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Original Research Article

Effect of habitat type on algal species diversity and distribution at high altitudes

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ABSTRACT

To investigate how habitat type influences species diversity and distribution of algae, 115 sampling sites across eight different habitats (stream, spring, lake, pool, wetland, ditch, trough, hot-spring) were randomly sampled from Ağrı province, Turkey. A total of 392 algal taxa (gamma diversity) were identified, of which 212 taxa (54.08%) belonged to Bacillariophyta while the rest (180 taxa) belonged to seven other groups (Chlorophyta, Charophyta, Euglenophyta, Cyanobacteria, Miozoa, Ochrophyta, and Cryptophyta). 150 taxa were encountered only once. The highest alpha diversity was found in ditches (H' =4.57, 235 taxa) followed by streams (H' = 4.40, 238 taxa), and the lowest diversity was recovered in troughs (H' = 2.62, 42 taxa). Relatively high Whittaker's beta diversity (Bw = 19) indicated a low level of similarity among sampling sites suggesting that no common taxonomic group was solely effective enough to change dominancy level of any species among the habitats. The first two axes of Canonical Correspondence Analysis accounted for 58.1 % of the total variance in the occurrence of 152 algal taxa (all taxa recovered from more than three samples) and described gradients across four environmental variables (habitat type, pH, elevation and water temperature). Ditches significantly contribution to alpha and gamma diversity in the province although they have relatively small surface area and shallow water compared to other habitat types. High alpha diversity in ditches may be related to the positive effect of geographic and climatic factors in mountainous area. Future possibilities are discussed.

1. Introduction

Whittaker (1972) defined three measures of biodiversity across spatial scales: alpha (α), beta (β), and gamma (γ) diversity. Gamma diversity is the total diversity (all species accounted) in a region while alpha diversity refers to diversity within a given area or ecosystem, usually expressed by the number of species (or species richness) in that ecosystem or habitat. Beta diversity measures the variation (differences or dissimilarities) of species diversity between two or more different habitats (or ecosystems). In other words, measures of beta diversity attempt to quantify the number of different species between two or more habitats. High beta diversity indices represent a high degree of dissimilarity, while a low index value represents a high level of similarity. Legendre et al. (2005) argued that

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beta diversity is a key concept for understanding ecosystem function and for managing biodiversity.

Studies dealing with biodiversity estimation and distribution of aquatic organisms are generally carried out in large and/or continuous water bodies like rivers and lakes (Della Bella et al., 2007; Nabout et al., 2007; Passy and Blanchet, 2007; Schuster et al., 2015; Bortolini et al., 2017; Jamoneau et al., 2018; Marra et al., 2018; Dunck et al., 2019; Pound et al., 2019). In contrast, shallow and small temporary waters have been received less attention. One of the extensive studies was conducted in water-filled tree caves which were classified as microhabitat (Williams, 2006). Water-filled tree holes are one of the phytotelma habitat (plant held waters) that host diverse aquatic flora and especially aquatic fauna (Lackey, 1940; Maguire, 1971; Frank and Lounibos, 1983; Yanoviak, 1999; Kitching, 2000).Temporary water bodies (e.g., wetlands, ditches) vary greatly in surface area and volume and can dry out quickly with variable frequencies and variable seasonality (Arle, 2002; Williams, 2006). However, such habitats are well known as reproductive and developmental areas for semi-terrestrial and semi-aquatic organisms. Some of previous studies have documented high faunal (aquatic insects, amphibian etc.) biodiversity in temporary water bodies (Williams, 2006). Therefore, temporary water bodies are described as the “cinderellas of aquatic science” because of being an important component of global landscape (Williams, 2006). For example, Nicolet et al. (2004) discussed the importance of temporary ponds as habitat for rare plant species. Lukács et al. (2013) illustrated the importance of temporary pools for the conservation of high alpha and beta plant diversity. Külköylüoğlu et al. (2013) found relatively high ostracod (Crustacea) diversity in troughs or so called “artificially natural habitats”. Accordingly, temporary wetlands (natural or artificial) with small surface size and shallow waters are considered as important habitats for diversity of taxa (Armitage et al., 2003; Williams 2006; De Bie et al., 2008; Külköylüoğlu et al., 2013).

In recent years, the number of studies investigating species diversity in temporary wetlands has increased, reflecting a growing interest and recognition of the importance of these habitats (e.g., Williams et al., 2003; De Bie et al., 2008; Balian et al., 2010; Stendera et al., 2012; Akdemir et al., 2016; Külköylüoğlu et al., 2019) but studies on the diversity of algae in different aquatic bodies are quite limited (Yung et al., 1986, Cardoso et al., 2012, Zarei-Darki, 2011; 2012). The first study in Eastern Anatolia conducted by Ehrenberg (1845) was focused on the diatoms of the Murat River (the biggest tributary of the Euphrates) from the hillside of Tendürek Mountain (Diyadin, Ağrı province) in the border of Muş province (Turkey). The second study in the region was conducted by Altuner (2017). However, sampling sites in these studies are not located within the boundaries of Ağrı province. Therefore, the current research is the first extensive study on algal flora in the region.

The present study provides an important contribution to our understanding of algal species richness, biodiversity and distribution in different aquatic bodies of Ağrı province in Turkey. The aims of the study are i) to investigate the role of habitat types on algal community composition in the Ağrı province, ii) to determine correlation between environmental factors and algal species distribution, and iii) to compare diversity levels (i.e., alpha, beta and gamma species diversity of algae) among eight different aquatic habitats in the province.

Table 1
Minimum (min), maximum (max), mean and standard deviation (SD) of 10 environmental variables measured from the 100 of 115 different sampling sites in Ağrı province.

		n	min	max	mean	±SD
Elevation	m a.s.l.	99	1477	2499	1821.01	228.04
Atm. pressure	mmHg	100	563.7	639	613.61	16.78
Atm. moisture	%	100	20.6	92.3	44.94	13.09
Wind speed		100	0	17.7	5.28	4.19
T_{atm}	°C	100	9.7	34.2	21.21	5.49
T_{wat}	°C	100	5.7	28.3	16.24	5.12
pH		100	6.38	9.99	8.39	0.55
DO	mg/L	100	1.71	11.13	6.46	1.92
EC	μS/cm	100	10.6	10983	529.81	1188.65
Salinity	ppt	100	0.01	6.58	0.31	0.72

2. Materials and methods

One hundred and fifteen different aquatic sites representing 11 different habitat types in Ağrı province in Eastern Anatolia were randomly sampled between 13-17 May 2015 by Külköylüoğlu et al. (2019) (Fig. 1). Fifteen sampling sites did not include specimens and were excluded from the analyses. Sampling sites were categorized as one of eight different aquatic habitats as follows: lake (8), pond (10), wetland (5), stream (47), spring (7), trough (4), ditch (18) and thermal water (1).

During field work, 10 different environmental variables (pH, dissolved oxygen (DO, mg/l), water and air temperature (T, °C), electrical conductivity (EC, μS/cm), salinity (ppt), atmospheric pressure (mmHg), moisture (%), wind speed (m/s), elevation (m)) were measured in situ before sampling. A YSI Multi Professional Plus was used to measure the first six variables, and a Testo 410-2 model anemometer was used to measure the remaining variables (Table 1). Coordinates of each sampling site were recorded with a GARMIN Etrex Vista H GPS (Table 1). More detailed information about the study area can be found in Külköylüoğlu et al. (2019). Algal samples were collected in 250 ml plastic bottles and fixed with 4% formaldehyde solution *in-situ*. Along with water samples, filamentous algae and bottom sludge (a mixture of epilithic and epipelic biofilms and well-conditioned detritus) samples were also collected according to the characteristics of the sampling sites. Samples were kept in coolers and brought to the Limnology Research Laboratory of Bursa Uludağ University. At least 300 individuals were counted in each sample to derive a measure of relative abundance. Species identification was done according to the taxonomic keys provided in several studies (e.g., Huber-Pestalozzi, 1941, 1950, 1955, 1961, 1982, 1983; Huber-Pestalozzi and Fott, 1972; Popovsky and Pfiester, 1990; Krammer and Lange-Bertalot, 1991a, b, 1997a, b; Komárek and Anagnostidis, 1999, 2005; John et al., 2003; Coesel and Meesters,

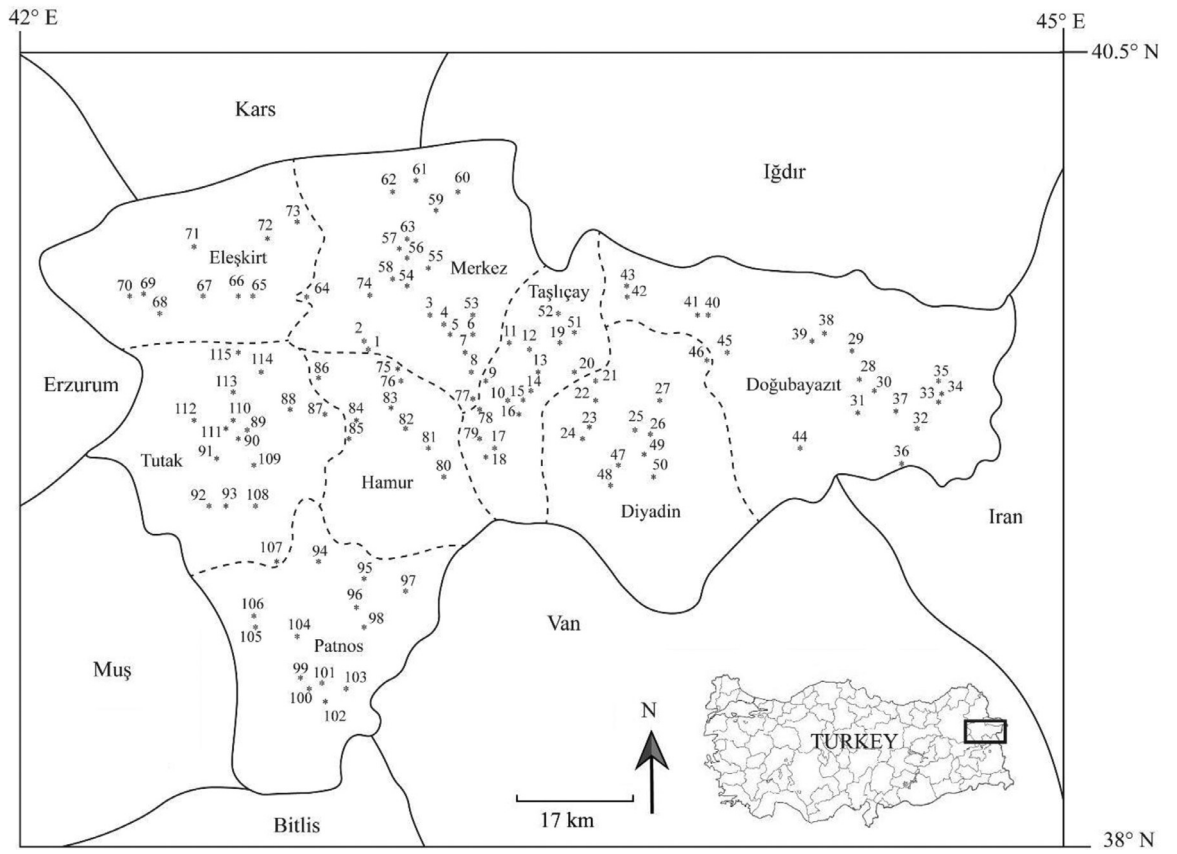

Fig. 1. Distribution of the 115 sampling sites in the border of Ağrı province (modified from Külköylüoğlu et al. (2019)).

2007, 2013; Komarek, 2013). Current names and systematic categories of taxa (species and higher taxonomic levels including divisions) were arranged according to AlgaeBase website (Guiry and Guiry 2019).

2.1. Statistical analyses

Multivariate statistical analyses were applied to determine the relationship between environmental variables and algal taxa. We used Canonical Correspondence Analyses (CCA) to evaluated species environmental relationships. Ten environmental variables were tested together by using forward selection method (ter Braak and Verdonschot 1995). According to forward selection procedure, only significant ($p < 0.05$) variables were used in the final CCA analysis. Taxa with three or fewer occurrences were excluded from the analyses (152 taxa were included) to minimize the influence of rare taxa and/or habitats with relatively low species numbers. Relative abundance of taxa and environmental variables were log transformed to reduce the arch effect of variables on ordination scores. However, prior to CCA, suitability of our data for CCA was tested by Detrended Correspondence Analysis (DCA) (Hill and Gauch, 1980) where, length of gradient three or more suggests suitability of data for CCA. CANOCO 4.5 (ter Braak and Smilauer, 2002) and SPSS 22.0 statistical packages were applied for multivariate statistical and comparative analyses, respectively.

The Shannon-Wiener (H') diversity index was utilized to determine intra-habitat diversity. Whittaker's beta diversity (Whittaker, 1972) was used to compare species diversity among different habitats. Henderson heterogeneity test was applied to estimate species richness of resident species and rate of migration to the habitat. Species Diversity and Richness 4 software (Seaby and Henderson, 2006) was used for the calculation of both diversity indexes and heterogeneity test. Similarity Percentage (SIMPER) analysis was applied to determine similarity and percent contribution of each taxa to the similarity by using the Community Analysis Package (CAP 4.1.3.) (Seaby and Henderson, 2007).

3. Results

Table 1 shows some of the physicochemical variables measured at sampling sites. Unsurprisingly large differences between the minimum and maximum values of measured environmental variables were found among sampling sites ranging from 1477 to 2499 m a.s.l. The highest electrical conductivity (EC) and salinity values and lowest pH value (6.58) were reported from the thermal water site. The lowest EC and salinity values were taken from a ditch and a stream located at 2476 and 2499 m a.s.l., re-

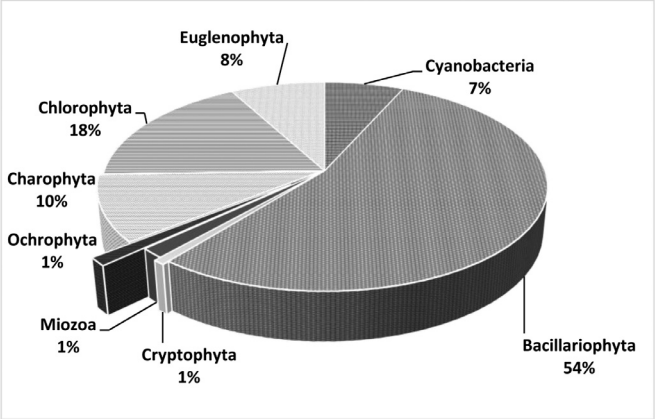

Fig. 2. Distribution of the algal divisions from Ağrı province.

Table 2
Summary table of CCA results.

CCA	1	2	3	4	Total inertia
Eigenvalues:	0.211	0.163	0.147	0.123	10.542
*Lengths of gradient:	6.890	5.923	3.650	5.214	
Species-environment correlations:	0.810	0.783	0.758	0.683	
Cumulative percentage variance of species data:	2.0	3.5	4.9	6.1	
Cumulative percentage variance of species-environment relation:	32.8	58.1	80.9	100.0	
Sum of all eigenvalues					10.542
Sum of all canonical eigenvalues					0.644

spectively. Both pH and DO concentrations were highest in lentic water bodies (i.e., pond and lake).

A total of 392 algal taxa (gamma diversity) (212 of Bacillariophyta, 69 of Chlorophyta, 40 of Charophyta, 31 of Euglenophyta, 26 of Cyanobacteria, 6 of Miozoa (superclass Dinoflagellata), 5 of Ochrophyta (3 of Chrysophyceae and 2 of Xanthophyceae), and 3 of Cryptophyta) were identified (Fig. 2, Appendix). The details of systematic categories of algal taxa were also given in Appendix. 150 taxa (38.26%) were observed only once, 54 taxa (13.77%) were found twice, and 37 taxa (9.44%) were encountered three times from different sites (Appendix).

The gradient length of the first two axes of DCA was 5.923 (Table 2), suggesting the suitability of our data for unimodal CCA (ter Braak and Prentice, 1988). The Monte Carlo (499 permutations) test results were significant for all canonical axes ($p = 0.002$), and the first two axes (λ_1: 0.211 and λ_2: 0.163) explained 58.1% of variance in taxa among sites. Forward selection retained four environmental variables (habitat type ($p = 0.002$, $F = 1.82$), pH ($p = 0.010$, $F = 1.46$), elevation ($p = 0.022$ $F = 1.46$), water temperature ($p = 0.038$ $F = 1.32$)) that showed significant effects on the ordination of algal taxa in Ağrı province (Fig. 3 and 4). Henderson's heterogeneity test showed a heterogeneous distribution of taxa among sampling sites where actual numbers of species sampled corresponds to the estimated species numbers (Fig. 5).

When seven different habitats were compared (except thermal water), ditches displayed the highest alpha diversity (235 taxa, H' = 4.57, JSE = 0.159) followed by streams (238 taxa) (H' = 4.40, JSE = 0.089) (Tables 3 and 4). The lowest alpha diversity was detected in troughs (42 taxa, (H'= 2.62, JSE = 0.264). Overall, Shannon-Wiener alpha habitat diversity index was 4.946 (JSE =0.072), and Whittaker's beta diversity was 19 (Table 3).

Minimum, maximum and mean species richness values of the five algal divisions with the highest species richness values for different habitat types are given in Table 5. Bacillariophyta diversity was highest in streams followed by ditches (Table 5, Fig. 6). Chlorophyta, Charophyta and Cyanobacteria diversity was highest in ditches followed by streams. Euglenophyta diversity was highest in ditches and wetlands.

SIMPER analyses revealed that 16 algal taxa (15 were diatoms) accounted for 70% of the total similarity (Table 5) while 52 taxa accounted for 90% of the total similarity (Appendix). Among the 16 algal most similar taxa, three diatom species (*Nitzschia linearis, N. palea* and *Ulnaria ulna*) accounted for 34% of the total similarity. Six diatom species (*Nitzschia palea, N. frustulum, N. linearis, Hantzschia amphioxys, Surirella minuta, Ulnaria ulna*) had Shannon-Wiener alpha species diversity values above 3, and the index value (H') of all species was 4.444 with a Jackknife Standard Error of 0.02119 (Table 5).

4. Discussion

Finding 392 algal taxa (γ-diversity) with relatively high alpha (H= 4.444) and beta (19) diversity values suggested high variation in the species composition at the local and regional scale of the Ağrı province where diatoms accounted 54% of the total number of taxa. This finding is

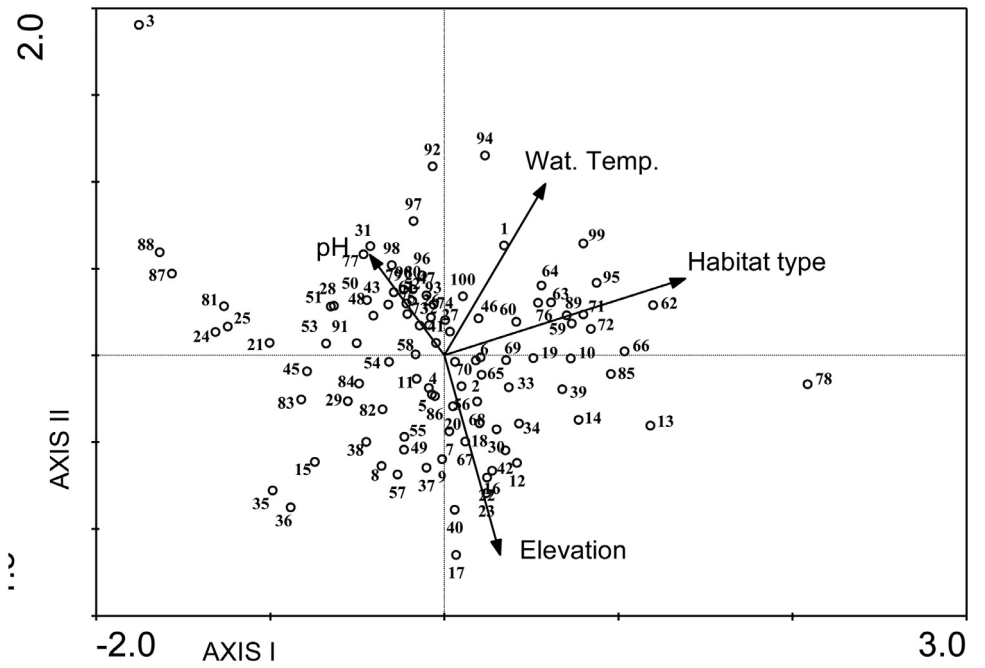

Fig. 3. Ordination of four significant environmental variables with 100 sampling sites based on CCA.

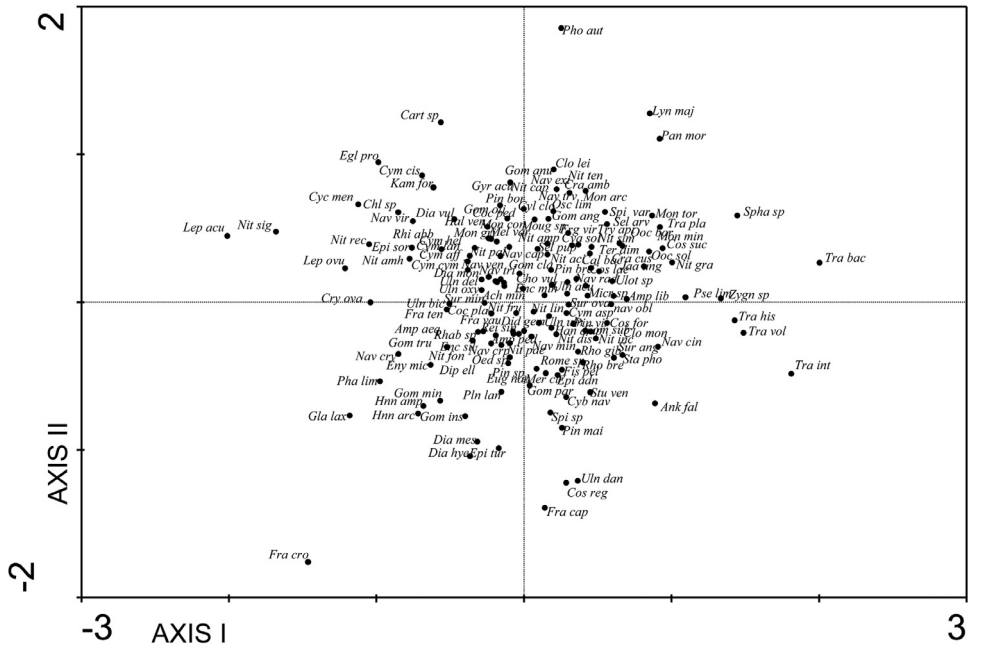

Fig. 4. Ordination of 152 algal taxa on CCA diagram. Abbreviations for algal taxa are given in Appendix.

consistent with the earlier studies that showed the benthic zones of the rivers and the lakes diatoms were indeed the most dominant group with relatively high diversity, abundance and occurrences compared to other algal groups (Lowe and LaLiberte, 2017). Most researchers associate this kind of dominancy and frequent occurrences of diatoms for the cosmopolitan characteristics of the group (Van Dam et al., 1994; Vanormelingen et al., 2008; Solak et al., 2012; Solak and Wojtal, 2012). In the present study, 15 out of 16 species responsible for 70% of the total similarity among habitats were the diatoms observed most commonly during the present study (Table 5). Similar to our findings,

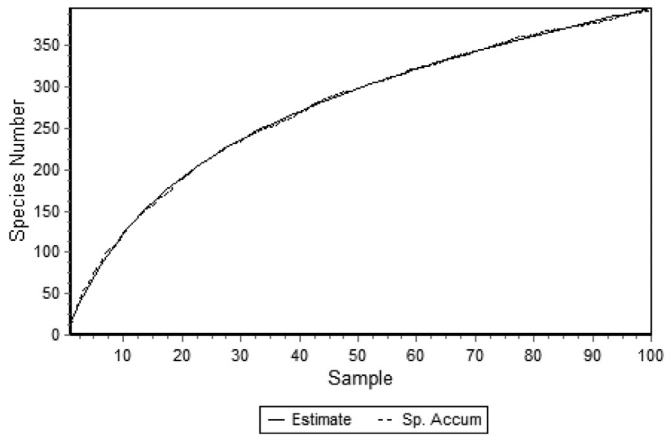

Fig. 5. Plot of Henderson's heterogeneity test

Table 3
Mean, minimum (min) and maximum (max) total species richness and diversity values (α and β) of different habitat types.

		Total Species Richness		α diversity		β diversity
	n_{samp}	n_{taxa}	mean (min -max)	H'	Jackknife SH	Whittaker's β
Lake	8	90	14.50 (2-40)	3.526	0.321	5.207
Pond	10	85	12.50 (7-26)	3.315	0.277	5.800
Wetland	5	93	24.20 (11-43)	3.679	0.367	2.843
Stream	47	238	20.83 (1-61)	4.400	0.089	10.760
Spring	7	94	19.14 (3-39)	3.660	0.185	3.910
Trough	4	42	13.50 (8-19)	2.622	0.264	2.111
Ditch	18	235	23.56 (2-66)	4.570	0.159	8.722
Thermal	1	7				
Total:	100	392				
All sample index:				4.946	0.072	19

Table 4
The mean, minimum (min) and maximum (max) species richness of the five algal divisions with the highest species richness values among the habitat types.

		Bacillariophyta		Chlorophyta		Charophyta		Euglenophyta		Cyanobacteria	
	n_{samp}	n_{taxa}	Mean (min -max)	n_{taxa}	Mean (min -max)	n_{taxa}	Mean (min -max)	n_{taxa}	Mean (min -max)	n_{taxa}	mean (min -max)
Lake	8	49	7.75 (0-16)	23	0.25 (0-15)	2	0.25 (0-2)	8	1.38 (0-3)	2	0.38 (0-1)
Pond	10	48	7.6 (0-18)	15	1.1 (0-3)	9	1.1 (0-4)	6	0.7 (0-5)	5	1.1 (0-2)
Wetland	5	56	14.8 (7-21)	11	1.2 (0-8)	5	1.2 (0-3)	15	3.4 (0-9)	4	1.8 (0-3)
Stream	47	161	17.55 (0-41)	31	1.04 (0-9)	23	1.04 (0-12)	12	0.45 (0-3)	10	0.68 (0-9)
Spring	7	73	15.86 (2-36)	4	0.86 (0-1)	6	0.86 (0-3)	4	0.57 (0-3)	6	1.14 (0-3)
Trough	4	31	10.5 (8-15)	6	0.5 (0-6)	2	0.5 (0-2)	1	0.25 (0-1)	2	0.5 (0-2)
Ditch	18	118	13.17 (1-47)	42	1.89 (0-19)	26	1.89 (0-12)	20	2.28 (0-9)	20	1.17 (0-5)
Thermal	1	6		0		0		0		1	
Total:	100	212		69		40		31		26	

different studies showed that these diatom species are indeed the most common species in Turkey (Aysel, 2005; Solak et al., 2012; Solak and Wojtal, 2012). Such species are also known as ecological generalists (Kociolek and Spaulding, 2000). However, our results differ from those of some other studies. For example, Zarei-Darki (2011) studied five different water bodies in Iran and found highest species richness in the Chloropyta (35% of the total taxa) followed by Bacillariophyta (23.5%). The findings in our study suggest that climatic factors (temperature), regional differences, altitudinal gradient and environmental factors are important determinants in algal species diversity and the predominance of algal divisions. Barinova (2011) revealed that altitude is a major factor that influenced diatom diversity and distributions in ecoregions of Eastern Mediterranean (Israel). Indeed, Barinova et al. (2013) stated that increasing species rate of diatoms was corresponded to increasing altitude at mountainous areas in Pakistan.

In the present study, alpha diversity (H') was highest in ditches, streams and wetlands, respectively (Table 3).

Table 5
Results of SIMPER analysis and Shannon-Wiener (H') diversity index values of 16 taxa. Occur. = Occurrence, Ave. Abund. = average abundance; Ave. Sim.: Average Similarity, Contr. % = contribution, Cum. % = cumulative contribution in %, All Samp. Ind. = All Sample Index; Exp. H' = expected diversity values; Var. H' = variance in diversity, Jackknife Std. Err. = Jackknife Standard Error.

		SIMPER Analysis results				Diversity Index results		
Taxa	Occur.	Ave. Abund.	Ave. sim.	Contr. %	Cum. %	H'	Var. H'	Exp. H'.
Nitzschia linearis	45	4.16	0.75357	13.3663	13.3663	3.177	0.00243	23.98
Ulnaria ulna	49	3.45	0.6188	10.9758	24.3421	3.059	0.00497	21.3
Nitzschia palea	52	2.46	0.55733	9.88552	34.2276	3.275	0.00641	26.44
Encyonema silesiacum	28	2.43	0.3102	5.50201	39.7296	2.861	0.00255	17.48
Fragilaria vaucheriae	31	1.91	0.25545	4.53088	44.2605	2.806	0.00684	16.55
Cocconeis placentula	32	2.37	0.24687	4.37877	48.6392	2.635	0.00664	13.95
Hantzschia amphioxys	34	0.67	0.16267	2.8853	51.5245	3.148	0.01849	23.3
Nitzschia frustulum	30	0.78	0.14985	2.65793	54.1825	3.177	0.00808	23.97
Melosira varians	21	1.99	0.13899	2.4653	56.6478	2.276	0.00744	9.739
Gomphonema parvulum	30	1.01	0.13273	2.35422	59.002	2.828	0.01357	16.9
Achnanthidium minutissimum	27	0.87	0.12496	2.21636	61.2183	2.854	0.01268	17.35
Navicula veneta	28	0.96	0.12358	2.19187	63.4102	2.489	0.02388	12.05
Romeria sp.	23	0.4	0.10432	1.85035	65.2606	2.976	0.01521	19.62
Planothidium lanceolatum	24	0.83	0.10134	1.79757	67.0581	2.774	0.01084	16.02
Surirella minuta	26	0.44	0.09821	1.7419	68.8	3.118	0.01291	22.61
Cymbella affinis	21	1.36	0.0738	1.309	70.109	1.9	0.0143	6.689
Ave. Sim.:			2.35858					
All samp. Ind.:						4.444		
Jackknife Std. Err.:						0.02119		

Similarly, Külköylüoğlu et al. (2019) found the highest alpha diversity for freshwater ostracods collected during the same sampling campaign in streams, ditches and ponds. Uçak et al. (2014) reported the highest and lowest alpha diversity values for non-marine ostracod species where in natural habitats (e.g., ponds, streams, springs and creeks) and artificial habitats (e.g., canals, troughs), respectively. In contrast, De Bie et al. (2008) documented the highest species richness of Cladocerans in lakes. However, Zarei-Darki (2011) found the highest algal species richness in reservoirs and rivers, the lowest diversity values from that study were reported from lakes.

In total, 241 taxa (61.48%) occurred in three or fewer samples. Low occurrence values of algal species contributed to a high beta diversity value in Ağrı province, indicating highly variable species composition across sites. The highest beta diversity values were found in streams and ditches. Pound et al. (2019) argued that beta diversity was influenced by a combination of stress and heterogeneity. This corresponds to our findings since both habitats (streams and ditches) are subjected to natural (e.g., changes in water flow regimes due to dryness) and artificial (e.g., anthropogenic activities) disturbances. High beta diversity values from other habitats types in Ağrı province may also be related to habitat heterogeneity. Passy and Blanchet (2007) found that human impact (e.g., stream restoration, water discharge etc.) caused a significant decrease in beta diversity values by causing geomorphic degradation in streams. Similarly, Dunck et al. (2019) indicated that cultural eutrophication increased functional homogeneity in urban wetlands, causing an increase of algal species with similar ecological preferences. These studies suggest that sensitive species are replaced by tolerant species (e.g., cosmopolitan species) causing a critical reduction in biodiversity as a response to habitat degradation.

We expected highest species richness in streams since the majorities (47 samples) of samples were taken from streams. Sampling effort in ditches (n = 18) was nearly 2.5 times smaller than in streams, but a similar number of taxa were reported from each habitat (238 and 235 taxa, respectively, Table 3). Similar species richness between these two habitats may be related to the characteristics of aquatic sites. For example, ditches are usually prone to dryness that most species urged to adapt such conditions. On the other hand, streams are always in movement and such movement prevent occurrence of many species in a certain site. Wetland habitats were one of the least sampled in the current study. However, the highest mean number of taxa per site was detected in wetland habitats (24.20). Sampling effort must be considered when assessing relationships between species and environmental factors. We argue that all of our habitat types have been sampled adequately to estimate species richness. Henderson's heterogeneity test also suggested heterogeneous distribution of algal taxa among sampling sites where actual numbers of species sampled correspond to the estimated species numbers.

The maximum number of taxa in a sample (66) was recovered from a ditch, followed by a stream (61) and wetland (43). Another remarkable point here is that the highest ranges of species richness (minimum-maximum) values were also observed in these three habitat types (Table 3). We interpret this as a response to higher levels of disturbance in these habitat types. The fluvial geomorphology of streams (streambed structure, flow velocity, channel structure) is different from other habitats and can cause high-intensity disturbance for algae. High flow disturbance can have negative effects on the colonization of algae and cause a reduction in taxa richness (Biggs and Smith, 2002). Ditches are shallow habitats with depths less than 30 cm and small surface areas. They have a short hy-

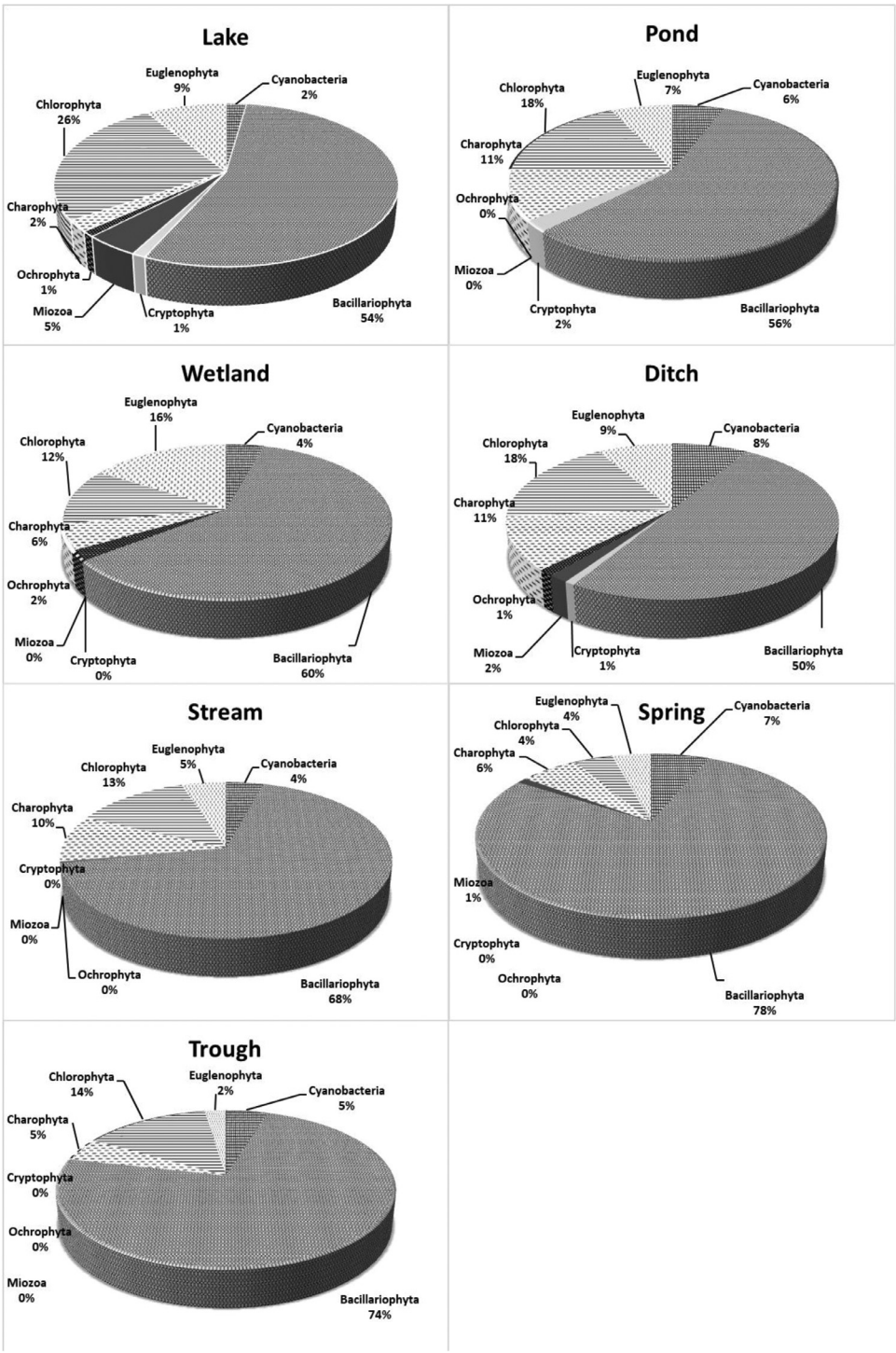

Fig. 6. Pie charts showing distributions of the seven algal divisions according to habitat types.

droperiod, so they dry out rapidly during dry seasons, especially in low rainfall and at high atmospheric temperatures. However, these habitats also present ideal reproductive conditions with high nutrient content for many organisms. Williams (2006), however, illustrated that a decline in hydroperiod length caused a decrease in invertebrate species richness in three ditches. In such aquatic habitats, water temperature increases with increasing atmospheric

temperature during the daytime, and dissolved oxygen may reach high concentrations as a result of increasing algal photosynthetic activity. Algae can quickly colonize when environmental conditions are suitable for algal growth, since they are microscopic organisms. Additionally, algae generally have short lifespans relative to other aquatic organisms such as benthic macroinvertebrates and macrophytes.

Wanormelingen et al. (2008) noted that diatom community structure and diversity are affected by geographical factors independent of environmental conditions. The significant effects of water temperature and elevation in the present study (Fig. 3) support this hypothesis. The study area is located in south east Anatolia (Turkey) and spans a substantial vertical gradient (> 1500 m). Large fluctuations in temperature and humidity are not observed in Ağrı province due to its terrestrial climatic conditions. The mean air temperature for the last 30 years is about 12.1°C and the average annual temperature is 6.2°C in May (MGM, 2019). Consequently, ditches may not have been strongly affected by temperature fluctations, at least for the past 30 years. Using data collected during the same sampling campaign, Külköylüoğlu et al. (2019) also found high non-marine ostracod species richness (referring to alpha diversity) in ditch habitats. Due to the regional climatic conditions, ditch habitats may be less ephemeral than elsewhere, positively influencing alpha diversity in the province. A good understanding of the physiology and ecology of temporary water bodies and modeling them to larger ecosystems can help to answer many ecological and evolutionary questions (De Meester et al., 2005).

Bacillariophyta was the dominant group in all habitat types. However, the degree of dominance varies according to habitat types. Highest Bacillariophyta taxa richness was observed in streams (161 taxa), followed by ditches (118 taxa) (Table 4). However, Bacillariophyta also made up the smallest proportion of taxa in ditch habitats (50%) (Fig. 6). The highest proportion of Bacillariophyta occurred in spring habitats, followed by the troughs. Troughs are examples of artificially transformed natural water bodies (springs, ground-waters), (Külköylüoğlu et al., 2013) while springs are natural habitats (in this study). Accordingly, finding relatively similar abundance values for Bacillariophyta in both habitats (Fig. 6) can be associated with the number of common species of the group where most (if not all) algal species are tolerant to the environmental fluctuations.

The high number of algal taxa (392 taxa) detected across habitat types in Ağrı province shows the importance of large-scale geographical sampling. Stomp et al. (2011) stated that microorganism diversity may show significant geographical variation. The high level of Beta diversity in this study (Whittaker's ß: 19) indicates a low level of similarity between sampling sites, and there are no common species among many sampling sites.

5. Conclusions

Total of 392 algal taxa (gamma diversity) belonging to seven algal groups were identified from 100 sampling sites along with relatively high alpha (H' = 4.946) and beta diversity (Bw= 19) values. Diatoms were determined as the dominant group, covering about 54.08 % of the total species richness. Habitat type, elevation and some phsicochemical variables (water temperature and pH) were found the most effective factors on algae species composition, diversity and distribution in the province Ağrı. Results showed that temporary water bodies were the most important habitats of algal species composition that highest species richness was determined from streams (238 taxa) and ditches (235 taxa). However, the highest alpha diversity was found in ditches (H' =4.57, 235 taxa) and streams (H' = 4.40, 238 taxa), even though the number of samples was less than half that of streams. SIMPER analyses indicated that 16 algal taxa (15 were diatoms) accounted for 70% of the total similarity. Six diatom species (*Nitzschia palea, N. frustulum, N. linearis, Hantzschia amphioxys, Surirella minuta, Ulnaria ulna*) known as ecological generalists and cosmopolitan species, had Shannon-Wiener alpha species diversity values above 3. One of the most interesting findings in this study was the highest alpha diversity values in ditch habitats, even though the number of samples was less than half that of streams (see Table 3). This indicated that ditches contribute significantly to the alpha and gamma algal species diversity in the province. For the conservation of biological diversity, temporary water bodies need to be better studied and protected. Gibbs (1993) pointed out the importance of small wetlands for local populations of aquatic organisms. Brock et al. (2003) stated that temporary water bodies are rich gene beds for both plant seeds and zooplankton eggs. These findings suggest that the conservation status of shallow, temporary and small-scale aquatic resources should be re-emphasized and carefully considered in future studies.

Conflict of Interest

The authors declare no conflict of interest.

Ethical statement

Authors state that the research was conducted according to ethical standard.

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Supplementary materials

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References

Akdemir, D., Külköylüoğlu, O., Yavuzatmaca, M., Sari, N., 2016. Freshwater ostracods (Crustacea) of Gaziantep (Turkey) and their habitat preferences according to movement ability. Fund. Appl. Limnol. 187, 307–314. doi:10.1127/fal/2016/0665.

Altuner, Z., 2017. An investigation on the benthic diatoms of Murat River (Muş) and comparison with Ehrenberg's study. Journal of New Results in Science 6, 17–23.

Arle, J., 2002. Physical and chemical dynamics of temporary ponds on a calcareous plateau in Thuringia, Germany. Limnologica 32, 83–101. https://doi.org/10.1016/S0075-9511(02)80001-9.

Armitage, P.D., Szoszkiewicz, K., Blackburn, J.H., Nesbitt, I., 2003. Ditch communities: a major contributor to floodplain biodiversity. Aquat. Conserv. 13, 165–185. https://doi.org/10.1002/aqc.549.

Aysel, V., 2005. Check-list of the freshwater algae of Turkey. Journal of the Black Sea/Mediterranean Environment 11, 1–124.

Balian, E., Harrison, I., Butchart, S., Chambers, P., Cordeiro, J., Cumberlidge, N., Van Dijk, P.P., 2010. Chapter 2. Diversity of species in freshwater systems. In: Mittermeier, R.A., Farrell, T., Harrison, I.J., Upgren, A.J., Brooks, T. (Eds.), Freshwater – the essence of life. Conservation International and Cemex Conservation Book Series, Earth in focus editions, China, pp. 50–89.

Barinova, S., 2011. The effect of altitude on distribution of freshwater algae in continental Israel. Current Topics in Plant Biology 12, 89–95.

Barinova, S., Ali, N., Barkatullah, S.F, 2013. Ecological Adaptation to Altitude of Algal Communities in the Swat Valley (Hindu Cush Mountains, Pakistan. Expert. Opin. Environ. Biol 2 (2), 1–15. doi:10.2478/s13545-014-0150-y.

Biggs, B.J., Smith, R.A., 2002. Taxonomic richness of stream benthic algae: Effects of flood disturbance and nutrients. Limnol. Oceanogr. 47, 1175–1186.

Bortolini, J.C., Train, S., Rodrigues, L.C., 2017. The variability in the hydrosedimentological regime supports high phytoplankton diversity in floodplain: A 12-year survey of the Upper Paraná River. J. Limnol. 76, 3. https://doi.org/10.4081/jlimnol.2017.1509.

Brock, M.A., Nielsen, D.L., Shiel, R.J., Green, J.D., Langley, J.D., 2003. Drought and aquatic community resilience: The role of eggs and seeds in sediments of temporary wetlands. Freshw. Biol. 48, 1207–1218. https://doi.org/10.1046/j.1365-2427.2003.01083.x.

Cardoso, S.J., Roland, F., Loverde-Oliveira, S.M., de Moraes Huszar, V.L., 2012. Phytoplankton abundance, biomass and diversity within and between Pantanal wetland habitats. Limnologica 42, 235–241. https://doi.org/10.1016/j.limno.2012.01.002.

Coesel, P.F.M., Meesters, K.J., 2007. Desmids of the lowlands, Mesotaeniaceae and Desmidiaceae of the European Lowlands. KNNV Publishing, Zeist, The Netherlands https://doi.org/10.1163/9789004277922.

Coesel, P.F.M., Meesters, K.J., 2013. European flora of the desmid genera, Staurastrum and Staurodesmus. KNNV Publishing Zeist, The Netherlands https://doi.org/10.1111/fwb.12434.

De Bie, T., Declerck, S., Martens, K., De Meester, L., Brendonck, L., 2008. A comparative analysis of cladoceran communities from different water body types: patterns in community composition and diversity. Hydrobiologia 597, 19–27. https://doi.org/10.1007/s10750-007-9222-y.

De Meester, L., Declerck, S., Stoks, R., Louette, G., Van De Meutter, F., De Bie, T., Brendonck, L., 2005. Ponds and pools as model systems in conservation biology, ecology and evolutionary biology. Aquat. Conserv. 15, 715–725.

Della Bella, V., Puccinelli, C., Marcheggiani, S., Mancini, L., 2007. Benthic diatom communities and their relationship to water variables in wetlands of central Italy. Ann. Limnol-Int. J. Lim. 43, 89–99. https://doi.org/10.1051/limn/2007021.

Dunck, B., Felisberto, S.A., de Souza Nogueira, I., 2019. Effects of freshwater eutrophication on species and functional beta diversity of periphytic algae. Hydrobiologia 837, 195. https://doi.org/10.1007/s10750-019-03971-x.

Ehrenberg, C.H.G., 1845. Untersuchungen über die kleinsten lebensformen im quellenlande des Euphrat und Araxes. –Ber. 1844-*Bekannt*. Verh. Konigl. Preuss. Akad. Berlin 253–257.

Frank, J.H., Lounibos, L.P., 1983. Phytotelmata: Terrestrial plants as hosts for aquatic insect communities. Plexus Press.

Gibbs, J.P., 1993. Importance of small wetlands for the persistance of local population of wetland-associated animals. Wetlands 13, 25–31. https://doi.org/10.1007/BF03160862.

Guiry, M.D., Guiry, G.M., 2019. Algaebase. World-wide electronic publication. National University of Ireland, Galway http://www.algaebase.org.

Hill, M.O., Gauch, H.G., 1980. Detrended correspondence analysis: an improved ordination technique. In: Van der Maarel, E. (Ed.), Classification and ordination: Symposium on advances in vegetation science. Springer, Dordrecht, pp. 47–58.

Huber-Pestalozzi, G., 1941. Das Phytoplankton des Süßwassers – systematik und biologie. 2. Teil, 1. Halfte, Chrysophyceen, Farblose Flagellaten Heterokonten. Stuttgart.

Huber-Pestalozzi, G., 1950. Das Phytoplankton des Süßwassers – systematic und biologie. 3. Teil. Cryptophyceen, Chloromonadinen, Peridineen. Stuttgart.

Huber-Pestalozzi, G., 1955. Das Phytoplankton des Süßwassers – systematik und biologie. 4. Teil. Euglenophyceen. Stuttgart.

Huber-Pestalozzi, G., 1961. Das Phytoplankton des Süßwassers - systematik und biologie. 5. Teil Chlorophyceae (grünalgen) ordnung. Volvocales, Stuttgart.

Huber-Pestalozzi, G., Fott, B., 1972. Das Phytoplankton des Süßwassers – systematik und biologie. 6. Teil. Chlorophyceae (grünalgen) ordnung. Tetrasporales. Stuttgart.

Huber-Pestalozzi, G., 1982. Das Phytoplankton des Süßwassers – systematik und biologie. 8. Teil. Conjugatophyceae, Zygnematales und Desmidiales (excl. Zygnemataceae). Stuttgart. https://doi.org/10.1002/iroh.19840690122

Huber-Pestalozzi, G., 1983. Das Phytoplankton des Süßwassers – systematic und biologie. 7. Teil, 1. Hälfte. Chlorophyceae (grünalgen) ordnung. Chlorococcales. Stuttgart.

Jamoneau, A., Passy, S.I., Soininen, J., Leboucher, T., Tison-Rosebery, J., 2018. Beta diversity of diatom species and ecological guilds: Response to environmental and spatial mechanisms along the stream watercourse. Freshw. Biol. 63, 62–73. https://doi.org/10.1111/fwb.12980.

John, D.M., Whitton, B.A., Brook, A.J., 2003. The freshwater algal flora of the British Isles. An identification guide to freshwater and terrestrial algae. Cambridge University Press, Cambridge.

Kitching, R.L., 2000. Food webs and container habitats: The natural history and ecology of phytotelmata. Cambridge University Press.

Kociolek, J.P., Spaulding, S.A., 2000. Freshwater diatom biogeography. Nova Hedwigia 71, 223–241.

Komárek, J., 2013. Süßwasserflora von Mitteleuropa. Band 19/3. Cyanoprokaryota. 3.Teil / Part 3. Hetrocyytous genera. Spinger Spektrum Akademischer Verlag.

Komárek, J., Anagnostidis, K., 1999. Süßwasserflora von Mitteleuropa. Band 19/1. Cyanoprokaryota. 1. Teil. Chroococcales. Gustav Fischer, Stuttgart.

Komárek, J., Anagnostidis, K., 2005. Süßwasserflora von Mitteleuropa. Band 19/2. Cyanoprokaryota. 2. Tei / 2nd Part. Oscillatoriales. Spektrum.

Krammer, K., Lange-Bertalot, H., 1991a. Süβwasserflora von Mitteleuropa Bacillariophyceae 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. GustavFischer.

Krammer, K., Lange-Bertalot, H., 1991b. Süβwasserflora von Mitteleuropa Bacillariophyceae 4. Teil: Achnanthaceae, Kritische Ergänzungenzu Navicula (Lineolatae) und Gomphonema. Gustav Fischer.

Krammer, K., Lange-Bertalot, H., 1997a. Süβwasserflora von Mitteleuropa Bacillariophyceae 1. Teil: Naviculaceae. Spektrum Akademischer Verlag, Berlin.

Krammer, K., Lange-Bertalot, H., 1997b. Süβwasserflora von Mitteleuropa Bacillariophyceae 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. Spektrum Akademischer Verlag, Berlin.

Külköylüoğlu, O., Akdemir, D., Sari, N., Yavuzatmaca, M., Oral, C., Başak, E., 2013. Distribution and ecology of Ostracoda (Crustacea) from troughs in Turkey. Turk. J. Zool. 37, 277–287. https://doi:10.3906/zoo-1205-17.

Külköylüoğlu, O., Yavuzatmaca, M., Akdemir, D., Yılmaz, O., Çelen, E., Dere, Ş., Dalkıran, N., 2019. Correlational patterns of species diversity, swimming ability and ecological tolerance of non-marine ostracoda (Crustacea) with different reproductive modes in shallow water bodies of Ağrı region (Turkey). J. Freshw. Ecol. 34, 151–165. https://doi.org/10.1080/02705060.2019.1576551.

Lackey, J.B, 1940. The microscopic fauna and flora of tree-holes. Ohio Journal of Science 40, 186–192.

Legendre, P., Borcard, D., Peres-Neto, P.R., 2005. Analyzing beta diversity: partitioning the spatial variation of community composition data. Ecol. Monogr. 75, 435–450. https://doi.org/10.1890/05-0549.

Lowe, R.L., LaLiberte, G.D., 2017. Benthic stream algae: distribution and structure. In: Hauer, F.R., Lamberti, G.A. (Eds.), Methods in stream ecology. Academic Press, pp. 193–221.

Lukács, B.A., Sramkó, G., Molnár, A., 2013. Plant diversity and conservation value of continental temporary pools. Biol. Conserv. 158, 393–400. https://doi.org/10.1016/j.biocon.2012.08.024.

Maguire, B., 1971. Phytotelmata: Biota and community structure. Annual Review of Ecology and Systematics 2, 439–464.

Marra, R.C., Algarte, V.M., Ludwig, T.A., Padial, A.A., 2018. Diatom diversity at multiple scales in urban reservoirs in Southern Brazil reveals the likely role of trophic state. Limnologica 70, 49–57. https://doi.org/10.1016/j.limno.2018.04.001.

MGM, 2019. Ağrı'ya ait mevsim normalleri (1981-2010). Resource document. Turkish State Meteorological Service. https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=AGRI . Accessed 7 February 2020. (In Turkish).

Nabout, J.C., de Nogueira, I.S., de Oliveira, L.G., Morais, R.R., 2007. Phytoplankton diversity (alpha, beta, and gamma) from the Araguaia River tropical floodplain lakes (central Brazil). Hydrobiologia 575, 455–461. https://doi.org/10.1007/s10750-006-0393-8.

Nicolet, P., Biggs, J., Fox, G., Hodson, M.J., Reynolds, C., Whitfield, M., Williams, P., 2004. The wetland plant and macroinvertebrate assemblages of temporary ponds in England and Wales. Biol. Conserv. 120, 261–278. https://doi.org/10.1016/j.biocon.2004.03.010.

Passy, S.I., Blanchet, F.G., 2007. Algal communities in human-impacted stream ecosystems suffer beta-diversity decline. Divers. Distrib. 13, 670–679. https://doi.org/10.1111/j.1472-4642.2007.00361.x.

Popovsky, J., Pfiester, L.A., 1990. Süßwasserflora von Mitteleuropa. Band 6. Dinophyceae (Dinoflagellida). Spektrum AkademischerVerlag.

Pound, K.L., Lawrence, G.B., Passy, S.I., 2019. Beta diversity response to stress severity and heterogeneity in sensitive versus tolerant stream diatoms. Divers. Distrib. 25, 374–384. https://doi.org/10.1111/ddi.12865.

Schuster, K.F., Tremarin, P.I., Souza-Franco, G.M.D., 2015. Alpha and beta diversity of phytoplankton in two subtropical eutrophic streams in southern Brazil. Acta Bot. Bras. 29, 597–607. http://dx.doi.org/10.1590/0102-33062015abb0060.

Seaby, R.M., Henderson, P.A., 2006. Species diversity and richness Version 4. Pisces Conservation Ltd., Lymington, England.

Seaby, R.M., Henderson, P.A., 2007. Community analyses package (CAP 4.1.3.) Lymington. Pisces Conservation Ltd, England.

Solak, C.N., Wojtal, A.Z., 2012. Diatoms in springs and streams of Türkmen Mt.(Sakarya river basin) common in Turkish inland waters. Pol. Bot. J. 57, 375–425.

Solak, C.N., Ector, L., Wojtal, A.Z., Ács, É., Morales, E., 2012. A review of investigations on diatoms (Bacillariophyta) in Turkish inland waters. Nova Hedwigia 141, 431–462.

Stendera, S., Adrian, R., Bonada, N., Cañedo-Argüelles, M., Hugueny, B., Januschke, K., Hering, D., 2012. Drivers and stressors of freshwater biodiversity patterns across different ecosystems and scales: a review. Hydrobiologia 696, 1–28. https://doi.org/10.1007/s10750-012-1183-0.

Stomp, M., Huisman, J., Mittelbach, G.G., Litchman, E., Klausmeier, C.A., 2011. Large-scale biodiversity patterns in freshwater phytoplankton. Ecology 92, 2096–2107. https://doi.org/10.1890/10-1023.1.

ter Braak, C.J.F., Prentice, I.C., 1988. A theory of gradient analysis. Advances in Ecological Research 18, 271–317. https://doi.org/10.1016/S0065-2504(08)60183-X.

ter Braak, C.J.F., Smilauer, P., 2002. CANOCO reference manual and user's guide to CANOCO for windows, version 4.5. Microcomputer Power, New York.

ter Braak, C.J.F., Verdonschot, P.F.M., 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. Aquatic Sciences 57 (3), 255–289.

Uçak, S., Külköylüoğlu, O., Akdemir, D., Başak, E., 2014. Distribution, diversity and ecological characteristics of freshwater Ostracoda (Crustacea) in shallow aquatic bodies of the Ankara region, Turkey. Wetlands 34, 309–324. https://doi.org/10.1007/s13157-013-0499-5.

Van Dam, H., Mertens, A., Sinkeldam, J., 1994. A coded checklist and ecological indicator values of freshwater diatoms from Netherlands. Neth. J. Aquat. Ecol. 28, 117–184. https://doi.org/10.1007/BF02334251.

Vanormelingen, P., Verleyen, E., Vyverman, W., 2008. The diversity and distribution of diatoms: from cosmopolitanism to narrow endemism. Biodivers. Conserv. 17, 393–405.

Whittaker, R.H., 1972. Evolution and measurement of species diversity. Taxon 21, 213–251.

Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P., Sear, D., 2003. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biol. Conserv. 115, 329–341. https://doi.org/10.1016/S0006-3207(03)00153-8.

Williams, D.D., 2006. The biology of temporary waters. Oxford University press.

Yanoviak, S.P., 1999. Community structure in water-filled tree holes of Panama: effects of hole height and size. Selbyana 20, 106–115.

Yung, Y.K., Stokesz, P., Gorham, E., 1986. Algae of selected continental and maritime bogs in North America. Can. J. Bot. 64, 1825–1833. https://doi.org/10.1139/b86-241.

Zarei-Darki, B., 2011. Comparative Characteristics of phytoplankton of different water bodies of Iran. Hydrobiol. J. 47, 48–56. https://doi.org/10.1615/HydrobJ.v47.i3.60.

Zarei-Darki, B., 2012. Features of algae distribution of order Sphaeropleales (Chlorophyceae) in the different water bodies of Iran. International Journal on Algae 14, 323–330. https://doi.org/10.1615/InterJAlgae.v14.i4.30.