CN	LI	HS	IB	FF
Tw	1														
Sal.	0,894	1													
Con.	0,800	0,447	1												
pH	1,000**	0,894	0,800	1											
DO	-0,949	-0,707	-0,949	-0,949	1										
PN	1,000**	0,894	0,800	1,000**	-0,949	1									
PA	1,000**	0,894	0,800	1,000**	-0,949	1,000**	1								
PP	1,000**	0,894	0,800	1,000**	-0,949	1,000**	1,000**	1							
PV	1,000**	0,894	0,800	1,000**	-0,949	1,000**	1,000**	1,000**	1						
CV	1,000**	0,894	0,800	1,000**	-0,949	1,000**	1,000**	1,000**	1,000**	1					
CN	0,949	0,943	0,632	0,949	-0,833	0,949	0,949	0,949	0,949	0,949	1				
LI	1,000**	0,894	0,800	1,000**	-0,949	1,000**	1,000**	1,000**	1,000**	1,000**	0,949	1			
HS	0,800	0,894	0,400	0,800	-0,632	0,800	0,800	0,800	0,800	0,800	0,949	0,800	1		
IB	0,800	0,447	1,000**	0,800	-0,949	0,800	0,800	0,800	0,800	0,800	0,632	0,800	0,400	1	
FF	0,800	0,447	1,000**	0,800	-0,949	0,800	0,800	0,800	0,800	0,800	0,632	0,800	0,400	1,000**	1

The results of the Spearman rank correlation coefficient (Table 3) indicate that there was a strong positive correlation between the water temperature and pH. On the other hand, there was a weak positive correlation between salinity and electrical conductivity. There was a strong positive correlation between the water temperature and *P. newtoni*, *P. arcuata*, *P. producta*, *P. variegate*, *C. vidua*, and *L. inopinata*. There was a weak positive correlation between salinity and all other environmental variables, except for dissolved oxygen, but a strong positive correlation between conductivity and *I. bradyi* and *F. fabaeformis*. There was a weak negative correlation between dissolved oxygen and all other environmental variables. There was a positive correlation between pH and *P. newtoni*, *P. arcuata*, *P. producta*, *P. variegata*, *C. vidua*, and *L. inopinata*, but a weak positive correlation between pH and all other species, except for the five species mentioned earlier. There was a weak positive correlation between *P. newtoni* with *P. arcuata*, *P. producta*, *P. variegata*, *C. vidua*, and *L. inopinata*, and a positive correlation between *C. neglecta*, *H. salina*, *I. bradyi*, and *F. fabaeformis*.

The relationships between 13 species and six environmental variables were examined by CCA (Fig. 2).

Regarding the results of the CCA, the first two axes of the CCA explain 97.9 % of the relationships between 13 species and six environmental variables. The lengths of the arrows on the CCA graph show the strong effect of the water temperature, pH, salinity, and conductivity environmental variables on the distribution of ostracods (Fig. 2).

The results of the Shannon-Weaver diversity index maximum value (H' = 0.592) were calculated in November 2009, with minimum values (H' = 0.158) calculated in July 2009. Shannon-Weaver index values above 1 suggest a relatively rich ostracod community, while index values under 1 suggest an ostracod community with low diversity. Although the total number of individuals increased in the summer (H' = 0.158) and early autumn (H' = 0.247) periods, diversity was low. Although total species numbers were the same for all seasons, diversity values were low in summer and early autumn, but high in spring (0.327) and winter (0.592).

The ionic composition of the lake water shows that the lake has Na-Cl-HCO_3-Ca type water. Water quality standards are determined according to usage (drinking, agriculture, industry, energy, etc.) and water classes (river, lake, coastal and transitional waters, and ground water). According to the Water Pollution Regulation by the Ministry of Environment in Turkey [15], according to this official criteria, lake water is categorized as Class II for dissolved oxygen and Class IV for pH.

All the ostracod species identified in Lake Karagöl have previously been found in similar natural environments.

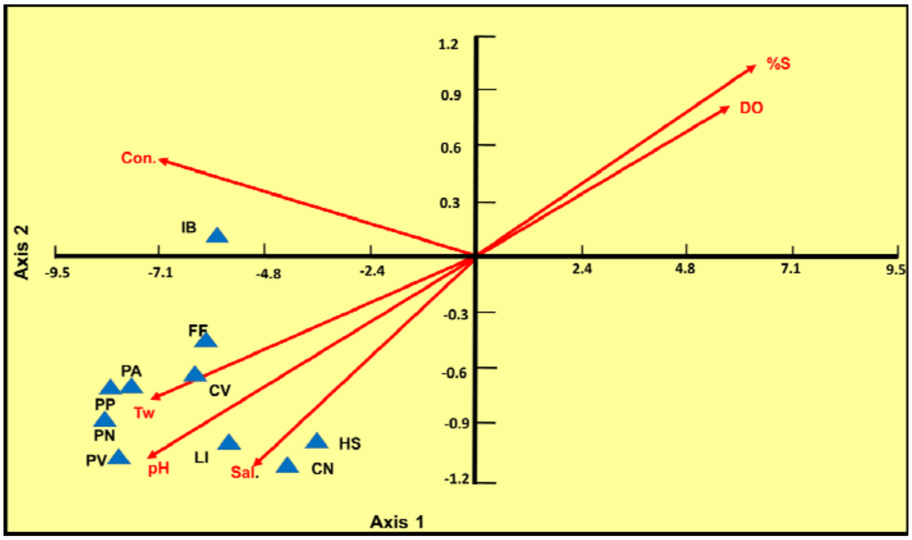

Fig 2: Graph of CCA showing the ordination of 13 species and the six environmental variables (red arrows) (Tw, pH, DO, S%, EC, and Sal.) from Lake Karagöl on the first and second axes. Triangles show species code **(**abbreviations are the same as in Table 1)

4. Discussion

A preliminary study that included *P. producta*, *P. newtoni*, *P. arcuata*, *P. variegata*, *C. vidua*, *C. neglecta*, *L. inopinata*, *H. salina*, *Daphnia longispina* (O.F. Muller 1785), *Cyclops strenuus* (Fischer 1851), *Arctodiaptomus pectinicornis* (Wierzejski, 1887), and *Haementeria costata* (Muller 1846) was made by Altınsaçlı and Altınsaçlı in 2009 [11]. A small fish species and a Caspian pond turtle (*Mauremys caspica*) (Gmelin 1774) were vertebrate animals observed in the lake [11]. According to the Bern Convention [16], *Mauremys caspica* is considered a species that needs to be carefully protected.

Eurytopic species *C. neglecta* was reported in the sandy substrate of the crater lake, Lake Karagöl by Altınsaçlı & Altınsaçlı [11] and in the sinkhole lake, Lake Meyil (in Konya) [5]. *C. neglecta* has been found to prefer sediment with no vegetation in some lakes [17], as with Lake Karagöl. Non-swimming and cosmopolitan species show high tolerance to temperature, pH, low dissolved oxygen levels, slightly saline conditions, and redox potential. The results of much research have shown that *H. salina* is a eurytopic and euryhaline cosmopolitan species; as such, it is a common species in Turkey [5, 6]. *H. salina* is known to inhabit pure freshwater and slightly salty coastal and inland waters [2, 18]. *Potamocypris variegata* has been recorded in ponds, gravel pits, rivers, the littoral zones of lakes, and, occasionally, interstitial habitats [2, 18]). *Potamocypris arcuata* is a dominant species in freshwater [2, 19] and also in oligohaline water [19, 20], and is found widely around the Mediterranean area [2, 21]. *F. fabaeformis* is often found in small, temporarily muddy, and swampy water bodies [2] and has been recorded in Europe, Asia, and North America (Holarctic) [2]. Both of these species have been found in the alkaline, sandy sediment, oxygen-rich, and littoral zones of Lake Karagöl and both have been found in compatible habitats. *Limnocythere inopinata* is a benthic detritivorous species typically found in the littoral zones of many permanent and temporary habitats, such as in Lake Karagöl. *L. inopinata* inhabits a wide variety of habitats including the shallow littoral zones of lakes, again as in Lake Karagöl. *L. inopinata* is present in a wide range of environmental conditions, ranging from the shallow littoral zones of lakes with sandy substrates to small ponds, ditches, slow brooks, rivers, and rice fields and from freshwater to highly alkaline water bodies [2, 5, 22]. *L. inopinata* tolerates high chloride levels, and is found in waters that rich of the sodium, bicarbonate, and carbonate ions [23], as in Lake Karagöl. The non-swimming and cosmopolitan species *I. bradyi* shows high tolerance to temperature, pH, low dissolved oxygen level, slightly saline conditions, and redox potential, as do many cosmopolitan species. This example of a cosmopolitan species occurs widely in a variety of water bodies, such as ponds, streams, paddy fields, and lakes [2]. *P newtoni* prefers small permanent, stagnant water bodies, such as (fish) ponds, ditches, and manmade basins and reservoirs [2]. It was reported in limnic, oligohaline, mesohaline, and even the lower polyhaline ranges, up to a maximum salinity of 25‰, in the Canary Islands by Meisch & Broodbakker [24]. The environmental conditions of Lake Karagöl are compatible for cosmopolitan and eurytopic *I. bradyi*. *P. newtoni* is distributed throughout the Palearctic, the Oriental, and the Ethiopian regions, which mainly feature shallow oligohaline and brackish waters [2]. Therefore, we believe that there is a positive correlation between the occurrence of this species in Lake Karagöl and the salinity level (0.2‰) of the lake water. All-female populations are the norm for *P. newtoni* but bisexual populations are common in southern regions [2]. *P. newtoni* populations included males in Lake Karagöl. Populations of all ostracod species mainly peak in the summer (see Table 1). The cosmopolitan and eurytopic species *C. vidua* can tolerate a wide range of environmental variables. According to Meisch [2], *C. vidua* inhabits various water bodies with rich vegetation. Although it was found in the environment containing very few macrophytes in Lake Karagöl, it cannot be a dominant species in this vegetation-poor lake. *Potamocypris producta* (Sars 1924) is easily distinguished from other *Potamocypris* species by its different carapace features and shape, for which reason Meisch [2] did not add this species to the list of European ostracod species. It is widely distributed over the whole African continent, south of the Sahara [25]. It was firstly reported in Turkey by Altınsaçlı & Altınsaçlı [11]. In the present study, it was recorded again under in similar environmental conditions.

Ostracods may use their second antenna for walking, swimming, digging, or climbing. In Lake Karagöl, 60% of the ostracod species were found to be good swimmers (*C. vidua*, *P. variegata*, *P. arcuata*, *P. producta*, *H. salina*, *P. newtoni*) and 40% were non-swimmers (*C. neglecta*, *F. fabaeformis*, *I. bradyi*, *L inopinata*). The nutrient-poor sandy substrata of the lake might limit the growth of macrophytes, which may be the reason why good-swimming ostracod species move more, in order to find more food in the lake. In this case, they would naturally be dominant. Organic debris carried by the rainwater and wind, dead organisms, and microorganisms might constitute the main food for benthic feeders like ostracods in this lake.

Poquet and Mesquita-Joanes [26] stated that the elevational range may increase regional diversity in warm or temperate climates because the water temperature, alkalinity, and conductivity values of aquatic bodies are high at low elevation. This result is compatible with our findings due to the current rich Ostracoda fauna (10 ostracod species) of Lake Karagöl.

Of the 63 major wetlands in Turkey, *C. neglecta* has been reported in 44, *H. salina* in 40, *C. vidua* in 39, *I. bradyi* in 36, *H. incongruens* in 31, *F. fabaeformis* in 19, *L. inopinata* in 19, *P. newtoni* in 5, *P. variegata* in 3, and *P. arcuata* in 2 [5]. As in Lake Karagöl, *C. neglecta*, *I. bradyi*, *F. fabaeformis*, *P. newtoni*, *C. vidua*, *L. inopinata*, and *H. salina* were found in the sandy sediment of Lakes Saklıgöl and Küçükboğaz by Altınsaçlı *et al*. [27]. The results of the present study show clearly that all the species identified interact with the environment variables investigated, as well as other elements in environment. Future work should therefore be supported by physiological, cytological, and genetic studies.

Our results suggest that cosmopolitan species have the advantage of a strong ability to disperse in a variety of aquatic habitats within the study area and that several ostracod species are cosmopolitan with a much wider geographical distribution and wide tolerance to environmental variables.

Fertilizer and pesticide input into the lake is low owing to the low population density and the high amount of non-agricultural land around of the lake. Therefore the trophic state of this lake shows typical oligo-mesotrophic freshwater characteristics. Because of the high ostracod diversity, Lake Karagöl deserves protection and should be placed under conservation by the Ministry of Forestry and Water Affairs and its surroundings should be declared a Geopark because of its clearly observable traces of volcanic activity.

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