LIMNOFISH-Journal of Limnology and Freshwater Fisheries Research 5(1): 47-59 (2019)

Journal of Limnology and Freshwater Fisheries Research

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Fossil and Recent Distribution and Ecology of Ancient Asexual Ostracod *Darwinula stevensoni* (Ostracoda, Crustacea) in Turkey

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A B S T R A C T

In order to determine distribution, habitat and ecological preferences of *Darwinula stevensoni*, data gathered from 102 samples collected in Turkey between 2000 and 2017 was evaluated. A total of 1786 individuals of *D. stevensoni* were reported from eight different aquatic habitats in 14 provinces in six of seven geographical regions of Turkey. Although there are plenty of samples from Central Anatolia Region, recent form of the species was not encountered. Unlike recent, fossil forms of species were encountered in all geographic regions except Southeastern Anatolia. The oldest fossil record in Turkey was reported from the Miocene period (ca 23 mya). Species occurred in all climatic seasons in Turkey. *D. stevensoni* showed high optimum and tolerance levels to different ecological variables. Results showed a positive and negative significant correlations of the species with pH (P<0.05) and elevation (P<0.01), respectively. It seems that the ecological preferences of the species are much wider than previously known. Our results suggest that if *D. stevensoni* is used to estimate past and present environmental conditions, attention and care should be paid on its ecology and distribution.

Keywords: Ecologic preference and characterization, seasonality, stevensoni

A R T I C L E I N F O

RESEARCH ARTICLE

Received : 28.08.2018
Revised : 21.10.2018
Accepted : 30.10.2018
Published : 25.04.2019

DOI:10.17216/LimnoFish.455722

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Eski Aseksüel Ostrakod *Darwinula stevensoni*’nin (Ostracoda, Crustacea) Türkiye’deki Ekolojisi, Fosil ve Güncel Dağılımı

Öz: *Darwinula stevensoni*’nin dağılımını, habitat ve ekolojik tercihlerini belirlemek için 2000 ve 2017 yılları arasında Türkiye’den toplanan 102 örnekten elde edilen veriler değerlendirilmiştir. Toplam 1786 *D. stevensoni* bireyi Türkiye’nin yedi coğrafi bölgesinin altısında bulunan 14 ildeki sekiz farklı sucul habitattan rapor edildi. İç Anadolu bölgesin de bol miktarda örnek olmasına rağmen, türün güncel formuna rastlanılmadı. Güncel formdan farklı olarak, türün fosil formu ile Güneydoğu Anadolu dışındaki tüm coğrafi bölgelerde karşılaşılmıştır. Türkiye’deki en eski fosil kayıt Miosen döneminden (yaklaşık 23 milyon sene önce) rapor edilmiştir. Türkiye’deki tüm mevsimlerde tür bulunmuştur. *D. stevensoni* farklı ekolojik değişkenlere yüksek optimum ve tolerans seviyeleri göstermektedir. Tür pH ile pozitif (P<0,05) fakat yükseklik ile negatif (P<0,01) anlamlı korelasyon göstermektedir. Görülmektedir ki türün ekolojik tercihleri daha önce bilinenden daha geniştir. Sonuçlar, *D. stevensoni*’nin güncel ve geçmiş çevre koşullarını tahmin etmek için kullanılması halin de ekolojisine ve dağılımına dikkat edilmesi gerektiğini göstermektedir.

Anahtar kelimeler: Ekolojik tercih ve karakterizasyon, mevsimsellik, stevensoni

How to Cite
Yavuzatmaca M, Külköylüoğlu O, 2019. Fossil and Recent Distribution and Ecology of Ancient Asexual Ostracod *Darwinula stevensoni* (Ostracoda, Crustacea) in Turkey. LimnoFish. 5(1): 47-59. doi: 10.17216/LimnoFish.455722

Introduction

Ostracods are small (0.3-5 mm long), bivalved (carapaces) aquatic creatures that are widely distributed in a variety of marine and non-marine environments (Meisch 2000). They show species-specific responses to the changes in different ecological conditions; therefore, they can be used as bioindicator species to estimate possible environmental deterioration (Benson 1990; Külköylüoğlu 1999). Also, because of the easily fossilization of calcium carbonated carapaces, they are commonly used in biostratigraphy, paleobiology, paleoclimatology, paleolimnology and paleoecology studies (Ruiz et al. 2013). In this sense, the autecology of individual species has an important role since ecology of recent species help paleontologists to widen their perceptions to understand types of paleoenvironmental conditions based on fossil ostracods (Carbonel et al. 1988).

The genus *Darwinula* is the type genus of the family Darwinulidae that includes only the type species *Darwinula stevensoni*. Because of the absence of males in fossils (since Mesozoic) and in living populations, superfamily Darwinuloidea have survived asexually over 200 million years (Martens et al. 2003). Similar to bdelloid rotifers (Mark Welch and Meselson 2000; Mark Welch et al. 2004) and oribatid mites (Maraun et al. 2004), darwinuloid ostracods (Schön and Martens 2003) have also been suggested as one of the “putative ancient asexual” groups in animal kingdom. However, although its persisting asexuality is known, a few reports of rare males of the species by Turner (1895) and Brady and Robertson (1870) and one male of *Vestalenula cornelia* (Smith et al. 2006) has also been questioned within the family. Subsequently, Martens and Schön *(2008)* indicated *D. stevensoni* as a strong candidate in darwinuloids to being a true ancient asexual. In support of this view, Schön et al. (2009) stated that occasional males may be produced in many asexual species because of mutations in the regulatory cascade controlling sex and the males produced are not functional. The presence of female fossils dating back to 25 million years (Straub 1952) and the absence of functional or atavistic males in recent and fossil species (Schön et al. 2009) enforce the ancient asexuality of *D. stevensoni*.

D. stevensoni is a small sized (0.6-0.8 mm in length) (Meisch 2000) ostracods. Carapace of species is characteristically cigar shaped with unequal valves (Figure 1). Right valve extends left valve on all sides except hinge. The posterior margin of carapace is wider than anterior. The widening of posterior part is due to the developing of a brood chamber since species is viviparous parthenogenetic unlike most of other ostracods (Cypridoidea and Cytheroidea) (Rossetti and Martens 1996). Generally, species obtain about ten eggs in this brood chamber, but this number can be changed up to 13 (Külköylüoğlu pers. obs.). Later, juveniles may have more than one molting stage within brood space until hatched. Muscle scars that control the opening and closing of valves arranged in a characteristic circular rosette shape, which includes 9 - 12 spots. Additionally, species do not swim because of the absence of natatory setae on the second antennae of species and so it is a typical benthic form (for more taxonomic remarks see Rossetti and Martens 1996; Meisch 2000).

D. stevensoni showed a cosmopolitan distribution (Meisch 2000) except from Antarctic region, Pacific region and Oceonic Islands (Martens et al. 2013). Van Doninck et al. (2003a) presented the global distribution of species (cf. Figure 2 in this paper). Species has been collected in lotic, lentic and interstitial habitats and it is ecologically characterized as thermoeuryplastic, oligorheophilic, titanoeuryplastic and mesohalophilic (Meisch 2000). Until now, the ecology of *D. stevensoni* has not been widely evaluated except some papers partially discussed its status in local and/or regional perspectives (e.g., Ranta 1979; Rossetti and Martens 1996; Gandolfi et al. 2001a, 2001b; Van Doninck et al. 2003a; Rossi et al. 2002, 2004; Higuti et al. 2009a; Van den Broecke et al. 2013). Therefore, the aims of the present study are to (i) determine geographic and local distribution of both fossil and living populations of the species among different aquatic habitats, (ii) estimate ecological preferences of *D. stevensoni* in Turkey, and (iii) evaluate species ecological tolerance and optimum ranges for those of particular environmental variables.

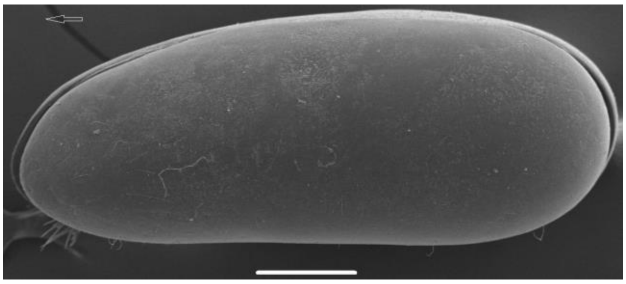

Figure 1. *Darwinula stevensoni*. Left valve external view (Scale bar 100 µm).

Materials and Methods

Study sites and Sampling

A total of 102 samples from 14 provinces (72 samples from Bolu, 1 in Gaziantep, 2 in Ordu, 3 in Adıyaman, 3 in Burdur, 2 in Hatay, 3 in Mardin, 2 in Muş, 4 in Kütahya, 1 in Mersin, 2 in Sakarya, 2 in Isparta, 3 in Antalya and 2 in Muğla) of Turkey were collected between the years 2000 and 2017 (Figure 2, Appendix). All the measurements were taken *in situ* before ostracods were collected to prevent the mixing of water and to obtain the actual values of variables. Ostracod samples were collected with a standard sized (200 µm) d-frame hand net and fixed in 70% ethanol.

Physico-chemical variables (*pH*, dissolved oxygen (*DO, mg/L*), percent oxygen saturation *(%DO*), water temperature (*Tw, °C*), electrical conductivity (*EC, µS/cm*), salinity (*Sal. ‰*), total dissolved solids (*TDS, mg/L*) and redox potential (*ORP, mV*)) were measured by a YSI-85 model of oxygen-temperature and HI-98150 pH-ORP meter from sapling sites in Bolu and Ordu where geographic data (coordinates and elevation) was recorded with a Garmin GPS-12XL. In Gaziantep and Hatay provinces, Tw, pH, EC and salinity values were obtained with a Delta OHM pH/conductivity meter while air temperature was recorded with a Testo 410-2 anemometer, and coordinates and elevation with a Garmin GPS-45. The measurements for the rest of the provinces were done by YSI Professional Plus and Testo 410-2 anemometer and a Garmin etrex Vista H GPS (for elevation and coordinates).

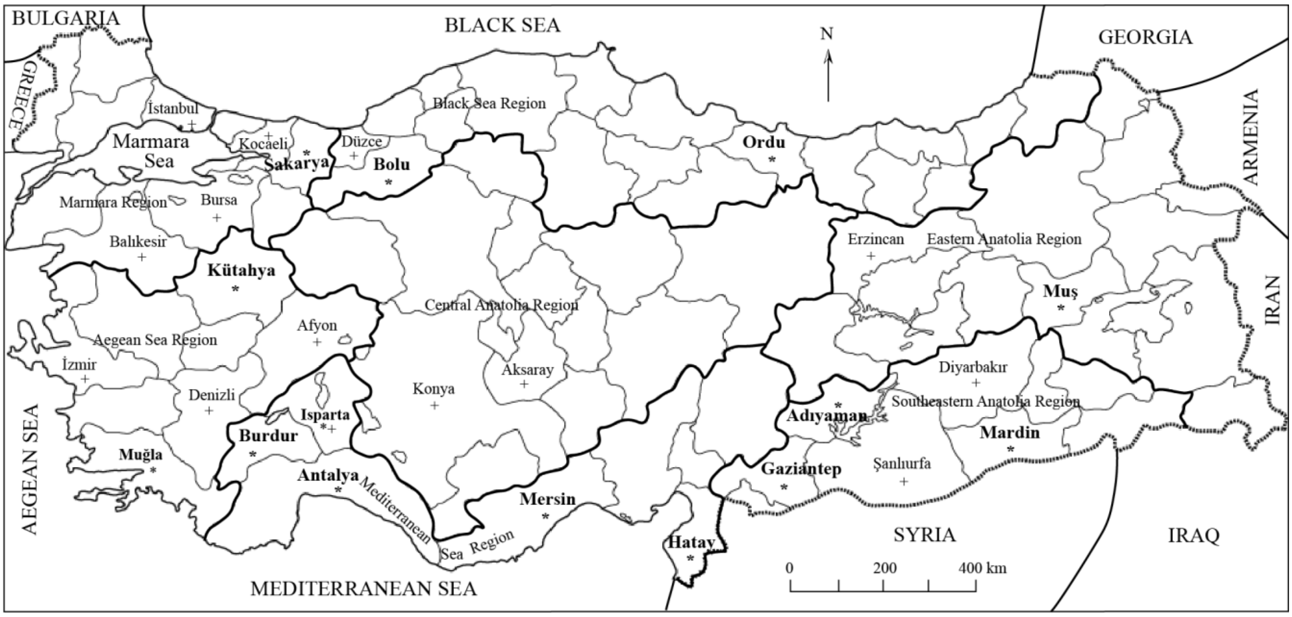

Figure 2. Distribution of living *D. stevensoni* in 27 provinces of Turkey. * indicates provinces (in bold) sampled during the current study, + represents the species previously reported in the literature. *+ displays the species records in this study and previously as well. Citations for the previous reports; İstanbul (Külköylüoğlu pers. obs. unpublished data), Kocaeli (Akdemir pers. obs. unpublished data), Bursa (Altınsaçlı and Griffiths 2001a); Balıkesir (Altınsaçlı and Griffiths 2001b); Düzce (Gülen 1985); Afyon (Gülen 1985); Denizli (Altınsaçlı and Mezquita 2008); İzmir (Meriç et al. 2010); Isparta (Özuluğ et al. 2001); Konya (Akdemir 2004); Aksaray (Altınsaçlı 2004); Şanlıurfa (Özuluğ and Dökümcü 2014); Diyarbakır (Gülen et al. 1996; Akdemir and Külköylüoğlu 2011); Erzincan (Akdemir and Külköylüoğlu 2014).

In the laboratory, samples were filtered through four standardized sieves (0.5, 1.0, 1.5 and 2.0 mm mesh size) under tap water and then specimens were separated from sediment under stereomicroscope and fixed in 70% ethanol for further studies. Taxonomic identification was done according to the carapace and soft body parts dissected in lactophenol solution by using taxonomic key of Meisch (2000) under a light microscope (Olympus BX-51). According to Meisch (2000), *D. stevensoni* was ecologically characterized for salinity limnetic (freshwater) range (<0.5 ‰), oligohaline (0.5-5 ‰), mesohaline (5-18 ‰), polyhaline (18-30 ‰), euhaline (30-40 ‰) and hyperhaline (≥40 ‰) and water temperature (cold stenothermal, oligothermophilic, mesothermophilic (between two previous), polythermophilic and warmstenothermal). On the other hand, because this ecological characterization does not classify water temperature ranges for freshwater habitats, we followed the offering of Chu et al. (2009) and Olivero-Sheldon et al. (2014). The ranges as very cold (<12.8 °C), cold (<18 °C), cold cool (>18 at <21 °C) and warm (>21 °C) were used. All the specimens were kept in Limnology Laboratory of Bolu Abant İzzet Baysal University, Turkey.

Statistical Analyses

The tolerance (t_k) and optimum (μ_k) estimates of the species for different ecological variables were calculated by using C2 software after using a transfer function of weighted averaging regression (Juggins 2003). A non-parametric Spearmen Rank Correlation was applied to see the the levels of correlations between species and different variables (IBM-SPSS Statistics version 21).

Results

We encountered 1786 individuals of *D. stevensoni* from eight different aquatic habitats in 14 provinces (Figure 3). These provinces were found in six geographical regions of Turkey except Central Anatolia Region (Figure 2). The highest (1117) and lowest (1) individual numbers were reported in dams and pond, respectively. Although the number of lakes and springs sampled were approximately 9 and 6 times more than the number of troughs, respectively, the number of individuals found in troughs (277) are more than the number of individuals in both habitats (234) (Figure 3). In general, *D. stevensoni* was mostly encountered in May, December, and January months of the seasons (spring and winter) when it was collected in all months of summer and autumn.

Accordingly, we found the species from all the four seasons in Turkey. The distribution of fossil forms of species throughout Turkey were given in the Figure 4. Accordingly, fossil records indicated that the species has been known from Miocene (about 25 mya) in Turkey.

The optimum and estimated tolerance levels of *D. stevensoni* for eight different variables are given in Table 1. *D. stevensoni* showed positive and negative significant correlations with *pH* (*r = 0.218, N = 82, P<0.05*) and elevation (*r = -0.280, N = 101, P<0.01*), respectively.

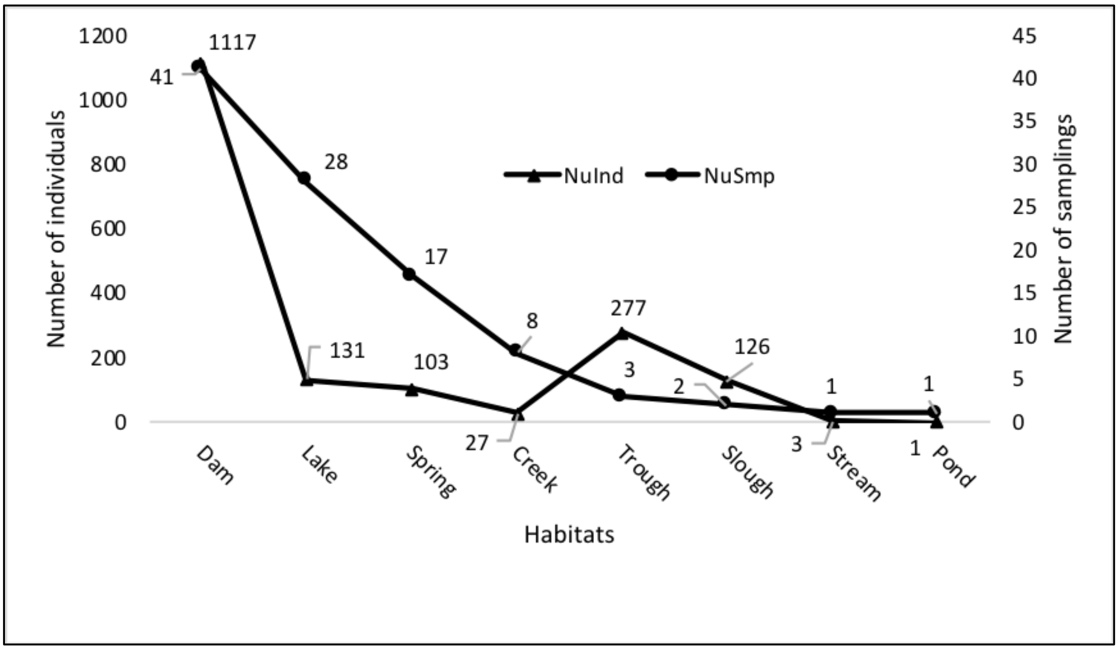

Figure 3. Sampling numbers (NuSmp) of eight different habitats and individual numbers of *D. stevensoni* (NuInd) in these habitats

Table 1. The optimum (*µk*) and estimated tolerance (*tk*) levels of *D. stevensoni* for *pH*, dissolved oxygen (*DO*), electrical conductivity (*EC*), water temperature (*Tw*), oxidation and reduction potential (*ORP*), elevation (*Elev*), salinity (*Sal*) and total dissolved solids (*TDS*). Abbreviations: Count, the number of sampling sites where species found; Max, the maximum number of individuals of concerned species among sampling sites and N_2, Hill's coefficient value that indicates the measure of effective number of occurrences.

				pH		DO		EC		Tw	
	Count	Max	N_2	*µk*	*tk*	*µk*	*tk*	*µk*	*tk*	*µk*	*tk*
Darwinula stevensoni	101	214	17.38	6.82	3.37	9.17	3.68	351.62	168.67	19.44	6.22
				ORP		Elev		Sal		TDS	
	Count	Max	N2	*µk*	*tk*	*µk*	*tk*	*µk*	*tk*	*µk*	*tk*
	101	214	17.38	114.92	82.56	708.62	232.33	0.13	0.07	142.00	104.31

The minimum and maximum values of *pH* (6.90-10.60), *DO* (0.32-18.31 mg/L), *DO%* (3.30-171.50 %), *EC* (21-844 *µS/cm*), *Tw* (6.10-31 °C), *Ta* (13-40.20 °C), *ORP* (-107.27-240.60 mV), *Elev* (39-2163 m a.s.l.), *Sal*. (0-0.42 ‰) and *TDS* (0.06-503.17 mg/L) of sampling sites where *D. stevensoni* collected. Accordingly, the species lives in waters with fresh to slightly brackish water ranges and it is characterized as a meso-polythermophilic.

Discussion

Along with the results of the present study and literature, recent living forms of the species has been now recorded from 27 provinces located in all seven geographic regions of Turkey (Figure 2). On the other hand, the fossil forms of the species *D. stevensoni* were only reported from 20 provinces covering six geographic regions of Turkey except Southeastern Anatolia. More than half of these 20 provinces were located in the western parts of

Turkey (Figure 4). Of these provinces, in Sakarya, dead specimens of *D. stevensoni* were taken from superficial sediments at 18 and 6 m depth of Lake Sapanca by Nazik et al. (2011) but they did not specify the age of these sediments. Meisch (2000) indicated that fossil record is known from Mid-Oligocene (ca 28 mya) to present but oldest fossil record in Turkey has been reported from the Miocene period (ca 23 mya) (see Figure 4). These data actually indicate the lack of paleontological studies dealing with ostracods in other parts (north, south, and east) of Turkey. As a result, *D. stevensoni* (in fossil and recent forms) has been reported in 44.4% of 81 provinces, Turkey. Among these provinces, eleven have fossil and recent forms and of the rest, 16 and nine provinces have only recent and fossil forms, respectively (Figures 1 and 3). Accordingly, with the current study, geographical distribution of *D. stevensoni* has been now expanded throughout Turkey.

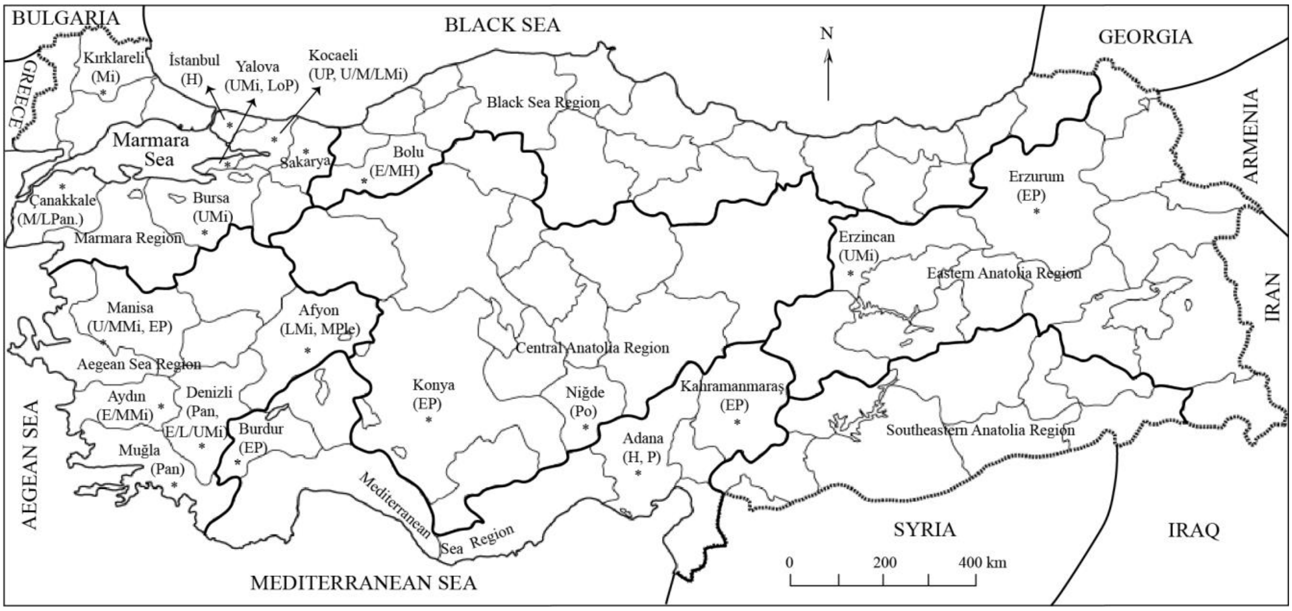

Figure 4. Fossil reports of *D. stevensoni* from Kırklareli (Witt 2011), İstanbul (Şafak et al. 1999; Meriç et al. 2000; Şekeryapan 2011), Yalova (Rückert-Ülkümen and Yiğitbaş 2007), Kocaeli (Matzke-Karasz and Witt 2005; Rückert-Ülkümen et al. 2006; Schneider et al. 2005), Sakarya (Nazik et al. 2011), Bursa (Freels 1980; Franz et al. 2006; Meriç et al. 2009; Nazik et al. 2011), Çanakkale (Atay and Tunoğlu 2002), Afyon (Demirer et al. 2017), Manisa (Witt 2003), Aydın (Tuncer and Tunoğlu 2015), Denizli (Gökçen 1979a, 1979b; Freels 1980; Şafak 2010), Muğla (Gökçen 1979a, 1979b), Burdur (Freels 1980), Adana (Nazik et al. 1992, 1999), Kahramanmaraş (Freels 1980), Konya (Freels 1980), Niğde (Nazik and Gökçen 1989), Erzincan (Freels 1980), Erzurum (Freels 1980) and Bolu (Tunoğlu et al. 2012) provinces in Turkey. Abbreviations: Early (E), Middle (M), Late (L), Lower (Lo), Upper (U), Miocene (Mi), Pannonian (Pan), Pontian (Po), Pliocene (P), Pleistocene (Ple), and Holocene (H).

Darwiula stevensoni prefers ponds, lakes and slow flowing streams (Meisch 2000). Szlauer-Łukaszewska (2014) and Ruiz et al. (2013) suggested *D. stevensoni* as a lake littoral species and benthos of shallow aquatic bodies, respectively. Pérez et al. (2011) and Marchegiano et al. (2017) indicated its negative correlation with depth. Contrary to common belief that species is generally found in shallow aquatic bodies, it has been reported from 0 to a maximum 20 m depth in literature (Meisch 2000; Pérez et al. 2010; Lorenschat and Schwalb 2013; Lorenschat et al. 2014) but species had a low optimum (2.3 m) and tolerance (3.8 m) levels to depth (Lorenschat and Schwalb 2013). The occurrence of species in the water bodies with a maximum 1 m depth herein supports the common occurrence of species in shallow waters although it has been encountered in a maximum of 20 m depth.

Additionally, species was commonly found in dam, lake, and springs (Figure 3). These habitats are generally permanent almost throughout the year. This confirms the suggestions of Palacios-Fest (2002-2003) as the occurrence of the species might be associated with long term water permanence. In addition, Escrivà et al. (2014) emphasized that *D. stevensoni* was one of the most common species in reservoirs. Until now, it has been reported from variety of habitats, such as ponds, slow flowing streams, lakes, springs, rivers, cenotes, troughs, coastal lagoons, wetlands (slough), artificial dam lakes, marshes, interstitial ground water, hot springs, reed beds, rice field, peat bogs, ditch and canal (Gülen 1985; Mezquita et al. 1999a, 1999b; Meisch 2000; Laprida et al. 2006; Higuti et al. 2009b; Pieri et al. 2009; Pérez et al. 2011; Akdemir and Külköylüoğlu 2014; Escrivá et al. 2014; Mazzini et al. 2014; the current study). Based on the data available, one may consider the fact that species seems to have high levels of plasticity for habitats as proposed by Ranta (1979). As seen in Figure 3, our results also reinforced the plasticity of species for habitats. This means that there are no specific habitat preferences of species, which may present certain conditions. However, highest numbers of individuals per site were reported from an artificial trough (92) that is followed by slough (63) and dam (27) (Figure 3). These habitats are sensitive to the outside effects of anthropogenic, seasonal and climatic changes (Külköylüoğlu et al. 2013; Uçak et al. 2014). Besides to habitat plasticity of the species, it has been collected from the habitats with sapropel (mud), sand, rocks, stones and gravel sediment types (Altınsaçlı and Griffiths 2001b; Szlauer-Łukaszewska and Kowaluk-Jagielska 2011; Lorenschat and Schwalb 2013) that reinforce the proposal of Ranta (1979). In addition, Külköylüoğlu and Vinyard (2000) reported it from muddy and sandy sediments with high dissolved oxygen concentration.

The reproduction periods of the species show slightly different patterns. For example, reproduction of the species takes from May to October (Meisch 2000) while it takes from March to September in a temperate pond in Belgium (Van Doninck et al. 2003b). These previous authors were also reported species from January to November in this temperate pond. Besides, Külköylüoğlu (1999) collected species from February to November from springs of Nevada. Martín-Rubio et al. (2005) reported species from Lake Caicedo de Yuso-Arreo (Spain) in January, February, March, April, June - August, and November when Scharf and Viehberg (2014) encountered species in February, April, June, July, September and October in Germany. The occurrence of the species in April from Lake Meyil (Konya, Turkey) (Akdemir 2008) and from May to January herein is now supported previously reported reproduction period of species. The occurrence of species in all climatic seasons and almost in all months in Turkey supports the founding of species throughout the year (Hiller 1972; Altınsaçlı and Griffiths 2001a). Martens and Tudorance (1991) also pinpointed that *D. stevensoni* is a perennial species in a tropical Ethiopian lake. Therefore, *D. stevensoni* is showed as a eurychronal species. All the data provided in here enforces its life cycle with about one or more years, during which two or more generations are produced. In each generation, females can carry maximum 11-12 embryos within their brood pouch (Van Doninck et al. 2003b; Gandolfi et al. 2001b). However, Horne et al. (1998) observed the presences of 15 juveniles in brood cavity. Accordingly, the species seems to have characteristics of K-selected or r-K continuum species (Van Doninck et al. 2003b). Furthermore, when comparing Darwinulids with other ostracods, they generally have low fecundity (Geiger 1998; Van den Broecke et al. 2013) and produce less eggs (0.02-0.07 layed eggs per day (Gandolfi et al. 2001b) and maximum 20 eggs per generation (Ranta 1979) that lower the number of cell division and thus the mutation rate falls in *D. stevensoni* (Van Doninck et al. 2003b).

Martens and Tudorance (1991) recorded the escape of species from the places with high temperature values in a tropical Ethiopian lake. Indeed, this observation was actually supported by the studies of Van Donnick et al. (2003a) that the species survival was shown to decrease with increasing temperature. Besides, Pérez et al. (2011) reporting a negative correlation between *D. stevensoni* and temperature confirmed the previous observation. When we look at the optimum and tolerance values of the species for water temperature 16.4-1.2 °C (Mezquita et al. 2005), 20.6-5.3 °C (Lorenschat and Schwalb 2013) and 19.44-6.22 °C (this study) (Table 1) it appears that species can tolerate a broad temperature range from cold to warm waters. Along with these information, wide temperature ranges of species from 4 (in subarctic) to 35 °C (Van Doninck et al. 2003b; Külköylüoğlu 2013) support the suggestion of Gandolfi et al. (2001b) and Anàdon et al. (2012) who characterized the species as eurythermal (tolerating and adapting to wide range of temperature) and thermoeuryplastic (a wide range of temperature tolerance), respectively.

When we look at the literature for the species occurrence patterns in different areas, it appears that its occurrence was reported to be positively related to biological oxygen demand (*BOD*), ammonium content (Mezquita et al. 1999a), *DO*, *pH* (Martens and Tudorance 1991), low (Rieradevall and Roca 1995) or highest water temperatures (Escrivá et al. 2014), warm water, carbonated water rich with sulfate and chloride (Mezquita et al. 1999b), but the relationship with iron content was negative (Iglikowska and Namiotko 2012). The result of the previous studies supports the suggestion of Külköylüoğlu and Vinyard (2000) as *D. stevensoni* prefers less saline waters. Similarly, Van Doninck et al. (2003a) suggested that survival of *D. stevensoni* is declined with increasing in salinity. Besides, Pérez et al. (2011) reported the species tolerating electrical conductivity optima at <700 μS/cm when Mezquita et al. (2005) and Lorenschat and Schwalb (2013) announced the optimum and tolerance level of species for electrical conductivity as followings 3.09 ± 0.39 mS/cm and 239.1 ± 35.3 µS/cm (for salinity 0-0.04 ‰), respectively. The low optimum and tolerance levels of species for EC (351.62 ± 168.67) and salinity (0.13 ± 0.07) herein (Table 1) strengthened these previous findings. On the other hand, Martens (1990) noted the presence of species in the East African Lake Shala with 16–21 g/L salinity. Recently, Mischke et al. (2014) indicated the overcoming of species to large specific conductivity fluctuation but suggesting low optimum and tolerance of the species in 3.164 µS/cm and 0.916 µS/cm of EC values. The minimum and maximum value of electrical conductivity 21–9600 (after 15 days 100 % mortality observe) µS/cm (the current study; Gandolfi et al. 2001a) and salinity range 0-15 ‰ (the current study; Meisch 2000) for the species in literature strengthen the tolerating ability of species to salinity and EC fluctuations. Consequently, all of them fortify the euryhaline characteristics of species (Gandolfi et al. 2001b) and the presence of species from distilled water to sea water (Van Doninck et al. 2003a).

The positive correlation of *D. stevensoni* with *pH* herein endorses the recommendation of Rossetti et al. (2004). They found a close association between species and *pH* in eutrophic freshwater wetlands of northern Italy. In contrast, negative correlation was recorded between the species and *pH* (Pérez et al. 2011; Marchegiano et al. 2017). However, the high optimum and tolerance levels of species for *pH* as following 7.74 ± 0.40 (Mezquita et al. 2005) and 8.62 ± 0.26 (Lorenschat and Schwalb 2013) were announced from several different aquatic bodies. When we compile all data and compare optimum and tolerance (6.82 ± 3.37, Table 1) levels of the species along with min/max values (5.5–10.60) (Ruiz et al. 2013; the current study) for *pH*, it can be clearly seen that the *D. stevensoni* is of wide ranges of *pH* tolerance.

Additionally, species was negatively correlated with elevation in the current study. Possible effects of elevation on the physico-chemical characteristics of the aquatic bodies are widely discussed (Reeves et al. 2007; Rogora et al. 2008). Accordingly, it seems that elevation can be effective on the abundance but its effect may not be significant on the occurrence and distribution of species at high elevations. This is because it has been reported from sea level (Külköylüoğlu pers. obs.) to 4000 m a.s.l. (Laprida et al. 2006). Indeed, generally individual numbers larger than 100 were found from the sampling sites between 700-900 m a.s.l. and at lowest elevation when the range is 39 (122 individuals) – 2163 (5 individuals) m a.s.l in the present study.

Ranta (1979) delineated that *D. stevensoni* prefers highly oxygenated waters to aerate its eggs in brood chamber as stated by Külköylüoğlu and Vinyard (2000) and Rossetti et al. (2004). The high optimum and tolerance of species for dissolved oxygen 8.4 ± 2.1 mg/L in Mezquita et al. (2005), 7.9 ± 3.1 mg/L in Lorenschat and Schwalb (2013) and herein (see Table 1) support the proposal of Ranta (1979). On the other hand, Escrivà et al. (2014) proposed preferences of species for lowest dissolved oxygen. Although species might die under oxygen depletion (Rieradevall and Roca 1995), species can live over one month (38 days) under hypoxic conditions (ca. 0.12 ml/L oxygen) in laboratory conditions (Rossi et al. 2002). The minimum and maximum DO ranges of the species (0.32-18.31 mg/L) herein indicate that species may tolerate from low to high oxygen concentrations. Moreover, there is no any studies dealing the number or quality of eggs of species in low and high DO concentration and so the proposal of Ranta (1979) may be acceptable until otherwise stated. In addition, minimum and maximum values of ambient air temperature (12-40.20 ºC) (Horne 2007; the current study), calcium (5.25-80.80 mg/L) (Higuti et al. 2009a; Pérez et al. 2015) and magnesium (2.30-100.80 mg/L) (Holmes 1997; Pérez et al. 2015) contents of water bodies where species collected.

The above-mentioned information and wide range of environmental variables for species confirm the presence of all characteristics of the idea called "general purpose genotype" (GPG) in *D. stevensoni* (Rossi et al. 2002; Van Doninck et al. 2002). GPG emphasizes the production of different phenotypes by a genotype across a wide range of environmental conditions that allow species survive with high fitness in a wide range of habitats (Baker 1965; Geiger et al. 1998). This character of *D. stevensoni* reinforce the idea of Vandel (1928) as that "parthenogenetic (i.e., ancient asexual *D. stevensoni* herein) forms can be found in much wider areas" and referring to its long living without sex. Accordingly, Külköylüoğlu (2013) called the species as "cosmoecious species" to distinguish it from other species because of its wide geographical distribution and with relatively wide ecological tolerance ranges in variety of aquatic habitats. This view implies to take attention of scientists who want to use *D. stevensoni* as a potential bioindicator species to estimate past conditions and to determine water quality values of the present habitats. Additionally, species is ecologically characterized as stated by Meisch (2000), thermoeuryplastic and it encountered from freshwater range to mesohaline range.

As mentioned above, fossils of the species are known from Miocene and distribution of fossils forms are mostly known from western parts of Turkey. Indeed, occurrences of both living and fossil forms partially overlap in some regions, indicating the long lasting surviving possibilities of the species in these regions. On the other hand, considering the fact that the species has not been found from hundreds of recent and paleontological samples, we may assume that *D. stevensoni* has not been able to reach to these regions. We believe that absence of the species from these samples may also be related to several other a/biotic factors but it is also possible that this is just a matter of time. Besides, as seen from Figures 1 and 2, as much as contemporary studies on living recent forms, paleontological studies are far away from understanding of their distribution in Turkey (if not the whole world). Thus, our study strongly suggests the need for future studies not only to understand for the distributional patterns of *D. stevensoni* but also other ostracods found from 4000 m below sea level to ca. 6000 m a.s.l.

Acknowledgements

This study is partially supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK, Project no: 213O172).

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Appendix

Sampling numbers (SpNu), name of the county, habitat type, date and number of individuals of *D. stevensoni* (Abundance). na means not available. Habitat types: 1, Lake; 2, Creek; 3, Trough; 4, Dam; 5, Stream; 6, Pond; 7, Spring and 8, Slough.

SpNu	County name	Habitat type	Date	Abundance
1	Bolu	4	30.06.2000	2
2	Bolu	4	28.07.2000	1
3	Bolu	4	28.07.2000	3
4	Bolu	4	31.08.2000	3
5	Bolu	4	29.09.2000	2
6	Bolu	4	29.09.2000	2
7	Bolu	4	29.09.2000	3
8	Bolu	4	29.09.2000	4
9	Bolu	4	29.09.2000	4
10	Bolu	4	29.09.2000	8
11	Bolu	4	29.09.2000	34
12	Bolu	4	29.10.2000	2
13	Bolu	4	29.10.2000	2
14	Bolu	4	29.10.2000	3
15	Bolu	4	29.10.2000	3
16	Bolu	4	29.10.2000	3
17	Bolu	4	29.10.2000	28
18	Bolu	4	29.10.2000	201
19	Bolu	4	26.11.2000	32
20	Bolu	4	31.12.2000	1
21	Bolu	7	31.05.2001	10
22	Bolu	4	30.06.2001	50
23	Bolu	4	26.07.2001	2
24	Bolu	4	26.07.2001	6
25	Bolu	4	26.07.2001	10
26	Bolu	4	26.07.2001	14
27	Bolu	4	26.07.2001	22
28	Bolu	4	26.07.2001	32
29	Bolu	4	26.07.2001	101
30	Bolu	7	28.08.2001	1
31	Bolu	4	28.08.2001	19
32	Bolu	4	28.08.2001	101
33	Bolu	4	30.09.2001	3
34	Bolu	4	30.09.2001	101
35	Bolu	4	30.09.2001	101
36	Bolu	1	6-7.10.2001	1
37	Bolu	1	13.10.2001	1
38	Bolu	1	13.10.2001	3
39	Bolu	1	14.10.2001	1
40	Bolu	4	30.10.2001	1
41	Bolu	4	30.10.2001	101
42	Bolu	4	30.10.2001	101
43	Bolu	1	11.11.2001	1
44	Bolu	4	30.11.2001	1
45	Bolu	4	30.11.2001	2
46	Bolu	4	30.11.2001	3
47	Bolu	1	31.05.2002	1
48	Bolu	1	31.05.2002	3
49	Bolu	1	30.07.2002	1
50	Bolu	1	29.08.2003	8
51	Bolu	1	31.08.2003	1

SpNu	County name	Habitat type	Date	Abundance
52	Bolu	1	26.10.2003	1
53	Bolu	1	26.10.2003	1
54	Bolu	1	31.10.2003	1
55	Bolu	1	31.10.2003	2
56	Bolu	1	31.10.2003	3
57	Bolu	7	15.11.2003	6
58	Bolu	1	30.11.2003	2
59	Bolu	7	13.12.2003	1
60	Bolu	7	17.01.2004	6
61	Bolu	1	29.05.2004	1
62	Bolu	1	29.05.2004	1
63	Bolu	1	28.07.2004	1
64	Bolu	1	28.07.2004	1
65	Bolu	7	27.08.2004	1
66	Bolu	7	27.08.2004	2
67	Bolu	1	30.08.2004	1
68	Bolu	7	18.09.2004	5
69	Bolu	1	25.09.2004	2
70	Bolu	7	17.10.2004	2
71	Bolu	7	13.11.2004	1
72	Ordu	3	15.06.2010	1
73	Ordu	1	15.06.2010	77
74	Gaziantep	7	21.07.2010	9
75	Adıyaman	7	17.07.2012	52
76	Adıyaman	6	18.07.2012	1
77	Adıyaman	4	19.07.2012	2
78	Hatay	2	01.08.2012	5
79	Hatay	2	06.08.2012	2
80	Burdur	7	31.08.2012	1
81	Mardin	2	14.08.2013	1
82	Mardin	3	14.08.2013	62
83	Mardin	5	15.08.2013	3
84	Muş	7	18.08.2013	1
85	Muş	1	19.08.2013	5
86	Sakarya	7	10.05.2014	1
87	Sakarya	8	10.05.2014	122
88	Kütahya	4	21.09.2014	3
89	Kütahya	8	21.09.2014	4
90	Kütahya	2	21.09.2014	9
91	Kütahya	3	21.09.2014	214
92	Mersin	7	06.10.2015	3
93	Antalya	2	17.08.2017	6
94	Isparta	1	18.08.2017	2
95	Antalya	2	19.08.2017	2
96	Burdur	1	21.08.2017	3
97	Muğla	1	22.08.2017	2
98	Muğla	2	25.08.2017	1
99	Antalya	2	13.10.2017	1
100	Isparta	1	16.10.2017	2
101	Burdur	1	19.10.2017	3
102	Bolu	7	na	1