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

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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 groups: 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

REZÜMЕ
Сахин, Б., Акар, Б., Баринова, С. Недиатомовые водоросли высокогорных озер Артабель-Лэйкс, Гюмюшхане, Турция. Впервые исследовано 18 озер природного парка Артабель-Лэйкс, Турция. Было идентифицировано 154 вида недиатомовых водорослей из четырех таксономических отделов. Представители отдела Charophyta (73 такона) преобладают в основном за счет видов рода Cosmarium (37). Так же впервые представлены отделы Cyanobacteria (42), Chlorophyta (30) и Eunlenozoa (9). Новые находки для флоры водорослей Турции представлены 31 такономическим разрядом, большинство из которых принадлежит родам Cosmarium (15) и Staurastrum (5). Редкие виды цианобактерий найдены в сообществах озер 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 недиатомовых водорослей. Биоиндикация 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: недиатомовые водоросли, биоиндикация, высокогорные озеры, 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 & Sigee 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, Bories 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, Svaci et al. 2013). In this study, for the ecological evaluation of the water ecosystems in the...
Artabel Lakes Nature Park we visited 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 Kongol River basin (Yıldız and Acembol Lakes). The total basin area is approximately 58.2 km², 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 (3), 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 (İsimiz 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, İsimiz 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 epipelic, epilithic and epiphytic algae samples were taken from 17 lakes and a pond. Epipelic 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
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 under a 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 & Courc (1991), Gábor (1995), Lenzenweger (1996, 1997, 1999), John et al. (2003), Komárk & Anagnostidis (1998, 2005), Wotowski & Hindak (2005), Hindak (2008), Kadlubowska (2009), Brook & Williamson (2010), Stastny (2010), Coesel & Meesters (2007, 2013), Park (2012), Komárk (2013), Kim (2013, 2015), Lee (2015), Vironytė & 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/cm²).

When Table 1 (Şahin et al. 2019b) examined, it is seen that there are linear, negative, strong relationships between altitude and water temperature (T) (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 *Systrinema coactile* and *Katagynmene 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 each lake and relative abundances. Functional 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).

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Comparative floristics

Comparative floristics 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

| Indicator | Taxa | Lake |
|-----------|------|------|
| Charophyta | Chlorophyta | Cyanobacteria | Euglenozooa (Euglenophyta) |
| Species richness | 29 | 4 | 5 | 9 | 8 | 7 | 15 | 8 | 8 | 13 | 1 | 20 | 27 | 30 | 15 | 30 | 27 | 32 |
| Abundance sum of scores | 55 | 35 | 29 | 21 | 16 | 1 | 10 | 22 | 21 | 11 | 14 | 60 | 40 | 57 | 60 | 64 | 31 | 49 | 55 |
| Index Saprobity SI | 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 |
| Habitat | B | 17 | 2 | 2 | 4 | 5 | 1 | 5 | 4 | 1 | 6 | 1 | 6 | 11 | 10 | 7 | 13 | 8 | 9 | 13 |
| P-B | 8 | 1 | 3 | 2 | 3 | 4 | 6 | 3 | 5 | 1 | 6 | 1 | 2 | 12 | 10 | 14 | 7 | 11 | 8 | 10 | 11 |
| P | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 1 | 2 | 2 | 4 | 4 |
| Ep | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Temperature | eterm | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| temp | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oxygen | 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 | 2 | 0 | 0 | 0 | 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 |
| pH | acf | 10 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 0 | 4 | 0 | 2 | 1 | 5 | 2 | 8 | 4 | 8 | 4 |
| alf | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| ind | 11 | 0 | 1 | 3 | 4 | 3 | 8 | 4 | 3 | 6 | 0 | 10 | 8 | 11 | 8 | 10 | 6 | 7 | 15 |
| Salinity | hb | 3 | 0 | 0 | 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 | 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 | 0 |
| Water Quality | Class 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 0 | 1 |
| Class 2 | 5 | 2 | 2 | 3 | 2 | 2 | 4 | 0 | 2 | 5 | 7 | 8 | 4 | 6 | 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 |
| Trophic state | o | 2 | 0 | 1 | 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 | 2 | 0 | 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 |
| c | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 2 | 1 | 2 | 1 | 0 | 2 | 2 | 1 |
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

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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)

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 & Niyatkbechov 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 6A can be seen as a predominance of Chlorophyta species accompanied by Cyanobacteria species richness. Algae in Artabel Park grows with benthic and planktobenthic 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
algal 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: Acembol 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.

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