

ECOLOGICAL CHARACTERISTICS AND HABITAT PREFERENCES OF OSTRACODA (CRUSTACEA) WITH A NEW BISEXUAL POPULATION RECORD (MUĞLA, TURKEY)

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Abstract. In order to compare the ecological characteristics of non-marine ostracods with different reproductive modes, 68 sites including 11 different habitat types were examined in the province of Muğla during July of 2014. A total of 28 taxa were found and 11 of them were new reports for Muğla. Sexual populations of *Psychrodromus olivaceus* and *P. fontinalis* were encountered from the same sampling site. Males of the latter species were reported for the first time from Turkey. The female/male ratio of these species was higher at low altitudes while it was about the same at medium altitudes. Numbers of species in sexual and/or parthenogenetic populations with/without swimming setae and individuals in natural and artificial habitats did not show significant difference ($P > 0.05$). Troughs were described as the richest habitats for ostracods. The first two axes of Canonical Correspondence Analysis explained 66.2% of the relationships between species and environmental variables when the water temperature was the most effective factor on species composition ($P < 0.01$). Results suggest that type of reproductive modes did not show significant relationship with species distribution among different water bodies. Hence, it seems distribution of species is most probably affected by several biotic and abiotic factors.

Keywords: *non-marine species, distribution, natural-artificial habitats, altitudes, swimming ability*

Introduction

Although, freshwater habitats occupy only small parts of the Earth's surface with a ratio of 0.8%, they host approximately 6% of species known in the world (Dudgeon et al., 2006). In this respect, freshwaters are considered to be one of the main sources of biological diversity on the Earth. However, these habitats are known to be affected at global (e.g. climate changes) and local (e.g. species invasion, habitat degradation, water pollution) scales by a variety of biotic and abiotic factors (Dudgeon et al., 2006). Thus, different kinds of habitat destruction lead to changes in species composition, their geographic distribution, and also cause a decrease in species diversity (Finlayson et al., 2013). However, some features of the organisms including (i) morphological characteristics (e.g., to occupy different ecological niches with different movement types (Wiens, 2011), (ii) phenotypic plasticity (e.g., fitting ability of the size and shape

as a response to the changes in environmental conditions (Carbonel et al., 1988)), (iii) biological characteristics (e.g., to tolerate rapid or great environmental changes with different reproductive modes (Cohuo et al., 2015)), and (iv) ecological characteristics (e.g., to endure unpredictable environmental conditions with high ecological tolerance levels (Külköylüoğlu, 2004)) allow species to cope with the changes and elevate their survival chances in a variety of habitats. These biological and ecological features of the species also determine the degree of their distribution and abundance at spatiotemporal scale in relation to habitat conditions (Heino and Tolonen, 2018).

Ostracods, small bivalved crustaceans, are an important part of biological diversity in freshwater habitats with approximately 2330 extant species (Meisch et al., 2019). They can be fossilized due to their carapace (two valves) which consists of low Mg-calcite. The first record of fossil ostracods dates back to Early Ordovician (ca. 485 Ma), and thus ostracods are known as one of the oldest groups in microfauna (Williams et al., 2008). Besides, they have different reproductive modes of sexual, parthenogenetic (asexual) and/or mixed populations, and exhibit specific ecological requirements and species-specific tolerance levels. The different types of reproductive modes of the ostracods can be related to taxonomic and ecological features of particular species (Gülen, 1985a; Cohen and Morin, 1990; Martens et al., 2008) and may depend on geographical and/or ecological isolation (Mayr and Ashlock, 1991). All these features contribute to their widespread geographic distribution and high species diversity and also make them a particularly valuable group for a number of purposes in palaeo- and neoenvironmental studies. If the ostracod species' morphological features and ecological preferences are known, they can be used to estimate water quality conditions and rate of environmental changes (Wagner, 1964; Mezquita et al., 1999; Külköylüoğlu, 2004). In addition, the knowledge of the present-day distributional patterns of ostracods according to their reproductive modes in different region and/or environmental conditions can also be used as an informative marker for non-marine ostracods in the ecological sense.

Studies on ostracods in Turkey exhibited that distribution of both parthenogenetic and sexual populations were widespread throughout the country (Külköylüoğlu et al., 2015; Yavuzatmaca et al., 2017). Nevertheless, the distributional pattern and habitat preferences of species according to their reproductive modes have not been discussed and explained the Muğla province in the south-western part of Anatolia. Therefore, the main aim of the study is to investigate ecological preferences and distribution of species with different reproductive modes among the different aquatic bodies of the region.

Materials and methods

Site description

The province of Muğla, which is located on the south-west corner of Turkey, was chosen as a research area because of the possibility to find a variety of aquatic habitats and the lack of extensive studies on ostracods in this area. It represents typical Mediterranean climatic conditions where summers are very hot, long and dry, winters are cool and rainy. In total, 68 sites containing 11 habitat types (lake, reservoir, pond, pool, ditch, canal, creek, stream, spring water, trough, and waterfall) were randomly chosen from sea level to 1093 m of altitude between the 12 and 15 of July 2014 (Fig. 1).

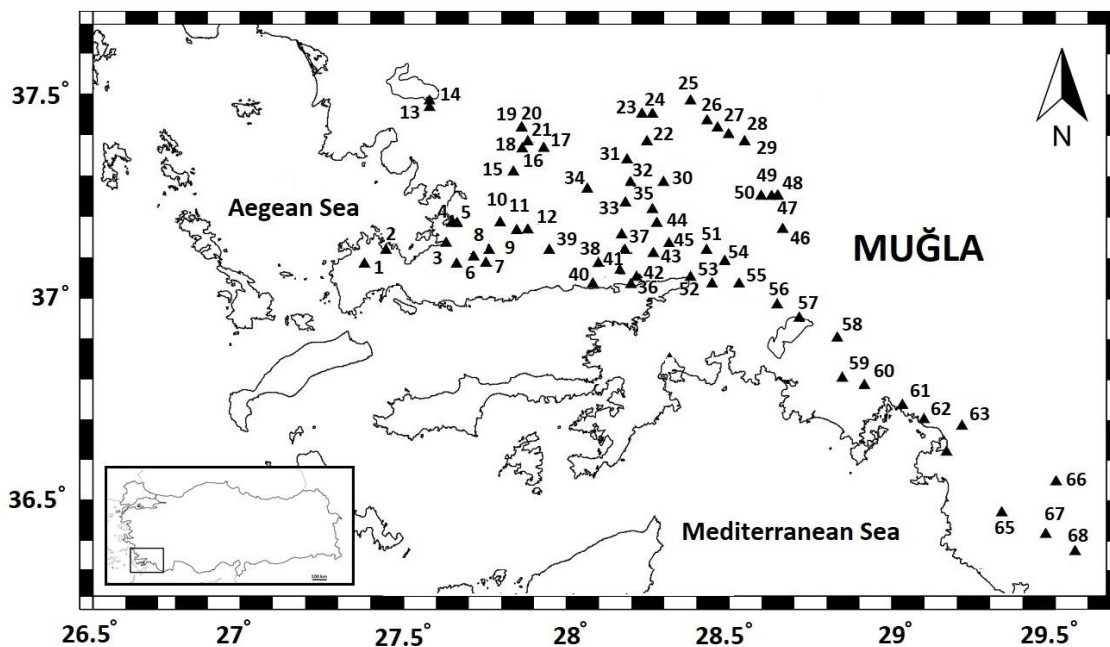


Figure 1. Distribution of the 68 sampling sites in the Muğla province

Sampling and measurements

Ostracod samples were collected with a standard sized hand net (200 μm mesh size) from the surface of sediments within an area of approximately 100 cm^2 and a depth of up to 100 cm. At each site, approximately 100 g of sediments were gathered and fixed with 70% ethanol in 250 ml plastic containers *in situ*. In the laboratory, sediments including ostracods were washed and filtered through 4 standard sized sieves (1.00, 0.25, 0.16, 0.08 mm mesh size) under tap water and fixed in 70% ethanol for long term storage. Ostracod samples were sorted from sediments by using fine needles and Pasteur pipettes under a stereo microscope (Meiji-Techno). Soft body parts of ostracods were separated from the carapace and dissected in Lactophenol – Orange G solution. The carapace and valves were preserved in micropaleontological slides. Subsequently, species identification was carried out under a binocular microscope (Olympus-CX41) based on the dissected soft body parts and carapace structures by using the standard taxonomic works of Broodbaker and Danielopol (1982), Gonzalez Mozo et al. (1996), Meisch (2000) and Karanovic (2012). However, some species were identified at the genus-level because of damaged individuals, lack of soft body parts or only the presence of juveniles.

Environmental variables were measured *in situ* before sampling to avoid possible results of Pseudoreplication (Hurlbert, 1984). Dissolved oxygen (DO, mg L^{-1}), oxygen saturation (S, %), electrical conductivity (EC, $\mu\text{S cm}^{-1}$), water temperature (T_w , $^{\circ}\text{C}$), salinity (Sal, ppt) and total dissolved solids (TDS, mg L^{-1}) of aquatic habitats were measured with a YSI professional plus device (Table A1 in the Appendix). Geographical data (latitude, longitude, elevation) from each sampling site were determined with a Garmin GPS 45 XL (Fig. 1) while air temperature (T_a , $^{\circ}\text{C}$), moisture (Moi, %), wind (m s^{-1}) and atmospheric pressure (Atm, mmHg) were measured with a Testo 410-2 anemometer (Table A1 in the Appendix).

A 100 ml of water was taken from each sampling site in plastic bottles and preserved in a container at 4 °C for the analyses of cations (sodium (Na^{+1}), potassium (K^{+1}), magnesium (Mg^{+2}), calcium (Ca^{+2})), and anions (fluoride (F^{-1}), chloride (Cl^{-1}), sulphate (SO_4^{-2})). Analyses of these major ions were conducted in the laboratory of the Engineering Department of Bolu Abant İzzet Baysal University. The standard method no: 4110 using Ion Chromatography (Dionex 1100) was followed during the analyses. Also, sediment samples were collected from each site in eppendorf tubes for in/organic phosphate and total phosphate (mg kg^{-1}) analyses. In the laboratory, sediment samples were dried in oven at 40 °C (at least 24 h) and were subsequently analyzed according to Ruban et al. (1999) with a sequential extraction procedure (Table A1 in the Appendix).

Statistical analyses

A Detrended Correspondence Analysis (DCA) was applied to confirm the suitability of the data for Canonical Correspondence Analysis (CCA) (ter Braak, 1986). The length of gradient in DCA was calculated as 3.64 referring the suitability of our data for CCA. CCA was performed to estimate most effective environmental variable(s) on species composition by using the CANOCO version 5 program (ter Braak and Šmilauer, 2012). The significance of the environmental variables used in CCA was tested by Monte Carlo permutation test (499 permutations). To eliminate possible multicollinearity, rare species were not used during the analyses. Shannon-Wiener (or Shannon, H') index values were calculated by using a Species Diversity and Richness 4 software (Seaby and Henderson, 2006) to determine the species diversity in different habitat types where the values of H' (1.5 and 3.5) for ecological data suggest poor to rich diversity, respectively. In order to understand possible correlations among species and environmental variables measured here, Spearman Correlation Analyses were conducted in the SPSS program version 6.0. The C2 Software was used to measure ecological tolerance (t_k) and optimum (u_k) estimates of individual species along with Hill's coefficient (measure of effective number of occurrences) (Juggins, 2003). The chi-square test was used to determine whether there was a significant difference between the numbers/abundances of species in sexual and parthenogenetic populations with or without swimming setae in natural and artificial habitats. During the analyses, only adult individuals, occurred at least three or more times in different habitats, were used. The ostracod materials were deposited at the Limnology Laboratory of the Department of Biology, Bolu Abant İzzet Baysal University, Bolu, Turkey. Additional information about the sampling sites and species reported here can be available upon request from the authors.

Results

During this study, a total of 28 taxa (24 living and 4 sub-fossil) were reported among 11 habitat types while 11 of the living species (*Candona weltneri*, *Psychrodromus fontinalis*, *Heterocypris barbara*, *Ilyocypris gibba*, *I. hartmanni*, *Limnocythere inopinata*, *Potamocypris arcuata*, *P. producta*, *P. unicaudata*, *P. villosa* and *Trajancypris leavis*) were new for Muğla. The sexual population of *P. fontinalis* was found for the first time, while *P. producta* was recorded for the second time in Turkey.

The first two axes of the CCA explained about 66.2% of the relationship between 12 species and 5 environmental variables ($F = 2.9$, $P = 0.04$) (Table 1). According to CCA,

the water temperature ($P = 0.008$, $F = 1.8$) showed a significant effect on the ordination of species (Fig. 2). Except *L. inopinata*, four species (*C. neglecta*, *I. bradyi* and *P. olivaceus*, *P. fontinalis*) without (reduced or short) swimming setae on A2 were located on the left side of the CCA diagram, while species with swimming setae were situated on the right side of the diagram. However, one of the species with reduced swimming setae, *Cyprideis torosa*, was placed separately from other species on the CCA diagram (Fig. 2).

Table 1. Summary table of CCA. Test of significance of first axis, $F = 2.9$, $P = 0.04$; and all canonical axes, $F = 1.5$, $P = 0.028$.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.483	0.186	0.173	0.116	7.699
Species-environment correlations	0.763	0.464	0.514	0.413	
Cumulative percentage variance of species data	6.3	8.7	10.9	12.4	
Cumulative percentage variance of species-environment relation	47.8	66.2	83.3	94.8	
	Sum of all eigenvalues				7.699
	Sum of all canonical eigenvalues				1.010

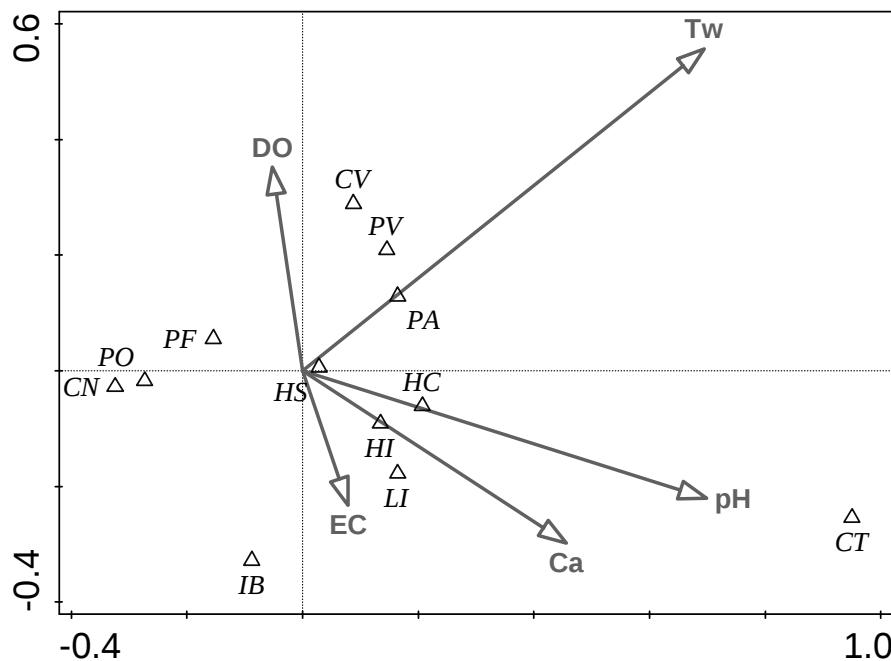


Figure 2. CCA diagram of five environmental variables (arrows) and 12 species (triangle). Abbreviations are given in Tables 4 and A1 in the Appendix

According to the results of Spearman Correlation Analyses, *H. salina* showed negatively significant correlations with *P. olivaceus* and *P. fontinalis* while the correlation was positive with *I. bradyi* ($P < 0.01$). *P. fontinalis* exhibited a negative correlation with *L. inopinata* ($P < 0.01$). Among the species, *C. torosa* indicated strong

and significant positive correlations with Ca^{+2} and Mg^{+2} values of the water bodies, when *P. variegata* showed negative correlation to Ca^{+2} and electrical conductivity ($P < 0.01$). *Potamocypris variegata* displayed low ecological tolerance values for dissolved oxygen, electrical conductivity, Na^+ , Mg^{+2} , and Ca^{+2} when *C. torosa* showed the highest tolerances for total phosphates in the sediment, and several other major ions of the water bodies. Also, *I. bradyi* had the lowest tolerance levels for pH but the highest tolerances for conductivity and water temperature. *Heterocypris salina* displayed the highest tolerance levels for dissolved oxygen and pH (for more details see Table 2).

Table 2. Ecological tolerance (t_k) and optimum (u_k) levels of the 11 species occurred at least three times

Species	Count	Max	N2	DO		pH		Tw		EC		Na		Mg	
				u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k
<i>C. neglecta</i>	3	6	1.68	3.68	1.39	7.24	0.77	18.14	6.98	297.75	235.62	10.16	9.44	3.96	4.15
<i>C. vidua</i>	7	46	3.11	4.45	2.27	7.98	0.41	26.99	5.20	408.68	196.94	4.89	3.47	2.43	2.98
<i>P. olivaceus</i>	15	172	6.63	5.15	2.23	7.44	0.57	17.50	2.98	296.25	211.68	11.29	11.33	4.27	6.52
<i>P. fontinalis</i>	10	146	3.39	7.32	2.94	7.98	0.52	23.57	4.61	567.02	205.16	4.21	6.43	41.75	25.44
<i>H. incongruens</i>	6	265	2.16	5.10	1.94	8.69	0.56	25.82	1.93	563.31	227.39	39.82	38.39	13.93	9.98
<i>H. salina</i>	13	320	3.77	5.18	3.06	7.45	0.82	21.90	3.83	555.33	234.71	12.45	7.38	18.58	19.61
<i>H. chevreuxi</i>	4	105	1.22	3.83	1.82	7.99	0.70	22.66	7.03	339.60	216.42	5.99	19.88	5.51	1.92
<i>I. bradyi</i>	6	67	1.73	9.24	3.04	8.07	0.26	13.10	7.64	328.66	303.95	4.58	8.36	9.01	12.12
<i>L. inopinata</i>	7	60	3.70	6.34	1.28	8.29	0.46	22.96	4.51	549.13	258.97	8.60	6.47	24.55	20.03
<i>P. arcuata</i>	4	85	2.30	4.62	2.85	8.01	0.81	26.84	4.87	374.41	225.98	26.90	12.85	5.18	2.53
<i>P. variegata</i>	4	804	1.24	6.61	0.48	8.15	0.31	31.09	2.88	252.55	43.80	5.22	1.56	2.48	1.45
			Mean	5.59	2.12	7.94	0.56	22.78	4.77	412.06	214.60	12.19	11.41	11.97	9.70
			Min.	3.68	0.48	7.24	0.26	13.10	1.93	252.55	43.80	4.21	1.56	2.43	1.45
			Max.	9.24	3.06	8.69	0.82	31.09	7.64	567.02	303.95	39.82	38.39	41.75	25.44

Abbreviations: Count, numbers of species occurrence; Max, maximum numbers of individuals; N2, Hill's coefficient (measure of effective number of occurrences); u_k , optimum values; t_k , ecological tolerance values. See Tables 4 and A1 in the Appendix for the other abbreviations

Numbers of species with (17 spp.) and without (20 spp.) swimming setae on A2 were not significantly different ($P > 0.05$) between artificial (e.g., trough, reservoir, canal etc.) and natural (e.g., lake, spring, creek etc.) habitats (Table 3). Among the species, 13 species were commonly found in both natural and artificial habitats. Parthenogenetic populations herein were encountered from all of the habitat types, while only five sexual populations (*Candona neglecta*, *C. weltneri*, *N. monacha*, *P. olivaceus* and *P. fontinalis*) were obtained from four natural habitats (spring water, pool, ditch, waterfall), and one artificial habitat (trough). A total of 17 species were represented with parthenogenetic populations but bisexual populations of two (*P. olivaceus* and *P. fontinalis*) of them were also reported in artificial habitats. 12 of 17 species carried swimming setae when five species had reduced setae. All of the obtained specimens of *Potamocypris* spp. have long swimming setae and three of them (*P. producta*, *P. unicaudata* and *P. villosa*) were reported only from the artificial habitats (troughs) with an accompanying swimming species (*Heterocypris barbara*). In contrast, 4 sexual and 17 parthenogenetic species were encountered in natural habitats. Among them, 11 and 9 species were with and without swimming setae, respectively. The species *C. neglecta*, *C. weltneri*, *C. torosa*, and *P. zenkeri* are non-swimmers while *I. decipiens*, *N. monacho* and *T. leavis* are known as swimmers established solely in natural habitats (Table 3).

Table 3. Species occurrences based on their swimming ability and types of reproduction in artificial and natural habitats. Note that sexual and parthenogenetic populations of *P. olivaceus*, also parthenogenetic populations of *P. fontinalis* were found in artificial and natural habitats. On the other hand, sexual population of *P. fontinalis* was found in only artificial habitats. This situation was taken into consideration for total numbers of species

		Artificial habitat	Natural habitat	Total
Sexual species	Without swimming setae	2	3	4
	With swimming setae	-	1	1
Parthenogenetic species	Without swimming setae	5	7	7
	With swimming setae	12	10	14
	Numbers of species	17	20	24
	Numbers of individuals	2388	2081	4469

According to Shannon-Wiener index results, among the habitat types, troughs were shown as the richest habitats with regards to species diversity (up to 14 spp.) (Table 4) and numbers of individuals (2147 of 4469 ind.). On the other hand, numbers of species per site (ca. 0.54) were almost the lowest in troughs in comparison to the other habitats. In addition, although the number of troughs (26) was significantly higher than the creeks (12) and ponds (9), Shannon-Wiener (H') values for troughs ($H' = 2.34$), creeks ($H' = 2.33$) and ponds ($H' = 2.11$) were very close to each other (Table 4). H' values of the other habitats were relatively low and close to or less than 1.5 degree, which implies to be poor in diversity.

Although sexual populations of *P. olivaceus* and *P. fontinalis* are less-known in the literature, sexual population of them were found herein from a trough (Site 37) but individual populations of both species with different reproductive modes were also found from other habitats (Table 5). The dominance of females against males (female-biased sex ratio) was especially remarkable at low altitudes (Sites 15, 16, 33) while the ratio was almost equal at medium altitudes (Table 5).

Discussion

Along with the 28 ostracod taxa herein, the number of recent freshwater ostracod species of the Muğla province is now increased to 49 with the addition of previous reports (e.g. Gülen, 1985a; Aygen et al., 2004).

According to CCA and Spearman correlation analyses, the water temperature was the most effective factor on species occurrences and composition (Fig. 2). Especially, the ecological tolerance and optimum values of the commonly occurring species were found relatively higher than the other species. For example, common occurrences of *P. olivaceus* in many aquatic habitats (with 15 independent occurrences) agree with the literature (Meisch, 2000) that pinpointed the relatively high ecological tolerance levels of this species for many ecological variables. Also, Külköylüoğlu and Yılmaz (2006) suggested that *P. olivaceus* have a broader geographical distribution as long as habitat conditions are suitable.

In the present study, there was no statistical difference between the population density or the number of species in the natural or the artificial habitats. On the other hand, while the number of the swimming and non-swimming species were close to each other in the natural habitats with 11 and 10 spp., respectively, the number of the

swimming species (12 spp.) was higher than the numbers of non-swimmers (7 spp.) in the artificial habitats (Table 3). Species in such habitats can alter their location faster in active way (using swimming setae) than passive one due to unpredictable ecological conditions of artificial habitats (e.g., troughs). Thus, such ability of active movement may increase their survival chances by finding new location. Along with these movement abilities, the importance of ecological fitting abilities of species and habitat suitability should not be ignored for the survival success of species in different niches or wider range of habitats.

Table 4. Species diversity and population density of different habitat types

Habitat type	N.St	N.Sp	N.Ind	Spp/St	Obs	Obs/St	Var H'	Exp H'	H'	Species
Canal	4	5	168	1.25	3	0.75	0.08	5.00	1.61	PO, HS, HC, IB, LI
Creek	12	11	254	0.92	9	0.75	0.02	10.31	2.33	CT, PO, PF, HI, HS, IB, LI, PZ, Asp*, Cysp, Psp
Ditch	2	3	11	1.50	2	1.00	0.11	3.00	1.10	CV, HC, NM
Lake	2	1	7	0.50	2	1.00	0.00	1.00	0.00	CT
Pond	9	9	1154	1.00	5	0.56	0.03	8.22	2.11	CN, CV, HC, IG, IH, PA, PV, TL, Csp
Pool	1	1	6	1.00	1	1.00	0.00	1.00	0.00	CN
Reservoir	3	6	73	2.00	3	1.00	0.07	5.74	1.75	CV, PF, IH, LI, Csp, Psp
Spring water	6	6	578	1.00	6	1.00	0.05	4.87	1.58	CN, PO, PF, HS, HBr, IB
Stream	2	3	19	1.50	1	0.05	0.11	3.00	1.10	IB, ID, LI
Waterfall	1	4	52	4.00	1	1.00	0.09	4.00	1.39	CW, PO, PF, IB
Trough	26	14	2147	0.54	22	0.85	0.02	10.37	2.34	CV, PO, PF, HB, HI, HS, HC, HBr, IG, PA, PP, PU, PV, Pvi
All sample index	28								2.97	
Jackknife standard error	4.05								0.14	

Abbreviations: N.St., number of site; N.Sp., number of species; N.Ind., number of individual; Spp/st, ratio of number of species per site; Obs., number of observation; Obs/St, ratio of number of observations per site; H', Shannon-Wiener Index value; Var. H', variance H'; Exp H', expected value of H'. Species codes: CN: *Candona neglecta*, CW: *Candona weltneri*, CT: *Cyprideis torosa*, CV: *Cypridopsis vidua*, PO: *Psychrodromus olivaceus*, PF: *Psychrodromus fontinalis*, HB: *Heterocypris barbara*, HI: *Heterocypris incongruens*, HS: *Heterocypris salina*, HC: *Herpetocypris chevreauxi*, HBr: *Herpetocypris brevicaudata*, IB: *Ilyocypris bradyi*, ID: *Ilyocypris decipiens*, IG: *Ilyocypris gibba*, IH: *Ilyocypris hartmanni*, LI: *Limnocythere inopinata*, NM: *Notodromas monacha*, PA: *Potamocypris arcuata*, PP: *Potamocypris producta*, PU: *Potamocypris unicaudata*, PV: *Potamocypris variegata*, PVi: *Potamocypris villosa*, PZ: *Prionocypris zenkeri*, TL: *Trajancypris leavis*, Cysp: *Cypris* sp., Psp: *Pseudocandona* sp., Csp: *Cypridopsis* sp., Asp: *Aurila* sp. *brackish water taxon

Among habitats, troughs are generally located in/near villages to provide water for drinking, cleaning and/or irrigation purposes and they are used as microhabitats by ostracods (Külköylüoğlu et al., 2013). Such kind of artificial habitats (e.g., troughs) can open new possibilities for other species, although the establishment of troughs from natural sources can cause irreversible changes in species diversity and habitats. Because, waters of troughs come from underground sources, springs and/or surface waters, and these connections with those of natural habitats may influence species diversity (Külköylüoğlu et al., 2013). Except these water connections, different transportation vectors (e.g., air, insect, fish, birds, humans) may enrich species diversity

since ostracods can be distributed passively between different aquatic habitats by such kind of vectors (Mezquita et al., 1999). All of these explain the high Shannon-Wiener index value of troughs among habitats.

Table 5. The distribution of sexual and parthenogenetic populations of *P. olivaceus* and *P. fontinalis* at different habitats from 14 m to 1093 m of altitude

Species			<i>Psychrodromus olivaceus</i>		<i>Psychrodromus fontinalis</i>		<i>Candona neglecta</i>		<i>Candona weltneri</i>		<i>Notodromas monacho</i>	
St. No.	Alt. (m)	Habitat type	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
62	14	Creek	6									
65	114	Creek	35		15							
63	136	Trough	5									
17	294	Spring water	3		6							
66	296	Canal	126									
39	351	Spring water	36		14							
33	362	Spring water	80	15			1					
19	484	Reservoir			3							
20	490	Trough	1									
47	504	Creek			2							
49	540	Trough			146							
35	609	Ditch									3	4
18	656	Trough	85									
68	656	Pond	30		14				5	2		
15	669	Spring water	152	20								
16	669	Spring water	146	10								
36	699	Pool					3	3				
50	769	Trough			124							
46	799	Trough	3		7							
38	808	Trough	1									
42	839	Pond					1					
37	1093	Trough	12	6	21	8						
Total			721	51	352	8	5	3	5	2	3	4

Potamocypris producta was commonly found in Africa (see e.g., Sars, 1924; Martens, 1984) but it was also reported from Europe (Macedonia, Petkovski, 1964), Japan (Okubo, 1976), and Turkey. Males of the species were only reported from South Africa by Sars (1924). 48 female individuals of *P. producta* in a trough along with *P. olivaceus* and *H. Barbara* were found. This record of *P. producta* herein makes an important contribution to the distribution and ecological preferences of species. This indicates that the species can also be found in artificial habitats.

The occurrence of parthenogenetic and sexual populations of *P. olivaceus* and *P. fontinalis* in troughs (Table 5) contribute to the knowledge of the habitat preferences of these species with different reproduction modes. This situation probably signals to a passive dispersal of them by subaquatic/nearby springs or underground waters, since these two species are known to prefer spring waters, flowing waters and pond fed by springs (Meisch, 2000). Fox (1965) claimed that males of *P. fontinalis* were found in northern Italy but later, Baltanás et al. (1993) stated that these specimens belong to another species, *P. betharrami*, collected from a subterranean stream in the Cave of Betharram (France). Sexual populations of *P. fontinalis* were described for the first time

in Macedonia by Petkovski and Meisch (1995). Until now, there is no any report of the sexual populations of these species from Turkey. Therefore, the sexual population of *P. fontinalis* herein is the first report from Turkey. However, males of *P. olivaceus* are already known from different countries of Europe (Petkovski, 1959, 1966; Järvekülg, 1959; Petkovski and Meisch, 1995). In Turkey, the male of *P. olivaceus* was found for the first time by Gülen (1985b) in the Lake Karamık (Afyon) and followed by other studies (Külköylüoğlu and Yılmaz, 2006; Rasouli et al., 2014; Külköylüoğlu et al., 2015; the present study).

Among these records, similar distribution patterns of *P. producta* and *P. fontinalis* were recorded from Macedonia and Turkey, and this may be explained with different passive dispersion ways. For instance, it is well known that Anatolia is an important migration route and works as a bridge between the Balkans and Africa for some migratory birds (Deinet et al., 2013). Ostracods can attach to the external surface of the birds, and so they are transported passively among the different geographic regions. Additionally, the record of *P. producta* from Japan is an interesting finding and might signal a human-mediated dispersal. Considering that the success of the species transported is related to the habitat suitability, and the ecological and biological features of the species, these records show the fitting ability under suitable environmental conditions of these two species.

Although troughs have relatively high ostracod diversity, the numbers of species per trough is not the highest among habitats (Table 4). Comparing to other sites, this situation may be explained with more samplings from these artificial habitats. However, another interesting point here is that although the number of individuals in troughs was prominently high, most of the individuals (1111 of 2147) collected from troughs belonged to two well-known cosmopolitan species (*H. incongruens* and *H. salina*). Moreover, finding at least two other species (e.g., *P. olivaceus*, *Potamocypris unicaudata*) with high densities in these habitats suggests that such artificial habitats can provide some chance of survival mainly for species with relatively high ecological tolerance ranges. Actually, troughs are routinely cleaned out and emptied by local people. Eventually, such process can cause a huge impact on the populations. In such case, ostracods may leave their desiccation resistant eggs until troughs are filled by water again. It means that the species with their cosmopolitan features as well as their adaptive values to harsh environmental conditions can easily colonize in the troughs. If troughs are accepted as newly development habitat after habitat degradation, in the case of recolonization, high ostracod richness and strong dominance of cosmopolitan species in troughs are inevitable. Therefore, this situation indicates the “primer succession” of species with high ecological tolerance levels as transitional and/or opportunistic populations. Additionally, most of the species found from troughs were parthenogens, even though some species were represented with sexual populations in a trough. A similar case observed in a newly developed spring in Turkey (Külköylüoğlu, 2009) supports this previous statement. The dominance of the parthenogens in following colonization may be the sign of the transition to stability or predictability in the environmental conditions, because it is known that if environmental deterioration continues as a result of stochastic and drastic changes, such kind of habitats can be established by sexual populations (Hewitt, 1999; Horne and Martens, 1999). Thus, it can be argued that the different reproduction modes of species can be effective as well as their relatively wide ecological tolerance levels for the initial colonization of the habitats.

As seen in Table 5, sexual populations of *P. olivaceus* and *P. fontinalis* co-occurred in a trough (St. 37) and there is a difference in the sex ratio of the individuals of both species. Generally, one of the reasons of female-biased sex ratio can be explained by the presence of the females of species with both reproductive modes from the same sampling site. On the other hand, although it is not the scope of this study, some genetic factors can play a role such as the greater longevity of females that lead to the skewed sex ratio in the population (Butlin et al., 1998). Thus, the possible reasons of the skewed sex ratio can be better understood by means of genetic data to determine the proportion of the fully sexual and parthenogenetic females.

In contrast to Gülen (1985b) who reported the sex ratio of *P. olivaceus* as about 1/2 favoring males (16 females and 33 males), the ratio in our study was almost about 1/8 favoring the females. The dominance of females against males (female-biased sex ratio) was especially remarkable at low altitudes (e.g., cf. stations 15, 16, 33) where the population densities were high. However, both the numbers of female and male became close to each other, and population densities were low at medium altitude (st. 37, 1093 m). In addition, the first record of the sexual forms of *P. olivaceus* was given by Petkovski (1959) from the moderately medium altitudes (1300 m) to high altitudes (ca. 2200 m) favoring the females. In the present study, a sexual population of *P. olivaceus* was found from two spring waters and one trough located at different altitudes that put into the previously known altitudinal ranges. Unlike *P. olivaceus*, the sexual populations of *P. fontinalis* were only found from a trough at 1093 m in Muğla. Males of *P. fontinalis* were also known from a small mountain spring water at 1600 m a.s.l (Petkovski and Meisch, 1995). The ranges of altitude (312-1262 m, Külköylüoğlu et al., (2012b) where species occur in literature reinforce the statement of Külköylüoğlu et al. (2012a) as parthenogenetic populations of *P. fontinalis* had the highest tolerance values for altitude. Similarly, parthenogenetic populations of *P. fontinalis* were found at various altitudes ranging from 114 m to 1093 m a.s.l. in the present study.

Parthenogenetic populations of the species were found from sea level to 1093 m, while sexual populations were obtained in a limited number of habitats located between 327 and 1093 m a.s.l. Külköylüoğlu et al. (2012b) showed no relationship between occurrence of sexual and parthenogenetic forms at different altitudes, although Peck et al. (1998) suggested that population densities of parthenogens exhibited the tendency to occur in northern areas at high altitudes.

According to the hypotheses of the distributional patterns of ostracods in terms of reproduction modes, both circum-Mediterranean shelters staying after the Pleistocene glaciation, and the fluctuating environmental conditions of the early Holocene, persisted some sexual populations in southern regions (i.e., post glacial invasion/re-colonization hypothesis). The following Holocene climatic stability provided more common dispersion and increase of frequencies of the parthenogens (Holocene stability hypothesis) (Horne and Martens, 1999). Similarly (but not in the same way), during this glaciation period, Anatolia played a critical role for the survival of both sexual and parthenogens providing opportunity to recolonize species in the other regions (Gülen, 1985a; Hewitt, 1999; Külköylüoğlu et al., 2012b). Additionally, as stated above, since Anatolia is an important route for the migration of birds, the ostracods species can be transported via passive dispersion from different regions to Anatolia. Then, other factors, such as different climatic conditions, latitudes in Anatolia, allow the colonization of the species in new locations. Thus, finding the males of *P. fontinalis*

along with *P. olivaceus* supports the idea that “there are so many sexual populations in Turkey” (Külköylüoğlu et al., 2012b).

Conclusion

Overall, along with ecological preferences and tolerance levels of the species, if it is created the distributional patterns of ostracods according to their reproductive modes, ostracods can be used as an informative marker for monitoring environmental changes for the neo-studies. On the other hand, to know (i) how species diversity is affected when species faced with changes in habitat degradation, (ii) which species are the first members of the new colonization or (iii) that there is any remarkable alteration favoring the parthenogens or sexual in time after the dramatic environmental changes provides useful information for invisible environmental shifts (e.g. volcanic eruptions, drought) in the palaeo-studies. Due to short sampling time, our results, however, cannot be generalized at the moment but they support the idea that parthenogenetic species (and populations as well) clearly show a much wider geographical distribution than their sexual counterparts. Therefore, different factors and/or combination of them that affect this distribution (ecological, historical, and biological) should be investigated comprehensively.

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APPENDIX

Table A1. Minimum–maximum values of the geographical data and physicochemical variables from 11 different aquatic habitat types with station numbers in Muğla province

		Ta	Atm	Moi	Wind	Alt	pH	DO	S
Canal	Min	21.700	727.300	34.700	0.000	17.000	8.220	3.260	42.400
	Max	33.800	754.800	63.600	6.400	296.000	8.520	7.360	83.600
	Mean	30.275	745.500	45.200	3.075	110.500	8.353	5.538	63.025
	St dev	3.139	26.103	11.020	4.506	308.349	0.638	2.352	22.683
Creek	Min	23.600	702.600	27.500	0.000	5.000	7.090	2.000	22.500
	Max	33.200	757.400	67.400	7.700	790.000	8.820	8.060	83.800
	Mean	30.275	735.175	46.917	2.783	272.750	7.893	4.761	56.308
	St dev	2.800	25.877	11.099	4.413	308.862	0.639	2.351	22.918
Ditch	Min	29.500	705.300	38.700	2.200	19.000	8.150	3.020	37.500
	Max	31.500	755.600	49.200	4.200	609.000	8.330	6.630	86.000
	Mean	30.500	730.450	43.950	3.200	314.000	8.240	4.825	61.750
	St dev	2.797	26.454	10.740	4.594	310.429	0.652	2.406	23.301
Lake	Min	28.500	752.900	44.500	3.200	17.000	8.690	4.840	65.900
	Max	32.800	759.100	52.600	9.500	17.000	8.760	4.870	68.500
	Mean	30.650	756.000	48.550	6.350	17.000	8.725	4.855	67.200
	St dev	2.816	26.636	10.782	4.630	311.697	0.662	2.386	22.953
Pond	Min	23.100	685.000	26.300	0.000	40.000	7.810	2.140	5.980
	Max	33.900	754.000	55.900	15.700	839.000	9.810	7.420	97.600
	Mean	30.122	719.722	41.678	5.556	434.000	8.772	5.984	69.531
	St dev	2.884	26.536	10.812	4.611	310.229	0.700	2.335	24.465
Pool*	Mean	29.200	697.500	35.400	8.900	699.000	7.080	3.300	33.400
Spring water	Min	27.700	701.000	28.800	0.000	294.000	6.450	3.300	37.500
	Max	33.500	773.500	49.100	4.800	669.000	8.040	10.340	93.700
	Mean	32.100	722.600	35.900	3.533	493.500	7.313	5.643	57.150
	St dev	2.808	26.412	10.675	4.489	301.974	0.677	2.428	23.166
Stream	Min	30.900	750.100	47.500	2.700	0.000	8.390	5.120	59.000
	Max	32.100	751.700	51.800	3.900	43.000	8.390	5.360	60.400
	Mean	31.500	750.900	49.650	3.300	21.500	8.390	5.240	59.700
	St dev	2.798	26.472	10.788	4.591	313.260	0.654	2.384	22.919
Reservoir	Min	22.200	708.800	32.400	0.000	57.000	8.320	2.500	29.700
	Max	32.600	752.400	55.400	7.500	574.000	9.250	5.750	75.400
	Mean	28.733	726.533	45.937	4.267	371.667	8.657	4.307	54.500
	St dev	2.961	26.189	10.849	4.600	307.379	0.665	2.394	23.120
Trough	Min	26.000	665.700	23.400	1.400	11.000	6.490	2.450	29.000
	Max	35.300	758.600	64.400	34.000	1093.000	8.980	14.450	112.700
	Mean	30.900	713.942	37.920	5.252	504.731	7.761	5.579	58.238
	St dev	2.679	26.801	10.926	5.181	315.476	0.629	2.587	23.185
Waterfall*	Mean	29.700	698.800	42.100	0.000	656.000	7.380	10.400	91.700

Abbreviations: Ta, air temperature (°C); Atm, atmospheric pressure (mmHg); Moi, moisture (%); Wind, (m s⁻¹); Alt, Altitude (m); DO, dissolved oxygen (mg L⁻¹); S, oxygen saturation (%); Tw, water temperature (°C); Sal, salinity (ppt); EC, electrical conductivity (µS cm⁻¹); TDS, total dissolved solids (mg L⁻¹); Na⁺, sodium (mg L⁻¹); K⁺, potassium (mg L⁻¹); Mg²⁺, magnesium (mg L⁻¹); Ca²⁺, calcium (mg L⁻¹); F⁻, fluoride (mg L⁻¹); Cl⁻, chloride (mg L⁻¹); SO₄²⁻, sulphate (mg L⁻¹); Tot-Ph; total phosphate (mg kg⁻¹); In-Ph, inorganic phosphate (mg kg⁻¹); Or-Ph; organic phosphate (mg kg⁻¹), b.d.l. below detectable limits; *single sampling

Table A1. Continuation

		Tw	Sal	EC	TDS	Na⁺¹	K⁺¹	Mg⁺²	Ca⁺²
Canal	Min	16.900	0.030	271.400	0.209	2.195	0.313	6.913	10.884
	Max	28.900	0.380	736.000	0.410	18.152	3.898	40.088	93.513
	Mean	22.450	0.203	538.350	0.319	7.542	1.671	17.153	52.465
	St dev	5.261	8.701	247.021	8.113	67.140	22.478	30.256	50.092
Creek	Min	16.300	0.060	148.600	0.089	0.378	0.409	1.444	0.487
	Max	32.200	73.180	1150.860	65.780	35.002	113.541	195.433	237.959
	Mean	22.008	7.789	593.498	6.931	8.595	18.062	49.252	80.255
	St dev	5.243	11.696	265.480	10.931	66.260	25.952	37.440	55.475
Ditch	Min	20.100	0.090	62.100	0.131	9.998	0.656	1.619	44.557
	Max	29.800	0.270	185.000	0.364	34.042	17.408	9.395	72.609
	Mean	24.950	0.180	123.550	0.248	22.020	9.032	5.507	58.583
	St dev	5.312	9.006	252.891	8.360	69.616	23.324	31.175	50.961
Lake	Min	29.600	2.230	254.510	2.756	554.518	18.293	50.098	29.502
	Max	30.300	14.070	466.900	15.210	554.518	140.824	58.081	200.468
	Mean	29.950	8.150	360.705	8.983	554.518	79.558	54.090	114.985
	St dev	5.351	9.121	248.412	8.526	97.051	28.672	31.566	54.076
Pond	Min	23.600	0.100	83.700	0.145	3.252	0.361	1.207	12.546
	Max	34.100	0.700	399.300	0.910	34.068	19.395	20.041	238.423
	Mean	29.211	0.201	254.167	0.271	11.062	7.652	7.854	49.126
	St dev	5.416	8.588	244.248	7.942	66.192	22.158	29.928	53.863
Pool*	Mean	16.400	0.140	0.184	236.300	8.507	0.329	3.291	b.d.l
Spring water	Min	10.300	0.090	165.000	0.133	2.067	0.587	1.068	4.722
	Max	21.900	0.410	694.000	0.533	29.259	4.009	10.727	46.601
	Mean	16.683	0.198	345.750	0.267	19.072	1.757	4.704	25.391
	St dev	5.525	8.759	249.534	8.113	68.557	22.962	30.852	50.758
Stream	Min	21.200	0.240	481.300	0.329	5.687	0.424	14.705	37.110
	Max	22.400	0.300	564.000	0.397	5.935	0.980	30.134	37.993
	Mean	21.800	0.270	522.650	0.363	5.811	0.702	22.419	37.551
	St dev	5.252	9.005	248.131	8.360	69.641	23.312	31.080	50.964
Reservoir	Min	24.200	0.080	183.600	0.115	4.372	0.597	2.122	14.346
	Max	29.700	0.170	369.100	0.226	17.790	2.267	6.258	46.339
	Mean	27.033	0.137	298.233	0.170	11.150	1.558	3.833	30.153
	St dev	5.272	8.943	247.683	8.361	69.086	23.132	31.029	50.811
Trough	Min	15.800	0.070	113.200	0.093	2.060	0.100	0.495	3.258
	Max	32.100	0.650	913.000	0.845	108.242	12.396	68.254	126.984
	Mean	24.054	0.321	462.350	0.432	16.715	2.149	19.002	48.008
	St dev	4.951	7.811	250.365	7.217	60.527	20.357	29.113	47.648
Waterfall*	Mean	9.800	0.140	0.184	200.800	1.776	0.336	5.860	b.d.l

Table A1. Continuation

		F⁻¹	Cl⁻¹	SO₄⁻²	Tot-Ph	In-Ph	Or-Ph	Station numbers
Canal	Min	0.056	2.564	1.943	0.239	0.269	0.054	64, 66, 11, 56
	Max	0.140	38.574	146.011	0.598	0.737	0.126	
	Mean	0.098	13.143	40.965	0.429	0.468	0.089	
	St dev	0.485	39.211	110.086	0.267	0.206	0.066	
Creek	Min	0.026	0.721	0.324	0.051	0.096	0.008	2, 5, 10, 21, 25, 31, 47, 48, 52, 58, 62, 65
	Max	0.183	69.199	356.561	0.629	0.892	0.190	
	Mean	0.110	14.055	80.035	0.330	0.282	0.067	
	St dev	0.498	39.077	114.608	0.257	0.196	0.067	
Ditch	Min	0.036	8.526	13.864	0.648	0.336	0.356	4, 35
	Max	0.917	53.448	13.864	0.648	0.336	0.356	
	Mean	0.477	30.987	13.864	0.648	0.336	0.356	
	St dev	0.517	40.564	113.620	0.280	0.187	0.083	
Lake	Min	1.603	0.000	0.000	0.314	0.100	0.003	14, 57
	Max	1.603	0.000	0.000	0.314	0.171	0.027	
	Mean	1.603	0.000	0.000	0.314	0.136	0.015	
	St dev	0.561	41.012	114.528	0.276	0.185	0.069	
Pond	Min	0.060	4.676	0.491	0.040	0.001	0.010	3, 7, 8, 12, 41, 42, 44, 45, 51
	Max	0.406	64.564	799.695	0.612	0.351	0.214	
	Mean	0.216	17.382	104.214	0.293	0.145	0.058	
	St dev	0.472	38.838	142.439	0.269	0.185	0.070	
Pool*	Mean	9.170	b.d.l.	10.291	3.837	0.160	0.257	36
Spring water	Min	0.025	2.605	2.030	0.170	0.100	0.019	15, 16, 17, 33, 39, 67
	Max	2.563	45.591	70.574	1.720	0.314	0.064	
	Mean	0.903	25.669	29.196	0.610	0.190	0.036	
	St dev	0.632	39.909	111.036	0.338	0.184	0.068	
Stream	Min	0.117	6.171	9.430	0.153	0.100	0.006	59, 61
	Max	0.117	9.341	43.900	0.657	0.549	0.046	
	Mean	0.117	7.756	26.665	0.405	0.324	0.026	
	St dev	0.511	40.450	112.690	0.278	0.191	0.069	
Reservoir	Min	0.046	7.004	10.279	0.083	0.045	0.003	19, 30
	Max	0.081	36.789	28.626	0.197	0.129	0.063	
	Mean	0.063	19.040	17.301	0.123	0.084	0.024	
	St dev	0.505	40.136	111.841	0.276	0.187	0.068	
Trough	Min	0.010	2.330	1.880	0.213	0.138	0.040	1, 9, 13, 18, 20, 22, 23, 24, 26, 27, 28, 29, 32, 34, 37, 38, 40, 43, 46, 49, 50, 53, 54, 55, 60, 63
	Max	0.266	285.837	152.303	0.464	0.448	0.160	
	Mean	0.101	34.196	24.818	0.345	0.305	0.064	
	St dev	0.454	46.757	96.951	0.262	0.180	0.067	
Waterfall*	Mean	45.792	b.d.l.	2.229	1.648	0.219	0.156	68