

COMPARISON OF OSTRACODA (CRUSTACEA) SPECIES COMPOSITION BETWEEN LAKES AND STREAMS AT HIGH ELEVATIONS IN TURKEY

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Ostracods are one of the most suitable organisms because of their ecological and morphological preferences for habitat types to study the diversity between streams and lakes. In this study, 24 streams and 16 lakes were sampled in 2019 to evaluate the species compositions between streams and lakes. Environmental heterogeneity in the sense of the physico-chemical variables was found among the habitats. 24 of the 29 species with 923 individuals were found in the lakes when 13 species with 898 individuals were found in the streams. Eight species were common in both habitat types. Species contributing about 70.81% to the significant differences in the species composition between the habitats showed cosmopolitan characteristics. Species variation among the replicates of lakes was higher than streams. Results indicated that the species composition was probably associated to dissolved oxygen and electrical conductivity in lakes and streams, respectively. Overall, results suggested that the determination of influential local factors (e.g., dissolved oxygen, electrical conductivity) in different aquatic bodies can provide important contributions to the estimation of which habitat types can be chosen by species and the use of species as bioindicators.

Key words: elevational range, lotic and lentic, benthonic and nektonic, environmental heterogeneity, cosmopolitan species, Ostracoda, Crustacea.

INTRODUCTION

Waters flowings in one direction along a slope are called lotic (e.g., streams, rivers), but stagnant water bodies (e.g., lakes) are termed as lentic habitats. Unlike lotic systems, lakes bear different water flows regimes into, out, and throughout their basins (WETZEL 2001). These flowing regimes cause the variability of water renewal times of lentic habitats when compared to lotic habitats with continuous water renewal times (WETZEL 2001). This allows distinguishing the lotic and lentic habitats environmentally and spatiotemporally (HOF *et al.* 2008). In addition, both habitat types also show differences in the physico-chemical parameters (e.g., pH, dissolved oxygen, etc.) (MISHRA & YADAV 1978, LOTTIG *et al.* 2011), which lead to change species compositions. Recently, DUNN *et al.* (2020) underlined the prevailing of Ephemeroptera, Plecoptera, and Trichoptera in lotic habitats while micro-crustaceans like Copepoda, Cladocera, and Ostracoda in lentic habitats.

Ostracods, one of the small crustaceans (0.3-5 mm long), are found in various aquatic habitats, from marine to freshwaters (MEISCH 2000). They can be carried out over long distances via vectors (e.g., birds, humans) (MCKENZIE & MORONI 1986), but they can change their location using their swimming setae on their second antennae (A2) in the habitats where they live. Due to the presence of swimming setae on A2, they are categorized as 1) nektonic species that have swimming setae reaching and/or passing to the tips of terminal claws of A2, and 2) benthonic species that bear reduced swimming setae extending up to the middle of the penultimate seta of A2 or shorter (MEISCH 2000). Along with the physico-chemical parameters of aquatic bodies (KÜLKÖYLÜOĞLU 2013), habitat type is showed as one of the important environmental variables for the occurrence and composition of ostracods (MARMONIER *et al.* 1994, KÜLKÖYLÜOĞLU 2004). HIGUTI *et al.* (2007) declared the association of freely swimming ostracods with littoral (non-floating) macrophyte beds of lakes in the Paraná River floodplain (Brazil) and then AKDEMİR *et al.* (2016) stated the preferences of non-swimming ostracod species for lotic rather than lentic systems. KÜLKÖYLÜOĞLU *et al.* (2019a) reported that benthonic ostracods might prefer unstable aquatic bodies (lotic) rather than stable aquatic bodies (lentic) when compared with nektonic species. From the information mentioned above, one can interpret that both systems (lotic and lentic) can be an essential factor in ostracod species' occurrence. What matters here is whether the morphological characteristics (e.g., swimming setae) or ecological tolerances of the species are more important in these habitat preferences. Most recently, YAVUZATMACA (2020a) pinpointed the importance of ecological tolerance of species rather than a morphological character for the habitat preferences, but he also underlined that more works are needed to clarify this issue. Therefore, studies discussing this issue will make a significant contribution to use ostracods as habitat indicators.

While evaluating ostracod distribution and their ecological and habitat preferences, the importance of elevation should not be ignored as a regional factor. In literature, the effect of elevation on the distribution of ostracods is still a controversial issue (e.g., YAVUZATMACA *et al.* 2018, YAVUZATMACA 2019 and citations therein). Although the conducted studies gave different results, it is widely believed that elevation is not the primary factor, but as a secondary factor, it affects the distribution of ostracods. YAVUZATMACA *et al.* (2018) and references therein discussed it in detail and supported the secondary effect of elevation on the distribution of ostracods. This is because of the dependence of the air and water temperatures on the elevation, and then changes of physico-chemical parameters due to the water temperature fluctuations in water played an important role to support this view. DEHLING *et al.* (2010) used elevation as a factor for habitat diversity in a region and reported that widening of elevation range resulting in a decrease in species richness for lentic but

an increase for lotic habitats. Also, citations in the same study suggested an ascending species richness for lotic and lentic habitats along with the elevational range extending. In the sense of ostracods, KÜLKÖYLÜOĞLU *et al.* (2016) proposed a clear relationship between habitat diversity and species richness in Çankırı province (Turkey). In the light of this information, the change in ostracod species richness in a region with the widening and narrowing of the elevational range as a factor of habitat diversity is one of the issues that need to be investigated because such information contributes to environmental protection and biodiversity studies both in time and economically. Apart from the discussion relating to elevation, elevation as a habitat diversity factor will be examined by comparing the results of the present study with the literature for ostracods. Along with this important point of this study, (1) testing of hypothesis, “no difference in the species composition between streams and lakes”, (2) determination of the effectiveness of dissolved oxygen, water temperature, electrical conductivity, pH and elevation on the distribution of ostracods, and (3) estimation of ecological tolerance and optimum values of species are the other main objectives of the study.

MATERIAL AND METHODS

Study area – The present study was conducted in the borders of 6 provinces located in the Black Sea (Artvin) and Eastern Anatolia (Erzurum, Ardahan, Kars, Van, and Bitlis) of Turkey (Fig. 1). According to Köppen-Geiger climate classification systems, temperate oceanic (Artvin), warm-summer humid continental (Artvin, Erzurum, Ardahan, and Kars), Mediterranean influenced warm-summer humid continental (Van and Bitlis), and the Mediterranean influenced hot-summer humid continental (Bitlis) climates are commonly observed in the borders of studied provinces (CLIMATE-DATA.ORG 2020). Sixteen lakes with an elevation range from 1007 (L16) to 2358 (L12) m asl. and 24 streams with the elevation ranging from 1510 (S12) to 2340 (S2) m asl. were chosen for the ostracod samplings (Fig. 1). Six lakes (L1, L3, L8, L11, L12, and L16) and five streams (S7, S10, S19, S22, and S24) were sampled once in June when the rests were sampled three times in June, July-August, and September of 2019. Among streams, S1, S2, S5, S10, S12, S13, S21 and S24 are the second (2nd) order streams according to the Strahler stream ordering method (STRAHLER 1957), and others are the first (1st) order streams. All the sampled lakes and streams have permanent waters.

Geographical data (elevation and coordinates) (Tables S1 and S2) were recorded *in situ* with a GARMIN etrex Vista H global position system. To obtain the accurate values of environmental variables, dissolved oxygen concentration (DO, mg/L), water temperature (T_w , °C), electrical conductivity (EC, $\mu\text{S}/\text{cm}$) and pH were measured before ostracod sampling by a YSI Professional Plus multi-probe device (Table S2).

Sampling – To collect ostracod samples, a standard sized hand net (200 μm in mesh size) was used to gather 2–3 cm of upper surface of sediments and swept into the water body. Samples were collected up to a 1 m depth covering 1 m² area from the littoral region of lakes and from slow-flowing riparian zones of streams and subsequently fixed in 70% ethanol in 250 ml plastic bottles *in situ*.

Laboratory analyses – After washing samples under pressurized tap water, ostracod specimens were separated from the sediments under an Olympus ACH 1X stereomicroscope. Taxonomic keys provided in MEISCH (2000) and KARANOVIC (2012) were used for the identification of species based on using both soft body parts and the morphology of carapaces under a light microscope (Olympus BX-51).

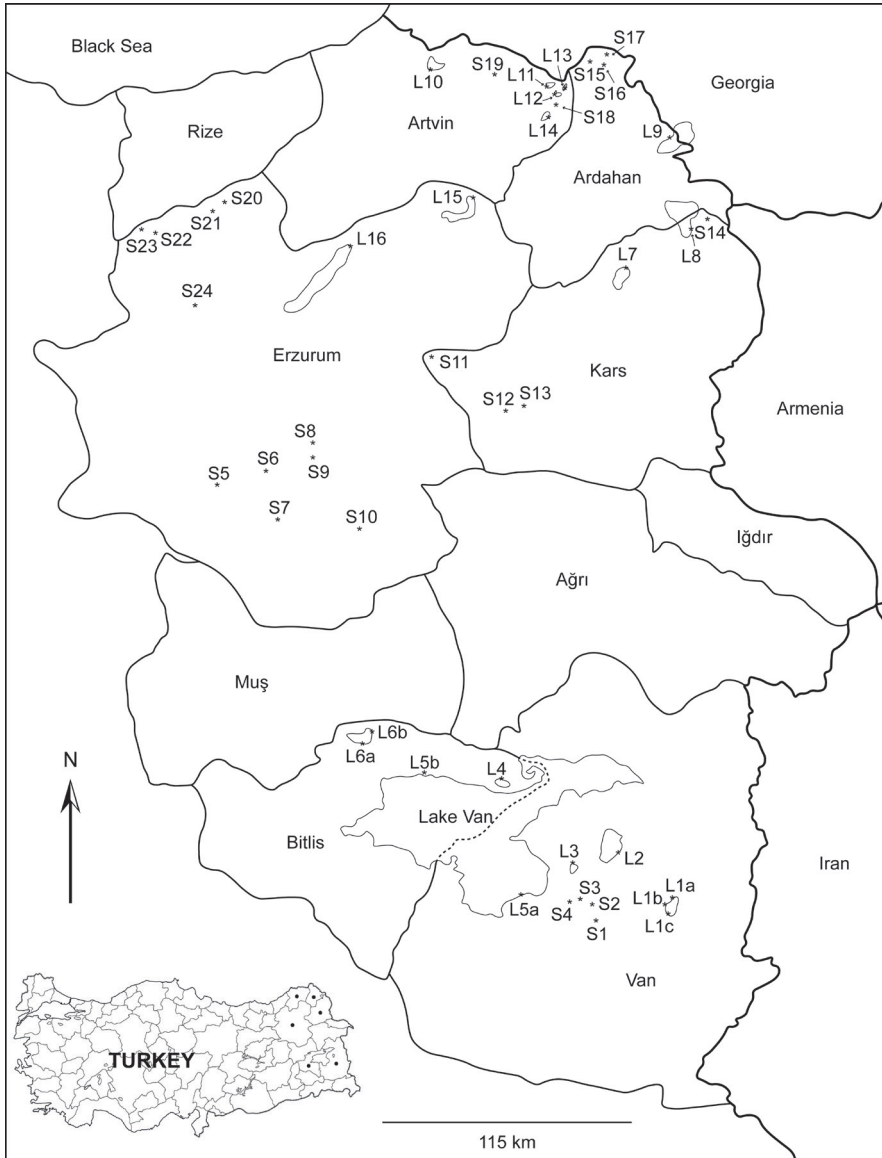


Fig. 1. Location of 16 lakes and 24 streams studied in the present study. L and S indicate lake and stream, respectively. Lowercase a, b and c show the multiple samplings in a lake

Statistical analyses – Independent-Samples t-test, along with the application of post-hoc analysis, was used to test significant differences in the mean values of environmental variables between lakes and streams (IBM-SPSS Statistics Version 21). When homogeneity of variance and normality of data was not fulfilled, the Mann-Whitney U test is run. A diversity permutation test with 9999 random matrices was performed to compare species richness and abundance of ostracods between lakes and streams (PAST 3.26 software (HAMMER *et al.* 2001)). To estimate species diversity, Shannon index values of lakes and streams were calculated using Species Diversity and Richness 4 software (SEABY & HENDERSON 2006). Possible significant correlations between Shannon index values and environmental variables for lakes and streams were checked by Spearman Correlation Analysis (IBM-SPSS Statistics Version 21). Species were categorized as eudominant (32 – 100%), dominant (10 – 31%), subdominant (0.32 – 9%), recedent (1 – 3.1%), subrecedent (0.32 – 0.99%) and sporadic (< 0.31%) according to their abundance percentages (ROMBACH 1999). A nonparametric Multivariate Permutational Variance Analysis, PERMANOVA, (ANDERSON 2001) was applied to test the null hypothesis “no difference in the species composition between streams and lakes”. Bray-Curtis and a total of 999 permutations were used as a dissimilarity matrix, and to measure the significance of differences, respectively (PRIMER 7.0 software package (CLARKE & GORLEY 2015)). Multivariate dispersion (MVDISP) indices were calculated (WARWICK & CLARKE 1993) to evaluate numerical indices of similarity among replicates of lakes and streams. In which, values closer to zero indicate no difference when larger values mean crucial dissimilarity. Variation in species composition, beta diversity, with the use of Bray-Curtis dissimilarity measure between lakes and streams, was calculated using Permutational Analysis of Multivariate Dispersions (PERMDISP) based on distances between sample units and centroid of the group (ANDERSON 2006, ANDERSON *et al.* 2006) and then its significance was tested with permutations (999 replicates). PERMANOVA (streams = or ≠ lakes) and PERMDISP (streams – streams = or ≠ lakes – lakes) test whether classes of each habitat type show differences in their variability in species composition (beta diversity) and in their within-classes dispersion or beta diversity, respectively. Also, PERMANOVA and PERMDISP with Euclidian distance matrixes were applied to test environmental variables composition and environmental heterogeneity between streams and lakes, respectively. Analysis of Similarity Percentage (SIMPER) was run to see which species or environmental variables is/are responsible for differences in species or environmental composition between lakes and streams when the PERMANOVA indicated a significant result (CLARKE & WARWICK 2001). All these multivariate statistical analyses were carried out with the PRIMER 7.0 software package. Principal Coordinate Analysis (PCoA) was applied with the same data used in PERMANOVA to visualize (dis)similarity of ostracod species composition between the streams and lakes (PAST 3.26 Software). Detrended Correspondence Analysis revealed that the longest gradient length was smaller than 3 for lakes and between 3 and 4 for streams (Table S3). In this situation, using a linear method was suggested by TER BRAAK & ŠMILAUER (2002). Therefore, Redundancy Analysis (RDA) was performed using CANOCO 4.5 software to explore relationships between environmental variables and ostracod species that occurred three or more times during the sampling, and the significance of variables was tested with Monte Carlo permutation test (499 permutations). Ecological optima (Opt) and tolerance (Tol) values of species seen at least three times for explanatory factor(s) were estimated by a transfer function of weighted averaging regression used in C2 Software (JUGGINS 2003). All analyses were carried out with undamaged adult individuals, and analyses relating to environmental variables were done for sampling sites bearing living adult individuals.

RESULTS

Mean values of electrical conductivity ($Z = -2.82$, $p = 0.005$, Mann-Whitney U test), water temperature ($t = 2.83$, $p = 0.006$, Independent samples t-test), and pH ($t = 2.80$, $p = 0.007$, Independent samples t-test) indicated significant differences between lakes and streams while elevation ($Z = -1.28$, $p = 0.199$, Mann-Whitney U-test) and dissolved oxygen concentration ($Z = -0.51$, $p = 0.61$, Mann-Whitney U-test) did not show significant differences (Fig. S1). PERMANOVA indicated a significant difference found in the variability of environmental gradients between lakes and streams (Pseudo-F = 16.296, $p = 0.001$). According to the SIMPER, electrical conductivity had great contribution (99.83%) to this difference. Environmental heterogeneity amid the lakes and streams (average distance of centroid and standard error in lakes = 7324.4 ± 928.47 and in streams = 235.37 ± 14.30) were significant ($F = 87.019$, $p = 0.001$). Results demonstrated that these habitat types had different environmental characteristics.

A total of 1821 individuals belonging to 29 ostracod species were reported in the present study (Tables 1 and S1). There is a significant difference ($p < 0.05$) in species richness and abundance between lakes (24 spp. and 923 ind.) and streams (13 spp. and 898 ind.). The number of nektonic species (species freely swimming, 4 spp.) is smaller than those of benthonic species (non-swimmer, 9 spp.) in streams, but these numbers are very close to each other in lakes (nektonic = 13 spp. and benthonic = 11 spp.) (see Table 1).

Shannon diversity index values of lakes and streams were ranged from 0.07 (L8 in June) to 1.251 (L15 in June), and from 0.23 (S16 in September) to 1.06 (S23 in July–August) with all index values equal to 2.151, and 1.187, respectively. Shannon index value showed moderately significant negative correlation with pH ($r_s = -0.41$, $p < 0.05$) but positive with dissolved oxygen ($r_s = +0.40$, $p < 0.05$) in lakes. In streams, no significant results were determined.

PERMANOVA revealed a significant distinctness in the species composition (Pseudo-F = 7.93, $p = 0.001$) between lakes and streams (Fig. 2). Eight species (*Cypridopsis vidua*, *Heterocypris incongruens*, *Ilyocypris bradyi*, *I. gibba*, *Neglecandona neglecta*, *Potamocypris fallax*, *Pseudocandona albicans*, and *Psychrodromus olivaceus*) were common in both habitat types (Table 1 and Fig. 2). However, only *I. bradyi* was found as eudominant in both habitat types among these species, while *C. vidua* and *I. gibba* recorded from streams, and *N. neglecta* from lakes were sporadic species (see Table 1). SIMPER showed 70.81% contributions of first seven species (*Limnocythere inopinata* (19.33%), *I. bradyi* (14.26%), *P. olivaceus* (9.64%), *C. vidua* (8.04%), *P. fallax* (7.46%), *Cypria ophthalmica* (6.16%) and *N. neglecta* (5.92%)) to the 99.17% of average dissimilarity between both habitat types.

Table 1. Number of individuals (abundance), dominance percentage (%) and locomotory ability of ostracod taxa in lakes and streams from June to September. DL = dominance % in lakes, DS = dominance % in streams, L = locomotory ability, N = nektonic, B = benthonic, VI = June, VII–VIII = July–August, IX = September.

Species	Code	Lakes			Streams			DL	DS	L
		VI	VII–VIII	IX	VI	VII–VIII	IX			
<i>Cypria ophthalmica</i>	Co	20	26	12				6.28		N
<i>Cypris pubera</i>	Cp	5						0.54		N
<i>Cypridopsis vidua</i>	Cv	34	50	10	1			10.18	0.11	N
<i>Fabaeformiscandona balatonica</i>	Fb					6			0.67	B
<i>Fabaeformiscandona</i> sp.1	Fp1				1				0.11	B
<i>Fabaeformiscandona</i> sp. 2	Fp2		5	2				0.76		B
<i>Heterocypris incongruens</i>	Hi		66	1	3	12	1	7.26	1.78	N
<i>Heterocypris salina</i>	Hs					4	22		2.90	N
<i>Ilyocypris bradyi</i>	Ib	320			5	60	308	34.67	41.54	B
<i>Ilyocypris decipiens</i>	Id			3				0.33		B
<i>Ilyocypris gibba</i>	Ig		6			1		0.65	0.11	N
<i>Ilyocypris monstifrica</i>	Im	36						3.90		N
<i>Limnocythere inopinata</i>	Li	122	21	25				18.20		B
<i>Limnocytherina sanctipatricii</i>	Ls	1	4	2				0.76		B
<i>Neglecandona neglecta</i>	Nn		1		4	18	54	0.11	8.46	B
<i>Physocypris kraepelini</i>	Pk	2						0.22		N
<i>Plesiocypridopsis newtoni</i>	Pn	14	35	3				5.63		N
<i>Potamocypris fallax</i>	Pf	1	1		19	33	38	0.22	10.02	B
<i>Potamocypris pallida</i>	Pp		29					3.14		B
<i>Potamocypris similis</i>	Ps				10	55	59		13.81	B
<i>Potamocypris unicaudata</i>	Pu			1				0.11		N
<i>Potamocypris variegata</i>	Pv		6					0.65		N
<i>Potamocypris zschokkei</i>	Pz		2					0.22		B
<i>Pseudocandona albicans</i>	Pa	1	13	2	1	3		1.73	0.45	B
<i>Psychrodromus olivaceus</i>	Po	4		1	24	61	87	0.54	19.15	B
<i>Psychrodromus robertsoni</i>	Pr					6	2		0.89	B
<i>Stenocypris fischeri</i>	Sf	33						3.58		N
<i>Trajancypris clavata</i>	Tc	1						0.11		N
<i>Trajancypris serrata</i>	Ts	2						0.22		N
Richness		15	14	11	9	11	8			
Number of individuals		596	265	62	68	259	571			

Samples of lakes (1.139) were indicated higher dissimilarities than streams (0.938) based on MVDISP. These results corroborated with SIMPER that displayed low similarity percentages in the lakes (10.18%) than streams (11.97%). Variability of species composition between lakes and streams did not show significant differences ($F = 0.37$, $p = 0.563$) when the average distance to centroid was 63.642 in lakes and 62.563 in streams.

The first two axes of Redundancy Analysis (RDA) explained high percentages of relationships between species (distribution + abundance) and environmental variables in lakes (89.5%) and streams (98%) (Table S3). In lakes, dissolved oxygen concentration (DO) exhibited a significant effect ($\lambda = 0.21$, $F = 6.35$, $p = 0.002$) on the distribution and abundance of species, while some of the other variables (electrical conductivity (EC, $\lambda = 0.07$, $F = 2.63$, $p = 0.056$), elevation (Elev, $\lambda = 0.08$, $F = 2.47$, $p = 0.062$), water temperature (Tw, $\lambda = 0.06$, $F = 2.09$, $p = 0.114$) and pH ($\lambda = 0.01$, $F = 0.46$, $p = 0.678$)) were not significant. *Stenocypris fischeri* and *Limnocytherina sanctipatricii* presented close relationships with DO and EC, respectively, while the distribution and abundance of *L. inopinata* were correlated with pH and Tw (see Fig. 3a). In streams, a meaningful effect of EC ($\lambda = 0.11$, $F = 5.43$, $p = 0.008$) was found on the distribution of species while the effects of DO ($\lambda = 0.02$, $F = 1.03$, $p = 0.328$), Elev ($\lambda = 0.01$, $F = 0.52$, $p = 0.586$), pH ($\lambda = 0.01$, $F = 0.34$, $p = 0.750$) and Tw ($\lambda = 0.01$, $F = 0.16$, $p = 0.918$) were insignificant. Abundance and distribution of *H. incongruens*, *H. salina*, *P. albicans* and *I. bradyi* showed positive associations with Tw but *N. neglecta* exhibited a negative relationship. *Potamocypris similis* displayed a negative correlation with EC (Fig. 3b). Estimated optimum (Opt) and toler-

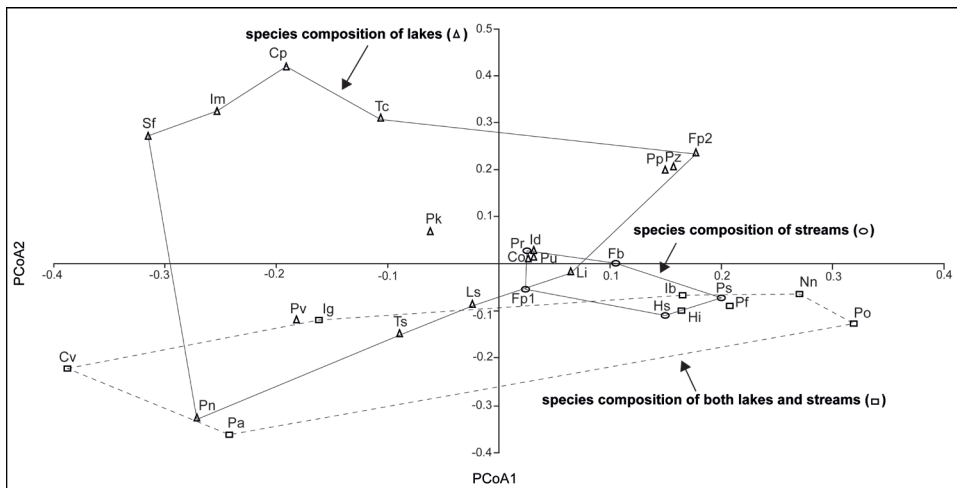


Fig. 2. Principal coordinate result for the variability in the species composition between lakes and streams

Table 2. Optimum (Opt) and tolerance (Tol) levels of species observed at least three times for elevation (Elev. m. asl.), water temperature (Tw, °C), pH, electrical conductivity (EC, µS/cm) and dissolved oxygen concentration (DO, mg/L). Abbreviations: Count, numbers of species occurrence; Max, maximum numbers of individuals and N₂, Hill's coefficient or measure of an effective number of occurrences. Species codes are the same with Table 1.

Code	Count	Max	N ₂	Elev.			Tw			pH			EC			DO		
				Opt	Tol	Tol	Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
Pf	16	18	9.45	2108.33	291.28	18.86	3.95	8.50	0.57	244.48	53.47	7.93	1.38					
Po	27	44	8.21	2066.03	175.12	18.31	3.77	8.59	0.43	160.43	72.00	7.61	1.09					
Nn	16	30	5.20	1904.33	191.86	17.32	3.24	8.04	0.40	76.20	32.73	8.11	0.89					
Li	14	54	5.15	2137.29	325.93	22.83	1.69	9.59	0.52	10490.70	4204.84	5.12	1.89					
Ib	19	320	3.75	2007.30	127.37	20.15	2.49	8.50	0.57	264.66	80.83	7.54	0.88					
Ls	4	3	3.27	1690.86	85.15	21.70	1.63	9.58	0.11	22677.90	1148.06	7.71	1.29					
Cv	9	50	3.19	1948.19	404.62	20.61	1.98	8.54	0.62	190.98	52.89	9.03	0.93					
Co	3	26	2.76	2357.55	0.62	16.13	1.90	8.56	0.75	116.35	28.00	9.18	1.19					
Hs	3	13	2.54	1979.38	136.10	22.18	2.01	8.80	0.34	387.73	45.20	7.69	0.67					
Ps	5	59	2.42	2044.02	21.02	16.39	4.03	8.61	0.22	78.12	30.97	8.13	1.57					
Sf	4	19	2.37	1696.82	351.02	22.11	2.60	7.58	0.57	139.27	92.00	7.47	1.58					
Pa	7	13	2.25	2058.70	350.89	20.90	3.63	8.75	0.36	203.56	65.51	8.99	1.13					
Pn	4	35	1.90	2113.33	131.65	20.46	1.88	8.81	0.31	173.02	13.51	9.42	0.80					
Ig	3	5	1.81	1324.57	773.15	19.54	1.55	8.92	0.21	205.23	46.47	8.50	0.85					
Hi	9	66	1.56	1869.90	214.03	23.37	2.50	9.23	0.51	269.47	33.70	7.64	1.65					

DISCUSSION

Along with the distinctness in the flow regimes of the studied lakes and streams at high altitudes in the present study, environmental variable composition unlikeliness of them were found in terms of water temperature (T_w), pH and especially in electrical conductivity (EC). This result conforms to the findings of LOTTIG *et al.* (2011), who noted the significant chemical differences between streams and lakes because of the inputs (flow regimes) to them. In addition, the negative relationships of these variables with elevation were also reported by WILCOX *et al.* (1957) and YAVUZATMACA (2020b). Electrical conductivity and elevation were also showed to cause the heterogeneities among three water basins in Turkey (YAVUZATMACA 2019). However, the non-significant differences of mean elevation values between lakes (1876.9 m) and streams (1971.41 m)

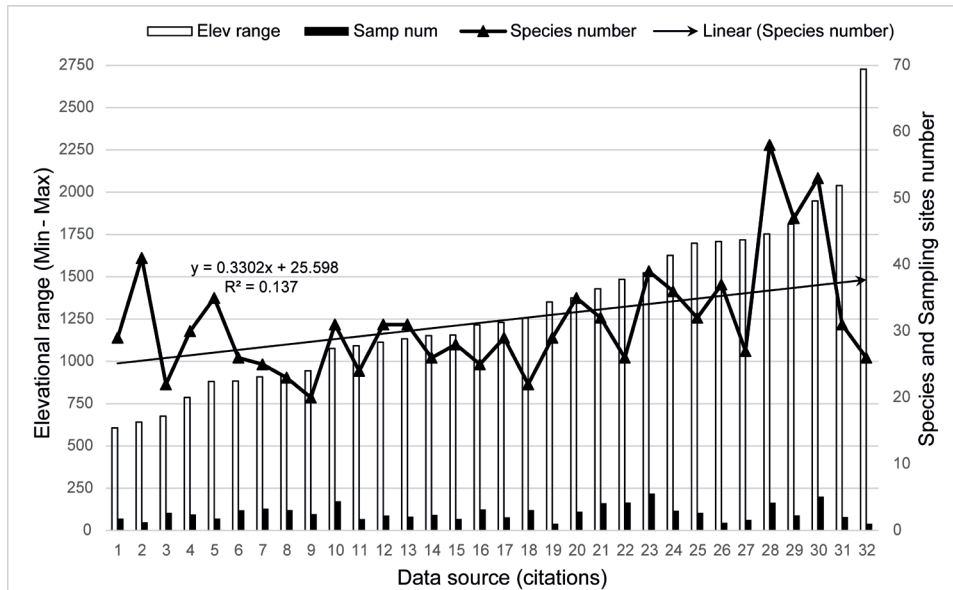


Fig. 4. Species richness across different elevational ranges (Elev range) and sampling sites (Samp num). Citations: 1 (AKDEMİR *et al.* 2016), 2 (IGLIKOWSKA & NAMIOTKO 2012), 3 (KÜLKÖYLÜOĞLU *et al.* 2017a), 4 (KÜLKÖYLÜOĞLU *et al.* 2012a), 5 (KÜLKÖYLÜOĞLU *et al.* 2019a), 6 (YAVUZATMACA *et al.* 2015), 7 (KÜLKÖYLÜOĞLU *et al.* 2016), 8 (KÜLKÖYLÜOĞLU *et al.* 2018), 9 (KÜLKÖYLÜOĞLU *et al.* 2021), 10 (UÇAK *et al.* 2014), 11 (AKDEMİR *et al.* 2020), 12 (AKDEMİR & KÜLKÖYLÜOĞLU 2014), 13 (YAVUZATMACA *et al.* 2018), 14 (YAVUZATMACA *et al.* 2017a), 15 (CUSMINSKY *et al.* 2020), 16 (BATMAZ *et al.* 2020), 17 (KÜLKÖYLÜOĞLU *et al.* 2012b), 18 (YAVUZATMACA *et al.* 2017b), 19 (the present study), 20 (KÜLKÖYLÜOĞLU *et al.* 2019b), 21 (KÜLKÖYLÜOĞLU *et al.* 2017b), 22 (KÜLKÖYLÜOĞLU *et al.* 2012c), 23 (PIERI *et al.* 2020), 24 (DALGAKIRAN *et al.* 2020), 25 (KÜLKÖYLÜOĞLU *et al.* 2013), 26 (RASOULI *et al.* 2014), 27 (YAVUZATMACA 2020a), 28 (KÜLKÖYLÜOĞLU *et al.* 2020), 29 (VAN DER MEEREN *et al.* 2010), 30 (PIERI *et al.* 2009), 31 (YAVUZATMACA 2019) and 32 (YAVUZATMACA 2020b)

indicated that elevation seems not to contribute significantly to the environmental variables' heterogeneity of both habitat types in the present study.

In contrast, the contribution of EC was more outstanding than those of pH and Tw. Alongside the pH, Tw, and EC's donation to the differences between lakes and streams, they were also pinpointed as the commonly found influential variables on the composition of ostracods among many previous studies compiled from literature by YAVUZATMACA (2019). Therefore, such differences among the habitats also affect their ostracod species composition because each species responds differently to these environmental variables.

The significant difference in the species composition between lakes and streams strengthens the statements mentioned above. Along with the differences in habitat types (KÜLKÖYLÜOĞLU 2004), this could be due to the differences in pH and water temperature, because pH is an important variable affecting the calcification of ostracods (HIGUTI *et al.* 2010) when the life history and body size of them are influenced by water temperature (AGUILAR-ALBEROLA & MESQUITA-JOANES 2014). In addition, 7 of the 8 species commonly found between the two habitat types (*C. vidua*, *H. incongruens*, *I. bradyi*, *I. gibba*, *N. neglecta*, *P. albicans*, and *P. olivaceus*) are well-known cosmopolitans (KÜLKÖYLÜOĞLU 2013, YAVUZATMACA 2019) except *P. fallax*. This result is expected because of the ecological plasticity of these species. For example, the well-known cosmopolitan species *I. bradyi* was found as an eudominant one in both habitat types. However, most of the species that cause the 70.81% of differences between the two habitat types are also cosmopolitan species (*L. inopinata*, *I. bradyi*, *P. olivaceus*, *C. vidua*, *P. fallax*, *Cypria ophtalmica* and *N. neglecta*). Similarly, YAVUZATMACA (2020a) most recently indicated cosmopolitan species (*P. olivaceus*, *N. neglecta*, and *H. incongruens*) as the most important species contributing to the dissimilarity between lakes and streams. These results show that although cosmopolitan species do not have specific habitat preferences, they make significant contributions to local and regional biodiversity (KÜLKÖYLÜOĞLU *et al.* 2012a) and the dis/similarities of habitats (YAVUZATMACA 2020a; the present study). Therefore, the importance of cosmopolitan species in diversity studies should not be underestimated, even though they are shown as the indicatives of the decrease in habitat quality.

Unlike species composition, species variations within lakes and streams did not significantly differ between both habitat types. However, greater species variability was reported among the replicates of lakes than streams based on the results obtained from MVDISP and SIMPER. Similarly, YAVUZATMACA (2020b) stated that species variability of lakes was higher than streams, and much of the streams (64%) in that study is 1st order streams when the rest are 2nd order. Also, CLARKE *et al.* (2010) reported that the presence of high beta diversity of macroinvertebrates in the dendritic riverine landscape could be due to high heterogeneity among streams rather than head-water streams. In

the present study, two-thirds of the streams are 1st order, and others are 2nd order. These streams start from high altitude and flow towards lower altitude by collecting water that allows one to think that their hydro morphological structures and environmental conditions are very similar to each other when compared to lakes. The reason is that snow and rainwater with low percolates into the soil directly flow to the stream bed at high elevations since the soil here is saturated with water and there is less transpiration (WILCOX *et al.* 1957). They also reported an increasing trend in the pH and salt contents of the soil profiles of the Mission Creek watershed from 6180 (1883.7 m asl.) to 1140 (347.5 m asl.) feet. Therefore, water bodies getting more seepage water from soil become more alkaline and saltier when compared with water bodies feeding directly with the surface flow. That explains why the average EC and pH values of lakes (EC = 5863.75 $\mu\text{S}/\text{cm}$, pH = 8.79) are greater than streams (EC = 177.89 $\mu\text{S}/\text{cm}$, pH = 8.28) in the present study. This result is because lake waters come from streams and seepage waters in a certain basin. All of them support the higher environmental heterogeneity and presence of many microhabitats in lakes compared to streams, and the 54.2% and 69.2% of species displaying a co-occurrence pattern in lakes and streams, respectively, are also strengthen this statement. This is because species exhibit co-occurrence pattern with the species having common environmental variable preferences. Thereby, while different microhabitats in the lakes allow species with different ecological preferences, the environmental similarity in the head water streams (1st and 2nd orders) herein has enabled species with the same ecological preferences to be found together.

The positive correlation between species number and different habitat types as a statement of "Habitat diversity hypothesis" (WILLIAMS 1943) were supported by different studies dealing with ostracods (e.g., UÇAK *et al.* 2014, KÜLKÖYLÜOĞLU *et al.* 2016). Also, HIGUTI *et al.* (2009) reported high species richness in lotic than lentic habitats because of higher environmental heterogeneity in lotic systems. As mentioned above, the lakes in the present study have higher environmental heterogeneity than streams that provide different microhabitats in lakes. Therefore, species richness and abundance between both habitat types are distinctly different, and the diversity index of lakes is higher than streams in the present study. Similarly, YAVUZATMACA (2020a) noted the presence of the higher Shannon diversity index values of lakes ($H' = 2.16$) than streams ($H' = 1.62$) when their species numbers equal (17 spp.). Another most recent study showed the occurrence of higher species number in lakes (18 spp.) than streams (12 spp.) when streams displayed a higher Shannon index value (YAVUZATMACA 2020b).

On the other hand, SMITH *et al.* (2003) underlined that streams have high ostracod species diversity because they were the combined zone of groundwater discharge and recharge. LANSAC-TÔHA *et al.* (2004) explained that the

species richness of lotic habitats comes from lentic habitats since lotic habitats are showed as a connection among lentic habitats. So this may increase the availability of different habitats (or heterogeneity of streams), resulting in species numbers ascend. Most recently, KÜLKÖYLÜOĞLU *et al.* (2021) declared that species numbers do not expose the significant difference between lotic and lentic habitats, and they also suggested the effectiveness of conditions in microhabitats rather than microhabitat types on freshwater ostracods. All these explain why species diversity in lakes is higher than in streams since environmental variables' heterogeneity caused many microhabitats.

Additionally, many microhabitats in lakes cause more species to emerge in lakes than streams, even with the same number of individuals (Table 1). Inasmuch as the presence of species with different ecological preferences in an environment prevents the dominance of certain species. Similarly, in the present study, the percentage of eudominant and dominant species in lakes (12.5%) was smaller than half of the ratio in streams (30.8%). In addition to the environmental variable's similarity, the low diversity in streams presented herein can be due to their size. This is because the size of streams starts to enlarge from 1st order streams to others (VANDER-VORSTE *et al.* 2017).

Along with the size, their heterogeneity is caused by tributaries added to the stream bed from different water bodies, so species richness begins to escalate with the size of streams (VANNOTE *et al.* 1980). This finding is also supported by VICTOR *et al.* (1981), who stated the differences in the number of ostracods at the upstream and downstream stations on the same stream because of the drifting of the ostracod species by stream waters. This is because ostracods from different water bodies (or tributaries) are dragged by the current and moved towards the lower parts of the stream.

The number of species is in favour of benthonic (9 spp.) in the streams when the number of nektonic (13 spp.) and benthonic (11 spp.) species are not significantly different from each other in the lakes. These results support the previous studies. For example, AKDEMİR *et al.* (2016) and YAVUZATMACA (2020a) emphasized the common occurrence of benthonic species in lotic and nektonic species in lentic habitats. However, KÜLKÖYLÜOĞLU *et al.* (2021) recently found opposite results (10 nektonic and 5 benthonic species in lentic: 7 nektonic and 8 benthonic species in lotic habitats) from the present study. It is clearly understood from these studies, benthonic species have an advantage over nektonic in lotic habitats because of the advantage of crawling on the bottom to reduce the effect of flow and/or drift (HIGUTI *et al.* 2007). Therefore, they are commonly encountered with higher abundance in lotic habitats. This is also the case in the present study since 854 of the 898 individuals in streams belong to 9 benthonic species. Similarly, AKDEMİR *et al.* (2016) registered the 1420 individuals belonging to 12 benthic species when 11 nektonic species are represented by 233 individuals in lotic habitats. DE CAMPOS *et al.* (2018) declared the effect of

aquatic macrophytes on the nektonic species because of their better dispersion ability rather than benthonic species at local scales in the 27 flood plain lakes in the Upper Paraná River floodplain (Brazil). This is because of the freely swimming ability of nektonic species where they found, flow regimes negatively affect their occurrence in lotic habitats, and so the number of benthonic species (9 spp.) herein are more than two times the number of nektonic species (4 spp.) in streams. Although nektonic species have an advantage over benthonic species in lentic habitats, benthonic species are also commonly encountered. For example, 13 nektonic and 11 benthonic species were represented by 363 and 560 individuals, respectively, in the present study. The higher abundance of benthonic species can be explained in two ways: i) nektonic species are actively moving and so the number of individuals corresponding to the sampling performed in 1 m² area is low and ii) that is maybe due to the sampling technique, but standard sampling technique was used during the study. Therefore, the validity of the first reason seems to be more appropriate than the second. Thereby, the ecological preference of species is the primary factor YAVUZATMACA (2020a). However, it cannot tolerate morphologically (e.g., the negative effect of flow on the nektonic species) even if it tolerates ecologically. So the view as the preferences of nektonic species for lentic and benthonic species for lotic habitats are supported. When looking at the common species in both habitat types, most of them are well-known cosmopolitans with wide tolerance levels to ecological variables, and so they adapt to almost all aquatic bodies unless there is a morphological obstacle. In light of this information, if there is a suitable environment, species can be found in every habitat system regardless of whether they are nektonic or benthonic, as Hoff (1942) stated.

Similar to the present study, the effect of dissolved oxygen on the ostracod species composition in lakes was also reported by DÜGEL *et al.* (2008) and ESCRÍVA *et al.* (2014). Besides, DE CAMPOS *et al.* (2018) recorded dissolved oxygen as one of the crucial variables influencing ostracods in lakes in the Upper Paraná River floodplain (Brazil) along with the water temperature, electrical conductivity, and richness of macrophytes. In addition to the importance mentioned above of microalgae (as nutrients) and macrophytes at the littoral region (as shelter) for ostracod diversity, their densities in lakes affect the level of dissolved oxygen. KÜLKÖYLÜOĞLU *et al.* (2018) recorded the strong positive relationships between total species numbers and dissolved oxygen. Its importance is also strengthened by finding a significantly positive correlation of Shannon index value with dissolved oxygen in lakes, but this correlation is negative with pH. RUIZ *et al.* (2013) said that freshwater ostracods generally occur in alkaline or slightly acidic waters, and a pH range from 7 to 9 was shown as the common range for many species. In the present study, a range from 7.12 to 10.1 with a mean equal to 8.76 was found for lakes bearing living ostracods. This alkaline mean value may explain this negative correlation

because most of the species in lakes did not show a close relationship with pH except *L. inopinata*. Other species in lakes also show different relationships to environmental variables according to their optimum and tolerance levels. The situation is similar in streams. For example, *S. fischeri* was located on the opposite side of pH with the lowest pH optimum value. The close relationship of *S. fisheri* and *N. neglecta* with dissolved oxygen endorsed the indicator potential of them for high dissolved oxygen (YAVUZATMACA 2020a). *Potamocypris similis* had a negative relationship with electrical conductivity, and it is one of the species that had the lowest optimum and tolerance values among species.

The low electrical conductivity in the streams seems a limiting factor, and so it was found as the only influential environmental variable that controlled the species composition in streams. SMITH *et al.* (2003) pointed out the strong relationship of stream species with ionic composition. Thus, salinity related to EC was indicated as a key factor for species distribution of ostracods (RUIZ *et al.* 2013). As known, conductivity in water is a combination of negatively (e.g., chloride, sulfate) and positively (e.g., calcium, magnesium) charged inorganic dissolved solids. Alongside the osmoregulation effect of ion composition, ions like calcium and magnesium in ostracod carapaces come from waters where they were found (KESLING 1951, PALACIOS-FEST & DETTMANN 2001). This information suggests the importance of EC for ostracod species composition in the streams.

Finally, significant species composition was found between both habitat types due to the environmental heterogeneity in lakes and similarity in headwater streams herein, and the variation in species composition in lakes is larger than in streams. It was seen that ostracods are mostly tied to dissolved oxygen and electrical conductivity in lakes and streams, respectively. There was no difference in the frequency occurrence of benthonic and nektonic species in lakes, while benthonic densely occurs in streams. In general, albeit a little positive relationship was observed between elevational range and ostracod species richness. This indicated that elevation range as a regional factor might influence the species composition as well as species distribution. Accordingly, determining regional and local factors based on habitats will help us easily interpret ostracod species diversity, so the number of such studies should increase.

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SUPPLEMENTARY MATERIALS

Table S1. Station code, provinces where they found, and coordinates of lakes and streams sampled in the present study. Lowercase a, b and c display the multiple samplings in a lake.

Station code	Habitat type	Province	Coordinates
L1a	Lake	Van	38°29'45.29"N, 43°55'27.73"E
L1b	Lake	Van	38°29'26.71"N, 43°54'50.24"E
L1c	Lake	Van	38°28'32.74"N, 43°55'05.08"E
L2	Lake	Van	38°37'59.32"N, 43°36'20.98"E
L3	Lake	Van	38°43'44.80"N, 43°33'57.70"E
L4	Lake	Bitlis	38°48'53.33"N, 43°00'35.37"E
L5a	Lake	Van	38°25'34.64"N, 43°15'50.26"E
L5b	Lake	Bitlis	38°45'15.29"N, 42°30'28.59"E
L6a	Lake	Bitlis	38°50'13.63"N, 42°16'10.20"E
L6b	Lake	Bitlis	38°50'56.16"N, 42°20'34.53"E
L7	Lake	Kars	40°46'24.40"N, 43°00'34.60"E
L8	Lake	Kars	40°59'14.88"N, 43°17'37.98"E
L9	Lake	Ardahan	41°12'16.82"N, 43°11'12.84"E
L10	Lake	Artvin	41°23'04.77"N, 41°51'12.67"E
L11	Lake	Artvin	41°25'09.91"N, 42°27'06.18"E
L12	Lake	Artvin	41°24'29.59"N, 42°30'39.76"E
L13	Lake	Artvin	41°21'57.08"N, 42°30'16.85"E
L14	Lake	Artvin	41°17'16.15"N, 42°27'39.02"E
L15	Lake	Erzurum	40°55'30.35"N, 42°11'44.93"E
L16	Lake	Erzurum	40°39'21.12"N, 41°39'29.16"E
S1	Stream	Van	38°23'31.34"N, 43°34'55.20"E
S2	Stream	Van	38°26'27.38"N, 43°32'49.34"E

Table S1 (continued)

Station code	Habitat type	Province	Coordinates
S3	Stream	Van	38°25'59.74"N, 43°30'31.90"E
S4	Stream	Van	38°26'0.276"N, 43°27'18.50"E
S5	Stream	Erzurum	39°39'16.60"N, 41°19'38.82"E
S6	Stream	Erzurum	39°44'59.03"N, 41°32'8.556"E
S7	Stream	Erzurum	39°35'3.120"N, 41°38'55.97"E
S8	Stream	Erzurum	39°53'10.57"N, 41°43'28.24"E
S9	Stream	Erzurum	39°50'43.87"N, 41°44'23.75"E
S10	Stream	Erzurum	40°02'57.44"N, 41°37'28.02"E
S11	Stream	Kars	40°18'39.89"N, 42°10'45.48"E
S12	Stream	Kars	40°10'45.48"N, 42°36'10.69"E
S13	Stream	Kars	40°12'40.61"N, 42°41'27.38"E
S14	Stream	Kars	41°03'15.70"N, 43°15'13.43"E
S15	Stream	Ardahan	41°31'50.81"N, 42°37'13.87"E
S16	Stream	Ardahan	41°34'19.34"N, 42°40'19.99"E
S17	Stream	Ardahan	41°34'12.86"N, 42°40'17.26"E
S18	Stream	Artvin	41°20'34.01"N, 42°29'32.53"E
S19	Stream	Artvin	41°23'56.94"N, 42°09'59.11"E
S20	Stream	Erzurum	40°40'7.07"N, 40°59'27.67"E
S21	Stream	Erzurum	40°39'45.79"N, 40°58'14.84"E
S22	Stream	Erzurum	40°28'50.41"N, 40°41'5.71"E
S23	Stream	Erzurum	40°31'11.39"N, 40°38'58.74"E
S24	Stream	Erzurum	40°17'07.04"N, 41°00'18.68"E

Table S2

(digital supplement only; DOI 10.17109/AZH.67.4.377.TS2.2021)

Table S3. Summary tables of RDA for lakes and streams. * indicates DCA results.

Axes		1	2	3	4	Total variance
Lakes	Eigenvalues	0.306	0.081	0.041	0.004	1
	*Lengths of gradient	0	2.70	0.87	2.51	
	Species-environment correlations	0.79	0.555	0.469	0.292	
	Cumulative percentage variance					
	of species data	30.6	38.8	42.8	43.3	
	of species-environment relation	70.8	89.5	98.9	99.9	
	Sum of all eigenvalues					1
	Sum of all canonical eigenvalues					0.433
Streams	Eigenvalues	0.131	0.021	0.002	0.001	1
	*Lengths of gradient	3.41	3.52	2.39	2.24	
	Species-environment correlations	0.449	0.353	0.219	0.183	
	Cumulative percentage variance					
	of species data	13.1	15.2	15.4	15.5	
	of species-environment relation	84.3	98	99.2	99.6	
	Sum of all eigenvalues					1
	Sum of all canonical eigenvalues					0.155

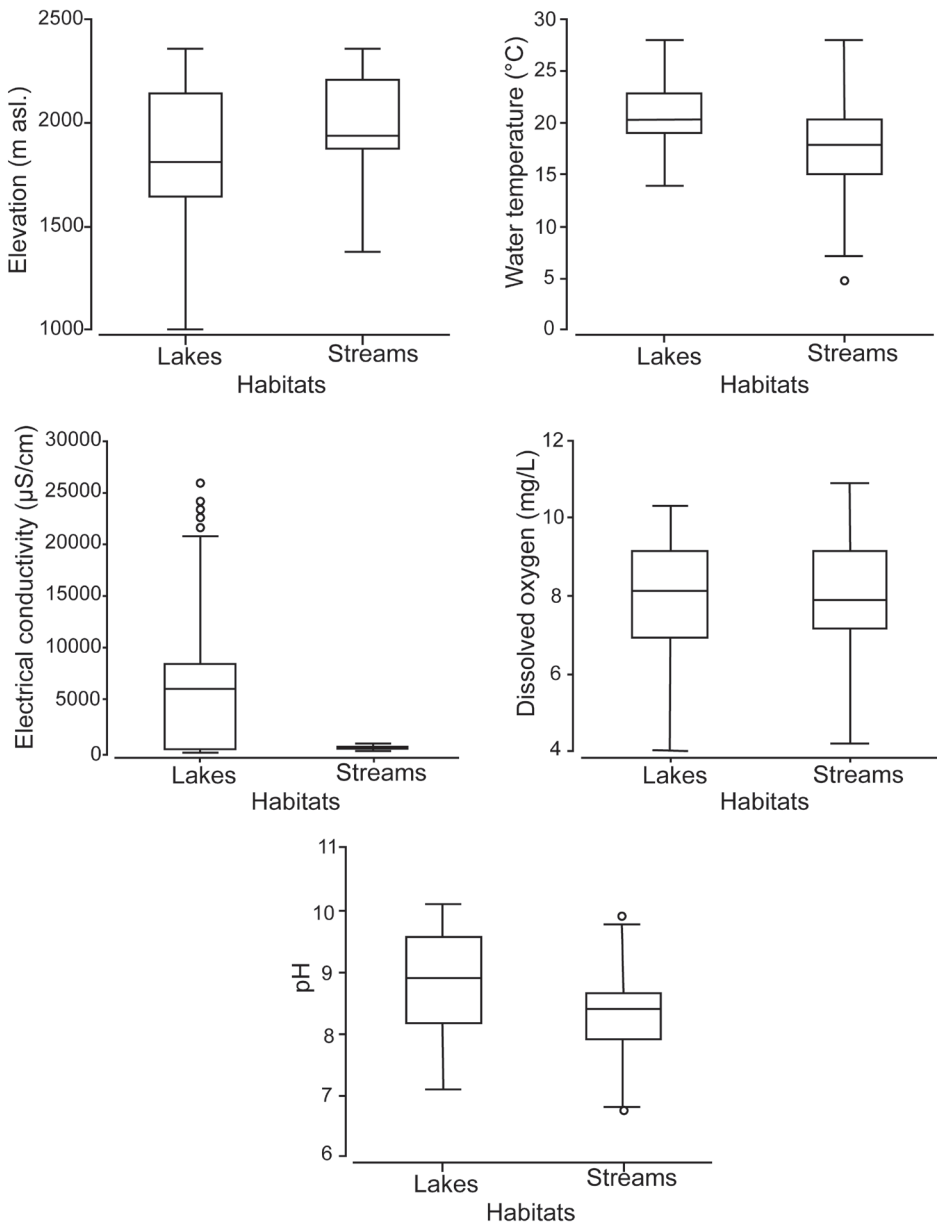


Fig. S1. Comparison of the mean values of elevation, water temperature, electrical conductivity, dissolved oxygen and pH between lakes and streams in the present study

