Botanica SERBICA

(2020) 44 (1): 11-25

DOI: https://doi.org/10.2298/BOTSERB2001011S
journal homepage: botanicaserbica.bio.bg.ac.rs

Original Scientific Paper

Cohabitant charophyte algal flora and its ecology in high-mountain lakes of the Artabel Lakes Nature Park (Gümüşhane, Turkey)

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ABSTRACT:
The composition of charophyte taxa and their habitat preferences in water bodies of the Artabel Lakes Nature Park were investigated on 15 August 2013 and 13 August 2016. A total of 73 taxa belonging to Conjugatophyceae (Zygnematophyceae) and Klebsormidiophyceae were recorded. The genera *Cosmarium* (37), *Staurastrum* (10) and *Closterium* (7) were most abundant. The partly unexpected presence of certain desmid taxa, i.e., taxa characteristic of eutrophic water, was recorded. Filamentous charophytes were represented by three taxa. The Willis curve for the distribution of species to genera had a trend line of R^2 = 0.9123. Bioindication, statistical methods and comparative floristic results show that water in all of the studied lakes was fresh, of low-conductivity, circum-neutral and with little organic pollution. Four groups of lakes were identified as a result of statistical comparison of their environmental and biological variables. Bioindication results can be used as references for future monitoring of the lakes in protection of the species found in the Artabel Lakes Nature Park and can also be included in the National Water Quality Standard System of Turkey.

Keywords:
Artabel Lakes Nature Park, high-mountain lakes, Charophyta, Turkey

UDC: 582.263.3:581.9(560)

Received: 25 October 2019
Revision accepted: 13 January 2020

INTRODUCTION

Algae are one of the parameters of aquatic ecosystems used in ecological evaluation of water quality (Bellinger & Sigee 2010; Stevenson 2014), and many algal species are used as environmental indicators. Diatoms, especially, are among the most important living groups of benthic communities, and for this reason they are usually an indispensable element in studies involving determination of water quality (Ács *et al*. 2004). According to the literature (Coesel 1984; Borics *et al*. 1998; Feher 2003), several species of desmids are closely tied to certain types of aquatic habitats and can be used as indicators of changes in pH values or nutrient supply. In addition, Coesel (1998) maintained that desmids are excellent bio-indicators of the stability of ecosystems. The bio-indication approach to water monitoring has been used in many countries during recent years (Barinova & Krassilov 2012; Barinova *et al*. 2012; 2013, 2015, 2016; Jienbekov *et al*. 2018; Niyatbekov & Barinova 2018). Barinova (2011) noted that this method gives reliable results in ecological assessment of water quality. Diatom communities were generally used in bio-indication studies performed in Turkey (Solak *et al*. 2012; Sivaci *et al*. 2013). In the present study, desmid communities were used for the ecological evaluation of aquatic ecosystems in the Artabel Lakes Nature Park, and this is a first for Turkey.

The eastern Black Sea region is one of the most significant centres of high mountains in Turkey. The region has an extensive water network with many rivers, lakes and ponds. Moreover, the habitats in question are far from industrial and human influences. These factors have an important effect on development of the algal flora in the region. In these waters, a special community of algae (especially desmids) adapted to extreme environmental conditions arose and developed over the course of many centuries. According to Medvedeva (2001) and Sterlyagova (2008), desmids are an important component in benthic habitats of high-mountain lakes in the Northern Hemisphere.

Despite its remoteness and limited accessibility, the number of algological studies in the region has increased in recent years (Şahin 1998, 2000, 2002, 2007, 2008, 2009; Şahin & Akar 2007; Akar & Şahin 2014). However, the diversity and distribution of the region´s algae and the quality of its waters are still not sufficiently known. The Artabel Lakes Nature Park is one of the most important nature parks in the region and has 23 high-mountain lakes. The first written record of the algal flora, including Charophyta, in this nature park was published by Atici (2018).

The goals of the present study were to evaluate the current ecological condition of high-mountain lakes in the Artabel Lakes Nature Park on the basis of the composition of the charophyte taxa (especially desmid communities) and ascertain water quality using methods of bio-indication.

MATERIALS AND METHOD

The study area. The Artabel Lakes Nature Park is situated on the borders of Torul county of Gümüşhane province. Total area of the park is about 5859 hectares, and it is located at a latitude of 40°21'36"- 40°26'42" N and longitude of 39°0'24"- 39°8'23" E (Fig. 1). Its grassland, bare area, forest and aquatic ecosystems constitute 71.5, 26.9, 1.4 and 1% of the park, respectively (Anonymous 2013).

In the Artabel Lakes Nature Park, there are three stream basins, viz., the Gümüştuğ stream basin (Kara and Beş Lakes), the Artabel stream basin (Artabel Lakes) and the Kongel stream basin (Yıldız and Acembol Lakes). The total basin area is approximately 58.2 km^2 and is composed of five different lake sites, including the Artabel Lakes (ARL), Acembol Lakes (ACL), Beş Lakes (BL), Kara Lakes (KL) and Yıldız Lakes (YL). There are 23 lakes, which belong to the following groups: Artabel Lakes (six lakes), Acembol Lakes (three), Beş Lakes (five), Kara Lakes (six) and Yıldız Lakes (three). Some lakes of different size lakes are linked to each other, while others are independent (Anonymous 2013). There is also a previously unnamed lake (Isimsiz Lake: IL) and a small pond [Yıldız Lakes Pond (YLP)]. These lakes are of glacial origin, covered with a layer of ice at least 8 months of the year and situated in the alpine zone (2687-3030 m a.s.l.). It was not possible to fully describe the charophyte flora all year long because of access difficulties.

For the purposes of this study, 17 lakes and one pond situated at different elevations above sea level (2687-2980 m a.s.l.) were selected. Some physical and chemical parameters of the lakes were studied, as well as their epipelic, epilithic and epiphytic algae.

Fig. 1. Map of Artabel Lakes Nature Park (Anonymous 2013).

Sampling and laboratory studies. In the course of this research, lakes in the Artabel Lakes Nature Park were visited at two different times. The first visit took place on 15 August 2013. Algae and water samples were taken from the Artabel (ARL) and Beş (BL) Lakes. The second visit was made on 13 August 2016, at which time samples were taken from the Acembol (ACL) and Yıldız (YL) Lakes, the İsimsiz Lake (IL) and the Yıldız Lakes Pond (YLP). The Kara Lakes could not be visited because terrain conditions were difficult. Also, there was no water in the Lake BL5, so algal and water samples could not be taken. In total, 43 epipelic, epilithic and epiphytic algae samples were taken from 17 lakes and a pond. Epipelic samples were collected with the aid of a glass tube from sediment surface at all the water bodies except the Lake BL2. Epilithic samples were taken from the ARL1, ARL2, BL2, ACL1, ACL2, ACL3 and IL Lakes. Randomly chosen stones were scraped with a toothbrush and then washed into plastic bottles. For epiphytic samples, mosses *Hygrohypnum luridum* (Hedwig) Jennings] and filamentous alga (*Microspora* sp.) were taken from the ARL1, ARL3, YL1, YL2, YL3, ACL2, ACL3, IL lLakes, and from the YLP Pond. All samples were fixed in a solution of 4% formaldehyde (Round 1953; Sladeckova 1962). In addition, water temperature, pH, dissolved oxygen, total dissolved matter and electrical conductivity were measured in the field using Orion4Star and YSI 55 portable measuring instruments at each sampling station. In the laboratory, samples were

Table 1. List of benthic charophyte taxa of studied lakes in the Artabel Lakes Nature Park. (H: Habitat; 1: Epipelic, 2: Epilithic, 3: Epiphytic; F: Frequences; ARL: Artabel Lakes, BL: Beş Lakes, YL: Yıldız Lakes, ACL: Acembol Lakes, IL: İsimsiz Lake, YLP: Yıldız Lakes Pond; *: New record for the algal flora of Turkey).

CHAROPHYTA	H	F	LAKES
Class: Conjugatophyceae (Zygnematophyceae)			
Order: Desmidiales			
Family: Closteriaceae			
Genus: Closterium			
Closterium acerosum Ehrenberg ex Ralfs	1,2	VR	ACL2
**Cl. cornu* Ehrenberg ex Ralfs	1	VR	YL3
Cl. incurvum Brébisson	1,2,3	VR	BL4, IL
Cl. jenneri var. *cynthia* (De Notaris) Petlovany	3	VR	YL2
Cl. lunula Ehrenberg & Hemprich ex Ralfs	1	VR	ARL4, ACL1, YL2
Cl. parvulum Nägeli	3	VR	YL2
Cl. strigosum Brébisson	1	VR	YL3
Family: Desmidiaceae			
Genus: Actinotaenium			
Actinotaenium cucurbita (Brébisson ex Ralfs) Teiling	3	VR	YL2, YLP
**A. curtum* (Brébisson ex Ralfs) Teiling ex Růžička & Pouzar	3	VR	IL
Genus: Cosmarium			
**Cosmarium anceps* P.Lundell	3	VR	YL2
**C. boitierense* Kouwets	1	VR	BL4
C. botrytis Meneghini ex Ralfs	1,2,3	R	BG2, AC3, YG2, YG3, YGG
**C. botrytis* var. *gemmiferum* (Brébisson) Nordstedt	1,3	VR	YL1, YL2
C. botrytis var. *tumidum* Wolle	1,3	VR	ACL3, YL1
C. contractum O.Kirchner var. *minutum* (Delponte) Coesel	3	VR	ARL1, ARL3
**C. cucumis* Corda ex Ralfs	3	VR	YL2
C. galeritum Nordstedt	3	VR	YL2
**C. holmiense* P.Lundell var. *hibernicum* (West) Schmidle	3	VR	YL2
C. impressulum Elfving	1,3	R	ARL1, BL1, BL5, ACL1
**C. impressulum* var. *alpicola* Schmidle	2,3	VR	ACL1, IL
C. laeve Rabenhorst	1,2,3	R	BL2, ACL1, ACL2, ACL3, YL2, IL
C. margaritatum (P.Lundell) J.Roy & Bisset	3	VR	ACL3
**C. norimbergense* Reinschvar. *depressum* (West & G.S.West) Willi Krieger & Gerloff	1,3	VR	ARL1, ACL2
**C. notabile* Brébisson var. *subnotabile* (Wille) Coesel	2	VR	BL2
C. notabile var. *transiens* Insam & Willi Krieger	1,3	VR	ARL1, BL1
C. obtusatum (Schmidle) Schmidle	1,3	VR	ARL1, ARL5
**C. paragranatoides* Skuja var. *dickii* Krieger & Gerloff	1,3	VR	ARL1, ARL5
**C. pokornyanum* (Grunow) West & G.S.West	3	VR	YL3
**C. polygonum* (Nägeli) W. Archer var. *hexagonum* Grönblad	3	VR	ARL1

**C. pseudonitidulum* Nordstedt	3	VR	ARL1
C. pseudoornatum B.Eichler & Gutwinski	1	VR	ACL3, YLP
C. punctulatum Brébisson	1	VR	BL1
C. regnellii Wille	2,3	R	ARL1, BL2, ACL3, IL
C. regnellii var. *pseudoregnellii* (Messikommer) Willi Krieger	3	VR	IL
C. regnellii var. *minimum* Eichler & Gutwinski	1	VR	ACL3
C. reniforme (Ralfs) W.Archer	1,2,3	VR	ACL2, ACL3
**C. reniforme* var. *compressum* Nordstedt	3	VR	ACL3
**C. simplicius* (West & G.S.West) Grönblad	3	VR	ARL1
C. sportella Brébisson ex Kützing	1,3	VR	ACL3
C. subcostatum Nordstedt	1,2,3	C	ARL1, ARL5, BL1, ACL1, ACL3, YL1, YL3, IL, YLP
C. subcostatum var. *minus* (West & G.S.West) Kurt Föster	3	R	ARL1, ACL2, YL1, IL
C. subcrenatum Hantzsch	1,3	R	ARL5, BL4, YL1, YLP
**C. subspeciosum* Nordstedt var. *transiens* Messikommer	1,2,3	R	ACL2, YL2, YL3, YLP
C. tinctum Ralfs	3	VR	ARL1
C. turpinii Brébisson	1	VR	ACL1
C. vogesiacum Lamaire var. *alpinum* (Schmidle) Laporte	1,3	VR	BL4, ACL3
Genus: Euastrum			
Euastrum bidentatum Nägeli	3	VR	ARL1
E. binale Ehrenberg ex Ralfs var. *gutwinskii* (Schmidle) Homfeld	3	VR	ARL3
E. oblongum Ralfs	1	VR	BL1, BL4
Genus: Micrasterias			
Micrasterias americana Ehrenberg ex Ralfs	3	VR	IL
**M. truncata* Brébisson ex Ralfs	3	VR	YL2
Genus: Spondylosium			
**Spondylosium papillosum* West & G.S.West	3	VR	ARL1
Genus: Staurastrum			
Staurastrum bieneanum Rabenhorst	3	VR	ACL3
S. boreale West & G.S.West	1	VR	ARL4
**S. dilatatum* Ehrenberg ex Ralfs	1,3	VR	YL1, IL
S. dispar Brébisson	1,2,3	R	ARL6, BL1, BL4, ACL2, ACL3, YL1, IL
**S. dybowskii* Woloszynska	1	VR	ARL4
**S. glaronense* Messikomer	3	VR	ARL1
**S. lapponicum* (Schmidle) Grönblad	1,3	VR	ACL3, IL,YLP
S. pilosum Brébisson	1	VR	ACL1
S. punctulatum Brébisson	1,2,3	F	ARL1, ARL4, ARL5, ARL6, BL1, BL3, BL4, ACL1, YL1, YL3, IL
**S. punctulatum* var. *pygmaeum* (Brébisson ex Ralfs) West & G.S.West	3	VR	YL3

Genus: Teilingia			
**Teilingia excavata* (Ralfs ex Ralfs) Bourrelly var. *subquadrata* (West & G.S.West ex N.Carter) Stein	1,3	VR	ARL1, BL4
T. granulata (J.Roy & Bisset) Bourrelly	3	VR	ARL1
Genus: Tetmemorus			
**Tetmemorus laevis* Ralfs ex Ralfs	3	VR	YL2, YL3
Family: Gonatozygaceae			
Genus: Gonatozygon			
Gonatozygon monotaenium De Bary	3	VR	YL1
Family: Peniaceae			
Genus: Penium			
Penium margaritaceum Brébisson	1,3	VR	BL4, ACL2, IL
Order: Zygnematales			
Family: Mesotaeniaceae			
Genus: Cylindrocystis			
Cylindrocystis brebissonii (Ralfs) De Bary	3	VR	ARL1
Genus: Netrium			
Netrium digitus (Brébisson ex Ralfs) Itzigsohn & Rothe	3	VR	YL2
Family: Zygnemataceae			
Genus: Spirogyra			
Spirogyra oligocarpa C.-C.Jao	1,3	VR	BL1, YLP
S. tenuissima (Hassall) Kützing	1,2,3	VR	IL
Genus: Zygnema			
Zygnema pseudocylindricum Gauthier-Lièvre Figure 6H	2	VR	BL2
Class: Klebsormidiophyceae			
Order: Klebsormidiales			
Family: Klebsormidiaceae			
Genus: Klebsormidium			
Klebsormidium klebsii (G.M.Smith) P.C.Silva, K.R.Mattox & W.H.Blackwell	1	VR	YLP

examined on temporary slides under a Leica DM 2500 light microscope. Algae were photographed with a Leica DFC 290 camera attached to the microscope.

All of the taxa were identified according to West & West (1904, 1905, 1908, 1912, 1923), Prescott (1962), Ružička(1977), Lind & Brook (1980), Huber-Pestalozzi (1982), Dillard (1990, 1991, 1993), Bourrelly & Coute (1991), Lenzenweger (1996, 1997, 1999), John *et al.* (2003), Coesel & Meesters (2007, 2013), Kadlubowska (2009), Brook & Williamson (2010), Stastny (2010), Kim (2015) and Lee (2015). The current status of nomenclature of all taxa was checked at the Algaebase web site (Guiry & Guiry 2019). Desmid records new for Turkey were clarified by consulting Maraşlioğlu & Gönülol (2019) and Şahin (2019).

Calculation of similarity was done in the GRAPHS program (Novakovsky 2004), and network analyses in JASP were performed using the botnet package in the R Statistica package of Love *et al.* (2019). Bioindication analysis was done with knowledge of ecological preferences of the revealed desmid algae species (Barinova *et al.* 2006, 2019).

Frequencies of algal taxa were recorded according to the following scale based on the total number of lakes

Fig. 2. A. *Closterium acerosum*, B. *Cl. incurvum*, C. *Cl. jenneri* var. *cynthia*, D. *Cl. lunula*, E. *Cl. parvulum*, F. *Cl. Strigosum*. Scale bar: 20 µm.

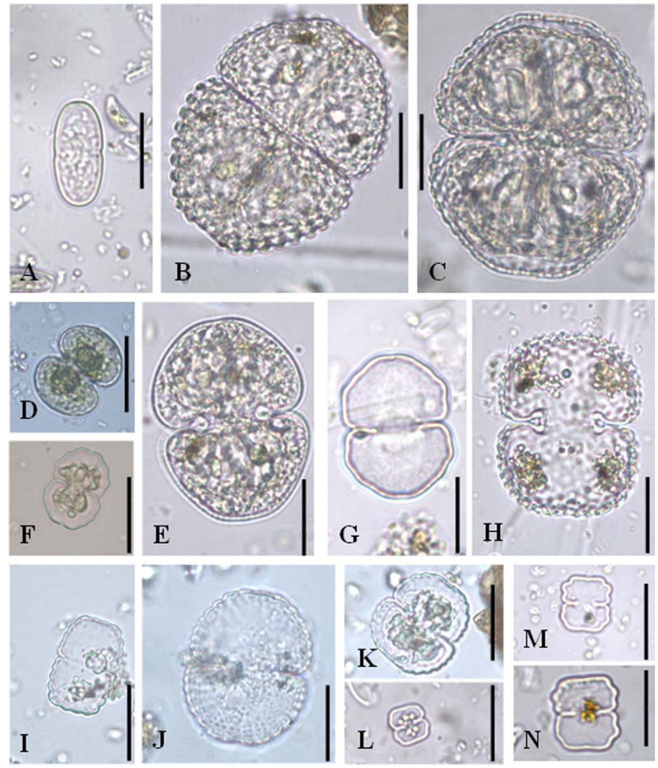

Fig. 3. A. *Actinotaenium cucurbita*, B. *Cosmarium botrytis*, C. *C. botrytis* var. *tumidum*, D. *C. contractum* var. *minutum*, E. *C. galeritum*, F. *C. impressulum*, G. *C.* laeve, H. *C. margaritatum*, I. *C. notabile* var. *transiens*, J. *C. obtusatum*, K. *C. punctulatum* L. *C. regnellii*, M. *C. regnellii* var. *pseudoregnellii*, N. *C. regnellii* var. *minimum*. Scale bar: 20 µm.

Table 2. List of the Charophyta genera with the number of taxa.

Genus	Number of taxa	Genus	Number of taxa
Actinotaenium	2	*Netrium*	1
Closterium	7	*Penium*	1
Cosmarium	37	*Spirogyra*	2
Cylindrocystis	1	*Spondylosium*	1
Euastrum	3	*Staurastrum*	10
Gonatozygon	1	*Teilingia*	2
Klebsormidium	1	*Tetmomerus*	1
Micrasterias	2	*Zygnema*	1

studied in the Artabel Lakes Nature Park: very rare (VR), taxa recorded in 1-20% of the investigated lakes; rare (R), taxa recorded in 21-40% of the investigated lakes; common (C), taxa recorded in 41-60% of the investigated lakes; frequent (F), taxa recorded in 61-80% of the investigated lakes; and very frequent (VF), taxa recorded in 81-100% of the investigated lakes (Kocataş 1992).

RESULTS AND DISCUSSION

Physical and chemical analyses. The results of some physical and chemical analyses of the studied waters are given in another paper (Şahin & Akar 2019a). According to the results, waters temperatures ranged from 10.1 to 19.1°C. The values of t pH varied from 6.19 to 7.52. On

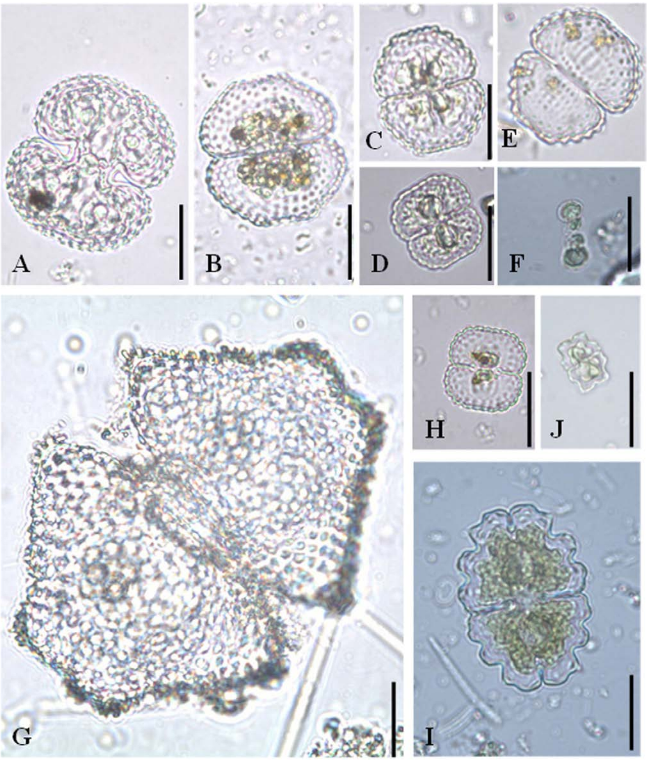

Fig. 4. A. *Cosmarium reniforme*, B. *C. sportella*, C. *C. subcostatum*, D. *C. subcostatum* var. *minus*, E. *C. subcrenatum*, F. *C. tinctum*, G. *C. turpinii*, H. *C. vogesiacum* var. *alpinum*, I. *Euastrum bidentatum*, J. *E. binale* var. *gutwinskii*. Scale bar: 20 µm.

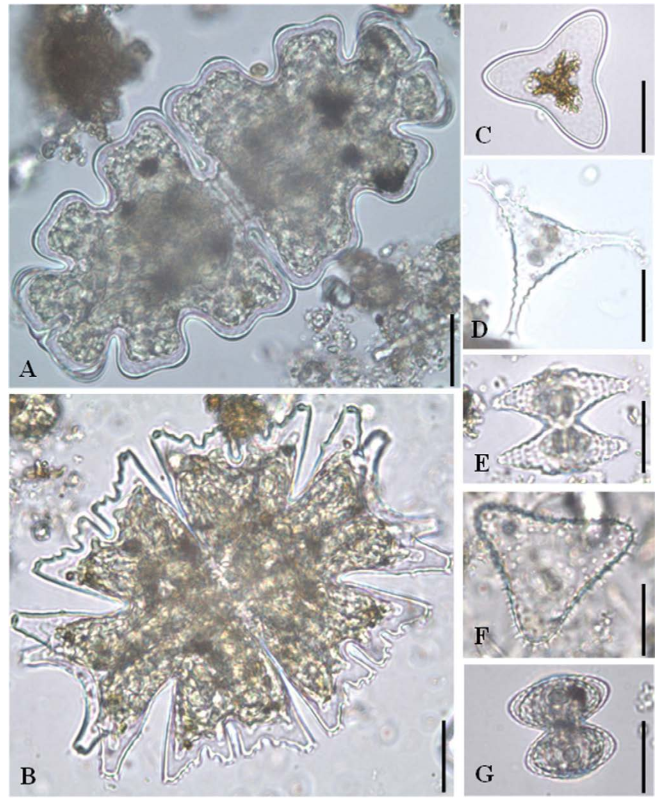

Fig. 5. A. *Euastrum oblongum*, B. *Micrasterias americana*, C. *Staurastrum bieneanum*, D. *S. boreale*, E. *S. dispar*, F. *S. pilosum*, G. *S. punctulatum*. Scale bar: 20 µm.

the basis of these values, it can be said that waters of the Artabel Lakes Nature Park are acidic and circum-neutral. The concentrations of dissolved oxygen (DO) and total dissolved solids (TDS) varied from 2.10 to 9.45 mg/L and from 6 to 30.55 mg/L, respectively. The values of water conductivity (C) of the studied waters can be characterised as low (12.0-49.9 µS/cm).

It can be seen from Table 1 (Şahin *et al.* 2019) that there is a linear, negative, high-level relationship between altitude and water temperature (T) ($r = -0.701$, $p<0.01$). This means that as altitude of the lakes increases, the water temperature decreases. There is also a linear, negative, moderate relationship between total dissolved solids (TDS) and dissolved oxygen (DO) ($r = -0.574$, $p<0.01$). This means that as the amount of total dissolved solids increases, the amount of dissolved oxygen decreases. In addition, it can be seen that there is a linear, positive, high-level relationship between total dissolved solids (TDS) and conductivity (C) ($r = 0.738$, $p<0.01$). This means that as the amount of total dissolved solids increases, the conductivity increases.

General remarks. In total, 73 taxa of Charophyta were recorded in epipelic, epilithic and epiphytic samples of studied waters in the Artabel Lakes Nature Park (Table 1). Twenty-six taxa are records new for the desmid flora of Turkey, and they are marked with an asterisk in Table 1. Descriptions, ecologies and geographic distributions of these taxa were given in a separate paper (Şahin & Akar 2019b). The taxa found are subdivided into two classes: Conjugatophyceae (Zygnematophyceae) and Klebsormidiophyceae (Table 1). The richest class is Conjugatophyceae (Zygnematophyceae), which included 98.63% of the taxa. The other class was represented by only one taxon (Table 1) and constituted 1.36% of the total taxa. The observed taxa were classified into seven families and 16 genera (Table 1, 2). Photographs of some species are presented in Figs. 2-6. In investigated waters of the Artabel Lakes Nature Park, the families Desmidiaceae and Closteriaceae are predominant. These families comprised 89.04% of all taxa. This result supports the conclusions of other authors (Stamenković *et al.* 2008; Sterlyagova 2008; Šovran *et al.* 2013) that these families are most diverse in northern mountainous areas. Other families represented 10.95% of all taxa. Qualitatively, the genus *Cosmarium* was dominant (37 taxa, 50.68%), subdominant was *Staurastrum* (10 taxa, 13.69%), whereas the genus *Closterium* was represented by seven taxa (9.58%). Other genera were represented by one or two taxa (Table 1, 2). According to Getzen (1985), a high number of single-species families and genera with few species is typical of northern floras. These three genera represented 73.97%

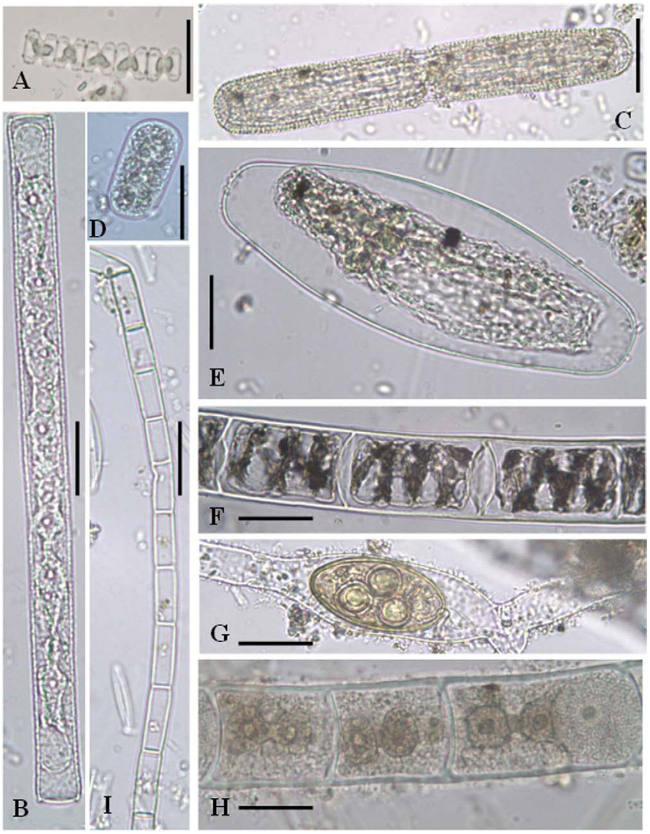

Fig. 6. A. *Teilingia granulata*, B. *Gonatozygon monotaenium*, C. *Penium margaritaceum*, D. *Cylindrocystis brebissonii*, E. *Netrium digitus*, F. *Spirogyra oligocarpa*, G. *Sp. tenuissima*, H. *Zygnema pseudocylindricum*, I. *Klebsormidium klebsii*. Scale bar: 20 µm.

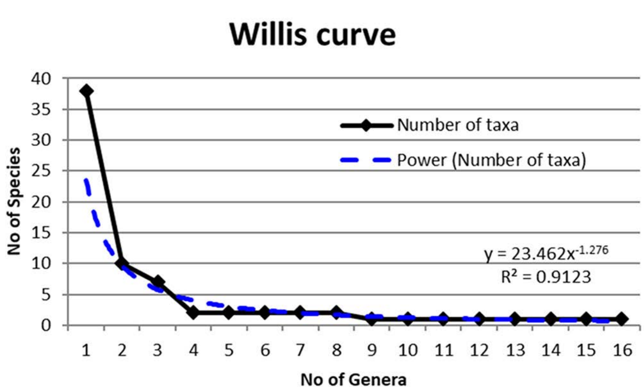

Fig. 7. Willis curve for desmid flora of the Artabel Lakes Nature Park showing the number of species per genus (such as 1 genus with 15 species, 2 genera with 6 species, etc.).

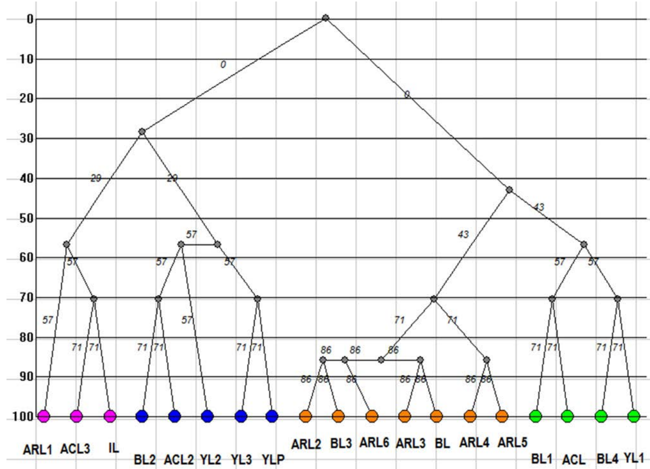

Fig. 8. Comparative floristic tree of desmid algae in the Artabel Lakes Nature Park. Four floristic clusters are marked by colours on a similarity level of 30%. Abbreviations of lake names are as in Table 1.

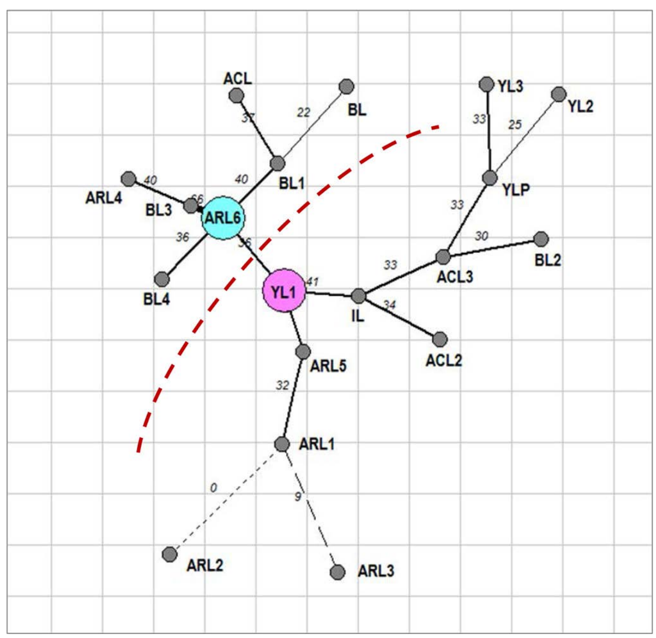

Fig. 9. Comparative floristic dendrite of desmid algae in the Artabel Lakes Nature Park. Two floristic cores are divided by a dashed line. Abbreviations of lake names are as in Table 1.

of the flora. Such taxonomic composition is typical of the northern flora (Getzen 1985; Medvedeva 2001; Şahin 2005; Stamenković *et al.* 2008; Briskaite *et al.* 2016). John *et al.* (2003) and Wehr & Sheath (2003) noted that the members of these genera are very common in acidic and oligotrophic waters, while Sigee (2005) pointed out that they develop well in lakes with soft waters. From the results of physico-chemical analyses (Şahin & Akar 2019a), it can be seen that the lakes and pond in the Artabel Lakes Nature Park contain mostly circum-neutral and acidic soft water with low mineral content. The genera *Cylindrocystis* and *Teilingia* had the lowest number of taxa, although they are typical genera of northern mountainous regions (Coesel 1996). The desmid flora of the Artabel Lakes Nature Park showed great similarity to that of other mountainous regions (Sterlyagova 2008; Briskaite 2016).

Table 3. Pearson correlations matrix for desmid species abundance in lake communities of the Artabel Lakes Nature Park. Highest correlation coefficients are indicated in boldface. Significance = * p < .05, ** p < .01, *** p < .001.

	ARL1	ARL3	ARL4	ARL5	ARL6	BL1	BL2	BL3	BL4	BL5	ACL1	ACL2	ACL3	YL1	YL2	YL3	IL	YLP
ARL1	—																	
ARL3	0.026	—																
ARL4	0.484 ***	-0.032	—															
ARL5	0.655 ***	-0.04	**0.644** ***	—														
ARL6	0.483 ***	-0.027	**0.816** ***	**0.631** ***	—													
BL1	0.648 ***	-0.051	0.584 ***	**0.721** ***	**0.73** ***	—												
BL2	0.04	-0.043	-0.049	-0.061	-0.041	-0.078	—											
BL3	0.567 ***	-0.02	**0.918** ***	**0.716** ***	**0.893** ***	**0.656** ***	-0.03	—										
BL4	0.346 **	-0.053	**0.655** ***	**0.632** ***	**0.817** ***	0.595 ***	-0.081	**0.734** ***	—									
BL5	0.253 *	-0.02	-0.023	-0.028	-0.019	0.31 **	-0.03	-0.014	-0.037	—								
ACL1	**0.621** ***	-0.051	**0.624** ***	0.721 ***	0.574 ***	**0.764** ***	0.112	**0.656** ***	0.431 ***	0.31 **	—							
ACL2	0.015	-0.056	-0.063	-0.079	0.161	0.062	0.175	-0.039	0.122	-0.039	0.062	—						
ACL3	0.143	-0.077	-0.087	0.2	0.096	0.277 *	0.498 ***	-0.054	0.035	-0.054	0.277 *	0.243*	—					
YL1	0.575 ***	-0.055	0.551 ***	**0.802** ***	**0.692** ***	**0.72** ***	-0.084	**0.623** ***	**0.652** ***	-0.039	**0.607** ***	0.201	0.278 *	—				
YL2	-0.243 *	-0.08	-0.038	-0.113	-0.076	-0.144	0.376 **	-0.056	-0.149	-0.056	0.051	0.268*	0.119	-0.119	—			
YL3	0.5	-0.054	0.575 ***	0.71 ***	0.566 ***	**0.635** ***	0.106	**0.648** ***	0.421 ***	-0.038	**0.635** ***	0.055	0.266 *	0.595 ***	0.195	—		
IL	0.559 ***	-0.075	0.488 ***	**0.602** ***	**0.624** ***	**0.629** ***	0.223	0.565 ***	0.505 ***	-0.053	**0.655** ***	0.321 **	0.422 ***	**0.711** ***	-0.04	0.51 ***	—	
YLP	0.117	-0.057	-0.065	0.416 ***	-0.054	0.253 *	0.141	-0.04	0.052	-0.04	0.218	0.083	0.422 ***	0.331 **	0.26*	0.491 ***	0.165	—

Only *Staurastrum punctulatum* was labeled as a frequent (F) (1.36%) taxon. A common (C) recorded taxon was *Cosmarium subcostatum* (1.36%). Rare (R) taxa (*Cosmarium botrytis*, *C. impressulum*, *C. laeve*, *C. regnelli*, *C. subcostatum* var. *minus*, *C. subcrenatum*, *C. subspeciosum* var. *transiens* and *Staurastrum dispar*) comprised 10.95% of all taxa encountered. Remarkably, 86.30% of all taxa are reported as very rare (VR) (Table 1). *Staurastrum punctulatum* is an important taxon of the flora. It was found in epipelic, epilithic and epiphytic samples of 11 studied lakes, where it was recorded as frequent (F) (61.11%) (Table 1). This taxon is cosmopolitan and occurs in the benthos and tychoplankton of acidic and circum-neutral (pH 6.7-7) oligotrophic waters, as well as in bogs, in marshes, among other algae and mosses and in the Alps up to an altitude of 2800 m (Lenzenweger 1997, 1999; John *et al.* 2003; Coesel & Meesters 2007, 2013). *Cosmarium subcostatum* was found in all benthic habitats of nine studied waterbodies and was recorded as

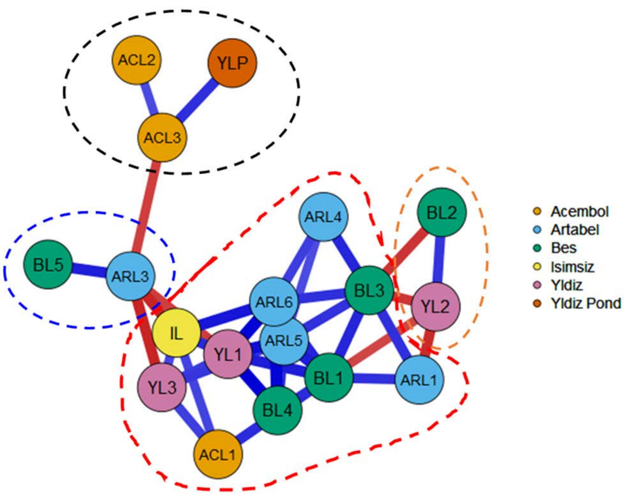

Fig. 10. JASP correlation plot of desmid algae in the Artabel Lakes Nature Park. Four cores of lake community similarity are marked by dashed lines. Abbreviations of lake names are as in Table 1. Blue lines – positive correlations, red lines – negative correlations.

common (C) (50%) (Table 1). According to Lenzenweger (1999) and John *et al.* (2003), *C. subcostatum* is widespread in arctic-alpine waters (pH 6.9-7.2) up to an altitude of 2500 m and is an inhabitant of nutrient-poor lakes. The results obtained in physicochemical analyses of the examined waters support the data mentioned above (Şahin & Akar 2019a).

Closterium acerosum and *Cl. strigosum* are known as inhabitants of eutrophic waters (Coesel 1998). They are also indicators of α- and α–β-mesosaprobity (Ružička 1977; SEV 1977; Gulyas 1998). That is why the finding of these taxa in the Artabel Lakes Nature Park was noteworthy. They were recorded as very rare (VR) in epipelic and epilithic samples from the Lakes ACL2 and YL3. These species do show any special preferences, since they were found in all types of water bodies (Huber-Pestalozzi 1982; Shakhmatov *et al.* 2018). A taxon such as *Cosmarium margaritatum*, which was recorded as very rare in epiphytic samples from the Lake ACL3, is included in the Red List of the Netherlands (Coesel 1998).

Mesotrophic desmids, which are 56.52% of all desmid taxa are dominant in the desmid community of studied waters in the Artabel Lakes Nature Park. In total, oligotrophic, oligo-mesotrophic and meso-oligotrophic inhabitants comprised 27.53% of all desmid taxa. On the other hand, meso-eutrophic and eutrophic desmids were also recorded. However, they represented a small share in the desmid community (15.94%).

Atici (2018) reported only four desmid species (*Closterium attenuatum*, *Cosmarium formosulum*, *C. impressulum* and *Staurastrum cyclocanthum*) belonging to the Charophyta division in the algal flora of the Artabel Lakes Nature Park. Thanks to the present research, detailed information has been obtained for the first time about the taxonomic structure and ecological properties of the charophyte flora (especially desmids) of the Artabel Lakes Nature Park. It is the richest and most diverse desmid flora among the other high-mountain lakes studied up until now in the eastern Black Sea region (Şahin 1998, 2000, 2002, 2007, 2008, 2009; Şahin & Akar 2007; Akar & Şahin 2014). In addition, the existence of members of the genera *Klebsormidium*, *Spirogyra*, and *Zygnema* in the algal flora of the Artabel Lakes Nature Park is something that is here noted for the first time in high-mountain lakes of the region (Table 1) (Atici 2018). They were recorded in epipelic, epilithic and epiphytic samples from the BL1, BL2, IL Lakes and the YLP Pond with very rare (VR) abundance (Table1). The majority of desmid taxa recorded during this study are cosmopolites with a global distribution. A relatively large number of desmid taxa are holarctic, boreal, boreal-arctic, arctic-alpine, or alpine taxa, the number of such species including *Actinotaenium cucurbita*, *Cosmarium anceps*, *C. cucumis*, *C. galeritum*, *C. sportella*, *Eunotia bidentatum* and *Tetmemorus laevis* (Coesel 1996; Lenzenweger 1996, 1997, 1999; Kosteviciene *et al.* 2003; Sterlyagova 2008). The presence of these desmid taxa in the investigated lakes indicates that their waters are strongly affected by glaciers (Stamenković *et al.* 2008; Fužinato *et al.* 2011a, b). Based on the results of physicochemical analyses, it is concluded that the lakes and pond in the Artabel Lakes Nature Park are mostly circum-neutral and acidic soft-water ecosystems with low mineral content (Şahin & Akar 2019a). The relatively high number of records of desmid from these habitats is therefore not surprising.

Floristic analysis. Comparative floristic methods were used to reveal peculiarities of the desmid flora in the studied lakes. The first step of the analysis was to describe representativeness of the species list of desmids in the Artabel Lakes Nature Park. Constructed for this purpose was the Willis curve (Fig. 7) reflecting the distribution of species number in relation to the number of genera. Earlier, Barinova (2017) found that the species list can represent most species in the flora when the distribution line is similar to the power trend line on the graph. As shown in Fig. 7, it can be concluded that the revealed species list of desmids in the Artabel Lakes Nature Park can be analysed from floristic positions.

Thus, we can consider desmid species diversity in the studied lakes using comparative methods (Novakovsky 2004). Figure 8 shows the dendrogram of comparison as a tree of similarity of desmid algae flora lists in the studied lakes constructed on the basis of the Sorensen-Chekanovsky indices. Four clusters can be seen with a similarity level of 50%. The first (pink) cluster combines three floras, which include 41 species, mostly represented by 27 members of the genus *Cosmarium* and six species of *Staurastrum*. All these taxa are for the most part benthic inhabitants that prefer circum-neutral and low acidic, low saline, mesotrophic

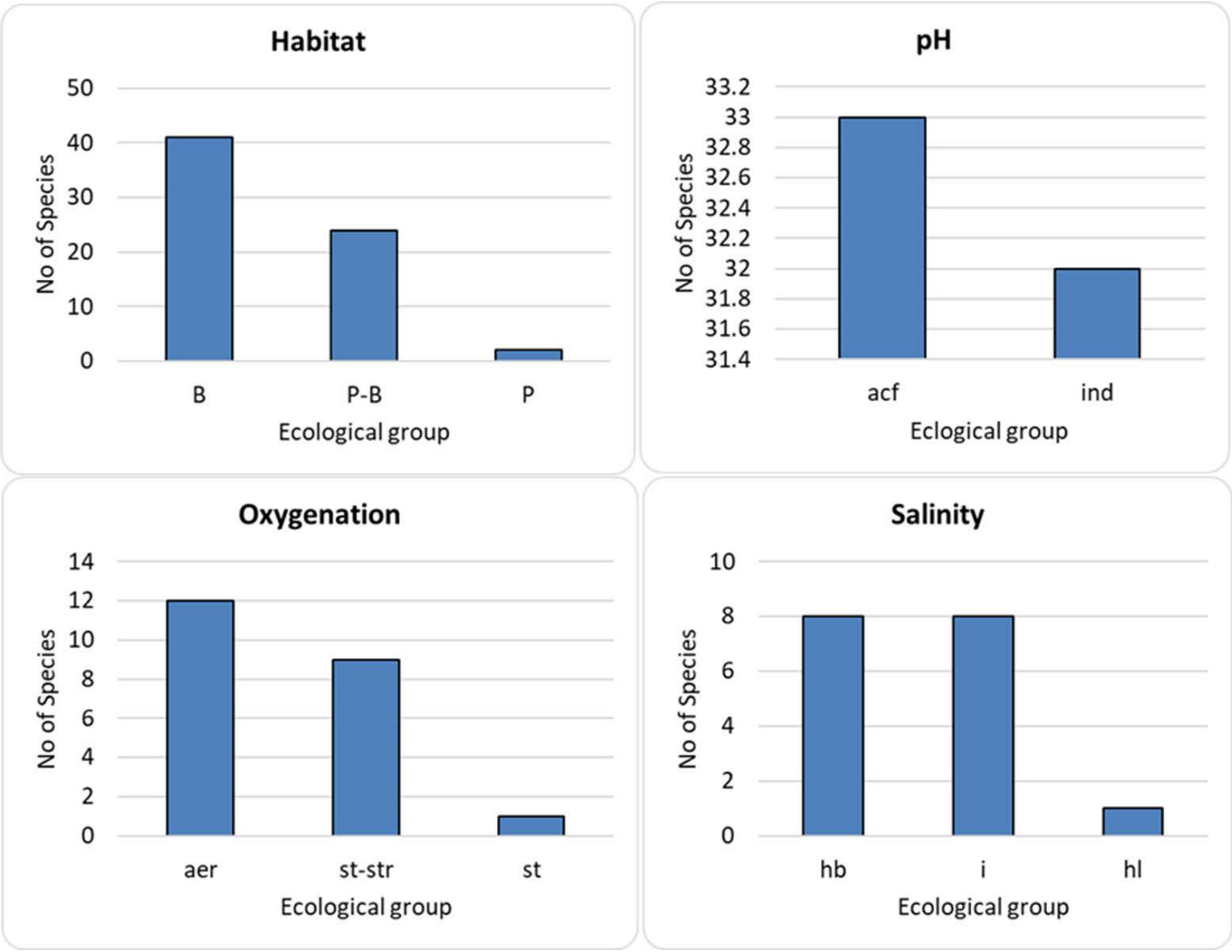

Fig. 11. Distribution of indicator species of desmid algae in ecological groups of habitat preferences, pH, oxygen saturation and water salinity in the Artabel Lakes Nature Park. Abbreviations of ecological groups: Substrate preferences: P – planktonic, P-B – plankton-benthic, B – benthic. Acidity degree (pH): ind – indifferents; acf – acidophiles. Oxygenation and water mobility: st – standing water, st-str – slowly streaming water, aer – aerophiles. Salinity degree: hb – halophobes, i – oligohalobes-indifferent, hl – halophiles.

waters with little organic pollution. The second (blue) cluster included floras of six lakes and encompasses 35 species, mostly from the genus *Cosmarium* (23). Members of this diversity group prefer benthic, plankton-benthic and aerophytic habitats in circum-neutral oligo-mesotrophic waters with little organic pollution. The third (orange) cluster of seven lakes contains the most similar desmid floras with a total of 12 species, of which six were taxa of *Cosmarium* and four of *Staurastrum*. This diversity inhabited clear circum-neutral mesotrophic waters with little organic pollution. The fourth and last (green) cluster included four floras only, 24 species of which are mostly members of the genus *Cosmarium* (12) that prefer circum-neutral mesotrophic waters of low salinity.

We attempted to combine revealed species in the lakes´ floras using the comparative method of species including-overlapping. Figure 9 shows a dendrite of overlapping

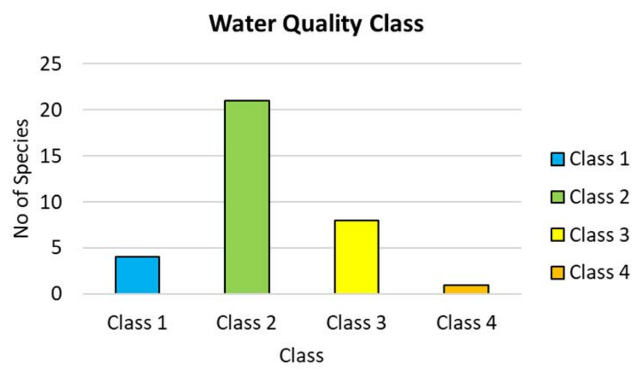

Fig. 12. Distribution of indicator species of desmid algae in ecological groups of water quality classes in the Artabel Lakes Nature Park. Colours of classes are the same as in the EU and USA colour code.

in which the floras of all studied lakes were divided into two different cores. The smaller one included seven floras with only 21 species, most of which overlapped desmids of the ARL6 Lake. The blue-core species are benthic and plankton-benthic inhabitants that prefer circum-neutral and weakly acidic mesotrophic or meso-eutrophic waters with low levels of salinity and organic pollution. The second (pink) core combines 12 floras with 66 species, most of which are members of the genus *Cosmarium* (41), but because this core combines most of the studied lists, it also includes *Staurastrum*, *Closterium* and other genera in the total flora of the Artabel Lakes Nature Park.

Thus, the implemented analysis reveals a high similarity of species content in different combinations of groups (Table 3). We therefore chose an additional type of analysis, one which compares structure of the diversity revealed in each lake with the aid of the JASP statistical program. Figure 10 shows a correlation graph in which blue lines are positive correlations, while red lines are negative correlations. The studied lakes´ names are in the circles. The colour of the circles shows affiliation of the lake to the geographical group represented in Fig. 1. The studied flora of desmids in 16 lakes can be divided into four different groups. Each group in Fig. 10 is separated from the others by red lines of negative correlation. It can be seen that the diversity structure is similar, and species content has a positive correlation in desmid floras of the ACL2, ACL3, and YPL Lakes, 24 species of which inhabit mesotrophic waters.

Bioindication. Ecological preferences of the revealed species of desmids were assessed using an ecological database (Barinova *et al.* 2006, 2019) and summarised in Figs. 11 and 12. It can be seen that desmid species in the Artabel Lakes Nature Park are ones that prefer benthic habitats (Fig. 11). Its mostly acidophilic species prefer well-oxygenated waters of low salinity. Organic pollution in the studied protected lakes is practically absent since the species-indicators are affiliated with class 2 of water quality (Fig. 12), clear natural waters with a high level of self-purification.

CONCLUSION

In conclusion, we can say that waters of the Artabel Lakes Nature Park are among prime examples of natural systems unaffected by any pollution until now. The identified taxa, their ecology and the results of physicochemical analysis of waters support this assertion. Also, desmid species especially will be an important source of data for future monitoring of the park and for assessment of the effects of anthropogenic pollution.

Acknowledgements - This Project was financially supported by Karadeniz Technical University (BAP: FBA-2016-5487). We are grateful to teacher Vehbi YALÇIN for his support in the field.

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REZIME

Botanica SERBICA

Flora harofita i njihova ekologija u visokoplaninskim jezerima parka prirode Artabel jezera (Gümüşhane, Turska)

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Taksonomski sastav flore Charophyta i njihove preferencije ka staništu su proučavane 15. avgusta 2013. i 13. avgusta 2016. godine u parku prirode Artabel jezera. Zabeleženo je 73 taksona koji pripadaju familijama Conjugatophyceae (Zygnematophyceae) i Klebsormidiophyceae. Najčešći su rodovi *Cosmarium* (37), *Staurastrum* (10) i *Closterium* (7). Konstatovano je i delimično neočekivano prisustvo određenih dezmida, odnosno taksona karakterističnih za eutrofne vode. Končaste harofite su prisutne sa tri taksona. Willis kriva distribucije vrsta u okviru rodova ima trend liniju $R^2 = 0.9123$. Bioindikacija, statističke metode i komparativni floristički rezultati pokazuju da je voda u svim istraživanim jezerima sveža, sa slabom provodljivošću, cirkumneutralna i slabo zagađena organskim polutantima. Četiri grupe jezera su identifikovane kao rezultat komparacije sredinskih i bioloških varijabli. Rezultati bioindikacije se mogu koristiti kao referenca za budući monitoring jezera u zaštiti vrsta konstatovanih u parku prirode Artabel jezera i mogu biti uključeni u Standardni sistem kvaliteta voda Turske.

Ključne reči: Park prirode Artabel jezera, visokoplaninska jezera, Charophyta, Turska