



# Non-diatom algae of the high mountain protected lakes in the Artabel Lakes Nature Park, Gümüşhane, Turkey

Bülent Şahin<sup>1</sup>, Bülent Akar<sup>2</sup>, Sophia Barinova<sup>3\*</sup>

Bülent Şahin<sup>1</sup>  
e-mail: bsahin@trabzon.edu.tr

Bülent Akar<sup>2</sup>  
e-mail: akarblnt@gmail.com

Sophia Barinova<sup>3\*</sup>  
e-mail: sophia@evo.haifa.ac.il

<sup>1</sup>Department of Biology Education,  
Fatih Education Faculty, Trabzon  
University, Söğütü-Trabzon, Turkey

<sup>2</sup>Department of Food Engineering,  
Faculty of Engineering and  
Natural Sciences, Gümüşhane University,  
Gümüşhane, Turkey

<sup>3</sup>Institute of Evolution,  
University of Haifa, Haifa, Israel

\* corresponding author

Manuscript received: 23.12.2019  
Review completed: 08.06.2020  
Accepted for publication: 15.06.2020  
Published online: 18.06.2020

## Electronic Appendix:

[http://www.geobotanica.ru/bp/2020\\_09\\_02/BP\\_2020\\_9\\_2\\_sahin\\_app\\_A1.pdf](http://www.geobotanica.ru/bp/2020_09_02/BP_2020_9_2_sahin_app_A1.pdf)

## ABSTRACT

For the first time, we studied 18 lakes of the Artabel Lakes Nature Park and revealed 154 species of non-diatoms algae from four taxonomic Divisions. Charophyta (73 taxa) prevails in the flora and mainly represented by the genus *Cosmarium* (37). Cyanobacteria (42), Chlorophyta (30) and Eunlenozoa (9) are also present. New records for the Turkish algae flora are represented by 31 taxa, most of which belong to *Cosmarium* (15) and *Staurastrum* (5). Rare species from benthic cyanobacteria were revealed in communities of the Artabel Lake. Statistical methods revealed a high individuality of the algae communities and divided it into two major group: Acambol-Yıldız, and Beş-Artabel, which belong to different River Basins. The altitude of the lakes appears to be the major environmental variable that controls the non-diatom algal diversity. Bioindication characterized the water of studied lakes as temperate by temperature, middle saturated with oxygen, neutral to low acidic pH, low saline, Class 2–3 of Water Quality and mesotrophic.

**Keywords:** non-diatom algae, bioindication, high mountain lakes, Artabel Lakes Nature Park, Turkey

## РЕЗЮМЕ

Сахин, Б., Акар, Б., Баринова, С. Недиадомовые водоросли высокогорных охраняемых озер Природного Парка Артабель Лэйкс, Гюмюшхане, Турция. Впервые исследовано 18 озер природного парка Артабельских озер. Было идентифицировано 154 вида недиадомовых водорослей из четырех таксономических отделов. Представители отдела Charophyta (73 таксона) преобладают в основном за счет видов рода *Cosmarium* (37). Также представлены отделы Cyanobacteria (42), Chlorophyta (30) и Eunlenozoa (9). Новые находки для флоры водорослей Турции представлены 31 таксоном, большинство из которых принадлежит родам *Cosmarium* (15) и *Staurastrum* (5). Редкие виды цианобактерий найдены в сообществах озера Артабель. Статистические методы выявили высокую индивидуальность сообществ водорослей и разделили их на две основные группы: Акамболь – Йылдыз и Беш-Артабель, относящиеся к разным речным бассейнам. Высота озер является основной переменной среды, которая регулирует разнообразие недиадомовых водорослей. Биондикация позволила характеризовать воду исследуемых озер как умеренную по температуре, умеренно насыщенную кислородом, от нейтрального до низкого кислотного pH, с низким содержанием солей, 2–3 класса качества и мезотрофную.

**Ключевые слова:** недиадомовые водоросли, биондикация, высокогорные озера, Природный Парк Артабель Лэйкс, Турция

High mountain lakes are ecosystems with extreme living conditions. The first is the low pH, followed by the lack of nutrients, and low temperature. Moreover, intensive UV radiation or darkness for months makes high mountain lakes extraordinary habitats. Such extreme conditions are the reason why many species of algae live only in high mountain lakes (Psenner 2003). Therefore, it is very important to know about algal diversity in the high mountain lakes because they can be used as environmental indicators (Barinova & Krupa 2017). One of the parameters of the aquatic ecosystem used in the ecological evaluation of water quality is also algae (Stevenson 2014, Bellinger & Sigeo 2010). Therefore, many algal species are used as environmental indicators. Diatoms, especially, are ones of the important alive groups of benthic communities, and that is why they are usually an indispensable element of the water

quality determination studies (Ács et al. 2004). According to the literature (Coesel 1984, Borics et al. 1998, Feher 2003), several species of desmids are also closely related to certain types of aquatic habitats and may be used as indicators of changes in pH or nutrient supply. In addition, Coesel (1998) expresses that desmids are excellent bio-indicators for the stability of ecosystems.

Bio-indication approaches for waters monitoring are used in many countries during the recent years (Barinova et al. 2006, 2013, Barinova & Fahima 2017, Jienbekov et al. 2018, Barinova & Niyatbekov 2018, 2019). Barinova (2011) noted that this method gives efficient results in ecological assessment of water quality. In the bio-indication studies performed in Turkey, diatom communities were generally used (Solak et al. 2012, Sivacı et al. 2013). In this study, for the ecological evaluation of the water ecosystems in the

Artabel Lakes Nature Park we used non-diatom algae communities first time in Turkey.

The main characteristics of the Eastern Black Sea region are the high mountains and temperate climate. Also, the region has an extensive water network with many rivers, lakes, and ponds. Moreover, these habitats are far from industrial and human influences. These conditions contribute to the formation of rich algal diversity in the region. In these waters, for many centuries, a special community of algae (especially desmids) adapted to extreme environmental conditions has formed and developed (Şahin 1998, 2000, 2001, 2002, 2003, 2004, 2008, Şahin & Akar 2005, Akar & Şahin 2006, Kolaylı & Şahin 2009, Şahin et al. 2010). However, there are still many high mountain lakes in the Eastern Black Sea Region, which are unknown for algal diversity. Artabel Lakes Nature Park is one of the most important natural parks in the region. It includes 23 high mountain lakes. Atıcı (2018) published the first written record concerning algae of these lakes.

This study focuses on the assessment of the taxonomic diversity of non-diatom algae and the current ecological state of high-altitude lakes in the Artabel Lakes Nature Park using statistical, comparative floristic, and bioindication methods, to identify environmental variables that control the development of algal communities in alpine protected areas.

### Study site description

The Ministry of Forestry of the Republic of Turkey declared Artabel Lakes as Nature Park in 1998. The park is located between latitudes 40°21'36" and 40°26'42"N and longitudes 39°00'24" and 39°08'23"E within the boundary of Gümüşhane province in the north of Turkey. The park territory with an area 5859 ha had formed as the result of volcanic activities at different geologic epochs. There are four types of soil: bare rocks, debris, high mountain meadow, and non-calcareous brown soil, in the park. The climate of the region is semi-arid and moist. In terms of average temperature values of the area, while it is -3°C at 3000 m above sea level (a.s.l.), the mean temperature at the lower parts of the park at 2100 m a.s.l. is 4°C higher (Doğa Koruma ve Milli Parklar Genel Müdürlüğü 2013).

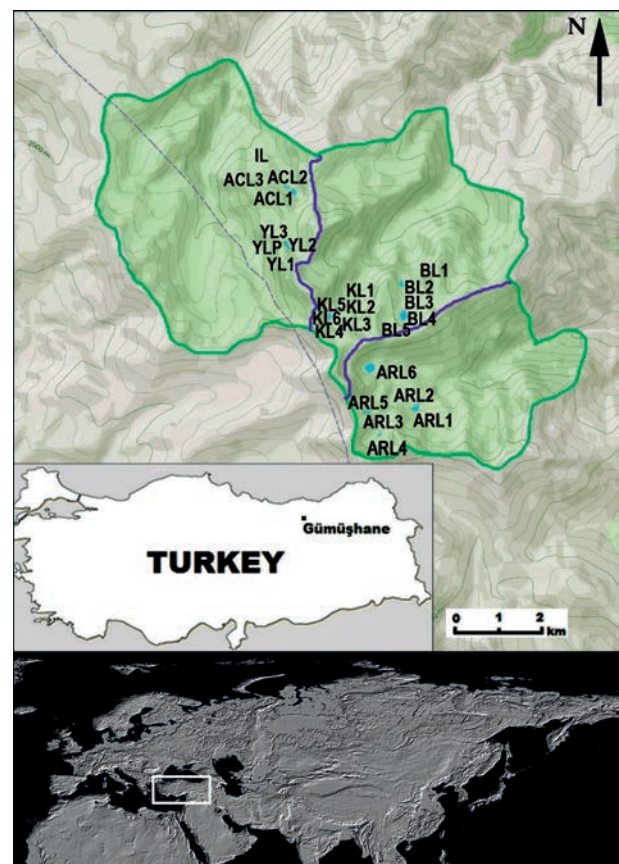
Artabel Lakes Nature Park includes terrestrial and aquatic ecosystems with rich biodiversity, so it has an important place in protected areas in Turkey. In the area, there are endemic taxa listed in the International Nature Conservation Union (IUCN) and the Berne Convention Annex I, II and III (Doğa Koruma ve Milli Parklar Genel Müdürlüğü 2013).

The area includes three river basins. These are Gümüştuğ River basin (Kara and Beş Lakes), Artabel River basin (Artabel Lakes), and Kongel River basin (Yıldız and Acembol Lakes). The total basin area is approximately 58.2 km<sup>2</sup>, and it composed of five different lake sites including Artabel Lakes (ARL), Acembol Lakes (ACL), Beş Lakes (BL), Kara Lakes (KL) and Yıldız Lakes (YL). There are 23 lakes, which belong to Artabel Lakes (6), Acembol Lakes (3), Beş Lakes (5), Kara Lakes (6), and Yıldız Lakes (3). Some of the different size lakes have been linked to each other or are independent (Doğa Koruma ve Milli Parklar Genel Müdürlüğü 2013). There is also a previously unnamed lake (İsimsiz Lake: IL) and a small pond (Yıldız Lakes Pond (YLP)) (Fig. 1).

## MATERIAL AND METHODS

### Sampling

Within the scope of this research, the lakes in the Artabel Lakes Nature Park were visited two times. The first visit took place on 15 August 2013. Algae and water samples were taken from Artabel (ARL) and Beş (BL) Lakes. The second visit was made on 13 August 2016 and samples were taken from Acembol (ACL) and Yıldız (YL) Lakes, İsimsiz Lake (IL) and Yıldız Lakes Pond (YLP). Kara Lakes could not be visited, because the 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 epipellic, epilithic and epiphytic algae samples were taken from 17 lakes and a pond. Epipellic samples were collected employing a glass tube from a sediment surface at all the water bodies except Lake BL2 (Round, 1953; Sládečková 1962). Epilithic samples were taken from 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 (1913:287)) and filamentous alga (*Microspora* Thuret 1850) were taken from ARL1, ARL3, YL1, YL2, YL3, ACL2, ACL3, IL lakes, and YLP Pond. Filamentous green algae such as *Microspora*, *Oedogonium*, and *Ulothrix* were taken by hand. All samples were fixed in a solution of 4 % neutral formaldehyde. In the field, water temperature, pH, dissolved oxygen, total dissolved solids (TDS), and electrical



**Figure 1** Map of Artabel Lakes Nature Park (Doğa Koruma ve Milli Parklar Genel Müdürlüğü 2013) with three streams basins defined by purple line and places of studied lakes

conductivity were measured using an Orion4Star and YSI 55 portable measuring instruments at each sampling station. Samples were transported to the laboratory in the icebox.

### Laboratory processing

In the laboratory, samples were examined in temporary slides and under a Leica DM 2500 model light microscope. Algae were photographed with camera Leica DFC 290 attached to the microscope. All of the taxa were identified according to West & West (1904, 1905, 1908, 1912, 1923), Prescott (1962), Ruzicka (1977), Lind & Brook (1980), Huber-Pestalozzi (1982), Dillard (1990, 1991, 1993), Bourrelly & Coute (1991), Gábor (1995), Lenzenweger (1996, 1997, 1999), John et al. (2003), Komárek & Anagnostidis (1998, 2005), Wotowski & Hindak (2005), Hindak (2008), Kadlubowska (2009), Brook & Williamson (2010), Stastny (2010), Coesel & Meesters (2007, 2013), Park (2012), Komárek (2013), Kim (2013, 2015), Lee (2015), Vitonyté & Kasperovičienė (2015). The current status of nomenclature of all the taxa has been checked in the Algaebase web site (Guiry & Guiry 2019).

Calculation of similarity was done in the GRAPHS program (Novakovsky 2004) and biological and environmental data relationships analysis were done in the Statistica 12.0 and CANOCO (Ter Braak & Šmilauer 2002) programs. Bioindication analysis was done with the help of ecological preferences of revealed desmid algae species (Barinova et al. 2006, 2019).

Frequencies of algal taxa were determined according to the following scale based on the number of lakes studied in Artabel Lakes Nature Park. Very rare (1): taxa recorded in 1–20 % of investigated lakes; rare (2): in 21–40 %; common (3): in 41–60 %; frequent (4): in 61–80 %; and very frequent (5): in 81–100 % of 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 (Table 1), waters temperatures ranged from 10.1 to 19.1°C. The values of the pH varied from 6.19 to 7.52. According to the values, the waters of the Artabel Lakes Nature Park are acidic and circumneutral. 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 characterized as low (12.0–49.9 µSm·cm<sup>-1</sup>).

When Table 1 (Şahin et al. 2019b) examined, it is seen that there are linear, negative, strong relationships between altitude and water temperature (I) ( $r = -0.701$ ,  $p < 0.01$ ). This means that as the altitude of the lakes increases, the temperature decreases. There are also linear, negative, moderate relationships between total dissolved solids (TDS) and dissolved oxygen (DO) ( $r = -0.574$ ,  $p < 0.01$ ). This finding suggests that as the amount of total dissolved solids increases, the amount of

dissolved oxygen decreases. Also, it is seen that there are linear, positive, strong relationships 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.

### Algal flora

The examination of all samples of epipellic, epilithic and epiphytic from Artabel Lakes Nature Park showed the presence of 154 non-diatom taxa. The systematical structure analyses of algal flora in Artabel Lakes Nature Park revealed Charophyta (73 taxa) as the richest order. The following divisions were Cyanobacteria (42 taxa), Chlorophyta (30 taxa), and Euglenozoa (9 taxa) (Table A1). As a result of the comparison of the benthic communities of the studied lakes were observed differences both in taxon compositions of each lake and relative abundances. Floristically, Charophyta had more diversity than other divisions in each studied water bodies. Qualitatively, the genus *Cosmarium* was dominant (37 taxa) and *Staurastrum* (10 taxa) subdominant. While the genera *Closterium* and *Trachelomonas* were represented by 7 taxa, the genera *Desmodesmus* and *Oscillatoria* were represented by 6 taxa. Whereas, the genera *Chroococcus* and *Merismopedia* were represented by 5 taxa each. The other genera were represented by four or less taxa (Table A1).

Despite the fact that the algae in the Artabel Lakes Nature Park were studied for the first time and therefore are new to this protected area, we revealed 32 new taxa (Table A1, asterisk) for the Turkish algae flora (Taşkın 2019). A large number of new records are 26 Charophyta taxa (Şahin 2019), most of which belong to the genera *Cosmarium* (15) and *Staurastrum* (5) (Şahin & Akar 2019a). Three Chlorophyta newly revealed species belong to Chlorococcales and Chlamydomonadales and are commonly distributed taxa, which has been revealed only with a detailed study of collected samples (Şahin & Akar 2019b). No new taxa from euglenoids whereas three cyanobacteria contain rare species *Scytonema coactile* and *Katagnymene accurate* (Şahin & Akar 2019b).

**Table 1.** Averaged environmental variables in studied lakes of the Artabel Lakes Nature Park, Turkey in August 2013. The groups of the lakes are toned by a different color. “-”, variables were not measured in highest lake

Lake	Altitude, m a.s.l.	Temperature, °C	DO, mg/L	pH	TDS, mg/L	Conductivity, µSm/cm <sup>-1</sup>
ARL1	2687	17.5	8.71	6.19	16	32.6
ARL2	2763	16.7	8.42	6.4	22	45.5
ARL3	2875	16.3	8.76	6.19	24	49.9
ARL4	2890	15.7	9.45	6.73	10	21.5
ARL5	2930	12.4	8.95	7.02	13	26.2
ARL6	2863	15.9	8.97	6.98	10	21.3
BL1	2831	13.9	9.14	7.06	10	21.4
BL2	2863	12.5	9.32	6.75	18	36.3
BL3	2915	10.1	9.2	7.01	16	33.1
BL4	2924	15.5	8.3	7.04	6	13.2
BL5	3015	-	-	-	-	-
ACL1	2713	15.5	3.25	7.04	24.1	30.6
ACL2	2712	15.3	2.1	7.09	30.6	38.5
ACL3	2711	17.9	2.94	7.52	20.8	27.7
YL1	2980	14.6	2.27	6.85	16.3	19.7
YL2	2980	11.5	2.88	6.89	26.7	30.7
YL3	2980	14.1	3.12	7.01	24.1	29.5
YLP	2980	14.5	2.34	7.2	23.4	29.2
IL	2668	19.1	4.25	6.78	9.1	12.0



**Table 2.** Distribution of species richness in taxonomic Divisions and average number of indicator taxa over studied lakes of the Artabel Lakes Nature Park, Turkey in August 2013, 2016. Note: Abbreviation of the lakes name: ARL: Artabel Lakes, BL: Beş Lakes, YL: Yıldız Lakes, ACL: Acembol Lakes, IL: İsimiz Lake, YLP: Yıldız Lakes Pond. Abbreviation of the ecological groups of indicators (Barinova et al. 2006): Habitat preferences (Hab): P – planktonic, P-B – planktonic-benthic, B – benthic, wide range, need some substrate; Ep – epiphytes. Water temperature preferences (T): warm – warm-water inhabitants; temp – temperate water temperature inhabitants or indifferent; eterm – eurythermic. Oxygenation indicators (Oxy): st – standing water, st-str – low streaming water, aer – aerophiles. Salinity (Sal): hb – oligohalobes-halophobes, i – oligohalobes-indifferents, mh – mesohalobes, hl – halophiles. Acidity (pH) degree indicators (pH): alf – alkaliphiles, ind – indifferents; acf – acidophiles. Trophic state indicators (Tro): o – oligotraphentic; o-m – oligo-mesotraphentic; m – mesotraphentic; me – meso-eutraphentic; e – eutraphentic. SI: species-specific index saprobity SI.

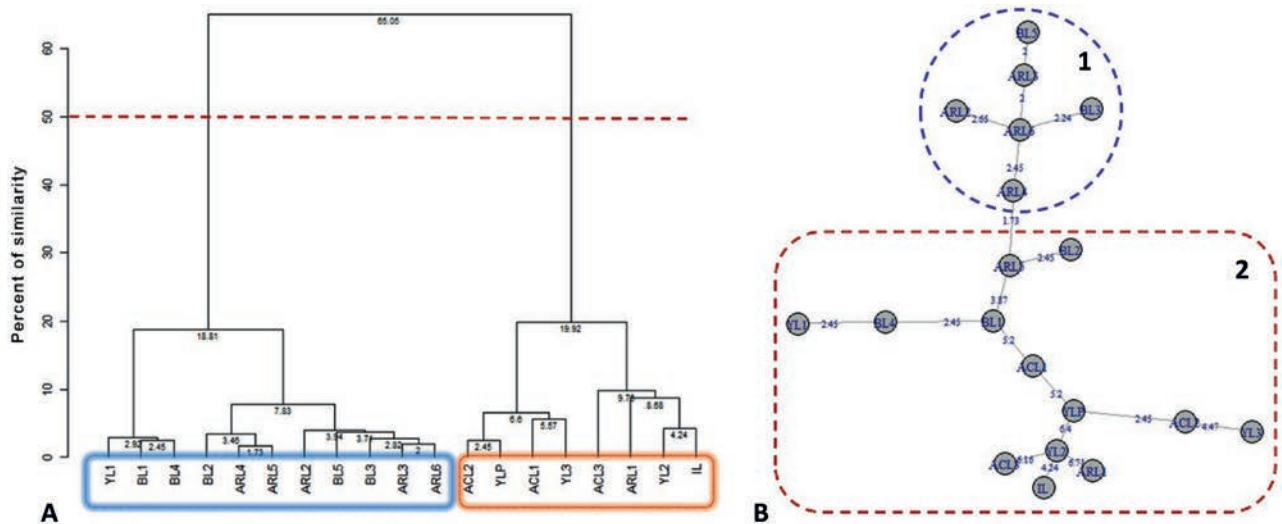
Indicator	Lake																		
	ARL1	ARL2	ARL3	ARL4	ARL5	ARL6	BL1	BL2	BL3	BL4	BL5	ACL1	ACL2	ACL3	YL1	YL2	YL3	YLP	IL
<b>Taxa</b>																			
Charophyta	20	0	2	4	5	2	8	5	1	9	1	8	8	15	9	15	9	9	15
Chlorophyta	2	0	1	0	0	1	2	2	1	1	0	7	9	11	0	6	12	7	5
Cyanobacteria	5	4	1	3	2	3	3	1	3	3	0	4	9	4	5	7	6	9	11
Euglenozoa (Euglenophyta)	2	0	1	2	1	1	2	0	3	0	0	1	1	0	1	2	0	2	1
<b>Species richness</b>	29	4	5	9	8	7	15	8	8	13	1	20	27	30	15	30	27	27	32
<b>Abundance sum of scores</b>	55	35	29	21	16	1	10	22	21	11	14	60	40	57	60	64	31	49	55
<b>Index Saprobity SI</b>	1.58	1.75	1.63	1.84	1.98	1.60	1.40	2.01	1.96	1.44	1.85	1.88	1.56	1.38	1.63	1.59	1.81	1.74	1.94
<b>Habitat</b>																			
B	17	2	2	4	5	1	5	4	1	6	1	6	11	10	7	13	8	9	13
P-B	8	1	2	2	3	4	6	3	5	6	0	12	10	14	7	11	8	10	11
P	1	0	0	0	0	0	0	0	0	0	0	1	3	3	1	2	2	2	4
Ep	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1
<b>Temperature</b>																			
eterm	1	0	1	0	1	0	1	0	2	0	0	1	0	0	1	1	0	1	1
warm	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
temp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<b>Oxygen</b>																			
acr	2	1	1	0	1	0	0	0	1	1	0	2	3	2	1	8	7	3	1
st	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
st-str	3	0	1	3	4	2	4	3	5	4	0	8	10	8	5	6	5	7	10
<b>pH</b>																			
acf	10	0	2	0	2	0	2	0	0	4	0	2	1	5	2	8	4	4	2
alf	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
ind	11	0	1	3	4	3	8	4	3	6	0	10	8	11	8	10	6	7	15
<b>Salinity</b>																			
hb	3	0	0	0	0	0	2	1	0	2	0	2	2	3	1	2	0	0	1
hl	1	0	0	1	1	1	1	0	1	2	0	1	3	3	1	1	2	1	1
i	5	0	1	1	4	2	5	2	3	0	0	8	3	8	5	7	5	8	9
mh	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<b>Water Quality</b>																			
Class 1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2	1	0	1
Class 2	5	2	2	2	3	2	4	0	2	5	0	7	8	6	4	8	4	5	8
Class 3	4	1	2	3	2	4	5	2	2	2	1	9	6	6	4	8	7	8	9
Class 4	2	0	0	2	1	1	1	0	2	2	0	1	4	2	2	0	0	2	2
<b>Trophic state</b>																			
o	2	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	4
o-m	4	0	0	1	1	2	2	0	1	2	0	2	2	0	3	5	4	2	4
m	12	0	1	3	2	1	5	2	0	5	1	4	4	9	5	10	3	5	6
me	2	0	0	1	2	1	1	2	2	3	0	2	4	6	4	1	0	2	6
e	2	0	0	1	1	1	1	0	0	1	0	2	1	2	1	0	2	2	1

## Comparative floristics

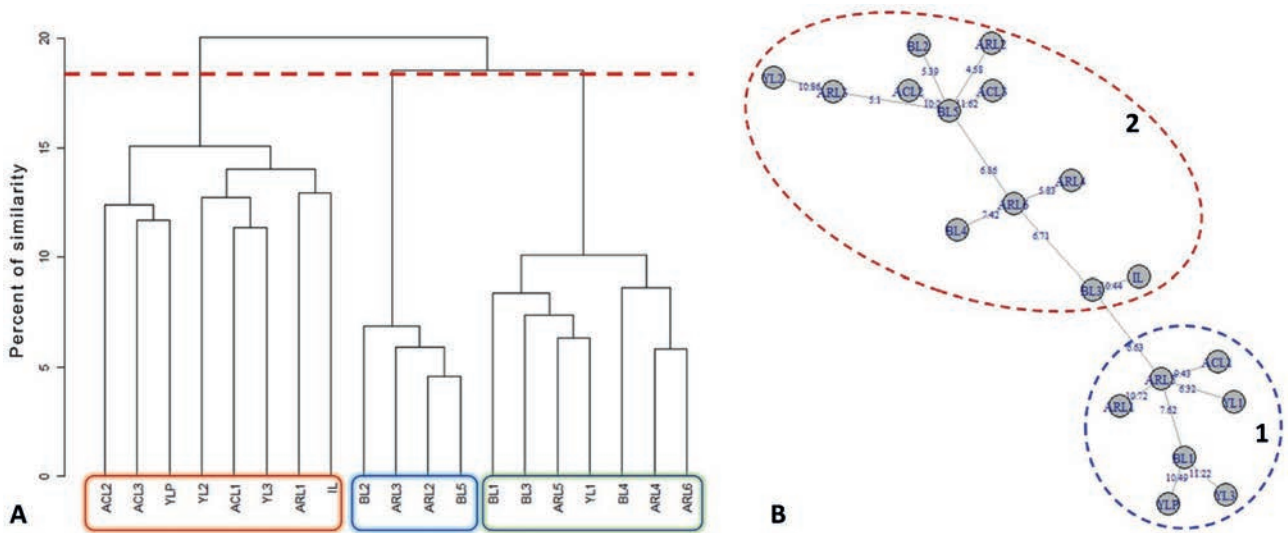
Comparative floristic methods were used for the construction of graphs for the purpose of revealing which community of studied lakes in the Artabel Lakes Nature Park are most similar. Our calculations were done on the base of algae and cyanobacteria species distribution in studied lakes (Table A1). In the first step, we take into account the species saturation in taxonomic Divisions that can give us total preferences of non-diatoms in the lakes' environment. Figure 2 shows the tree of similarity (a) and the overlapping of the species content in the lakes (b). It can be seen that on the level of less than 50 % similarity, the

community is strongly divided into two clusters. The first cluster (blue) included most of Artabel lakes group as well as Beş lakes and Yıldız lake 1 communities. Second, cluster (orange) combined taxa on the Divisional level in lakes Acembol group, most of Yıldız group, and İsimiz Lake. The dendrite (Fig. 2b) helps to divide studied lakes communities also into two clusters first of which included Artabel and Beş lakes and second all other.

Species-level similarity calculation (Fig. 3) show three clusters in the comparative tree. First (orange) combine communities of Acambol, Yıldız groups, and İsimiz Lake (Fig. 3a). Second (blue) represent of Beş and Artabel



**Figure 2** Comparative floristic based on Species richness in taxonomic Divisions of communities in the lakes of the Artabel Lakes Nature Park in August 2013, 2016: Tree of similarity (a); An inclusion-crossing dendrite (b)

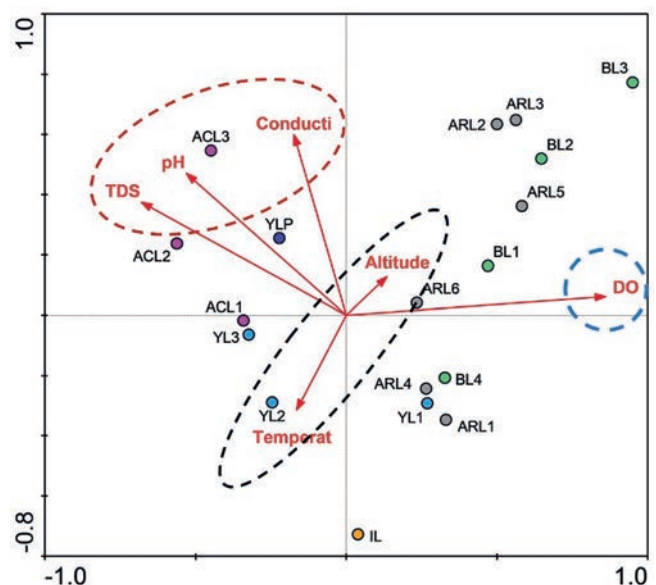


**Figure 3** Comparative floristic based on total Species richness in communities of the lakes in the Artabel Lakes Nature Park in August 2013, 2016: Tree of similarity (a); An inclusion-crossing dendrite (b)

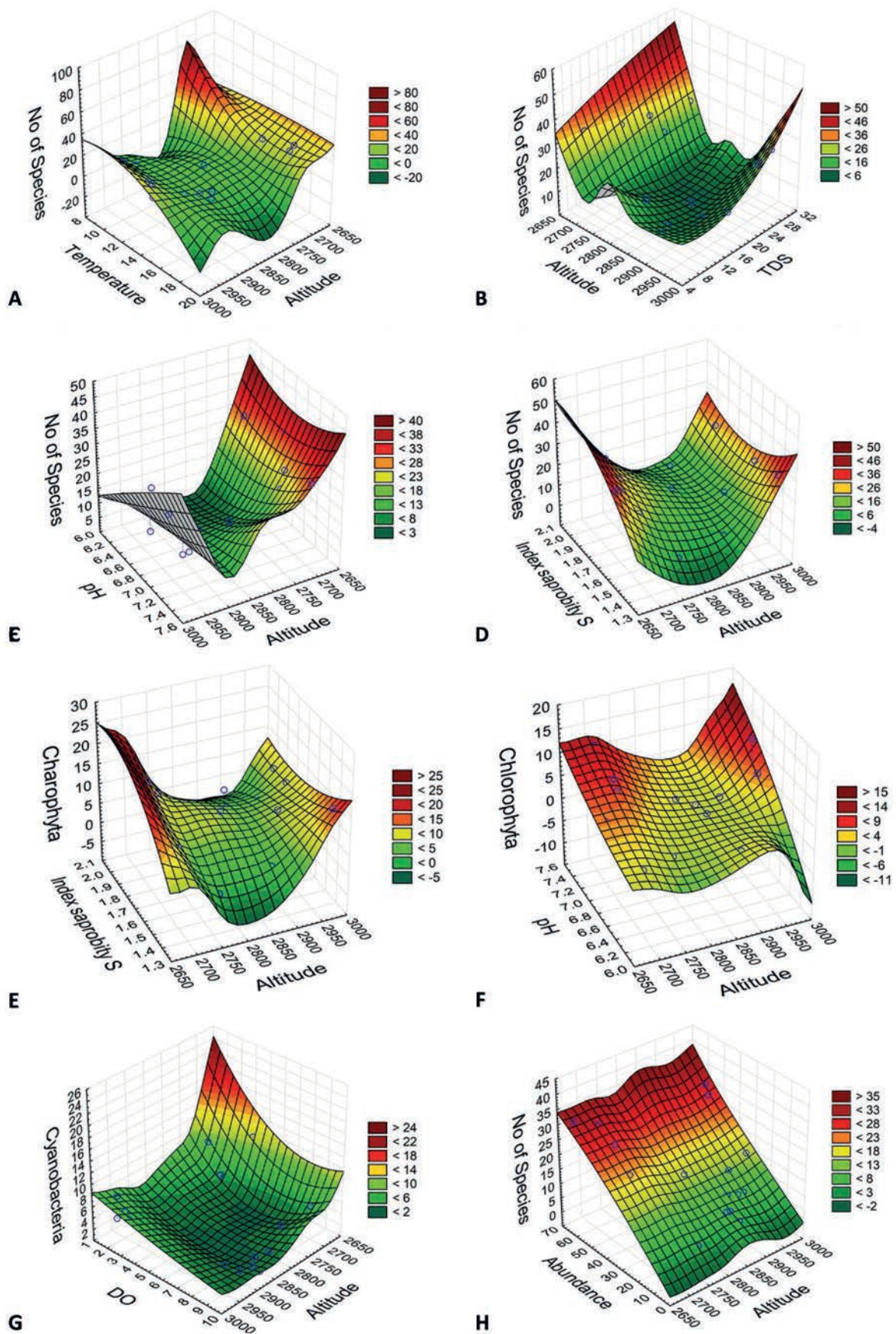
groups, and third (green) unified communities of different groups of lakes. However, the dendrogram (Fig. 3b) divided communities of studied lakes on two cores also as in the Division level (Fig. 2b). The first core included most of the lakes of Artabel group, as well as parts from Acembol, Beş, and Yıldız groups. All others are staying in core 2.

**Statistics**

So different combined list of lakes in Divisional and species comparison can be specified with calculation of the relationships between taxa and environmental variables in studied lakes. Therefore, CCA plot (Fig. 4) constructed on the data in Tables 1 and A1 represent the result of calculation for species richness in communities and environmental variables of the lakes of the Artabel Lakes Nature Park. All environmental variables are divided into three different groups. Red-dashed round combined pH, Conductivity and TDS, basic variables of the studied lakes. Second group (blue-dashed round) included only oxygen saturation, which depends



**Figure 4** Canonical Correspondence Analysis (CCA) plot for species richness in communities and environmental variables of the lakes of the Artabel Lakes Nature Park in August 2013, 2016. The lakes' markers are colored in relation to the lake groups. Groups of variables are outlined by different colors



**Figure 5** 3D surface plots based on chemical variables and total Species richness in communities of the lakes of the Artabel Lakes Nature Park in August 2013, 2016: Species richness over altitude of the lake and water temperature (A); Species richness over altitude of the lake and water TDS (B); Species richness over altitude of the lake and water pH (C); Species richness over altitude of the lake and index saprobity SI (D); Charophyta species richness over the lake altitude and Index saprobity SI (E); Chlorophyta species richness over the lake altitude and water pH (F); Cyanobacteria species richness over the lake altitude and Dissolved oxygen (G); Total species richness over the lake altitude and algal species abundance in the lake community (H)

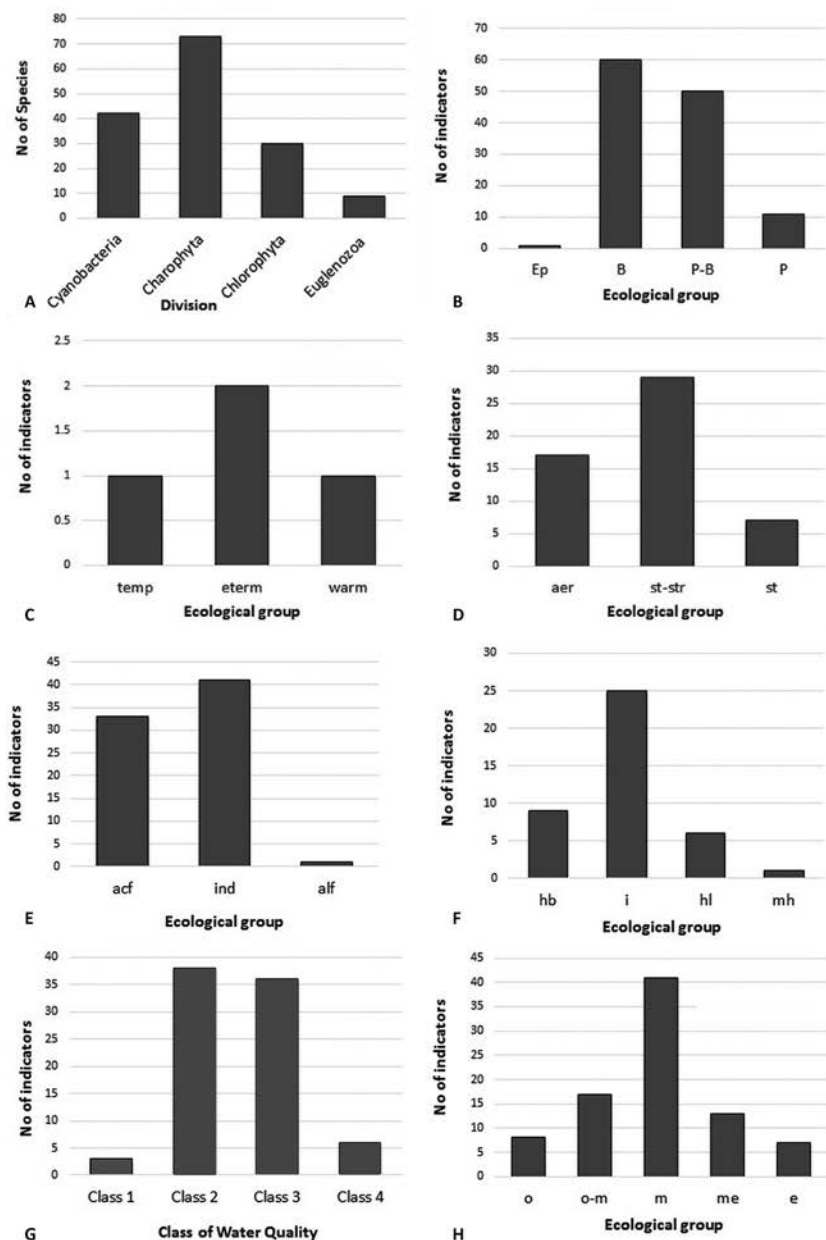


on altitude and water temperature. Two last mentioned variables (black-dashed round) represent two mutually negatively related variables as altitude of the lake and water temperature, which decreased with altitude. In this, the first group of variables is most favorable for non-diatom communities of Acembol lakes. The oxygen saturation stays in opposite with the first group of variables and is positive for mostly Artabel and Beş groups of lakes, and Yıldız Lake 1. Altitude has positive effect for communities of most of Artabel and Bes groups of lakes but negative for Yıldız Lake 2 for community of which the water temperature is important.

We tried to reveal special variables for the distribution of non-diatom communities in the Artabel Lakes Nature Park with the help of the 3D surface plots of the relationship construction. Figure 5 shows the water temperature and TDS have stimulated species richness of non-diatom algae in the studied lakes (Fig. 5A, B), whereas communities were species-rich in low water pH with high index saprobity SI (Fig. 5C, D). In any case, the distributions demonstrate two types of communities related to the altitude of the lakes. A similar distribution demonstrates the Charophyte algae (Fig. 5E) with the two-type community that species-rich in high altitude and organic enrichments. Chlorophyta species occur in high altitude lakes with high pH (Fig. 5F), and Cyanobacteria, on the contrary, lowermost altitude with lowest oxygen enrichments (Fig. 5G). So, the method of 3D surface construction, which we implemented earlier (Krupa et al. 2018) helps us to define that algae abundance is highest in species rich-communities and we don't reveal other factors even altitude from which abundance dependent (Fig. 5H). Therefore, this type of analysis reveals the altitude of the lakes as one of the major environmental variables which regulate the non-diatom algal community forming processes like in other high-mountain lakes in Pamir (Barinova & Niyatbekov 2018, 2019) and Hindu Cush (Barinova et al. 2013).

### Bioindication

Bioindication gives a total glance on the revealed species list in the protected area and can help to characterize the environment in which non-diatom species survived. So, Fig. 6 represents an indication of water properties of studied lakes in the Artabel Lakes Nature Park during the sampling period with the help of species-specific ecological preferences (Table 2) of revealed algae (Barinova & Fahima 2017). In



**Figure 6** Distribution of total species richness over taxonomic Divisions (A) and bioindication plots for the lakes of the Artabel Lakes Nature Park in August 2013, 2016: Habitat preferences (B); Temperature (C); Oxygen saturation (D); Water pH (E); Water salinity (F); Class of Water Quality based on the saprobity indices SI (G); Trophic state (H). Abbreviation of ecological groups as in Table 2

Figure 6A can be seen as a predominance of Chlorophyta species accompanied by Cyanobacteria species richness. Algae in Artabel Park grows with benthic and planktonic-benthic lifestyle (Fig. 6B), in medium temperature (Fig. 6C), medium saturated with oxygen waters (Fig. 6D), neutral to low acidic pH (Fig. 6E), low saline (Fig. 6F) waters Class of Water Quality 2–3 (Fig. 6G). Indicators show that the studied lakes can be mesotrophic because this group of indicators strongly prevails from five groups of the trophic state (Fig. 6H). It is contrary to studied aquatic ecosystem properties in the semi-arid regions like Israel (Barinova 2011) or Kazakhstan (Jienbekov et al. 2018, 2019), where water more alkaline and saline and therefore cannot give the charophyte

algae to survive excluding macroalgae of *Chara* and *Nitella* genera. In Artabel Park lakes prevail charophyte microalgae which prefer low saline neutral and low acidic waters with low organic pollution, therefore it can be a reference group for future monitoring of this protected area.

## CONCLUSION

We studied non-diatom algae diversity in the lakes of the Artabel Lakes Nature Park for the first time. One of the important things for new natural reserve studies is the revealing of the species diversity. As a result of our first step study based on material obtained in 2013 and 2016, we revealed 154 algal species belonging to four taxonomic divisions. Charophyta algae prevail with 73 taxa mostly of the genus *Cosmarium* (37), then Cyanobacteria (42 taxa), Chlorophyta (30 taxa), and Euglenozoa (9 taxa). Altogether 31 taxa represent the new records for the Turkish algae flora, from which Charophyta with 25 taxa enriched mostly with genera *Cosmarium* (15) and *Staurastrum* (5). Rare species from benthic cyanobacteria were revealed in communities of the Artabel Lake 2 (ARL2).

The analysis of the distribution of algal species and their ecological preferences based on Divisional diversity and bioindication results was done for the first time for these protected lakes and show high individuality of communities. Statistical methods divided algae lists of studied lakes into two major parts: Acambol and Yıldız group, and Beş and Artabel group which belong to different streams basins.

Environmental variables such as pH, Conductivity, and TDS are basic variables for the studied lakes and have stimulated species richness in the group of non-diatom communities of the lowermost Acembol lakes (about 2700 m a.s.l.). The oxygen saturation was important for Artabel and Beş groups of lakes (about 2800 m a.s.l.), whereas water temperature that is negatively related with altitude was important of the lake for Yıldız's highest group of lakes communities (about 2900 m a.s.l.). Statistical analysis confirms that the altitude of the lakes is a major environmental variable that regulates the non-diatom algal community forming process in the Artabel Park.

Bioindication based on species-specific ecological preferences of revealed algae can characterize the water of studied lakes like temperate temperature, middle saturated with oxygen, neutral to low acidic pH, low saline, Class of Water Quality 2-3, and mesotrophic.

Therefore, this assessment of the Artabel Lakes Nature Park protected lakes can serve as a reference for future investigations, which will receive new data about algal communities and environmental variables of this protected area.

## ACKNOWLEDGEMENTS

This Project was financially supported by Karadeniz Technical University (BAP: FBA-2016-5487). We are grateful to teacher Vehbi Yalçın for his support in the field. This work has been partly supported by the Israeli Ministry of Aliyah and Integration.

## LITERATURE CITED

Ács, É., K. Szabo, B. Tóth & K.T. Kiss 2004. Investigation of benthic algal communities, especially diatoms of some

Hungarian streams in connection with reference conditions of the Water Framework Directives. *Acta Botanica Hungarica* 46: 255–277.

Akar, B. & B. Şahin 2006. Benthic algal flora of Karanlık Lake and diversity of epipelagic algae. *Fresenius Environmental Bulletin* 15: 48–54.

Atıcı, T. 2018. Use of cluster analyze and similarity of algae in Eastern Black Sea Region Glacier Lakes (Turkey), Key area: Artabel Lakes Natural Park. *Gazı University Journal of Science* 31:25–40.

Barinova, S.S., L.A. Medvedeva & O.V. Anissimova 2006. *Diversity of algal indicators in environmental assessment*. Pilies Studio, Tel Aviv, 498 pp. (in Russian). [Баринова С.С., Медведева, Л.А., Анисимова, О.В. 2006. Биоазнообразне водорослей-индикаторов окружающей среды. Тель Авив: Pilies Studio. 498 с.]

Barinova, S. 2011. *Algal diversity dynamics, ecological assessment and monitoring in the river ecosystems of the eastern Mediterranean*. Nova Science Publishers, New York, 363 pp.

Barinova, S., N. Ali & S.F.M. Barkatullah 2013. Ecological adaptation to altitude of algal communities in the Swat Valley (Hindu Kush Mountains, Pakistan). *Expert Opinion on Environmental Biology* 2:1–15.

Barinova, S. & T. Fahima 2017. The development of the world database of freshwater algae-indicators. *Journal of Environment and Ecology* 8(1):1–7.

Barinova, S. & E.G. Krupa 2017. Diversity and ecology of periphytonic algae in the Arys River Basin, Kazakhstan. *Journal of Ecology and Natural Resources* 1:1–14.

Barinova S. & T. Niyatbekov 2018. Alpha-biodiversity of nondiatom algae in the Pamir aquatic habitats, Tajikistan. *Biodiversity International Journal* 2(3):236–363.

Barinova, S. & T. Niyatbekov 2019. Comparative analysis of diatom algae diversity in the Pamir Protected Lakes, Tajikistan. *International Journal of Advanced Research in Botany* 5(2):1–17.

Barinova, S.S., O.P. Bilous & P.M. Tsarenko 2019. *Algal indication of water bodies in Ukraine: methods and prospects*. Publishing House of Haifa University, Haifa, 367 pp. (in Russian). [Баринова С.С., Белоус Е.П., Царенко П.М. 2019. Альгоиндикация водных объектов Украины: методы и перспективы. Хайфа, Киев: Изд-во Университета Хайфы. 367 с.]

Bellinger, E.G. & D.C. Sigeo 2010. *Freshwater algae: identification and use as bioindicators*. John Wiley and Sons, Chichester, 290 pp.

Borics, G., J. Padisak, I. Grigorszky, I. Oldal, L.I. Peterfi & L. Momeu 1998. Green algal flora of the acidic bog-lake, Baláta-to SW Hungary. *Biologia* 53:457–465.

Bourrelly, P. & A. Coute 1991. *Desmidiées de Madagascar (Chlorophyta, Zygothryx)*. J. Cramer, Stuttgart, 349 pp.

Brook, A.J. & D.B. Williamson 2010. *A monograph on some British Desmids*. The Ray Society, London, 364 pp.

Coesel, P.F.M. 1984. The significance of desmids as indicators of the trophic status of freshwater. *Schweizerische Zeitschrift für Hydrologie* 45:388–393.

Coesel, P.F.M. 1998. Sieralgen en Natuurwaarden. *Wetenschappelijke Mededelingen KNNV* 224:1–56.

Coesel, P.F.M. & K.J. Meesters 2007. *Desmids of the lowlands, Mesotaeniaceae and Desmidiaceae of the European Lowlands*. KNNV Publishing, Zeist, 351 pp.



- Coesel, P.F.M. & K.J. Meesters 2013. *European flora of the desmid genera Staurostrum and Staurodesmus*. KNNV Publishing, Zeist, 357 pp.
- Dillard, G.E. 1990. *Freshwater algae of the Southeastern United States, Part 3. Chlorophyceae: Zygnematales: Zygnemataceae, Mesotaeniaceae and Desmidiaceae (Section 1)*. J. Cramer, Stuttgart, 172 pp.
- Dillard, G.E. 1991. *Freshwater algae of the Southeastern United States, Part 4. Chlorophyceae: Zygnematales: Desmidiaceae (Section 2)*. J. Cramer, Stuttgart.
- Dillard, G.E. 1993. *Freshwater algae of the Southeastern United States, Part 6. Chlorophyceae: Zygnematales: Desmidiaceae (Section 4)*. J. Cramer, Stuttgart.
- Doğa Koruma Ve Milli Parklar Genel Müdürlüğü 2013. Artabel Gölleri Tabiat Parkı uzun devreli gelişme planı analitik etüt ve sentez raporu. Doğa Koruma ve Milli Parklar Genel Müdürlüğü, Ankara (in Turkish).
- Feher, G. 2003. The desmid flora of some alkaline lakes and wetlands in Southern Hungary. *Biologia* 58:671–683.
- Gábor, U. 1995. *The green algal genera Scenedesmus (Chlorococcales, Chlorophyceae) with special attention to taxa occurring in Hungary*. Magyar Algalógiai Társaság, Budapest.
- Guiry, M.D. & G.M. Guiry 2019. *AlgaeBase, world-wide electronic publication*. National University of Ireland Press, Galway. Available from: <http://www.algaebase.org/>. Last accessed 20.06.2019.
- Hindák, F. 2008. Colour atlas of cyanophytes. VEDA, Publishing House of the Slovak Academy of Sciences, Bratislava.
- Huber-Pestalozzi, G. 1982. *Das Phytoplankton des Süßwassers Systematik und Biologie, 8. Teil, 1. Hälfte*. E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart.
- Jienbekov, A, S. Barinova, A. Bigaliev, S. Nurashov, E. Sametova & T. Fahima 2018. Bioindication using diversity and ecology of algae of the Alakol Lake, Kazakhstan. *Applied Ecology and Environmental Research* 16(6):7799–7831.
- Jiyenbekov, A, S. Barinova, A. Bigaliev, S. Nurashov, E. Sametova & T. Fahima 2019. Ecological diversity of algae in the Alakol Lake Natural Reserve, Kazakhstan. *Botanica Pacifica* 8(2):63–74.
- John, D.M, B.A. Whitton & A.J. Brook 2003. *The freshwater algal flora of the British Isles, an identification guide of freshwater and terrestrial algae*. Cambridge University Press, Cambridge.
- Kadlubowska, J.Z. 2009. Chlorophyta 8, Conjugatophyceae I: Zygnematales. In: *Süßwasserflora von Mitteleuropa, Freshwater flora of Central Europe, Bd. 16* (Ettl H., Gerloff J., Heynig H., Mollenhauer D., eds), pp. 1–532. Spektrum Akademischer Verlag, Stuttgart.
- Kim, Y.J. 2013. *Algal flora of Korea, Chlorophyta: Chlorophyceae: Chlorococcales II: Hydrodictyaceae, Coelastraceae Vol. 6/4*. National Institute of Biological Resources Ministry of Environment, Seo-gu Incheon.
- Kim, H.S. 2015. *Algal flora of Korea, Charophyta: Conjugatophyceae (Desmids III): Desmidiales: Desmidiaceae: Staurodesmus and Staurostrum I, Freshwater Green Algae Vol. 6/6*. National Institute of Biological Resources Ministry of Environment, Seo-gu Incheon.
- Kocataş, A. 1992. *Ekoloji (Çevre Biyolojisi)*. Ege Üniversitesi Matbaası, İzmir.
- Kolaylı, S. & B. Şahin 2009. Benthic algae (except Bacillariophyta) and their seasonal variations in Karagöl Lake (Borçka, Artvin-Turkey). *Turkish Journal of Botany* 33:27–32.
- Komárek, J. & K. Anagnostidis 1998. Cyanoprokaryota, 1. Teil/Part 1: Chroococcales. In: *Freshwater Flora of Central Europe. Vol.19/1*, (H. Ettl, J. Gerloff, H. Heynig & D. Mollenhauer, eds), pp. 1–548. Spektrum Akademischer Verlag, Heidelberg.
- Komárek, J. & K. Anagnostidis 2005. Cyanoprokaryota: 2. Teil/Part 2: Oscillatoriales. In: *Freshwater Flora of Central Europe. Vol.19/2*, (B. Büdel, G. Gärtner, L. Krienitz & M. Schagerl, eds), pp. 1–759. Spektrum Akademischer Verlag, Heidelberg.
- Komárek, J. 2013. Cyanoprokaryota: 3. Teil/Part 3: Heterocytous Genera. In: *Freshwater Flora of Central Europe. Vol.19/3*, (B. Büdel, G. Gärtner, L. Krienitz & M. Schagerl, eds), pp. 1–1130. Spektrum Akademischer Verlag, Heidelberg.
- Krupa, E.G., S.S. Barinova, L. Ponamareva & V.N. Tsoy 2018. Statistical mapping and 3-D surface plots in phytoplankton analysis of the Balkhash Lake (Kazakhstan). *Transylvanian Review of Systematic and Ecological Research "The Wetlands Diversity"* 20(1):1–16.
- Lee, O.M. 2015. Additions to the six taxa of the genus *Cosmarium* (Desmidiaceae, Charophyta) in Korea. *Journal of Ecology and Environment* 38:629–636.
- Lenzenweger, R. 1996, 1997, 1999. *Desmidiaceenflora von Österreich Teil 1–3*. J. Cramer, Stuttgart.
- Lind, E.M. & A.J. Brook 1980. Desmids of the English Lake District. *Freshwater Biological Association Scientific Publication* 42. The Freshwater Biological Association, Ambleside, Cumbria, 123 pp.
- Novakovskiy, A.B. 2004. *Abilities and base principles of program module "GRAPHS."* (Scientific Reports of Komi Scientific Center, Ural Division of the Russian Academy of Sciences, 27). 28 pp. (in Russian). [Новаковский А.Б. 2004. Возможности и принципы работы программного модуля "GRAPHS" (Автоматизация научных исследований). Сыктывкар, Коми научный центр УрО РАН. Вып. 27). 28 с.
- Park, J.G. 2012. *Algal flora of Korea, Cyanophyta: Cyanophyceae: Chroococcales, Oscillatoriales, Freshwater Cyanoprokaryota II. Vol. 5/2*. National Institute of Biological Resources Ministry of Environment, Seo-gu Incheon.
- Prescott, G.W. 1962. *Algae of the Western Great Lakes Area*. W.M. C. Brown Company Publishers, Dubuque, Iowa.
- Psenner, R. 2003. Alpine lakes: Extreme ecosystems under the pressures of global change. *EAWAG News* 55:12–15.
- Round, F.E. 1953. An investigation of two benthic algal communities in Malham Tarn, Yorkshire. *Journal of Ecology* 41:174–197.
- Ruzicka, J. 1977. *Die Desmidiaceen Mitteleuropa Band 1*. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.
- Sivacı, R.E., S. Barinova, C.N. Solak & K. Çobanoğlu 2013. Ecological assessment of Great Lota Lake (Turkey) on the base of diatom communities. *African Journal of Biotechnology* 12:453–464.
- Solak, C.N., S. Barinova, E. Ács & H. Dayıoğlu 2012. Diversity and ecology of diatoms from Felent creek (Sakarya river basin), Turkey. *Turkish Journal of Botany* 36:191–203.
- Sládečková, A. 1962. Limnological investigation methods for the periphyton ("Aufwuchs") community. *Botanical Review* 28:286–350.

- Štastný, J. 2010. Desmids (Conjugatophyceae, Viridiplantae) from the Czech Republic; new and rare taxa, distribution, ecology. *Fottea* 10:1–74.
- Stevenson, J. 2014. Ecological assessments with algae: a review and synthesis. *Journal of Phycology* 50:437–461.
- Şahin, B. 1998. Some new records of desmids from Turkey. *Pakistan Journal of Botany* 30:7–13.
- Şahin, B. 2000. Some new desmids records for the freshwater algal flora of Turkey. *Flora Mediterranea* 10:223–226.
- Şahin, B. 2001. Epipellic and epilithic algae of Dağbaşı Lale (Rize-Turkey). *Turkish Journal of Botany* 25:187–194.
- Şahin, B. 2002. Contribution to the desmid flora of Turkey. *Algological Studies* 107:39–48.
- Şahin, B. 2003. Biodiversity of benthic algal communities in some high mountain lakes of the Turkish Eastern Black Sea Region. *Cryptogamie, Algologie* 24:341–353.
- Şahin, B. 2004. Species composition and diversity of epipellic algae in Çatal Lake (Şebinkarahisar-Giresun, Turkey). *Turkish Journal of Biology* 28:103–109.
- Şahin, B. 2008. Species composition and diversity of epipellic algae in Limni Lake (Gümüşhane, Turkey). *Acta Botanica Hungarica* 50:397–405.
- Şahin, B. 2019. Charophyta. In: *Türkiye Suyosunları Listesi* (Turkey list of algae), (E. Taşkın, ed.), pp. 181–223. Ali Nihat Gökyiğit Vakfı Yayını, İstanbul.
- Şahin, B. & B. Akar 2005. Epipellic and epilithic algae of Küçükgöl Lake (Gümüşhane-Turkey). *Turkish Journal of Biology* 29:57–63.
- Şahin, B., B. Akar & İ. Bahçeci 2010. Species composition and diversity of epipellic algae in Balık Lake (Şavşat-Artvin, Turkey). *Turkish Journal of Botany* 34:441–448.
- Şahin, B. & B. Akar 2019a. New desmid records from high mountain lakes in Artabel Lakes Nature Park, Gümüşhane, Turkey. *Turkish Journal of Botany* 43:570–583.
- Şahin, B. & B. Akar 2019b. New records from Artabel Lakes Nature Park (Gümüşhane/Turkey) to the freshwater algal flora of Turkey. *Turkish Journal of Botany* 43:135–142.
- Taşkın, E. (ed.) 2019. *Türkiye Suyosunları Listesi* (Turkey List of algae). Ali Nihat Gökyiğit Vakfı Yayını, İstanbul.
- ter Braak, C.J.F. & P. Šmilauer 2002. *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5)*. Ithaca. Microcomputer Power Press.
- Vitonytė, I. & J. Kasperovičienė 2015. Phytobenthos cyanobacteria species new to Lithuanian rivers. *Botanica Lithuanica* 21:99–118.
- West, W. & G.S. West 1904, 1905, 1908, 1912, 1923. *A monograph of the British Desmidiaceae, vol. 1–5*. The Ray Society, London.
- Wotowski, K. & F. Hindak 2005. *Atlas of Euglenophytes*. VEDA, Publishing House of the Slovak Academy of Sciences, Bratislava.