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RESEARCH ARTICLE

Ostracoda (Crustacea) and limnoecological characteristics of Lake Karamurat (Bolu, Turkey): Testing pseudorichness hypothesis

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Abstract – To investigate the relationship between ostracod occurrence patterns, community assemblage, and abiotic factors, we sampled five sites on lake Karamurat (Bolu, Turkey) and two nearby rheocrene springs. Thirteen ostracod taxa (10 from the lake, three from the springs) were collected. Species exhibited clear habitat preferences, and lake and spring ostracods showed clear differences in their monthly and seasonal occurrences. *Darwinula stevensoni* and *Cypria ophtalmica* were the dominant species for the lake and *Psychrodromus cf. fontinalis* and *P. olivaceus* were only reported from the springs. Ostracod Watch Model illustrated that a rare species, *Notodromas monacha*, was only found in May to August from the lake while two species (*D. stevensoni*, *C. ophtalmica*) were encountered from all year around. Common species also exhibited relatively high levels of ecological tolerances to multiple environmental variables. Canonical correspondence analyses explained about 91% of correlation between species and environmental variables and indicated that four variables (water temperature, dissolved oxygen, pH and electrical conductivity) most strongly influenced species occurrences. Also, binary data of sample medians showed significant ($P < 0.01$) differences between ostracod assemblages from 13 lakes and reservoirs compared to Lake Karamurat. A significant correlation was detected between Lake Karamurat and two other lakes (Abant and Yeniçağa) located in the same region. The Pseudorichness Ratio (noncosmopolitan/cosmopolitan species) of the lake was very low (Pr = 0.25), indicating dominancy of cosmopolitan species over noncosmopolitans. Conservation efforts should be considered to addressed increasing anthropogenic impacts to Lake Karamurat.

Keywords: Autecology / Ostracod Watch Model / diversity and evenness / cosmoecious species / pseudorichness ratio

1 Introduction

Many lakes (if not all) are under pressure from human activities (*e.g.*, pollution and overexploitation). When coupled with climate change, anthropogenic disturbances can cause irreversible degradation of natural water bodies and resident species.

Ostracoda can be found in variety of natural (*e.g.*, marine and brackish waters, lakes, springs, creeks, ditches, ponds and pools) and artificial (*e.g.*, dams, reservoirs, canals) aquatic habitats. They bear two valves (the carapace) which cover the soft body parts and exhibit a variety of morphologic variability, often adaptive to specific habitats and environmental conditions (Wise, 1961; Benson, 1969). Approximately 65,000 ostracod species (fossil, marine and freshwater) are known (Meisch, 2000; Karanovic, 2012), about 2330 of which occur in freshwater (Meisch *et al.*, 2019). However, with the current new species descriptions, there are more than 2350 species, and more than 160 of which have been reported from Turkey (Külköylüoğlu, pers. obs.).

Seasonal occurrence patterns vary among ostracod species in response to multiple limnoecological (a/biotic) factors (Hoff, 1943; Külköylüoğlu, 1998, 1999; Rossetti *et al.*, 2004; Yavuzatmaca, 2020). Quantifying limnoecological effects on ostracod community structure can aid in predicting assemblage structure and community changes in response to ecological characteristics across habitats (*e.g.*, when and which ostracod species will cooccur (Veech, 2013) or disappear from that of habitat). An understanding of important environmental determinants can also allow for accurate estimations of species diversity and richness and how these metrics may change in the future. However, seasonal (Külköylüoğlu *et al.*, 1993, 1995; Balamurugan *et al.*, 2002; Lorenschat and Schwalb, 2013), and monthly studies on nonmarine (see Külköylüoğlu, 2005) and marine ostracods (Hull, 1997) are not

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common even though seasonality is considered one of the most unique chracteristics ofostracods.

Besides, most recently, Gürer and Külköylüoğlu (2019) suggested that ostracod occurrences and diversity were probably related to habitat type, highlighting differences between artificial (*e.g.*, troughs, canal) and natural (*e.g.*, lakes, creeks, wetlands) habitats. Multiple authors (Keyser and Nagorskaya, 1998; Mezquita *et al.*, 1999, 2000; Külköylüoğlu *et al.*, 2022) have argued that human activities (*e.g.*, wastewater discharge, industry and agricultural practices, exploitation of fisheries resources) negatively affect the number and prevalence of noncosmopolitan species and positively affect the number and prevalance of cosmopolitan (or cosmoecious) species. Perhaps counterintuitively though, artificial aquatic bodies (*e.g.*, reservoirs) tend to have higher ostracod diversity than natural lakes. However, the authors listed above pointed out that seasonality (seasonal changes along with influenced by climatic changes) and habitat type can have as much influence on ostracod community structure as anthropogenic impacts.

Seasonal changes can have indirect and/or direct influence on the physical and chemical characteristics of lakes, which are classified based on seasonal changes in their morphology (referring to stratification zones) such as monomictic, dimictic and polymictic lakes. In some parts, depending on the lake size, location and some other characteristics, eventually, lakes water qualities, especially littoral zones, fluctuate in time (Hutchinson, 1967). This, therefore, alters the physicochemical properties of the lakes, especially temperature. Indeed, compiling more than 44 different monthly and/or seasonal studies, Çapraz *et al.* (2022) showed that temperature, followed by electrical conductivity and pH, was found the most effective factor of more than 17 different environmental variables on the species.

The role of effective factors on the species can also vary between artificial and natural lakes. The ratio of cosmopolitan to noncosmopolitan ostracods (pseudorichness ratio) indicates water quality (Külköylüoğlu, 2013) and is a valuable metric for evaluating the response of lake organisms to environmental factors. Thus, the aims of the present study are to (1) determine monthly and seasonal occurrence patterns of ostracods in Lake Karamurat, (2) compare monthly and seasonal variation in diversity values among lakes, (3) test the hypotheses of pseudorichness, and (4) show autoecological characteristics of individual ostracod species reported from the lake. This is the first study of ostracods from Lake Karamurat.

2 Methods

2.1 Site description and sampling

Lake Karamurat (40°33′51′N, 30°57′19′E, 700m a.s.l.) (Fig. 1) is a small and shallow monomictic lake (this study) located in western Bolu province. There are no previous studies on the lake's ostracods. To investigate seasonality and compare species assemblages between littoral and limnetic lake zones and springs (the primary source of recharge for the lake), we sampled eight stations during 12 months from 2019 and 2021 (see the months and numbers of samplings in Tab. 1 and Fig. 1). Four stations (St 1–4) were in the littoral zone, two (St 5–6) were from the limnetic zone, and two (Sp-1 and Sp-2) were in spring runs (Fig. 1). Note that sampling did not occur in some months due to the Covid-19 pandemic.

Sediments were gathered from littoral zone stations (ca. 2.0 m^2 of area) using a plankton hand net (0.25 mm of mesh size) and from the pelagic zone using an Ekman dredge (Fig. 2). Samples were stored in 250 ml containers and fixed in 70% alcohol in situ. Dissolved oxygen (mg L^{-1}), oxygen saturation (%), water temperature (°C), electrical conductivity (μS cm^{-1}), pH, salinity (ppt), total dissolved solids (mg L^{-1}), and air pressure (mmHg) were measured with a YSI Professional Plus-Multiprobe. A 20 cm Secchi disk was used to measure the Secchi depth (a measure of water transparency). Geographic information (latitude, longitude, and elevation (m)) were recorded with a GARMIN etrex Vista H GPS. Atmospheric variables (wind speed (ms^{-1}), dew point (Dp, °C), heat index (HI, °C), relative humidity (Rh, %), wind chill (w. chill, °C), and air temperature (Ta, °C)) were taken with Kestrel 3000 Wind Meter anemometer.

In the laboratory, samples were serial filtered through four sieves (2:1:0.250:0.125 mm mesh size) and kept in 70% alcohol. Ostracods were picked from sediment under Olympus BX-51 stereo microscope. All samples were fully sorted. Adults were identified to species-level using Meisch (2000). For identification, carapace and/or valves are separated from the soft body parts within lactophenol solution on slides. Next, soft body parts are dissected with fine needles. Dissected specimens are then covered by a cover slip. The slides and all other materials are kept in the Limnology Laboratory of the department. Broken and/or damages individuals, juveniles, and subfossils (valves, carapace) were not used for analyses.

2.2 Statistical approaches

Seasonality of individual species was characterized using Ostracod Watch Model (OWM) (Külköylüoğlu, 1998). Binary data was used to compare Shannon-Wiener (S-W) alpha diversity values among the lakes using Species diversity and Richness program (Version 4) (Seaby and Henderson, 2006). S-W index is one of the most commonly used statistical approaches in limnological studies where S-W values are considered low (1.5) to high (3.5) species diversity (Magurran, 1988). Species occurrence data was used to run a Levene's test for homogeneity among the stations.

A *t*-test with unequal variances was used to compare the means of environmental variables among stations. Significance was set at $P \leq 0.05$. Analyses of variance (ANOVA) with *F*-test ($P < 0.05$) was used to test for differences in the mean species occurrences among stations. When the assumptions of normality were not met, nonparametric, Spearman Rank Correlation analyses using presence/absence data was used to show correlational patterns and clustering relationships among lakes. A dendrogram with Jaccard similarity values among 14 lakes was constructed using PAST 4.03 software program (Hammer *et al.*, 2001). Total of 13 lakes run together were chosen based on long-term (one year or more) seasonal or monthly studies completed. In here, our hypothesis is to estimate no difference between the mean number of species among the lakes investigated.

Canonical correspondence analysis (CCA) was used to show species-environmental correlations and to identify

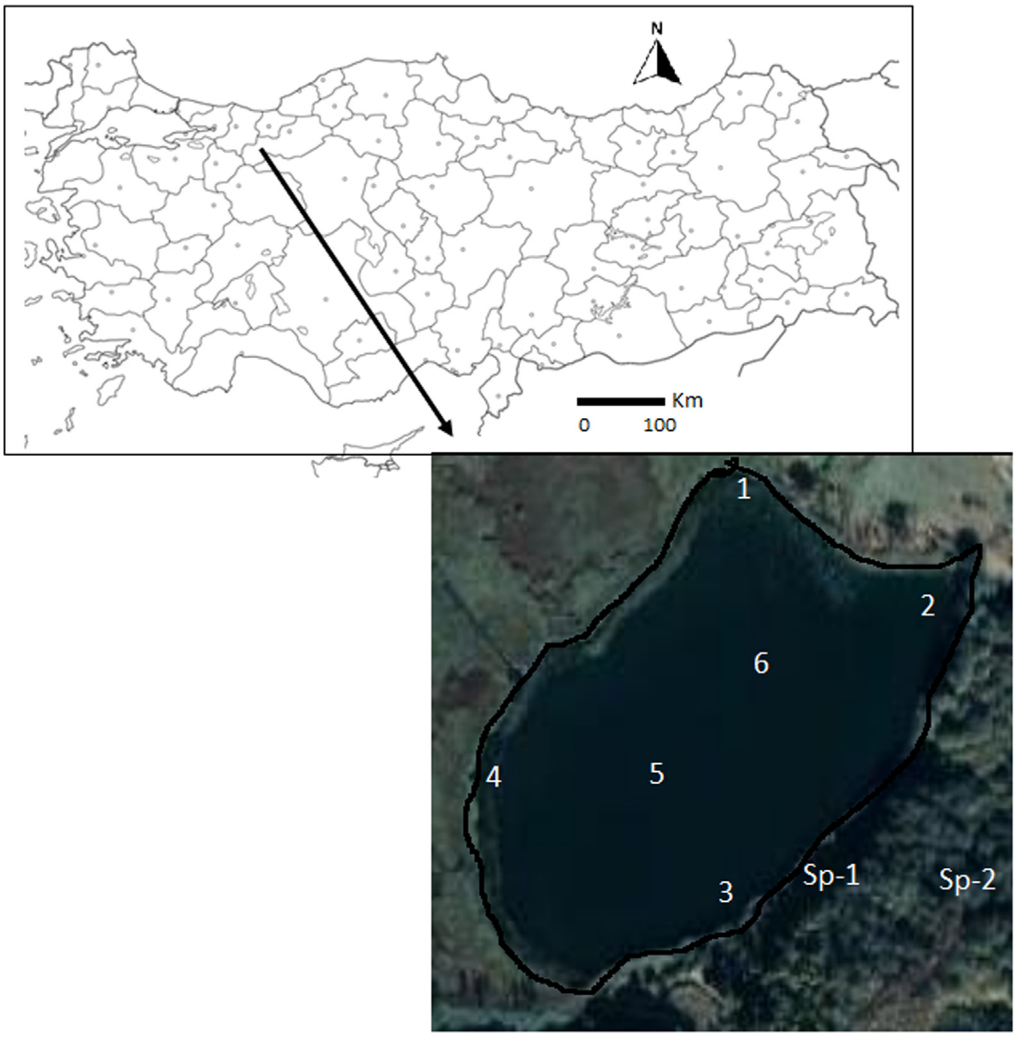

Fig. 1. Sampling stations in and around Lake Karamurat (Mudurnu, Bolu, Turkey). As explained in the text, sampling was irregular from stations 5-6 and Sp-1 (spring run reaching to the lake) and Sp-2 (head of an unnamed rheocrene spring).

whichenvironmental factors significantly correlate with ostracod occurrence patters in Lake Karamurat. CCA was run using CANOCO for Windows version 4.5 (ter Braak, 1986). A detrended correlation analysis (DCA) was run first to evaluate suitability of CCA. Monte Carlo test with 499 permutation was applied with CCA. Rare species were deleted to reduce the arc-effect, and only independent variables (*i.e.*, environmental variables) with inflation factors <10 were retained (ter Braak and Barendregt, 1986; Birks *et al.*, 1990). C2 program with a transfer function of weighted averaging regression was used to calculate ecological tolerance (tk) and optimum (uk) values for each species (Juggins, 2003). Species monthly occurrences were illustrated by Ostracod Watch Model (OWM) (Külköylüoğlu, 1998). The model provides figurative representation of a species monthly and/or seasonal occurrence patterns. This is the first model used in such a case. Accordingly, the followings are the characteristics of the model: (i) it makes interpretation possible about species ontogeny (although this was not the aim of the present study), (ii) it simplifies long-term occurrence patterns of species, (iii) it provides an easy way to compare seasonal occurrences of two or more species reported from different habitats, (iv) it gives possibility of comparing species occurrences among the sites, and (v) figurative results aid to relate ecological data with species occurrences. The pseudorichness ratio (Rp = noncosmopolitan/cosmopolitan) of the lake was calculated to estimate dominancy of cosmopolitan (co) over noncosmopolitans (nc) species (Külköylüoğlu, 2013). Hypothesis of the pseudorichness "...there is no statistically significant difference between the numbers of cosmopolitan and noncosmopolitan species distribution in the lake" was tested along with the three scenarios below (see discussion for the details):

- Case 1) nc / co > 1, number of cosmopolitans < number of noncosmopolitan.
- Case 2) nc / co = 1, equilibrium point.
- Case 3) nc / co < 1, number of cosmopolitans > number of noncosmopolitan.

Table 1. Mean, maximum (Max), and minimum (Min) values of environmental variables and occurrences of live taxa. Missed sampling dates (n values). Additional sample (sampling date 7/27/2019) was collected from a shallow water body in front of an unnamed rheocrene spring located about three km south of the lake. Abbreviations: Tw, water temperature (°C); Atm, atmospheric pressure (mmHg); DO (%), oxygen saturation (%); DO, dissolved oxygen concentration (mg L^{-1}); SEC, standard (at 25 °C) electrical conductivity (μS cm^{-1}); EC, electrical conductivity (μS cm^{-1}); TDS, Total dissolved solids (mg L^{-1}); Sal, salinity (ppt); Ta, air temperature (°C); Chill, wind chill (°C); Rh, relative humidity (%); HI, heat index (°C); Dp, dew point (°C); Wind, wind speed (ms^{-1}); Species abbreviations: CO, *Cypria ophtalmica*; DS, *Darwinula stevensoni*; NN, *Neglecandona neglecta*; CC, *Candona candida*; Csp1, *Candona* sp.1.; CV, *Cypridopsis vidua*; Cysp1, *Cypridopsis* sp.1; COv, *Cyclocypris ovum*; NM, *Notodromas monacha*; IB, *Ilyocypris bradyi*; PS, *Potamocypris cf. similis*; PF, *Psychrodromus cf. fontinalis*; PO, *Psychrodromus olivaceus*; j, juvenile.

		Tw	Atm	DO%	DO	SEC	EC	TDS	Sal	pH	Ta	Chil	Rh	HI	Dp	Wind	Taxa
Station 1	Mean	18	701	88.8	7.7	223	192	145	0.1	8.4	20	17.8	63	20	13	0.53	CO, DS, NN, CC, Csp1, CV, Cysp1, IB
	Max	26	705	182	13	393	402	255	0.2	9.2	29	29.3	90	32	23	1	
	Min	5.3	697	63.7	5.3	129	113	84	0.1	7.5	3.8	0.04	9.8	4.1	0	0	
Station 2	Mean	16	701	71.4	7.1	222	185	144	0.1	8.4	19	17	64	20	13	0.41	CO, DS, NN, Csp1, CV, COv, NMj
	Max	26	705	93.4	12	376	385	245	0.2	8.7	29	28.4	97	35	28	1.4	
	Min	4.6	696	13.2	1.3	131	115	85	0.1	7.5	5.3	0.04	9.8	5.5	0.4	0	
Station 3	Mean	18	702	86.6	8.6	229	201	149	0.1	8.1	18	17.4	68	18	12	0.81	CO, DS, NN, Csp1, CV, NM
	Max	27	706	171	19	369	378	241	0.2	9.3	30	29.4	81	30	22	2.4	
	Min	4.9	697	35.1	2.8	137	127	88	0.1	5.7	5.7	4.8	46	5.7	0.6	0	
Station 4	Mean	15	702	81.2	8.4	196	156	127	0.1	8	17	16.7	68	23	16	0.87	CO, DS, CCj, Csp1, CV, Cov, NM
	Max	25	706	136	16	329	218	214	0.2	8.6	28	28.8	88	82	72	2.4	
	Min	5	698	56.2	4.8	133	117	86	0.1	5.9	6.5	6.9	46	6.6	2	0.1	
Station 5	Mean	16	701	73.8	7.8	176	139	111	0.1	8	23	24.9	68	22	20	1.4	CO, DS, NN, Csp1, CV
	Max	25	703	97.7	12	209	145	137	0.1	8.5	23	24.9	68	22	20	1.4	
	Min	6.7	698	40.4	3.6	143	132	93	0.1	7	23	24.9	68	22	20	1.4	
Station 6	Mean	17	700	93.2	7.6	155	137	109	0.1	7.97	25	24	72	27	20	0.8	CO, DS, CV
	Max	24	703	94.2	11	199	137	127	0.1	8.51	25	24	72	27	20	0.8	
	Min	6.8	697	92.1	3.4	125	137	92	0.1	7.31	25	24	72	27	20	0.8	
Spring 1	Mean	11	701	98.4	11	219	173	160	0.1	8.4	19	19.7	68	36	14	0.23	CO, DS, COv, IB, PS, PF, PO
	Max	13	706	120	13	394	285	257	0.2	9.2	30	28.9	100	184	26	0.7	
	Min	9.6	697	80.2	8.7	29	106	92	0.1	7.5	4.3	4.4	48	4.3	2.7	0	
Spring 2	Mean	11	700	101	11	250	184	163	0.1	8.2	17	15.8	66	16	12	0.14	NN, Csp1, IB, PF, PO
	Max	12	704	119	13	405	297	269	0.2	8.5	25	25.4	84	28	23	0.4	
	Min	11	695	88	9.6	193	142	125	0.1	7.6	6.3	5.8	46	6.1	3.8	0	
Additional	7/27/2019	13	71	87.4	9.4	170	130	110	0.1	8.6	27	26.4	77	30	22	0.4	PF

3 Results

3.1 Limnoecology of the Lake Karamurat

Maximum length, width and depth of Lake Karamurat was 310 m, 186 m, and 9.25 m, respectively while Secchi disk transparency was about 4.5 m. The lake is monomictic (vertical mixing once per year). It receives inflow from two springs and has a single outflow. There was no significant difference in the mean values of the variables Tw, EC, DO, pH among stations ($P > 0.05$, *t*-test with unequal variances). Lake Karamurat is a well-oxygenated (8.38 mg L^{-1}), alkaline (pH 7.95), freshwater lake (EC 145 μS cm^{-1}) with cool average water temperature 15.33 °C. The humidity around the lake area averaged 68.44%, and air temperature averaged 22 °C during the study (Tab. 1).

3.2 Ostracod assemblages

Ten living taxa (Tab. 2, Supplementary material) were found with *Darwinula stevensoni* and *Cypria ophtalmica* being the dominant species at nearly all stations (Fig. 2). A rare species, *Notodromas monacha*, was collected from the lake in May and June. *Potamocypris cf. similis*, *Psychrodromus cf. fontinalis* and *P. olivaceus* was only reported from spring stations. Common (*i.e.*, cosmoecious species) species generally exhibited higher tolerance and lower optimum values (Tab. 3) than rare species. This corresponds to the known literature. Among the variables, Tw, DO, pH and EC appeared to have the greatest effect on species occurrences and accounted for 91% of the correlation between species and environmental variables in CCA (Fig. 3 and Tab. 4). CCA diagram also displayed a separation of the spring and lake water samples (Fig. 3) where DO seems to be the most effective variable on the spring fauna.

There was a significant ($P < 0.05$) difference in the number of species collected per month, suggesting that species distribution was not constant over time. Shannon–Wiener (S–H') alpha diversity (2.079) was lower than several other lakes in the region (Tab. 5). This was also supported by the other diversity indices. The number of species reported was significantly different ($P < 0.01$) among the 13 assessed lakes. Lake Karamurat exhibited similar species diversity and significant positive correlation (Fig. 4) and clustering relationship with two lakes (Lake Abant and Lake Yeniçağa) located

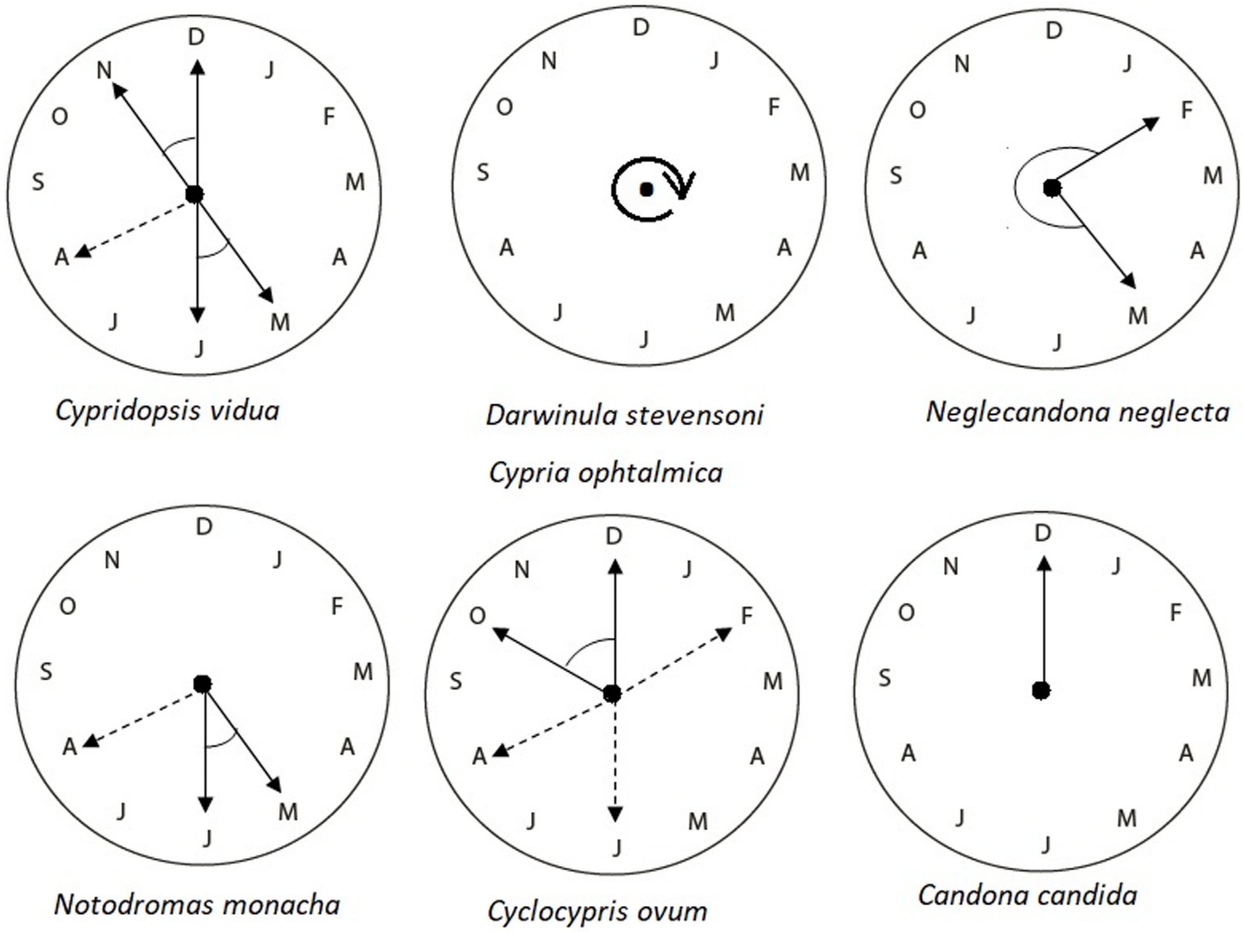

Fig. 2. Ostracod Watch Model (OWM) of seven species reported from Lake Karamurat. Months (January, February, March...) are shown with the capital letters as J, F, M, respectively. Angels indicate species occurrences, full circle shows all year around occurrences, broken lines display species occurrences for that of particular month.

Table 2. Habitat type and designation as cosmopolitan (C) or noncosmopolitan (NC).

Taxa	Habitat	C	NC
Cypria ophtalmica	lake	1	
Darwinula stevensoni	lake	1	
Neglecandona neglecta	lake	1	
Candona candida	lake	1	
Candona sp.1	lake	1	
Cypridopsis vidua	lake	1	
Cypridopsis sp.1	lake	1	
Cyclocypris ovum	lake		1
Notodromas monacha	lake		1
Ilyocypris bradyi	lake/spring	1	
Potamocypris cf. similis	spring		1
Psychrodromus cf. fontinalis	spring		1
Psychrodromus olivaceus	spring	1	

within the same geographic region (Fig. 5). Concluding the pseudorichness hypothesis, a significant difference ($P < 0.05$) between the mean number of cosmopolitan and noncosmopolitan species was detected. The pseudorichness ratio (noncosmopolitan/cosmopolitan species) (Case 3) of the lake ($Pr = 0.25 < 1$) illustrates dominancy of cosmopolitan species (8 spp.) over noncosmopolitans (2 spp.). Each species has its own species-specific ecological preference and occurrence pattern, but species with overlapping patterns exhibited similar ecological characteristics. Lake Karamurat is being impacted by human activities and warrants strict conservation programs.

- Case 1) nc / co > 1, number of cosmopolitans < number of noncosmopolitan.
- Case 2) nc / co = 1, equilibrium point.
- Case 3) nc / co < 1, number of cosmopolitans > number of noncosmopolitan.

4 Discussion and conclusion

4.1 Species diversity

Both alpha diversity ($H' = 2.08$; H′-variance = 0.05; Exp $H' = 8$ spp) and Pielou J evenness values of the lake were lower than many other lakes in Turkey (Tab. 5). Species richness (8 spp.) was below the mean value (10.5) of lakes compared

Table 3. Ecological optimum (Opt) (species tend to show relatively high abundance values and occurrences), and tolerance values (Tol = species tolerance value for studied environmental variables) of 13 taxa reported from the Lake Karamurat and springs. Abbreviations: Count (numbers of species occurrences); Max (maximum numbers of adult individuals); Hill′s coefficient (N2 = value or measure of effective number of species occurrences); TW, water temperature; DO (dissolved oxygen); EC (electrical conductivity).

				Tw		DO		EC		pH	
Taxa	Count	Max	N2	Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
Cypria ophtalmica	48	201	21.21	18.54	7.62	7.45	2.80	317	526.1	8.19	0.54
Darwinula stevensoni	43	121	11.34	19.72	5.60	6.61	2.46	341.9	609.2	8.3	0.38
Neglecandona neglecta	15	10	10.06	16.13	6.80	7.47	3.32	183.7	95.85	8.24	0.35
Candona candida	2	6	1.324	7.014	0.92	11.5	0.95	126.7	3.18	7.54	0.01
Candona sp.1	12	6	6.541	16.87	6.75	7.39	1.97	227.6	407.14	8.4	0.68
Cypridopsis vidua	10	8	6.025	14.04	9.00	8.65	2.66	146.7	22.319	8.08	0.64
Cypridopsis sp.1	1	1	1	20.60	5.71	6.31	2.12	175.9	224.17	8.26	0.44
Cyclocypris ovum	7	9	4.308	6.461	8.24	8.82	4.08	142.2	24.69	7.62	1.03
Ilyocypris bradyi **	6	32	1.67	10.32	3.77	10.5	1.42	145.6	23.42	7.63	0.55
Notodromas monacha	5	2	4.455	16.73	12.2	6.11	1.27	417.3	703.16	8.35	0.15
*Potamocypris cf. similis**	1	1	1	9.60	5.71	10.7	2.12	150.9	224.17	7.45	0.44
*Psychrodromus cf. fontinalis**	10	61	3.41	11.67	1.19	10.2	1.21	144.1	32.15	8.48	0.22
*Psychrodromus olivaceus**	7	31	4.237	11.07	0.75	11.7	1.17	150.4	18.631	8.21	0.32

*Spring water species.
**Species found in both lake and springs.

here. Although species richness, and species diversity may not be the only criterion for selecting sites to protect (Volvenko, 2011), they can be useful to identify conservation priorities (Singh *et al.*, 2021). Because of its structure, species evenness may also be uniquely informative for conservation and management decisions (Hill, 1973). Lower evenness values indicate the presence of rare species that are more prone to anthropogenic activities. The low alpha and evenness values suggest that Lake Karamurat may be impacted by anthropogenic activities, perhaps from residents living around the lake, including fishing and water withdrawal for irrigation. Such activities may impact water quantity and habitat quality, resulting in an ostracod assemblage dominated by cosmopolitan species (but see below).

4.2 Pseudorichness ratio and cosmoecious species

We rejected our hypothesis that the mean number of species would not differ among investigated lakes. Relative to the other lakes, Lake Karamurat was relatively species poor and had a low pseudorichness ratio. The pseudorichness ratio (Pr = 0.25) indicated dominancy of cosmopolitan species over noncosmopolitan species. Prevalence of agricultural fields and human settlements around the lake may negatively impact species diversity and evenness. However, I am not aware of previous studies on lake conditions, so cannot compare past and present water quality and conditions. Nevertheless, dominancy of at least eight common species supports long-term physicochemical fluctuations. As stated above, almost all these common species are tolerant of a wide range of ecological conditions. They are widely distributed among a variety of habitats. Külköylüoğlu (2013) called this kind of species cosmoecious. Such species are less affected by changes in water quality. In disturbed habitats, cosmoecious species may dominate over rare and/or endemic species. Lorenschat *et al.* (2014) showed that cosmopolitan species of Lake Ohrid were common in the northern parts of the lake where anthropogenic activities were high, and suggested that changes in physicochemical characteristics (*e.g.*, Tw, EC, pH) can favor those species with high tolerances. Similar results were observed in lakes and other water bodies in Turkey (Külköylüoğlu *et al.*, 2017; Gürer and Külköylüoğlu, 2019), and in the current study, we also found that such factors were strong predictors of community composition and favored cosmoecious species (Çapraz *et al.*, 2022). Accordingly, we predict that managing water quality is a more sufficient way to conserve diverse species assemblages.

4.3 Species assemblages and autecology

Not all of the Lake Karamurat ostracods were cosmopolitan. The rare species, *N. monacha*, is of special importance. The genus, *Notodromas*, includes six extant species from Holarctic (Nearctic + Palearctic) and Oriental zoogeographical regions (Meisch *et al.*, 2019). Members of the genus have been reported from different aquatic habitats including lakes, ponds, reservoirs, rivers and streams (Meisch, 2000; Smith *et al.*, 2022). There are two representatives of the genus in Turkey, *N. monacha* and *N. persica,* reported from a well, ponds, and lakes (Gülen, 1982; Dügel *et al.*, 2008; Yavuzatmaca *et al.*, 2018). *N. monacha*, along with *N. persica* and *Cypris pubera,* was first reported from an irrigation well (4 m diameter × 10 m depth) in Bodrum (Muğla, Turkey) by Gülen (1982). Individuals were collected on May 7, 1977, when the water temperature of the well was 18 °C. Since then, the species has only been reported rarely from lake littoral zones, always in relatively low abundance. This is also the case in the present study. Finding the species from May, June and August corresponds to the previous records from Turkey (Dügel *et al.*, 2008; Yavuzatmaca *et al.*, 2018; Akdemir *et al.*, 2020)

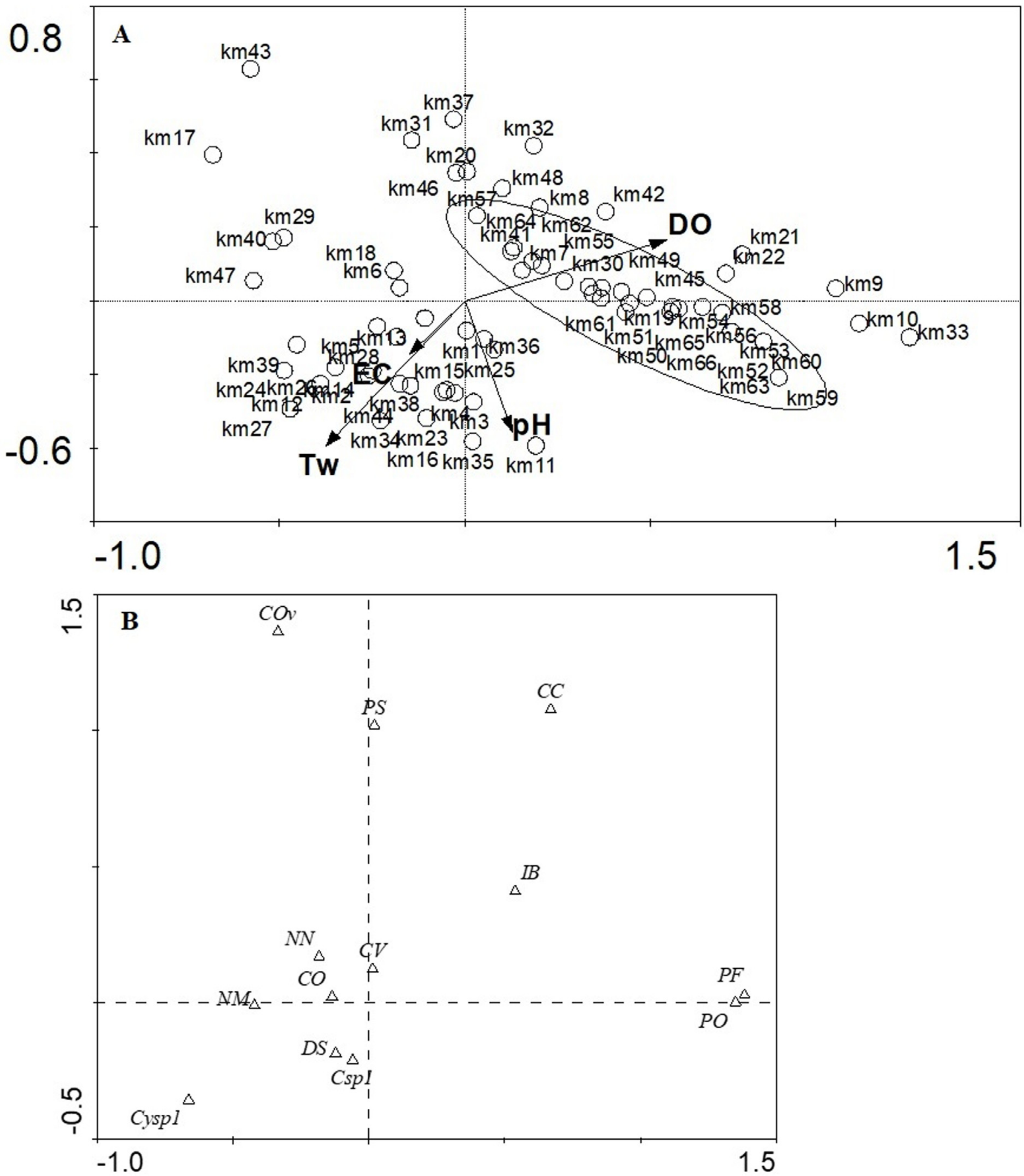

Fig. 3. CCA diagram showing correspondence between (A) Four environmental variables (DO, Tw, pH, EC) and stations, and (B) Species. Oval circle covers mostly spring samplings. Each sampling (km1, km2, ...) represents sampling number from Lake Karamurat. Rest of the abbreviations are given in Table 1.

and elsewhere (Petkovski, 1959, 1977; Hiller, 1972). For example, Hiller (1972) reported the species from shallow aquatic waters in Germany between May and August (water temperature ranged from 16.9 to 25.8 °C, respectively) while Petkovski (1977) found the species from the littoral zones of Lake Mindel (Germany) in June, when water temperature was recorded as 26 and 28 °C. Kiss (2002, 2007) encountered the species from two lakes (Kõhegyi and Fehér) in Hungary from April to October. Although knowledge about its ecological preferences is limited, it seems that this species is very active (due to its long swimming setae) in lentic habitats where it prefers cool and well oxygenated water (Külköylüoğlu *et al.*, 2008; Yavuzatmaca *et al.*, 2018; Akdemir *et al.*, 2020).

In contrast to *N. monacha*, two common species, *D. stevensoni* and *C. ophtalmica*, were the most common species in the lake. *D. stevensoni* is widely distributed in a variety of lentic and lotic nonmarine habitats (Meisch, 2000;

Table 4. Results of CCA. Eigenvalues reported in here are canonical and correspond to axes constrained by the environmental variables.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.149	0.052	0.016	0.007	2.785
Lengths of gradient	4.395	2.834	2.491	1.828	
Species-environment correlations	0.406	0.527	0.204	0.209	
Cumulative percentage variance of species data	5.4	7.2	7.8	8.0	
Cumulative percentage variance of species-environment relation	66.6	89.9	97.0	100.0	
Sum of all eigenvalues					2.785
Sum of all canonical eigenvalues					0.224

Table 5. Shannon-Wiener (S-H′) alpha diversity and Pielou J evenness values of 14 water bodies.

Site name	Pielou J Evenness	S-H′	Variance H′	Expexted H′
Lake Eğirdir	0.769	2.996	0.0237	20
Lake Usak	0.356	1.386	0.0937	4
Seben dam	0.534	2.079	0.0546	8
Reservoir Aladağ	0.500	1.946	0.0612	7
Reservoir Gölköy	0.591	2.303	0.0450	10
Lake Samlar	0.695	2.708	0.0311	15
Reservoir Gölcük	0.460	1.792	0.0694	6
Lake Yeniçağa	0.591	2.303	0.0450	10
Lake B.Cekmece	0.695	2.708	0.0311	15
Lake Çubuk	0.728	2.833	0.0276	17
Lake Sünnet	0.638	2.485	0.0382	12
Lake Karagöl	0.282	1.099	0.1111	3
Lake Abant	0.638	2.485	0.0382	12
Lake Karamurat	**0.534**	**2.079**	**0.0546**	**8**
All Sample Index	0.911	3.548		
Jackknife Std Error	0.032	0.124		

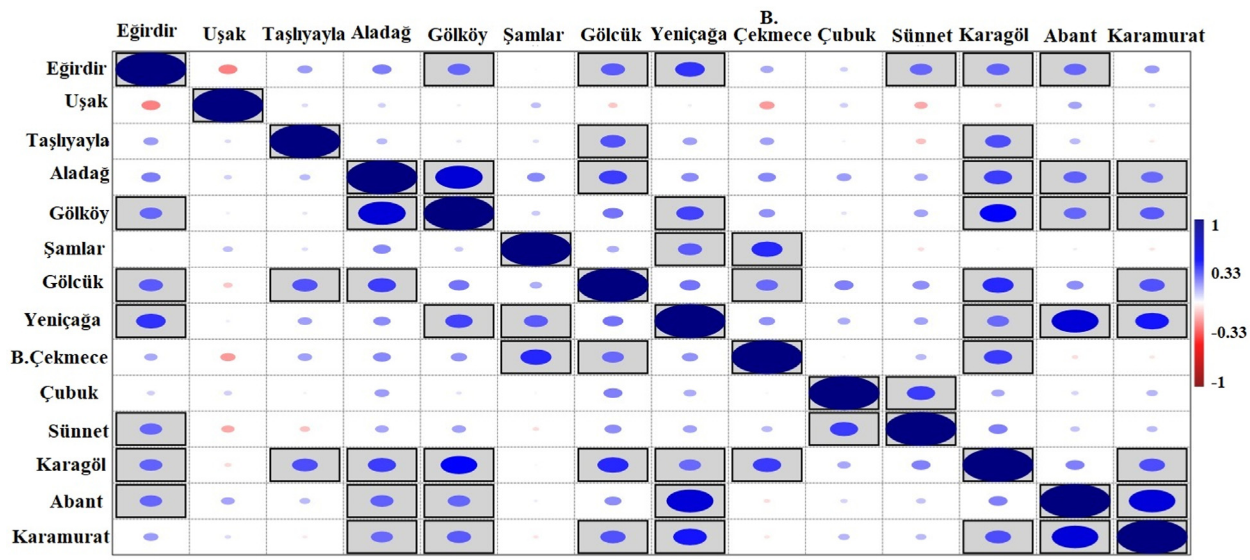

Fig. 4. Spearman correlation analysis. Size of blue (positive correlation) and red (negative correlation) colored elipse is proportion to strenth of correlation.

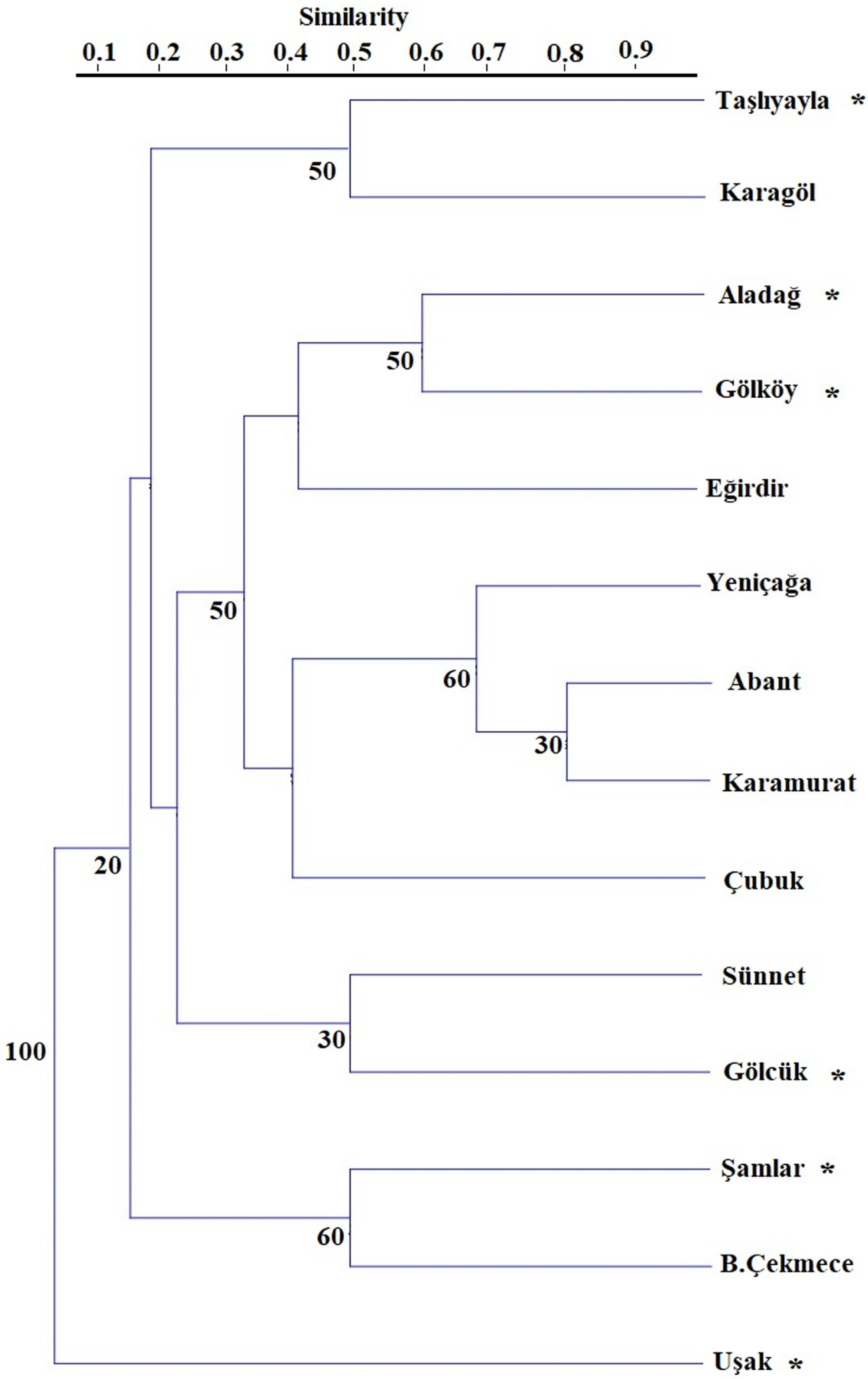

Fig. 5. Dendrogram based on Jaccard similarity values among eight natural lakes and six artificial (*) reservoirs. Lake Usak is used as the outgroup, based on its isolation, differences in species composition, and lowest species diversity.

Rossi *et al.*, 2004; Yavuzatmaca and Külköylüoğlu, 2019). The species lacks swimming setae and occupies shallow and deep benthic habitats of lakes, occurring year around (*cf.* Fig. 2). It prefers cool and oxygenated water but is tolerant of broad environmental conditions (Yavuzatmaca *et al.*, 2015). In the CCA diagram (Fig. 3), the species is located nearby the variable water temperature. This supports its close relationship to the temperature. Similar preferences were also found in earlier studies (Bronstein, 1947; Ranta, 1979; Külköylüoğlu, 2000; Meisch, 2000).

Unlike *D. stevensoni*, *C. ophtalmica* has long natatory setae on the second antenna and is able to swim. The widely distributed species has been generally encountered from the deeper parts of large water bodies such as lakes and ponds but is also known from streams, wetlands, canals, springs and caves (Bellavere *et al.*, 1999; Meisch, 2000; Rossetti *et al.*, 2006; Alkalaj *et al.*, 2019; Külköylüoğlu *et al.*, 2022). The species has comparatively high ecological tolerances to several environmental variables (Külköylüoğlu *et al.*, 2022). The species was encountered year around in the current study, as previously documented (Meisch, 2000; Martins *et al.*, 2010; Külköylüoğlu *et al.*, 2014, 2022). The species is located closer to the center of the CCA diagram, suggesting that its presence is not strongly correlated with measured environmental variables. Similar results were reported by Külköylüoğlu *et al.* (2022) who noted relatively high tolerance levels for the species.

Neglecandona neglecta is another common, bottom-dwelling species reported from the lake. Its seasonal occurrence pattern was like the two previous species (*D. stevensoni*, *C. ophtalmica*), except that *N. neglecta* was not found between the months February and May. Eurychronal occurrences in a variety of lotic and lentic habitats have previously been reported for this cosmopolitan species (Karanovic, 2012; Yavuzatmaca *et al.*, 2018). The broad distribution of the species has been attributed to broad tolerance to different abiotic factors (Meisch, 2000; Batmaz *et al.*, 2020). *N. neglecta* was among the two other common species with high tolerance to water temperature and dissolved oxygen (Tab. 3). It is surprising that the species was not encountered from February through May. *N. neglecta* may have a unique seasonal occurrence pattern in the lake, although the explanation remains unclear.

Unlike the most common eurychronal species discussed above, three species (*Cypridopsis vidua*, *Cyclocypris ovum*, *Candona candida*) displayed stenochronal occurrence patterns within some month(s) or season(s). Seasonality of two taxa (*Candona* sp.1., *Cypridopsis* sp.1) is not discussed here due to lack of identification at the species level. Among the stenochronal species, *C. vidua* occurred in spring-summer (May-June) and fall-winter (November-December) (Fig. 2). Although the species is common worldwide and occurs in variety of habitats (lakes, ponds, pools, springs, reservoirs, ditches, canals *etc.*), it is generally not encountered during winter. This pattern was recently refuted by Gürer and Külköylüoğlu (2019) who monitored its occurrence in a natural lake (Lake Karagöl) in Turkey for more than a year. The authors showed that *C. vidua* can be found all year round because it can grow one or two generations (Meisch, 2000). *C. vidua* is highly tolerant to a wide range of ecological factors. For example, Sánchez-Bayo and Goka (2007) demonstrated experimentally that *C. vidua* tolerated high amounts of insecticide (*i.e.*, imidacloprid), commonly used in rice fields. The species has been recorded from eutrophic lakes, such as Lake Mendota (USA) (Kitchell and Clark, 1979), and a eutrophic wetland (Külköylüoğlu, 2005). In addition to its broad ecological tolerance, the species is a good swimmer. High mobility can contribute to increased survival and may contribute to its worldwide distribution.

Cyclocypris ovum primarily occurred from November to December although individuals were occasionally collected in other months (Fig. 2). According to the Janz (1988), *C. ovum* has one generation per year and always occurs in low abundance although numbers increased during summer (in June). This was due to the death of the adults from earlier generation (Janz, 1988). These observations corroborate previous studies. For example, Mesquita-Joanes *et al.* (2002) collected the species from a karstic lake in Spain (Lake La Cruz) and showed that adults survived about 6–8 months in *in vitro* conditions. The authors reported that numbers of adults declined in summer and juveniles vanished until the next hatch. The species is one of several common species that plots around the center of the CCA biplot (Fig. 3). This species has very long natatory setae which aid in movement and dispersion. Like *C. vidua, C. ovum*'s high ecological tolerance contributes to a broad distribution and occurrence in a variety of aquatic habitats.

C. candida is a stenochronal species present in low numbers during a single sampling event. Interestingly, the species is very common elsewhere (Meisch, 2000), often co-occurring with *C. ophtalmica*, *I. bradyi*, *C. neglecta*, and *D. stevensoni*. Like *D. stevensoni*, this species is benthic and globally distributed. With one generation, adults live seven to nine months (Alm, 1915), but occurrence patterns vary depending on environmental conditions. For example, Hartmann and Hiller (1977) documented males and females year-round, suggesting a eurychronal occurrence. The authors stated that its occurrence may be correlated to water temperature below 18 °C during summer months. Only five females and a male were found in 7.2 °C water in December. However, these findings cannot be generalized at the moment due to lack of data.

I. bradyi was the only species found from both lake and spring habitats. In the lake, only a single female was observed in June (but valves and carapaces were collected from several months) while it was observed more frequently in spring habitats in different months. *I. bradyi* is one of the most common and widely distributed species from a variety of lotic and lentic ecosystems. The reasons for its scarcity in Lake Kara Murat is not clear, but may be related to water temperature. The mean of water temperature in the springs was 11.3 °C (9.6–12.2 °C) throughout the study while the lake temperature was 24.9 °C in June.

Three taxa occurred in the springs, but not the lake: *Potamocypris cf. similis, Psychrodromus cf. fontinalis,* and *Psychrodromus olivaceus*. *P. cf. similis* exhibited subtle morphological differences from the type specimens, that included color and carapace structure. We leave its' identity open for further taxonomic investigation, so general conclusions about its ecology and occurrence cannot be discussed. However, the species often co-occurs with *P. olivaceus*, which is another common species reported from springs and/or cold and well oxygenated spring-fed waters. Külköylüoğlu *et al.*, (2015) observed these two species year-round in a rheocrene spring in Turkey and noted that Mg/Ca ratio varied in *P. similis* but not in *P. olivaceus*. Variability in the stable isotope values for *P. similis* suggested that the species may show seasonal responses to environmental changes while stable isotope values for *P. olivaceus,* suggests a more stable habitat (*i.e.* groundwater) (Külköylüoğlu *et al.*, 2015). Overall, *P. olivaceus* has a much broader geographical distribution and higher environmental tolerance ranges relative to *P. similis*. Unlike *P. olivaceus* and *P. similis*, there is little information about *P. cf. fontinalis* (see details in Meisch, 2000). *P. cf. fontinalis* was generally encountered from June to November (excepting a single individual in February). Hence, its seasonality apparently overlaps with *P. olivaceus*. That these three species were apparently restricted to cold spring waters strongly supports the idea that they prefer a relatively stable and narrow range of environmental conditions (*i.e.*, cold, well-oxygenated slightly alkaline water bodies), as previously reported.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Supplementary Material

The Supplementary Material is available at https://www.limn.org/10.1051/limn/2022017/olm.

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