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Correlational patterns of species diversity, swimming ability and ecological tolerance of non-marine ostracoda (Crustacea) with different reproductive modes in shallow water bodies of ađrı region (Turkey)

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ABSTRACT

A total of 52 ostracod taxa (35 live spp. 17 subfossils) were collected from 70 shallow aquatic bodies with 11 different habitat types in Ađrı province (Turkey). *Fabaeformiscandona acuminata* is a new record for the Turkish ostracod fauna while 29 species were new for the province. Three types of habitats (stream, ditch and pond) contained the highest numbers of 24, 15, 11 species, respectively. Species were clustered into four main groups based on their distribution among habitats. Canonical Correspondence Analysis was able to explain 73.9% of the correlation between the 18 most frequently found species and five environmental variables. Water temperature and elevation were found to be the most effective factors on ostracods. Species with and without swimming setae tend to be found mostly in lentic and lotic habitats, respectively. Besides, species with swimming setae showed relatively higher ecological optimum and tolerance values for pH, electrical conductivity and water temperature than species without setae. The numbers of non-swimmer sexually reproducing species were twice the number of parthenogenetic species. Parthenogenetic species tend to have higher tolerance and optimum values for different environmental variables than sexual species. Results suggest a strong correlation among reproductive modes, swimming ability and ecological tolerances of the species.

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Introduction

Understanding how species inhabit their habitat(s) is crucial for several reasons, such as estimating patterns of species distribution, analyzing suitability of habitats, calculating species diversity, and using the information in habitat management (Hall et al. 1997;

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Krausman 1999; Akdemir and Külköylüoğlu 2011; Uçak et al. 2014; Yavuzatmaca et al. 2015; Külköylüoğlu et al. 2016). Species may or may not be found together in the same types of habitat depending on spatial and temporal conditions. When their habitat requirements are different, species diversity may be increased by habitat diversity. Accordingly, one may consider some kind of mutual relationship between species and habitat diversity (but see details in McGuinness 2000). This idea can also be applied for ostracods.

Ostracods, being small (ca. 0.5–5.5 mm) aquatic invertebrates, can be found in almost all kinds of aquatic habitats from deep sea (5000 m b.s.l.) (Benson 1972; Brandão and Yasuhara 2013) to high mountain waters and lakes (>4000 m a.s.l.) (Laprida et al. 2006; Mischke et al. 2007) as long as the habitat conditions are suitable (Külköylüoğlu and Sarı 2012; Uçak et al. 2014). Hence, variability of dispersion within this wide elevation range (ca. 10,000 m) in a variety of aquatic habitats may also be related to species broad ecological tolerances along with different adaptive values (Külköylüoğlu, Akdemir, et al. 2012, Külköylüoğlu and Sarı 2012, Külköylüoğlu, Sarı, et al. 2012, Külköylüoğlu, Yavuzatmaca, et al. 2012). They are one of the most abundant and diverse taxonomic groups in Crustacea and show different reproductive modes. Some species are only known as parthenogenetic (only females found in the population) while some others represent sexual (both males and females present) or mixed populations (McKenzie 1971; Butlin et al. 1998). According to Chaplin et al. (1994), parthenogenetic ostracod species can have better survival chances in freshwater habitats where environmental conditions are more or less stable. In contrast, species with sexual reproduction can do better in habitats where conditions are more changeable. Thereby, ostracods show different species-specific responses to those changes in environmental conditions and factors (Wise 1961; Delorme 1991; Külköylüoğlu 2003; Külköylüoğlu et al. 2003).

Ostracods having a pair of calcified valves, can walk, crawl, climb, swim and even jump in the water by using their extremities with a combined motion of their first (A1) and second antenna (A2). Detailed knowledge about the taxonomic and evolutionary importance of these characters has already been outlined in the literature (Martens 1987; Maddocks 2000; Meisch 2000; Karanovic 2005; Smith and Kamiya 2008). Almost all freshwater ostracods carry setae on A1 while the presence or absence of setae on A2 is one of the more distinguishing differences frequently used in taxonomic keys. The swimming ability (and eventual escape behavior) of ostracods not only helps them change their location in water but in turn also affect the availability and vulnerability of them to predators (e.g. fish). If presence or absence of a character (i.e., swimming setae) allows non-marine ostracods to survive in different habitats, the character or trait can be considered of “adaptive value”. The character(s) can also help offspring succeed in new environments (Ghalambor et al. 2007) when its occurrence can be correlated to habitat type and/or conditions in which species tend to be found more often.

A few previous studies (e.g. McGregor and Kesling 1969; Kamiya 1988) revealed that ostracods’ soft body parts as much as carapace shape were important for their reproductive and copulatory behavior in relation to their adaptation to different (micro)habitats. Indeed, swimming setae can greatly help ostracods’ movement ability. For example, Higuti et al. (2007) demonstrated that the number of swimming ostracods increased more during wet than dry seasons in the Parana River floodplain (Brazil). Similarly, Szlauer-Lukaszewska (2008) reported that species without swimming setae were more frequently found on the river bottom than in flooded basins nearby in Odra River (Poland). Most recently, Akdemir et al. (2016) found that non-swimmer ostracod species collected from a

variety of aquatic bodies of Gaziantep province in Turkey preferred lotic habitats more than lentic habitats (but see Discussion).

Although these studies showed the importance of the extremities for ostracod success in different habitats and/or conditions, they did not focus on possible relationships among ostracods' reproductive modes, species diversity, ecological tolerance and swimming abilities. On the other hand, species habitat selection can be affected directly or indirectly by its reproductive success and survival chances as ultimate reasons (Hilden 1965; Litvaitis et al. 1996).

Thus, the aims of this study are to (1) complete the first extensive study on ostracods in Ağrı province, (2) reveal regional (gamma) species diversity in the area, (3) estimate and compare ecological tolerance and optimum levels between parthenogenetic and sexually reproducing species, and (4) seek possible association for habitat preferences of the species with or without swimming setae on A2.

Materials and methods

Site description

Our study area includes the province (aka city) of Ağrı (39°05'–40°07'N, 42°20'–44°30'E) located at 1640 m a.s.l., covering ca. 11,376 km² of surface area in east of Turkey (Ağrı 2017). Because of high mountain ranges consisting of an Alpine-Himalayan volcanic system from east to west, the area is known for its harsh climatic conditions where winters are long and severe while summers are hot. Büyük Ağrı Dağı (Büyük Ağrı Mountain) is located in the area and is the highest peak in Turkey and Europe with about 5137 m of elevation. The average annual precipitation of the area is about 529 mm where the average air temperature is about 6.1 °C.

Sampling and laboratory analyses

We randomly collected 115 samples from 11 different aquatic habitat types (lake, pond, pool, wetland, river, stream, waterfall, spring, ditch, trough, thermal water) in Ağrı Province during 13–17 May 2014 (Figure 1). Twelve variables (pH, dissolved oxygen (DO, mg/l), per cent oxygen saturation (% sat.), water and air temperature (T°C), electrical conductivity (EC, µS/cm), total dissolved solids (TDS, mg/l), salinity (ppt), atmospheric pressure (mmHg), moisture (%), wind speed (m/s), elevation (m)) were recorded *in situ* (Table 1). A Testo 410-2 model anemometer was used to record air temperature, wind speed and air moisture while basic geographical data (elevation) were recorded with a geographical positioning system (GARMIN Etrex Vista H GPS). The other variables were measured by YSI Multi Professional Plus.

Each sample collected with a hand net (200 µm in mesh size) from not deeper than 100 cm of depth was fixed in 70% ethanol in plastic containers (250 ml) *in situ* after water quality measurements were taken. Samples were kept in a cooler during the field work and brought back to Limnology Laboratory of Department of Biology where each sample was washed and filtered through standard sized sieves (0.5, 1.0, 1.5 and 2.0 mm mesh size) under tap water and kept in 70% ethanol. Individual specimens were separated from the bulk material under a stereomicroscope (Olympus ACH 1X) but only adults were mounted in lactophenol solution. Carapaces and valves were kept in micropaleontological slides. During taxonomic description done under a light microscope (Olympus BX-51), both soft body parts and carapace structures were used following the taxonomic key of

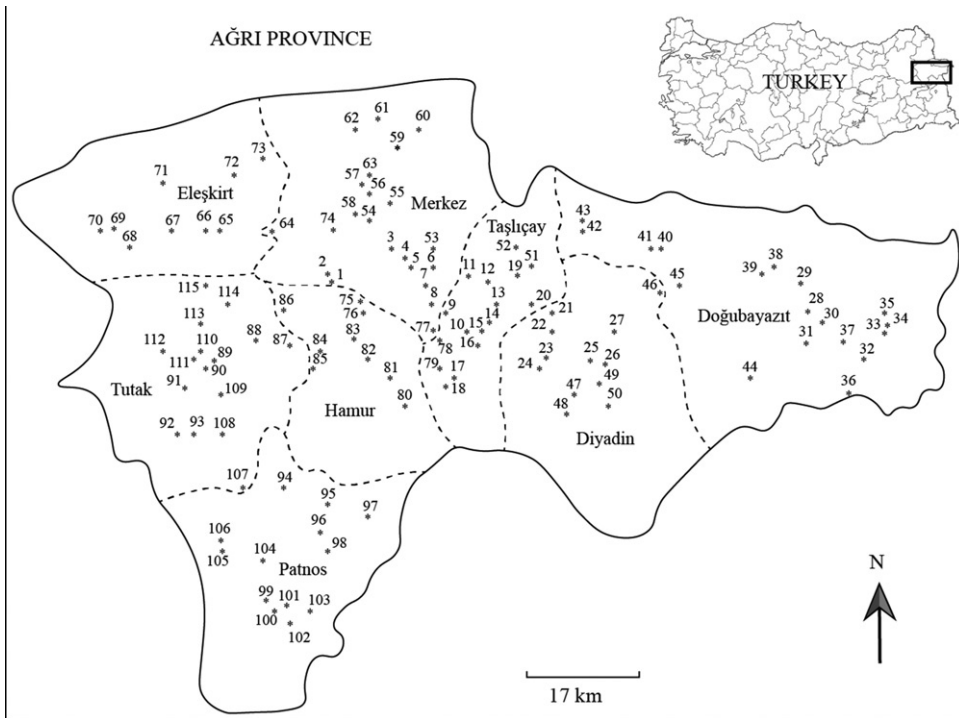


Figure 1. Total of 115 sampling sites in Ağrı.

Table 1. Mean, maximum (Max), minimum (Min), and standard deviation (Std) of 12 environmental variables measured from 70 of 115 different aquatic sites of Ağrı.

	pH	DO	%DO	EC	Tw	Ta	Atmp	Moist	Wind	Elev	Sal	TDS
Mean	8.34	6.5	65.54	547.7	17	21.6	613.9	44.1	4.75	1816	0.3	0.41
Max	9.75	11.1	109.8	10983	28	34.2	638.6	92.3	17.7	2370	6.6	7.48
Min	6.38	1.71	14.6	35.2	6.3	10	572.9	20.6	0	1489	0	0.03
Std	0.51	2	17.84	1298	5.3	5.91	15.32	13	3.66	207	0.8	0.89

Atmp = atmospheric pressure (mmHg); DO = dissolved oxygen (mg/l); %DO = per cent oxygen saturation (% sat.); EC = electrical conductivity ($\mu\text{S}/\text{cm}$); Elev = elevation (m); Moist = moisture (%); Ta = air temperature ($^{\circ}\text{C}$); TDS = total dissolved solids (mg/l); Sal = salinity (ppt); Tw = water temperature ($^{\circ}\text{C}$); Wind = wind speed (m/s).

Meisch (2000) and Karanovic (2012). Species dissected with males are assumed to have sexual reproduction while species without males are considered as parthenogenetics. Slides and other materials were deposited in the Limnology Laboratory of Abant İzzet Baysal University Bolu, Turkey and are available upon request.

Statistical analyses

Canonical Correspondence Analysis (CCA), a multivariate ordination technique, was used to understand most effective environmental factors on ostracod species. During which, rare species were removed and the data was long-transformed and tested with Monte Carlo Permutation test (499 permutation) (ter Braak 1987; Birks et al. 1990; McGarigal et al. 2000). We also ran Detrended Correspondence Analysis (DCA) (software package CANOCO for Windows 4.5) to confirm the suitability of our data for CCA. We found length of gradient in DCA as 3.2, suggesting that our data was good for CCA.

C2 software program with a transfer function of weighted averaging regression (Juggins 2003) was used to estimate tolerance and optimum values of 18 ostracod species (found at least 3 or more times in different sites) for five environmental variables. As stated by ter Braak and Barendregt (1986), optimum estimates are proportional to the frequency of species in the habitats sampled. Since species occurrence frequencies can vary depending on geographical, biological and/or environmental conditions of habitats, levels of tolerance and optimum values may show variations among the species. Accordingly, knowledge of species tolerance and optimum estimates can be used to evaluate present and future habitat conditions.

We used the Coleman heterogeneity test for species occurrence patterns in 11 different aquatic habitats. This method allows us to compare the levels of heterogeneity of habitats (Coleman 1981). If the expected curve shows a sharp increase or deviation from the origin, heterogeneity of habitats is greater than our expected values by random sampling only (Coleman et al. 1982; Colwell and Coddington 1994).

Also, alpha (Shannon-Wiener Diversity index) and beta species diversity values were calculated in Species Diversity and Richness version 4 program (Seaby and Henderson 2006). The range of S-W index values were considered between 1.5 (low) and 3.5 (maximum) (Magurran 1988).

The analysis of Similarity Percentage (SIMPER) was applied to determine the similarities and percentage contribution of individual ostracod species and habitats. The analysis based on Bray-Curtis measure of similarity makes it easy to point the species with the most important observed patterns of similarities amid others. Besides, Two Way Indicator Species Analysis (TWINSPAN) was used to show clustering relationships of the species among habitats. At each division, the effective habitat(s) where species tend to be found more are shown. The last two analyses were provided in the Community Analyses Package (CAP 4.1.3.) program (Seaby and Henderson 2007). Additionally, t-test with unequal variances (at 0.05 critical levels) in Microsoft Excel 2010 program was used to compare the mean numbers of parthenogenetic and sexual species with or without swimming setae on the second antenna.

Results

During the present study, 17 taxa (referring to those undescribed of sub fossil specimens at species level) and 35 species (*Candona neglecta*, *Cyclocypris ovum*, *Cypria ophthalmica*, *Cypridopsis vidua*, *Cypris pubera*, *Eucypris virens*, *Fabaeformiscandona acuminata*, *F. brevicornis*, *F. fabaeformis*, *Herpetocypris chevreuxi*, *H. helenae*, *Heterocypris incongruens*, *H. salina*, *Ilyocypris bradyi*, *I. decipiens*, *I. gibba*, *I. inermis*, *I. monstifica*, *Limnocythere inopinata*, *Paralimnocythere relictata*, *Plesiocypridopsis newtoni*, *Potamocypris arcuata*, *P. fallax*, *P. similis*, *P. smaragdina*, *P. variegata*, *P. villosa*, *Prionocypris zenkeri*, *Pseudocandona albicans*, *Psychrodromus fontinalis*, *P. olivaceus*, *Stenocyprina fischeri*, *Tonnacypris lutaria*, *Trajancypris clavata*, *T. serrata*) were found in 70 out of 115 aquatic sites of 11 different habitat types located at high altitudes ranging from 1489 m to 2370 m a.s.l. in Ağrı province (Table 2). Among the species, *F. acuminata* was a new record for Turkish ostracod fauna and 29 species were new for the area. Accordingly, the total number of living ostracod reported from Ağrı reached up to 39 species.

The most common three species were found in 8 (*Candona neglecta*, *Ilyocypris bradyi*) and 7 (*Heterocypris incongruens*) of 11 different aquatic types. SIMPER results outlined the fact that these three species alone were responsible for about 70% of the total similarities (Table 3) along with highest Shannon-Wiener alpha (Table 4) values (2.079, 2.079,



Table 2. Binary (presence and absence) data of 35 ostracod species (with (w) or without (wo) swimming setae (Setae) on A2) from 11 different aquatic habitats along with their reproductive mode (Mode).

Species	Code	Lake	Trough	Stream	Pond	River	Cold Spring	Ditch	Pool	Wetland	Hot spring	Waterfall	Mode	Setae
<i>Candona neglecta</i>	Cn	1	1	1	1	1	1	1	1	1		1	s	wo
<i>Fabaeformiscandona acuminata</i>	Faa									1			s	wo
<i>Fabaeformiscandona brevicornis</i>	Fbe			1									p	wo
<i>Fabaeformiscandona fabaeformis</i>	Ff						1	1					s	wo
<i>Ilyocypris bradyi</i>	Ib			1	1	1	1	1	1	1		1	p	wo
<i>Ilyocypris inermis</i>	Ii		1	1									s	wo
<i>Limnocythere inopinata</i>	Li			1									s	wo
<i>Paralimnocythere relicta</i>	Pr				1								s	wo
<i>Potamocypris fallax</i>	Pf			1					1				p	wo
<i>Potamocypris similis</i>	Psi			1									p	wo
<i>Prionocypris zenkeri</i>	Pz			1									p	wo
<i>Pseudocandona albicans</i>	Pal			1			1			1			s	wo
<i>Psychrodromus fontinalis</i>	Pof		1										s	wo
<i>Psychrodromus olivaceus</i>	Po			1			1		1				s	wo
<i>Tonnacypris lutaria</i>	Tl				1			1					s	wo
<i>Cylocypris ovum</i>	Cyv	1											s	w
<i>Cypria ophthalmica</i>	Cop	1		1				1		1			s	w
<i>Cypridopsis vidua</i>	Cv			1	1			1					p	w
<i>Cypris pubera</i>	Cpp			1	1			1					p	w
<i>Eucypris vires</i>	Ev			1				1					p	w
<i>Herpetocypris chevreauxi</i>	Hc							1					p	w
<i>Herpetocypris helenae</i>	Hh		1								1		p	w
<i>Heterocypris incongruens</i>	Hi	1		1		1	1	1	1				p	w
<i>Heterocypris salina</i>	Hsa			1	1		1	1					p	w
<i>Ilyocypris decipiens</i>	Id	1		1	1								s	w
<i>Ilyocypris gibba</i>	Ig						1	1					s	w
<i>Ilyocypris monstifica</i>	Im			1									s	w
<i>Plesiocypridopsis newtoni</i>	Pn	1											s	w
<i>Potamocypris arcuata</i>	Pa			1									p	w
<i>Potamocypris smaragdina</i>	Psm			1									p	w
<i>Potamocypris variegata</i>	Pv	1		1	1								p	w
<i>Potamocypris villosa</i>	Pvi			1									s	w
<i>Stenocypris fischeri</i>	Sf	1		1	1		1	1	1				p	w
<i>Trajanocypris clavata</i>	Tc												p	w
<i>Trajanocypris serrata</i>	Ts			1	1			1					p	w
Nu.Htyp.		3	3	24	7	3	6	14	5	3	1	1		
Nu.Spp.		8	5	24	11	2	9	15	6	6	1	2		
Spp/Htyp.		2.7	1.7	1	1.6	0.7	1.5	1.1	1.2	2	1	2		

Code = species code; Nu.Htyp. = numbers of habitat type; Nu.Spp. = numbers of species; p = parthenogenetic reproduction; s = sexual reproduction; Spp/Htyp. = ratio of numbers of species per habitat. Note that several of the parthenogenetic species listed herein may have sexual populations elsewhere but we only used the species we found in here.

Table 3. Outcomes of SIMPER analyses for habitats and the nine most abundant species. Average Similarity (Ave. Simil) for habitats and species are 32.2779 and 28.7681, respectively.

Habitat type	Ave. Abund	Ave. Simil	% Contr.	Cum. %
Stream	0.685714	18.9085	58.5803	58.5803
Ditch	0.428571	5.66866	17.5621	76.1424
Pond	0.314286	2.95843	9.16551	85.3079
Spring	0.257143	1.43428	4.44354	89.7515
Lake	0.228571	1.41298	4.37756	94.129
Species	Ave. Abund	Ave. Simil	% Contr.	Cum. %
<i>Ilyocypris bradyi</i>	0.727273	7.24035	25.168	25.168
<i>Candona neglecta</i>	0.727273	6.72107	23.363	48.531
<i>Heterocypris incongruens</i>	0.636364	6.01166	20.897	69.428
<i>Stenocypris fischeri</i>	0.545455	2.46799	8.57894	78.0069
<i>Cypris ophtalmica</i>	0.363636	0.919092	3.19483	81.2018
<i>Cypris pubera</i>	0.363636	0.845272	2.93823	84.14
<i>Heterocypris salina</i>	0.363636	0.780523	2.71316	86.8531
<i>Potamocypris fallax</i>	0.272727	0.577182	2.00633	88.8595
<i>Psychrodromus olivaceus</i>	0.272727	0.473829	1.64707	90.5065

Ave. Abund = average abundance; % Contr. = contribution in %; Cum. % = cumulative contribution in %.

and 1.95, respectively) when Whittaker beta diversity was 3.326. Three types of habitats (stream, ditch and pond) consisted of the highest number (24, 15, and 11) of species, respectively. Coleman curve (Figure 2) was slightly found above but closer to the observed ostracod species acquisition curve pointing some samples heterogeneity possibly due to random samplings applied during the study. The ratio of swimmers (20 spp.) and non-swimmers (15 spp.) was found to be different for each group. For example, within the groups of swimmers, 65% and 35% of the species were parthenogenetic (13 spp.) or sexually reproducing (7 spp.), respectively. Within the groups of nonswimmers, numbers of species with sexual reproductive mode was twice the parthenogenetics where 67% and 33% of the species were sexual (10 spp.) or parthenogenetic (5 spp.), respectively. The ratio of reproductive mode (17 sexual and 18 parthenogenetic spp.) was not significantly different among the species. However, dominance of each group with or without swimming ability was found to be different; for instance, 41% and 59% of the sexual species were nonswimmers or swimmers while the ratio was significantly different for the parthenogenetic species favoring nonswimmers (72%) over swimmers (28%). Non-swimmer species were abundantly found in shallow and changeable habitats such as trough, spring, pool and wetland while swimmer species were most common in deeper and relatively stable habitats such as lake, stream, pond, ditch and thermal waters (Table 2). Based on species occurrences amid different habitat types (Figure 3), TWINSpan dendrogram separated species in four main clustering groups. Besides, swimmer species exhibited higher optimum and tolerance values for pH, EC, Tw, and DO (for optimum value) than non-swimmer ostracods. Regardless of their swimming ability, in general, parthenogenetic species illustrated higher tolerance and optimum values for these variables herein used than sexual species (Table 5). CCA diagram displayed 73.9% of the correlation between 18 most frequently occurring species and five environmental variables with low variance (8.9%) where water temperature ($p = 0.042$, $F = 1.743$) and elevation ($p = 0.002$, $F = 3.721$) were the most effective factors on ostracods (Figure 4).

Discussion and conclusion

Hartmann (1964) was the first scientist to report one species (*Heterocypris rotundata*) from two samples of swamp water at Toprak Kale region of Ağrı. Most recently, Rausuli et al. (2014) reported 10 species (*Cypris pubera*, *Eucypris virens*, *E. lilljeborgi*, *Trajancypris*

Table 4. Shannon-Wiener (H) alpha species and habitat diversity index values (2.107, 3.301) were found relatively higher than in many other areas of Turkey.

Species	H	Var H	Exp H
<i>Candona neglecta</i>	2.079	0.0546	8
<i>Ilyocypris bradyi</i>	2.079	0.0546	8
<i>Heterocypris incongruens</i>	1.946	0.0612	7
<i>Stenocypris fischeri</i>	1.792	0.0694	6
<i>Cypria ophthalmica</i>	1.386	0.0937	4
<i>Cypris pubera</i>	1.386	0.0937	4
<i>Heterocypris salina</i>	1.386	0.0937	4
<i>Cypridopsis vidua</i>	1.099	0.1111	3
<i>Ilyocypris decipiens</i>	1.099	0.1111	3
<i>Potamocypris fallax</i>	1.099	0.1111	3
<i>Potamocypris variegata</i>	1.099	0.1111	3
<i>Pseudocandona albicans</i>	1.099	0.1111	3
<i>Psychrodromus olivaceus</i>	1.099	0.1111	3
<i>Trajancypris serrata</i>	1.099	0.1111	3
<i>Eucypris virens</i>	0.6931	0.125	2
<i>Fabaeformiscandona fabaeformis</i>	0.6931	0.125	2
<i>Ilyocypris gibba</i>	0.6931	0.125	2
<i>Ilyocypris inermis</i>	0.6931	0.125	2
<i>Limnocythere inopinata</i>	0.6931	0.125	2
<i>Tonnacypris lutaria</i>	0.6931	0.125	2
All Samp Ind	2.107		
Jackknife Std Err	0.09971		
Lake	2.079	0.057	8
Trough	1.609	0.08	5
Stream	3.178	0.019	24
Pond	2.398	0.041	11
River	0.693	0.125	2
Spring	2.197	0.049	9
Ditch	2.708	0.031	15
Pool	1.792	0.069	6
Wetland	1.792	0.069	6
Thermal	0	0	1
Waterfall	0.6931	0.125	2
All Samp Ind	3.301		
Jackknife Std Err	0.1962		

All Samp Ind = All Sample Index; Exp H = expected diversity values; Jackknife Std Err = Jackknife Standard Error; Var H = variance in diversity.

serrata, *T. clavata*, *Heterocypris incongruens*, *H. rotundata*, *H. barbara*, *Potamocypris villosa*, *P. unicaudata*) from five (three temporary water bodies and two lakes) sites in Ağrı. Three of their species (*E. lilljeborgi*, *H. barbara*, *P. unicaudata*) were new reports for the area. During the present study, we did not find these four species previously reported by these authors. In sum, at the moment, there are 39 ostracod species known from Ağrı which showed the highest known alpha diversity value (2.14) reported in Turkey. Actually, comparing the number of species and considering those undescribed taxa (not listed here) suggests that species diversity of the area is much higher than what we know at the present. Three species (*C. neglecta*, *I. bradyi*, *H. incongruens*) were highly responsible for the results of finding high values of occurrences. Indeed, these species or so called “cosmoecious species” (Külköylüoğlu 2013) not only have broad geographical distribution but also have wider tolerance ranges than many (if not all) other freshwater ostracods in the world. During the present study, they contributed almost about 70% of the total similarities among the sites. These results correspond with those of previous studies in Turkey (Sarı and Külköylüoğlu 2010; Akdemir and Külköylüoğlu 2014; Yavuzatmaca et al. 2015, 2017; Külköylüoğlu et al. 2017a, 2017b) where these species along with a couple of others increased the similarity values among the habitats studied. Although biotic

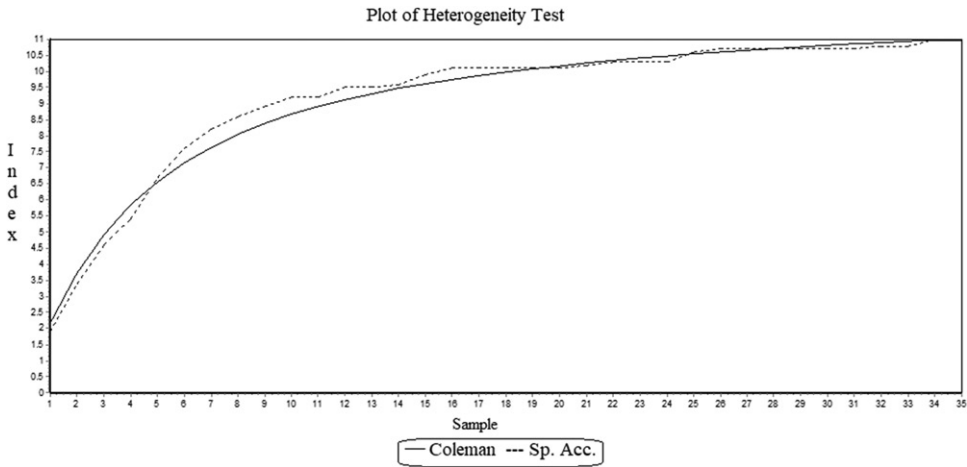


Figure 2. Coleman plot of heterogeneity test compares Coleman curve (solid line) and Species accumulation (Sp. Acc.) (dotted line).

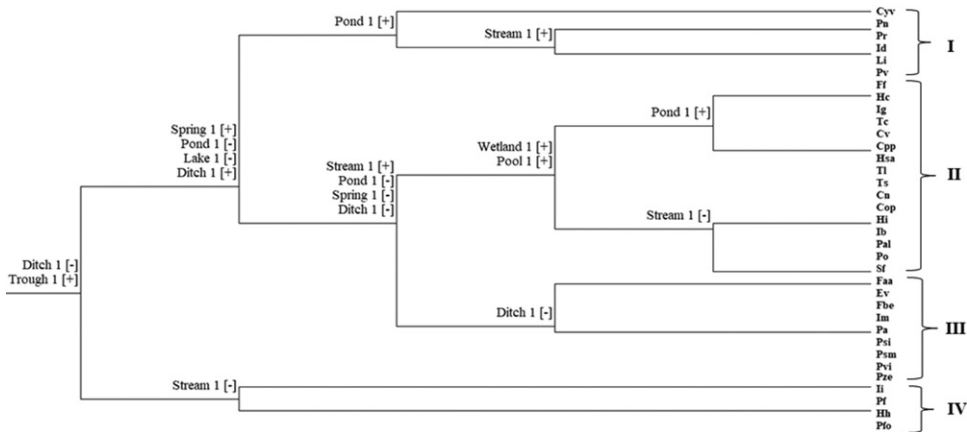


Figure 3. Twinspan dendrogram. Species are clustered into four groups (I–IV) on the right hand side while habitats are shown in each node of division. Values (+ and –) in paranthesis show right or left side of the branch. For abbreviations see Table 2.

factors (i.e., competition, predation) can affect diversity and richness, this part is out of the scope of the present study and not discussed here. However, frequent co-occurrence patterns and dominance of these species can be affected by a variety of abiotic factors such as habitat type, water quality and seasonality as well. For example, when Rossetti et al. (2004) did not find any of these three species mentioned above out of 19 species in 16 wetland sites of Northern Italy, Iglukowska and Namiotko (2012) reported the highest number of species from lake sites and the lowest from peat-bogs in Lapland (Poland) although these species were not dominant. In Germany, Scharf and Viehberg (2014) collected ostracods from the historical town moat of Bremen where *I. bradyi* and *C. neglecta* were subdominant but *H. incongruens* was absent. In contrast, none of the species found during the present study was reported from polygon ponds in the tundra of the Indigirka Lowland, north-east Siberia (Schneider et al. 2016). Notwithstanding the presence of differences among the habitats, previous works (e.g. Klkylođlu, Akdemir, et al. 2012, Klkylođlu and Sari 2012, Klkylođlu, Sari, et al. 2012, Klkylođlu, Yavuzatmaca,

Table 5. Tolerance (Tol) and optimum (Opt) values of 18 species that occurred in at least three or more sites in Ağrı province during the study.

Species	Count	Max	N2	pH Opt	Tol	DO Opt	Tol	EC Opt	Tol	Tw Opt	Tol	Elev.	
												Opt	Tol
<i>Candona neglecta</i>	20	23	7.6	8.36	0.36	6.39	1.82	432	355	17	7.43	1884	260
<i>Cypria ophtalmica</i>	6	19	2.4	8.57	0.45	7.8	2.18	209	154	11.7	4.59	2157	259
<i>Cypridopsis vidua</i>	7	9	4.14	8.44	0.64	5.81	2.66	313	153	20.1	8.02	1744	133
<i>Cypris pubera</i>	6	51	1.68	8.01	0.44	4.71	2.02	525	111	17.3	2.44	1776	136
<i>Heterocypris incongruens</i>	19	71	5.62	8.36	0.44	5.92	1.89	1226	1620	19.2	7.1	1759	179
<i>Heterocypris salina</i>	6	25	2.16	8.45	0.3	7.58	2.09	469	63	20	2.71	1686	82.3
<i>Ilyocypris bradyi</i>	30	163	7.74	8.21	0.61	7.77	3.06	503	195	18	4.7	1797	113
<i>Ilyocypris decipiens</i>	3	97	1.19	8.54	0.26	6.13	1.5	804	74.6	19.8	5.22	1638	79.6
<i>Ilyocypris gibba</i>	3	29	1.21	8.22	0.3	6.19	0.72	676	119	22.1	6.61	1672	169
<i>Ilyocypris inermis</i>	3	4	2	8.6	0.14	5.69	1.9	331	38	18.9	4.77	1750	184
<i>Limnocythere inopinata</i>	4	71	1.17	8.55	0.09	7.19	1.5	451	47.8	20.7	1.83	1652	50.8
<i>Potamocypris fallax</i>	6	15	3.59	8.52	0.25	7.37	1.17	137	126	11	3.69	2015	254
<i>Potamocypris variegata</i>	3	151	1.61	8.93	0.52	4.1	1.49	444	293	24	12.2	1620	110
<i>Prionocypris zenkeri</i>	3	151	1.08	8.65	0.34	5.16	0.51	367	46.9	20	1.79	1669	18.1
<i>Pseudocandona albicans</i>	5	4	3.57	8.25	0.34	6.91	1.3	335	163	18.7	6.79	2009	353
<i>Psychrodromus olivaceus</i>	6	17	3.3	8.39	0.27	6.15	1.11	438	286	14.5	4.28	1951	114
<i>Stenocypris fischeri</i>	11	209	3.96	8.4	0.43	4.35	1.46	535	182	20.6	4.17	1649	72.1
<i>Trajancypris serrata</i>	4	109	1.8	8.53	0.22	6.58	1.21	661	216	18.6	4.64	1783	334

Count = numbers of occurrences; DO = dissolved oxygen, mg/L; EC = electrical conductivity, μ S/cm; Elev. = elevation, m; Maxi = maximum numbers of individuals; N2 = Hill's coefficient value or measure of effective number of occurrences; Tw = water temperature, $^{\circ}$ C.

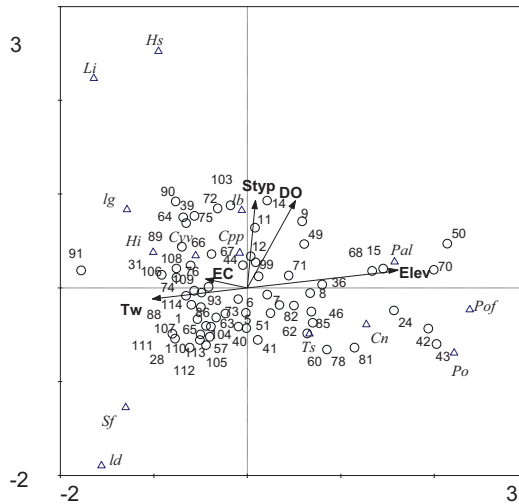


Figure 4. CCA digrams illustrates correlation between 18 species (triangles) and five most effective environmental variables (arrows) from 75 sites (circles). For abbreviations see Tables 1–2.

et al. 2012; Uçak et al. 2014; Yavuzatmaca et al. 2015, 2017) clearly pointed out and suggested that natural habitats (e.g. ponds, streams, springs, and creeks) with relatively high alpha values appear to contain higher ostracod diversity and abundance than artificial habitats. Indeed, during the present study, we found supportive evidence that species tend to be more abundant and diverse in three types of aquatic habitats (streams, ditches and ponds) than others.

The number of species with (20 spp.) or without (15 spp.) swimming setae was different. It seems that occurrence of the setae can be related to habitat types and some of those effective factors. For example, we found that shallow or temporary aquatic

habitats with unpredictable conditions tend to have more non-swimmer species (or these kind of species prefer such habitats) than deeper and relatively stable habitats where swimmers are common. Although there were no data on the ratio provided by the author, Hoff (1942) stated that species with or without setae were common in stagnant and flowing waters of Illinois, USA. Also, comparing the species characteristics in the moats of Bremen and Greifswald (Germany), Scharf and Viehberg (2014) stated that two swimming species (*Cypria ophthalmica*, *Cypridopsis vidua*) were not found in Greifswald because of relatively faster water flow velocity. These two species prefer stagnant waters. The authors also provided the ratio between nonswimmer and swimmer species in Bremen moats and Greifswald as 9:12 and 5:2, respectively. During the present study, the ratio between nonswimmers to swimmers was 15:20 (or 3:4) similar to Bremen. All these results indicate that species habitat preferences appear to be correlated to their swimming abilities.

The ratio of swimmers and nonswimmers was critically important within each group. For example, within the groups of swimmers, 65% and 35% of the species were parthenogenetic (13 spp.) or sexual (7 spp.). In contrast, numbers of nonswimmer species with sexual reproductive mode was twice that of the parthenogenetics where 67% and 33% of the species were sexual (10 spp.) or parthenogenetic (5 spp.), respectively. Regardless, the swimming ability, numbers of species with different reproductive mode (17 sexual and 18 parthenogenetic spp.) was not significantly different between them. However, within each group, dominance of species with or without swimming ability was found different; for instance, 41% and 59% of the sexual species were nonswimmers or swimmers, respectively. Contrary to this, the ratio was significantly different for the parthenogenetic species favoring nonswimmers (72%) over swimmers (28%). These results suggest that nonswimmer ostracods with sexual reproduction are better in unpredictable conditions since they are bottoming dependent inhabiting in or around the sediment with relatively low water velocity. This is opposite for swimmers with parthenogenetic reproduction in calm or stagnant waters. Our results are in accordance with previous works. For example, De Deckker (1983) mentioned that parthenogenetic ostracod species were mostly encountered from ephemeral environments while sexual species were found from stagnant habitats such as permanent or temporary lakes. Klkylođlu et al. (2012a) reporting more nonswimmer parthenogenetic species than swimmer sexual species in Ordu (Turkey), argued that sexual ostracods with swimming setae may increase their chance to find food, mate and energy that they demand in stable conditions. Contrary to our expectation, opposite results were also found by Iglukowska and Namiotko (2012) who reported the largest proportion of asexual ostracods (ca. 81.2%) from temporary waters while relatively stable habitats (e.g. peat-bogs and shallow lakes) displayed lower ratios (ca. 11.3%). The authors pointed out that lakes and peat-bogs with generally more stable conditions favor a more sexual reproduction mode than parthenogenetic. What they stated was actually different the results we discussed above (see discussion in De Deckker 2002; Klkylođlu et al. 2012a). One of the possible explanations for this conflict may be based on seasonal differences in their sampling time from different habitat types in Lapland and Poland. It is well known that most of the non-marine ostracods portray differences in their seasonal occurrences (e.g. Hoff 1943; Ferguson 1944; Meisch 2000). Also, habitat types and aquatic conditions can show regional differences; therefore, such conditions may possibly affect species occurrences. However, these authors did not focus on species with or without swimming setae. Having setae may provide free movement in stagnant conditions by means of reducing competitive interactions and occupying different niches in the same habitat

(McLay 1978a, 1978b) but does not significantly help species in flowing or unpredictable waters unless species inhabit littoral zones with no or less flow.

Our CCA diagram revealed that elevation and habitat types (in less extent) were the factors closely related to non-swimmer species while other factors (EC, Tw, habitat type and DO) appeared to be correlated to parthenogenetic swimmer species who show higher tolerance and optimum values for these variables. Similar results were outlined in Ordu (Turkey) by Külköylüoğlu et al. (2012a). Overall, these results may actually help to explain worldwide geographical distribution of many parthenogenetic species in a variety of habitats since they show wide ranges of tolerances. Indeed, TWINSPAN dendrogram clustered species into four different groups based on their occurrence among habitats but failed to distinguish their reproductive modes. It is probable that such failure may be due to habitat heterogeneity (McGuinness 2000) as suggested by Coleman curve and environmental conditions (Kolasa et al. 1998) that play critical role in structuring species distribution.

Finally, from the perspective of evolutionary ecology, the fundamental goal is to understand the processes effective on contemporary patterns of diversity and species richness (Davis et al. 2014). In relation to this view, our results simply imply possible relationships among ostracod species diversity, their habitat preferences along with different swimming ability and reproductive modes. However, this does not apply whether such character(s) is/are environmentally induced variation or not. Besides, we cannot generalize this relationship for other organisms because habitat preferences and/or selection is known as a complex multi-scale process in many animals (Jedlikowski and Brambilla 2017), including ostracods. Nevertheless, our results open a new window for possible future studies.

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Notes on contributors

Okan Külköylüoğlu is a limnecologist working on non-marine Ostracoda. He designed the study, run the statistical analyses, worked on the species identification and wrote the manuscript.

Mehmet Yavuzatmaca helped for sampling, identification and writing.

Derya Akdemir provided help on identification and designing the figures and tables, and writing.

Ozan Yılmaz helped to collect samples, sorting the materials and identification.

Ebru Çelen joined to interpret the data analyses and discussion, and prepared the manuscript for the journal.

Şükran Dere is a hydrobiologist working on phytoplankton, contributed on discussion.

Nurhayat Dalkıran is a hydrobiologist working on phytoplankton, provided discussion and interpretation on the results of the analyses.

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