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# Diversity and ecology of non-diatom algae in two high-mountain lakes of Çamlıhemşin (Rize, Turkey)

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**ABSTRACT**

In this study, reports the first comprehensive research of non-diatom algae flora in two high mountain lakes of Rize (Eastern Black Sea region of Turkey), in which 157 species of 5 phyla were identified. While Charophyta and Cyanobacteria members represented 81.92 % of the species composition, Desmdiaceae was the main family of benthic flora with 90 species. The two lakes are highly dissimilar in species richness and composition, having only 15 (9.55 %) species in common. The lakes, which are almost pristine, maintain diverse and valuable benthic algal floras, making them important sites in Turkey ecological network. 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, high mountain lakes, bioindication, Turkey

**РЕЗЮМЕ**

**Шахин Б., Баринова С. Разнообразие и экология недиатомовых водорослей в двух высокогорных озерах Чамлыхемшин (Ризе, Турция).** В данной работе представлено первое комплексное исследование флоры недиатомовых водорослей в двух высокогорных озерах Ризе (Восточное Причерноморье Турции), в котором было идентифицировано 157 видов из 5 филумов. В то время как представители Charophyta и Cyanobacteria составляли 81,92 % видового состава, Desmdiaceae были основным семейством бентосной флоры с 90 видами. Оба озера сильно различаются по видовому богатству и составу, имея всего 15 (9,55 %) общих видов. Озера, которые являются практически нетронутыми, поддерживают разнообразную и ценную флору бентосных водорослей, что делает их важными объектами в экологической сети Турции. Биоиндикация характеризует воду исследованных озер как умеренную по температуре, средненасыщенную кислородом, нейтральную или слабокислую по pH, слабосоленую, 2–3 класса качества воды и мезотрофную.

**Ключевые слова:** анедиатомовые водоросли, высокогорные озера, биоиндикация, Турция

Algae, an important component of high mountain lake ecosystems, form a specific taxonomic group here with rare and distinctive species as well as montane forms. At same time, algae, which are considered to be indicators of climate change, exhibit geographical, regional and stratigraphic characteristics in their species composition and relationships with water bodies and biotope types (Barinova et al 2019, Cantonati & Spitale 2009). Diatoms, green algae and charophytes are groups of algae that are generally found dominant or subdominant in the aquatic habitats of mountain ecosystems (Kawecka & Robinson 2008, Wojtal et al. 2014, Khuram et al. 2019).

As a country in the temperate climate zone, Turkey has seven geographical regions that are under the influence of different climatic, geographical, topographic and edaphic factors. One of these regions is the Black Sea Region. The eastern part of the region is the most striking part thanks to its geological structure, climatic features, high mountains (Kaçkar Mts 3932 m), different and rich biodiversity. Thanks to these features, many areas in the Eastern Black Sea Region have been taken under protection (such as Artabel Lakes Natural Park, Kaçkar Mountains Natural Park) by the Republic of Turkey. In the region, there are also habitats that are on the list of protected ecoregions declared by the IUCN (Heywood & Davis 1994).

Research on the algal compositions of high mountain lakes, which far from industrial influence, in the Eastern Black Sea Region began in the 90s (Şahin 1998, 2000, 2001, 2002, Şahin & Akar 2005, Akar & Şahin 2006, 2016, Kolaylı & Şahin 2009, Şahin et al. 2020a,b, Taş & Hamzaçebi 2020). The studies indicated that the lakes exhibit a high level of algal diversity in terms of composition, taxonomic structure, and distribution. With more than 685 glacial lakes (Geçen et al.2018), this region deserves to be one of the hotspots of Turkey's algal biodiversity. Therefore, these studies not only contributed to the determination of the algae flora of Turkey, but also provided the opportunity to compare the floras of high mountain lakes in other countries around the world. In addition, they also have a special importance in terms of revealing the effects of water and macro climatic parameters on the formation of algal flora in high mountain lakes. However, considering the number of lakes in the region, it is understood that data on algal diversity and especially on their individual taxonomic groups are insufficient.

The aim of this study was to investigate the species composition of non-diatom algae in the Avusor Great and Koçdüzü Great Lakes and to assess the ecological state of these lakes based on the occurrence of algal indicator species under current environmental conditions.

## MATERIAL AND METHODS

### The study area

Rize Province is located between 40°20' and 41°20'N – 40°22' and 41°28'E coordinates. The geological structure of Rize Province, which is part of the Eastern Black Sea mountain system, mainly consists of Granodiorite and Cretaceous flysch. Additionally, there are patches of Neogene deposits. The large mountain formation, which began during the Paleozoic (I Period) and Cretaceous periods (III Period), brought these structures to the surface (Anonymous 2006). Based on Turkey's climate classification system (Erinç 1969), the Rize province is categorized as having a very humid climate and is influenced by the Eastern Black Sea climate. The climate of the Eastern Black Sea region is characterised by cool summers, temperate winters, and rainfall throughout the year. The mountains' parallel extension to the shore is a relevant factor in this context. The average annual temperature in Rize is 14.3°C. The lowest temperature was recorded 3.4°C in February, while the highest was 26.7°C in August. The annual average rainfall is recorded as 2254.4 mm, while the annual average relative humidity is very high at 80 % (Polat & Sunkar 2017). Rize has five main soil types, which are alluvial, colluvial, red-yellow podzolic, grey-brown podzolic, non-calcareous forest, and high mountain meadow soils (Anonymous 2005). While these ecological features contribute to the creation of a rich biodiversity, they also increase the rate of endemism. For example, *Papaver lateritium*, *Barbarea trichopoda*, *Cochleria sintenisii*, *Sempervivum furseorum*, *Centaurea appendicigera* and *Alopecurus laguroides* are some of them (Anonymous 2006). Glaciers are common in the Eastern Black Sea Mts, which have many glacial lakes, due to the climatic conditions during the Little Ice Age (Anonymous 2006).

Avusor Great and Koçdüzü Great Lakes located in Çamlıhemşin district. Avusor Great Lake, which has an area of 0.03 km$^2$ and is situated at an altitude of 2678 m a.s.l., is located at 40°56'11"N 41°12'01"E coordinates. Koçdüzü Great Lake is located at 41°00'15"N 41°11'53"E coordinates. The lake, which is located an altitude of 2382 m a.s.l., has an area of 0.04 km$^2$ (Fig. 1).

### Sampling and laboratory studies

On 21 August 2019, epipelic algae were taken from the sediment surface of both lakes using a glass pipe. For epilithic and epiphytic algae, stones and macrophyte plants (*Potamegeton* sp. and *Juncus* sp.) were collected from Avusor Great and Koçdüzü Great Lakes, respectively, and then, they were scraped and washed into plastic bottles. In total, 13 bottles of epipelic, epilitic and epiphytic algae samples were taken from the both lakes (Round 1953, Sládecková 1962). All samples were fixed in 4 % formaldehyde. In the field, Thermo Orion-4-Star pH and YSI-55 portable measuring devices were used to measure the water temperature, pH, dissolved oxygen and conductivity of the lake waters. Analyses of other hydrochemical parameters were carried out in the DSI General Directorate Laboratories DSI 22nd Regional Directorate Quality Control and Laboratory Branch Office. In the laboratory, species were identified using a Leica DM 2500 model light microscope. A 6-point scale was used to estimate species abundance (Barinova & Medvedeva 1996). Ecological preferences of species were determined using bioindication methods (Barinova 2017).

Relevant sources Schmidle (1895), West & West (1904, 1905, 1908, 1912, 1923), Huber- Pestalozzi (1955), Prescott (1962), Ruzicka (1977), Lind and Brook (1980), Forster (1982), Croasdale et al. (1986, 1988, 1994), Ling & Tyler (1986), Dillard (1989, 1990, 1991a,b, 1993), Bourrelly & Coute (1991), Lenzenweger (1990, 1996, 1997, 1999), Gábor (1995), Kouwets (1997), Dingley (2001), John et al. (2003), Komárek & Anagnostidis (1998, 2005), Wotowski & Hindak (2005), Hindak (2008), Brook & Williamson (2010), Štastny (2010), Coesel & Meesters (2007, 2013) and Kim (2012, 2015) were used to identify the species. The current status of nomenclature of all the taxa has been checked in the Algaebase web site (Guiry & Guiry 2021).

## RESULTS

### Physical and chemical properties of waters

Considering the results of the physico-chemical analyzes of the lake waters, we can say that the lakes are circumneutral and alkaline, soft water features with low mineral content (Table 1).

### Floristic composition and diversity of non-diatom algae

At the end of the research, a total of 228 species, including 71 diatom species, were identified in the benthic habitats of both lakes. However, we also think that the number of species may increase in future studies, especially in Koçdüzü Great Lake. It is seen that the composition of 157 non-diatom species detected in the first stage can be compared with the non-diatom flora of high mountain lakes in similar climatic regions. Despite everything the species richness of the studied samples, the detailed study of the lakes and the fact that the sampling was carried out in August, which is suitable for the development of algae in this region, suggest that the flora is represented with the maximum species composition.

A total of 157 species, belonging to 45 genera, 24 families, 13 orders, 6 classes and 5 phyla of non-diatom algae, was identified (Table 2). The members of the Charophyta (107 species) were form the basis of the taxonomic list and represented 68.15 % all of the species. It was followed by Cyanobacteria (22 species, 14.01 %), Chlorophyta (17 species, 10.82 %), Euglenozoa (9 species, 5.73 %), and Ochrophyta (2 species 1.27 %) phyla, respectively. Most of the species diversity was contributed by the algae of Koçdüzü Great Lake (128 species; 81.52 %) (Table 2). The fact that the epiphytic samples taken from the lake had a rich desmid diversity was effective in this. The algae of Avusor Great Lake was showed low floristic and taxonomic diversity with only 44 species, and represented 28.02 % of the total algal flora (Table 2).

Cyanobacteria, which plays an important role in the nutrient cycle (Codd et al. 2005), has been the second phylum represented by the most species in the non-diatom algal flora. On the other hand, it is also remarkable that the

**Table 1.** Averaged physical and chemical data of the Avusor Great Lake and Koçdüzü Great Lake. (–): could not be detected.

| Parameters | Avusor Great Lake | Koçdüzü Great Lake |
|---|---|---|
| Teperature (°C) | 15.9 | 21 |
| Dissolved Oxygen (mg/L) | 10.2 | 9.2 |
| pH | 7.58 | 8.45 |
| Conductivity (µS/cm$^{-1}$) | 45.3 | 104.7 |
| Total Dissolved Matter (mg/L) | 28.01 | 6.88 |
| Total Hardness $CaCO_3$ (mg/L) | 18.96 | 12.94 |
| Potassium (mg/L) | 0.18 | 0.23 |
| Calcium (mg/L) | 5.53 | 3.12 |
| Magnesium (mg/L) | – | – |
| Ammonium (mg/L) | 0.14 | 0.16 |
| Chloride (mg/L) | 6.31 | 10.78 |
| Nitrate (mg/L) | 1.092 | – |
| Nitrite (mg/L) | 0.083 | 0.081 |
| Ammonium nitrogen (mg/L) | 0.11 | 0.12 |
| Nitrate nitrogen (mg/L) | 0.247 | – |
| Nitrite nitrogen (mg/L) | 0.025 | 0.024 |
| Medium phosphate (mg/L) | 0.07 | 0.072 |
| Phosphate ($P_2O_5$) (mg/L) | 0.0525 | 0.054 |

members of this phylum take the first place in the flora of Avusor Great Lake. Oscillatoria was the dominant genus of the phylum (Table 2).

*Desmodesmus* was the remarkable genus of the Chlorophyta phylum with 4 species. Surprisingly, all species were detected only in Koçdüzü Great Lake (Table 2). On the other hand, *Pseudopediastrum boryanum*, which was detected in both lakes, was the most common species in the phylum.

The members of the Euglenozoa phylum were not very important quantitatively in the algal flora of the both lakes. Only *Trachelomonas volvocina* reached remarkable numbers in the both lakes. while the Euglenozoa phylum was represented by two species in Avusor Great Lake, it was noteworthy that other species of the phylum were included in the flora of Koçdüzü Great Lake (Table 2).

Desmidiaceae (Charophyta, the largest phyla) is the basic family of algal flora with 86 species. It is followed by Closteriaceae (15 species), Oscillatoriaceae (6 species) and Scenedesmaceae (6 species) families. Other families were represented by 1 to 5 species in the flora (Table 2). *Cosmarium* is the genus with the highest number of species (41), followed by *Staurastrum*, *Closterium*, and *Euastrum* with 16, 15, and 12 species, respectively (Table 2). A total of 39 (37 desmids, 1 diatom and 1 Ochrophyta) species were identified as new records for the freshwater algal flora of Turkey. They are marked with an asterix (*) in Table 2. Information on taxonomic and ecological characteristics of new record species were given in separate publications (Şahin 2021a,b, 2022).

## Ecological properties

Epiphytic algae constituted 70.7 % of the species composition, followed by individuals of the epipelic habitat with 55.41 %. Epilitic individuals were represented by a very small share (4.45 %).

Ecological preferences of the detected species in this study can provide information about the habitat conditions of high mountain lakes such as the lakes that are the subject of the study. While mesotrophic desmid species constituted 43.39 % of the desmid flora, oligotrophic, oligo-mesotrophic and meso-oligotrophic desmids constituted 41.50 %. In the flora, meso-eutrophic and eutrophic desmids were also found (10.37 %).

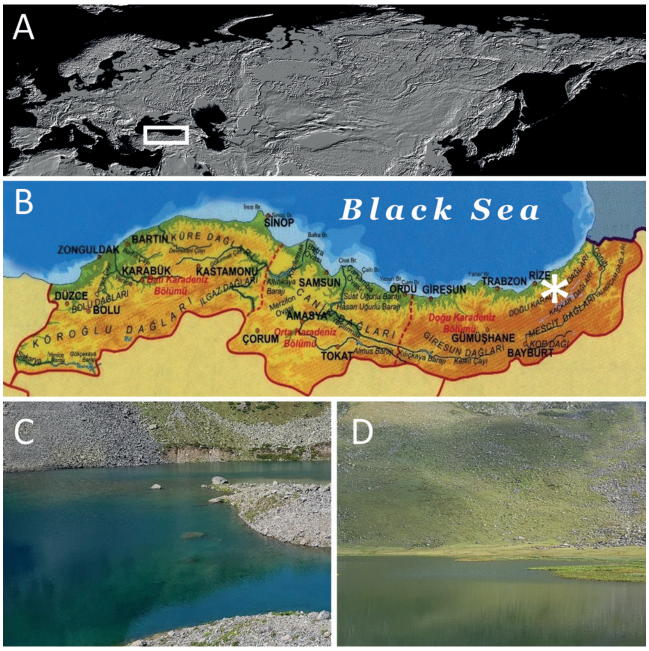


**Figure 1** A – general overview; B – the location of the study area is shown with an asterisk (https://bycografyam.wordpress.com); C – Avusor Great Lake, D – Koçdüzü Great Lake (photos by Bülent Şahin)

It is known that Euglenozoa members identified in the epipelic, epilitic and epiphytic habitats of the investigated waters have a cosmopolitan distribution and are known to thrive in stagnant waters (Predojevic 2015). It is therefore not surprising that Euglenozoa members are present here. Because the samples were taken in the summer, when there was suitable temperature and light for their growth and development.

## Bioindication

Bioindication gives a total glance on the revealed species list in the lakes and can help to characterize the environment in which non-diatom species survived. So, Fig. 2A represents an indication of water properties of studied lakes with the help of species-specific ecological preferences of revealed algae. While Charophyta constitutes the dominant phylum of the flora, Cyanobacteria is in second place. Benthic species dominated the examined samples. While plankto-benthic species ranked second, planktonic species were also encountered (Fig. 2B). Species characteristic of eurythermic conditions strongly predominate in the surveyed lakes (Fig. 2C). Three ecological groups of non-diatom species were found in relation to oxygenation, water velocity, and oxygen saturation. In the studied lakes, the species characteristics for low streaming water prevail (Fig. 2D).

Salinity is a crucial component of the total ion content in water, influencing the algal community. Bioindication based on water salinity reveals that the indifferent group of species dominates in the studied lakes. Groups of halophobes and halophiles followed. Mesohalobes group was detected only in Koçdüzü Great Lake (Fig. 2E). The results of the pH bioindication show that acidophiles species (55.85 %) are common in the non-diatom algal flora

**Table 2.** List of non-diatom algae in the Avusor Great Lake and Koçdüzü Great Lake with species abundance, habitat preferences and ecological properties. Abbreviation of the ecological groups of indicators: H: Habitat; 1: Epipelic; 2: Epilithic; 3: Epiphytic; AGL: Avusor Great Lake; KGL: Koçdüzü Great Lake; *: New record for Turkey. A: Abundance: Single = 2; Rare = 1. Ecological groups: Hab, substrate preferences: B, benthic, P-B, plankto-benthic, P, planktonic; Oxy, Oxygen indicators: aer, aerophiles, st-str, slowly moving waters, st, standing waters; Hal, salinity indicators: hb, halophobes, i, indifferent; pH, water pH indicators: acf, acidophiles, ind, indifferents, alf, alkaliphiles; Sap, saprobity indicators: x-o, xeno-oligosaprobiont; x, xenosaprobiont; x-b, xeno-beta-mesosaprobiont; o-x, oligo-xenosaprobiont; o, oligosaprobiont; o-b, oligo-beta-mesosapronion t; o-a, oligo-alpha-mesosaprobiont; Tro, trophic state indicators: ot, oligotraphentic; om, oligo-mesotraphentic; m, mesotraphentic; me, meso-eutraphentic; e, eutrophic; "–" property is unknown.

| Taxa | H | AGL /A | KGL /A | Hab | Tem | Oxy | Hal | pH | Sap | Tro | Index S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Aphanocapsa* sp. | 1 | 1 | | P | | | | | | e | |
| *Cyanothece aeruginosa* (Nägeli) Komárek 1976 | 1 | 2 | | P-B, Ep | | aer | | | x-b | e | 0.9 |
| *Gomphospaeria* sp. | 1 | 1 | | P | | | | | | | |
| *Kamptonema formosum* (Bory ex Gomont) Strunecký, Komárek & J.Smarda 2014 | 1 | | 2 | P-B,S | | st | | ind | a | me | 3.1 |
| *Komvophoron* sp. | 1 | 1 | | B | | | | | o-a | | 1.8 |
| *Merismopedia elegans* A.Braun ex Kützing 1849 | 1,2 | 2 | | P-B, Ep | | | i | ind | | me | |
| *Merismopedia glauca* (Ehrenberg) Kützing 1845 | 1,3 | 2 | 2 | P-B | | | i | ind | | e | |
| *Merismopedia tenuissima* Lemmermann 1898 | 1 | 2 | | P-B | | | hl | | | e | |
| *Merismopedia* sp. | 1 | 2 | | P | | | | | | e | |
| *Microcoleus amoenus* (Gomont) Strunecky, Komárek & J.R.Johansen 2013 | 1 | 2 | | P-B,S | | st-str | | alb | x | | 0.1 |
| *Nostoc* sp. | 1,3 | 1 | 1 | B | | | | | | | |
| *Oscillatoria anguina* Bory ex Gomont 1892 | 1 | 2 | | B,S | | | | | | | |
| *Oscillatoria limosa* C.Agardh ex Gomont 1892 | 1 | 2 | | P-B | | st-str | hl | alf | | | |
| *Oscillatoria subbrevis* Schmidle 1901 | 1,2 | 2 | | | | | | | b-a | | 2.4 |
| *Oscillatoria tenuis* C.Agardh ex Gomont 1892 | 1,2 | 2 | | P-B,S | | st-str | hl | | | | |
| *Oscillatoria* sp. | 1,2 | 2 | 2 | B | | | | alf | | | |
| *Phormidium inundatum* Kützing ex Gomont 1892 | 1 | 2 | | B,S | | aer | | | x | ot | 0.1 |
| *Planktolyngbya* sp. | 1 | 1 | | P-B | | | | | | | |
| *Pseudanabaena catenata* Lauterborn 1915 | 1 | 2 | | P-B | | st | | | a | e | 3.0 |
| *Pseudanabaena galeata* Böcher 1949 | 1 | 2 | | B | | | | | a | e | 3.3 |
| *Spirulina major* Kützing ex Gomont 1892 | 1 | | 2 | P-B,S | warm | st | hl | | | | |
| *Spirulina* sp. | 1 | | 1 | P-B | | | | | | e | |
| *Actinotaenium cucurbita* (Brébisson ex Ralfs) Teiling 1954 | 1 | | 2 | P-B | | aer | | acf | x-b | ot | 0.9 |
| **Actinotaenium cucurbitinum* (Bisset) Teiling 1954 | 3 | | 2 | P-B | | | | acf | | om | |
| *Actinotaenium curtum* (Brébisson ex Ralfs) Teiling ex Růžička & Pouzar 1978 | 3 | | 2 | P-B | | aer | | ind | x-b | om | 0.9 |
| **Actinotaenium rufescens* (Cleve) Teiling 1954 | 1 | | 2 | B | | | | acf | | m | |
| *Actinotaenium spinospermum* (Joshua) Kouwets & Coesel 1984 | 3 | | 2 | B | | | | acf | | m | |
| *Actinotaenium* sp. | 3 | | 2 | | | | | | | | |
| *Closterium abruptum* West 1892 | 1,3 | | 2 | P-B | | st-str | | acf | | m | |
| **Closterium abruptum* f. *nilssonii* (Borge) A.J.Brook & D.B.Williamson 2010 | 3 | | 1 | | | | | | | | |
| **Closterium angustatum* Kützing ex Ralfs 1848 | 1,3 | | 1 | B | | | | acf | | om | |
| **Closterium archerianum* var. *pseudocynthia* Ruzicka 1973 | 3 | | 2 | B | | | | acf | | m | |
| **Closterium baillyanum* (Brébisson ex Ralfs) Brébisson 1856 | 1,3 | | 2 | B | | | | ind | | om | |
| *Closterium calosporum* Wittrock 1869 | 3 | | 2 | B | | | | acf | | m | |
| **Closterium closterioides* var. *intermedium* (J.Roy & Bisset) Ruzicka 1973 | 1,3 | | 2 | B | | | | acf | o-x | om | 0.7 |
| **Closterium dianae* var. *brevius* (Petkoff) Willi Krieger 1935 | 3 | | 2 | | | | | | | | |
| *Closterium exiguum* West & G.S.West 1902 | 3 | | 2 | | | | | | | | |
| *Closterium juncidum* Ralfs 1848 | 3 | | 2 | P-B | | | hb | acf | | om | |
| *Closterium lunula* Ehrenberg & Hemprich ex Ralfs 1848 | 1 | | 2 | B | | | | ind | x-b | m | 0.8 |
| *Closterium macilentum* Brébisson 1856 | 1 | | 2 | P-B | | st-str | i | ind | | me | |
| *Closterium navicula* (Brébisson) Lütkemüller 1905 | 1,3 | | 2 | P-B | | | | acf | o-x | om | 0.7 |
| *Closterium ralfsii* var. *hybridum* Rabenhorst 1863 | 3 | | 2 | P-B | | | hb | acf | x-o | m | 0.5 |
| *Closterium rostratum* Ehrenberg ex Ralfs 1848 | 1 | | 2 | B | | aer | | ind | o-x | m | 0.7 |
| **Cosmarium amoenum* Brébisson ex Ralfs 1848 | 1,3 | | 1 | B | | | | acf | | om | |
| *Cosmarium botrytis* Meneghini ex Ralfs 1848 var. *botrytis* | 1,3 | | 2 | P-B | | st-str | i | ind | o-a | m | 1.9 |
| *Cosmarium botrytis* var. *tumidum* Wolle 1884 | 1 | | 2 | P-B | | | | ind | o-a | m | 1.9 |
| **Cosmarium caelatum* Ralfs 1848 | 1 | | 2 | B,aer | | aer | | ind | | m | |
| **Cosmarium canaliculatum* West and G.S.West 1896 | 3 | | 2 | | | | | | | om | |
| **Cosmarium connatum* Brébisson ex Ralfs 1848 | 3 | | 1 | B | | | | acf | | m | |
| *Cosmarium contractum* O.Kirchner 1878 var. *contractum* | 1 | | 2 | B | | | | acf | | om | |
| *Cosmarium contractum* var. *ellipsoideum* (Elfving) West & G.S.West 1902 | 3 | | 2 | | | | | | | | |
| **Cosmarium debaryi* W.Archer 1861 | 3 | | 2 | P-B | | | hb | ind | | m | |
| **Cosmarium difficile* var. *messikommeri* (Croasdale) Kouwets 1997 | 3 | | 2 | | | | | | | | |
| *Cosmarium holmiense* var. *integrum* P.Lundell 1871 | 1 | 2 | | B,aer | | aer | | acf | | m | |
| *Cosmarium laeve* Rabenhorst 1868 | 1,2 | 2 | 2 | P-B | | st-str | hb | ind | o-a | me | 1.9 |
| *Cosmarium majae* Ström 1922 | 1 | 2 | | P | | | | ind | | me | |
| *Cosmarium margaritiferum* Meneghini ex Ralfs 1848 | 1,3 | | 2 | B | | | i | acf | | m | |
| *Cosmarium neodepressum* var. *minutum* (Heimerl) G.J.P.Ramos & C.W.N.Moura 2020 | 3 | | 2 | | | | | | | | |
| *Cosmarium notabile* var. *transiens* Insam & Willi Krieger 1936 | 1 | 2 | | B,aer | | | | acf | | m | |
| *Cosmarium obtusatum* (Schmidle) Schmidle 1898 | 1,3 | 2 | 2 | B | | | i | ind | o | me | 1.3 |
| **Cosmarium porteanum* var. *nephroideum* Wittrock 1872 | 1,3 | | 1 | | | | | ind | | m | |
| *Cosmarium praemorsum* Brébisson 1856 | 3 | | 2 | P-B | | | hb | acf | o | m | 1.2 |
| **Cosmarium pseudoconnatum* Nordstedt 1870 | 3 | | 2 | | | | | acf | | om | |
| *Cosmarium pseudoornatum* B.Eichler & Gutwinski 1894 | 1 | | 2 | B | | | | acf | | m | |
| *Cosmarium pseudopyramidatum* P.Lundell 1871 | 3 | | 2 | B | | | | acf | | om | |
| *Cosmarium punctulatum* Brébisson 1856 var. *punctulatum* | 3 | | 2 | P-B | | | hb | ind | o | m | 1.3 |
| *Cosmarium punctulatum* var. *subpunctulatum* (Nordstedt) Børgesen 1894 | 1,3 | 2 | 2 | B | | | | ind | o | me | 1.3 |
| *Cosmarium pyramidatum* Brébisson ex Ralfs 1848 | 1,3 | | 2 | B | | | | acf | o | om | 1.3 |
| **Cosmarium raeticum* Messikommer 1935 | 1 | | 2 | | | | | acf | | m | |
| *Cosmarium regnellii* var. *pseudoregnellii* (Messikommer) Willi Krieger 1944 | 1,3 | | 2 | B | | | | acf | | m | |
| *Cosmarium reniforme* (Ralfs) W.Archer 1874 | 3 | | 2 | P-B | | st-str | hb | ind | o | me | 1.0 |
| **Cosmarium retusiforme* (Wille) Gutwinski 1892 var. *retusiforme* | 1,3 | | 1 | | | | | acf | | m | |
| **Cosmarium retusiforme* var. *incrassatum* Gutwinski 1890 | 1,3 | | 2 | | | | | acf | | m | |
| *Cosmarium sportella* Brébisson ex Kützing 1849 | 3 | | 2 | B | | | | ind | | e | |

**Table 2.** Continued.

| Taxa | H | AGL /A | KGL /A | Hab | Tem | Oxy | Hal | pH | Sap | Tro | S total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *_Cosmarium staurastroides_ Eichler & Gutwinski 1849 | 1,3 | | 2 | | | | | acf | | ot | |
| _Cosmarium subcostatum_ Nordstedt 1876 var. _subcostatum_ | 1,3 | 2 | 2 | P-B | | | i | ind | | e | |
| _Cosmarium subcostatum_ var. _minus_ (West & G.S.West) Kurt Förster 1981 | 1,3 | | 2 | B | | | | ind | | m | |
| _Cosmarium subcrenatum_ Hantzsch 1868 | 1 | 2 | | B,aer | | aer | | acf | o | m | 1.1 |
| *_Cosmarium subcucumis_ Schmidle 1893 | 1,3 | | 2 | B | | | | acf | | m | |
| _Cosmarium transitorium_ (Heimerl) Ducellier 1918 | 1,3 | | 2 | | | | | acf | | m | |
| _Cosmarium verrucosum_ var. _alatum_ (Wolle) J.D.Hall & K.Karol 2016 | 3 | | 2 | | | | | | | | |
| _Cosmarium vogesiacum_ Lemaire 1883 var. _vogesiacum_ | 1,3 | | 2 | B | | | | acf | | m | |
| _Cosmarium vogesiacum_ var. _bipunctatum_ (Børgesen) Kurt Förster 1981 | 1 | | 1 | | | | | | | | |
| _Cosmarium_ sp. | 1,3 | | 2 | | | | | | | | |
| _Desmidium swartzii_ C.Agardh ex Ralfs 1848 | 1,3 | | 2 | B | | | i | ind | | m | |
| _Euastrum aemoenum_ F.Gay 1884 | 1,3 | | 2 | P-B | | | | acf | x-o | m | 0.5 |
| _Euastrum ansatum_ Ehrenberg ex Ralfs 1848 | 1 | | 2 | P-B | | | | acf | x-o | om | 0.5 |
| _Euastrum bidentatum_ Nägeli 1849 | 1,3 | | 2 | P-B | | | hb | ind | x-o | | 0.5 |
| *_Euastrum elegans_ Ralfs 1848 | 3 | | 2 | P-B | | | hb | acf | x-o | | 0.5 |
| *_Euastrum humerosum_ Ralfs 1848 var. _humerosum_ | 1 | 2 | 2 | B | | | | acf | x-o | | 0.5 |
| _Euastrum humerosum_ var. _affine_ (Ralfs) Raciborski 1885 | 1 | 2 | 2 | B | | | | acf | x-o | om | 0.5 |
| _Euastrum insulare_ (Wittrock) J.Roy 1877 | 1 | | 2 | P-B | | | hb | acf | x-o | ot | 0.5 |
| _Euastrum luetkemuelleri_ var. _carniolicum_ (Lütkemüller) Willi Krieger 1937 | 1 | | 2 | B | | | | acf | x-o | om | 0.5 |
| _Euastrum oblongum_ Greville ex Ralfs 1848 | 1,3 | 2 | 2 | B | | | | acf | x-o | ot | 0.5 |
| *_Euastrum pulchellum_ Brébisson 1856 | 1,3 | | 2 | B | | | | acf | x-o | m | 0.5 |
| *_Euastrum turneri_ West 1892 | 3 | | 2 | B | | | | acf | o-x | m | 0.6 |
| _Euastrum_ sp. | 3 | | 2 | | | | | | x-o | | 0.5 |
| *_Micrasterias americana_ var. _boldtii_ Gutwinski 1890 | 1 | 2 | | B | | | | acf | x | | 0.3 |
| *_Micrasterias papillifera_ Brébisson ex Ralfs 1848 | 1,3 | | 2 | B | | | | acf | x | | 0.3 |
| _Micrasterias rotata_ Ralfs 1848 | 1 | | 2 | B | | | | acf | x | | 0.3 |
| *_Micrasterias thomasiana_ var. _notata_ (Nordstedt) Grönblad 1920 | 1,3 | | 2 | B | | | | acf | x | | 0.3 |
| _Micrasterias truncata_ Brébisson ex Ralfs 1848 | 1,3 | 2 | 2 | B | | | | acf | | ot | |
| _Netrium digitus_ (Brébisson ex Ralfs) Itzigsohn & Rothe 1856 | 1,3 | | 2 | P-B | | | i | acf | x-o | | 0.5 |
| _Penium cylindrus_ Brébisson ex Ralfs 1848 | 1 | | 2 | B | | | | acf | | m | |
| _Penium margaritaceum_ Brébisson ex Ralfs 1848 | 1 | | 2 | P-B | | | i | acf | x-o | | 0.5 |
| _Penium polymorphum_ (Perty) Perty 1852 | 1 | | 2 | B | | st | | acf | b-a | | 2.5 |
| *_Penium spirostriolatum_ J. Barker 1869 | 1 | | 2 | B | | | | acf | | | |
| _Pleurotaenium trabecula_ Nägeli 1849 | 1,3 | | 2 | P-B | | | i | ind | | om | |
| _Spirogyra_ sp. | 1,3 | 2 | 2 | P-B | | | | alf | | | |
| *_Staurastrum aculeatum_ Meneghini ex Ralfs 1848 | 3 | | 2 | B | | | | acf | i | | 4.8 |
| *_Staurastrum acutum_ Brébisson 1856 | 3 | | 2 | | | | | acf | o | | 1.3 |
| _Staurastrum anatinum_ Cooke & Wills 1881 | 3 | | 2 | P | | | i | | | m | |
| _Staurastrum bieneanum_ Rabenhorst 1862 | 1 | | 2 | B | | | | acf | | e | |
| _Staurastrum boreale_ West & G.S.West 1905 | 1 | | 2 | B | | | | ind | | m | |
| *_Staurastrum forficulatum_ P.Lundell 1871 | 3 | | 2 | | | | | acf | o | m | 1.3 |
| *_Staurastrum heimerlianum_ var. _spinulosum_ Lütkemüller 1893 | 3 | | 2 | | | | | acf | | m | |
| _Staurastrum lapponicum_ (Schmidle) Grönblad 1926 | 1 | 2 | | B | | | | ind | | m | |
| _Staurastrum pilosum_ Brébisson 1856 | 1 | 2 | | P-B | | st-str | | acf | | ot | |
| _Staurastrum punctulatum_ Brébisson 1848 | | 2 | 2 | P-B | | st-str | i | ind | | ot | |
| *_Staurastrum spongiosum_ Brébisson ex Ralfs 1848 var. _spongiosum_ | 3 | | 2 | B,aer | | aer | | acf | | me | |
| *_Staurastrum spongiosum_ var. _perbifidum_ West 1892 | 3 | | 2 | B,aer | | aer | | acf | b-o | | 1.6 |
| *_Staurastrum teliferum_ Ralfs 1848 | 1,3 | | 2 | | | | | | | | |
| _Staurastrum tetracerum_ Ralfs ex Ralfs 1848 | 1 | 2 | | P-B | | st-str | i | ind | o | om | 1.3 |
| *_Staurastrum tohopekaligense_ Wolle 1885 | 1 | | 2 | | | | | acf | | e | |
| _Staurastrum_ sp. | 1 | | 2 | | | | | | x-o | ot | 0.5 |
| _Staurodesmus dejectus_ var. _dejectus_ Teiling 1954 | 3 | | 2 | P-B | | | hb | ind | | om | |
| *_Staurodesmus octocornis_ (Ehrenberg ex Ralfs) Stastny, Skaloud & Neustupa 2013 | 1,3 | | 2 | P-B | | | hb | acf | | m | |
| _Teilingia granulata_ (J.Roy & Bisset) Bourrelly 1964 | 3 | | 2 | P-B | | | | ind | o | ot | 1.3 |
| _Tetmemorus laevis_ Ralfs ex Ralfs 1848 | 1 | | 2 | B,aer | | aer | | ind | x-o | om | 0.5 |
| _Asterococcus limneticus_ G.M.Smith 1918 | 1 | 1 | | P | | | | | | | |
| _Asterococcus superbus_ (Cienkowski) Scherffel 1908 | 3 | | 1 | P-B | | st | | | x-b | | 0.8 |
| _Bulbochaete_ sp. | 3 | | 1 | B | | | | | o | e | 1.2 |
| _Coenochloris fottii_ (Hindák) P.M.Tsarenko 1990 | 3 | | 1 | P-B | | st-str | | | | | |
| _Coenocystis subcylindrica_ Korshikov 1953 | 3 | | 1 | P | | | i | | | | |
| _Desmodesmus abundans_ (Kirchner) E.H.Hegewald 2000 | 1,3 | | 2 | P-B | | st-str | | alf | | | |
| _Desmodesmus armatus_ var. _longispina_ (Chodat) E.Hegewald 2000 | 1,3 | | 2 | P | | st-str | | alb | b | e | 2.2 |
| _Desmodesmus maximus_ (West & G.S.West) Hegewald 2000 | 1 | | 2 | P-B | | st | | | b | e | 2.1 |
| _Desmodesmus spinosus_ (Chodat) E.Hegewald 2000 | 1 | | 2 | P-B | | st-str | | alf | b | | 2.0 |
| _Gloeocystis banneerghattensis_ M.O.P.Iyengar 1971 | 1 | 1 | | | | | | | | | |
| _Gloeocystis_ sp. | 1 | 1 | | | | | | | | | |
| _Oedogonium_ sp | 1,3 | | 2 | B | | | | alb | | | |
| _Palmococcus hercynicus_ (H.Heynig) I.Kostikov, T.Darienko, A.Lukesová, & L.Hoffmann 2002 | 3 | | 1 | | | | | | | | |
| _Pseudopediastrum boryanum_ (Turpin) E.Hegewald 2005 | 1,3 | 2 | 2 | P-B | | st-str | i | ind | b | e | 2.1 |
| _Radiococcus sphaericus_ (Shin Watanabe) I.Kostikov, T.Darienko, A.Lukesová, & L.Hoffmann 2002 | 1,3 | | 2 | | | | | | | | |
| _Scenedesmus ecornis_ (Ehrenberg) Chodat 1926 | 1 | | 2 | P | | | i | alf | o-b | e | 1.5 |
| _Scenedesmus_ sp. | 1 | | 2 | P | | | | alb | | e | |
| _Euglena granulata_ (G.A.Klebs) F.Schmitz 1884 | 3 | | 1 | P-B | eterm | st-str | mh | ind | b | e | 2.25 |
| _Euglena oblonga_ F.Schmitz 1884 | 1 | | 1 | P | eterm | st-str | | ind | b-a | | 2.5 |
| _Euglena_ sp. | 3 | | 1 | P | | | | | o-a | | 1.9 |
| _Lepocinclis acus_ (O.F.Müller) B.Marin & Melkonian 2003 | 1 | | 1 | P | eterm | st | i | ind | b-a | | 2.4 |
| _Phacus acuminatus_ A.Stokes 1885 | 1 | | 1 | P-B | eterm | st-str | i | | b-a | | 2.5 |
| _Phacus orbicularis_ Hübner 1886 | 1 | | 1 | P-B | | st-str | i | ind | | | |
| _Phacus_ sp. | 1 | | 1 | P | | | | ind | | e | |
| _Trachelomonas volvocina_ (Ehrenberg) Ehrenberg 1834 | | 2 | 2 | P-B | eterm | st-str | i | ind | b | | 2.0 |
| _Trachelomonas_ sp. | 1 | 2 | | P | | | | | b | | 2.3 |
| _Hydrurus foetidus_ (Villars) Trevisan 1848 | 1 | 1 | | B | | | | | | | |
| *_Isthmochloron trispinatum_ (West & G.S.West) Skuja 1948 | 3 | | 1 | P | | | oh | | | | |

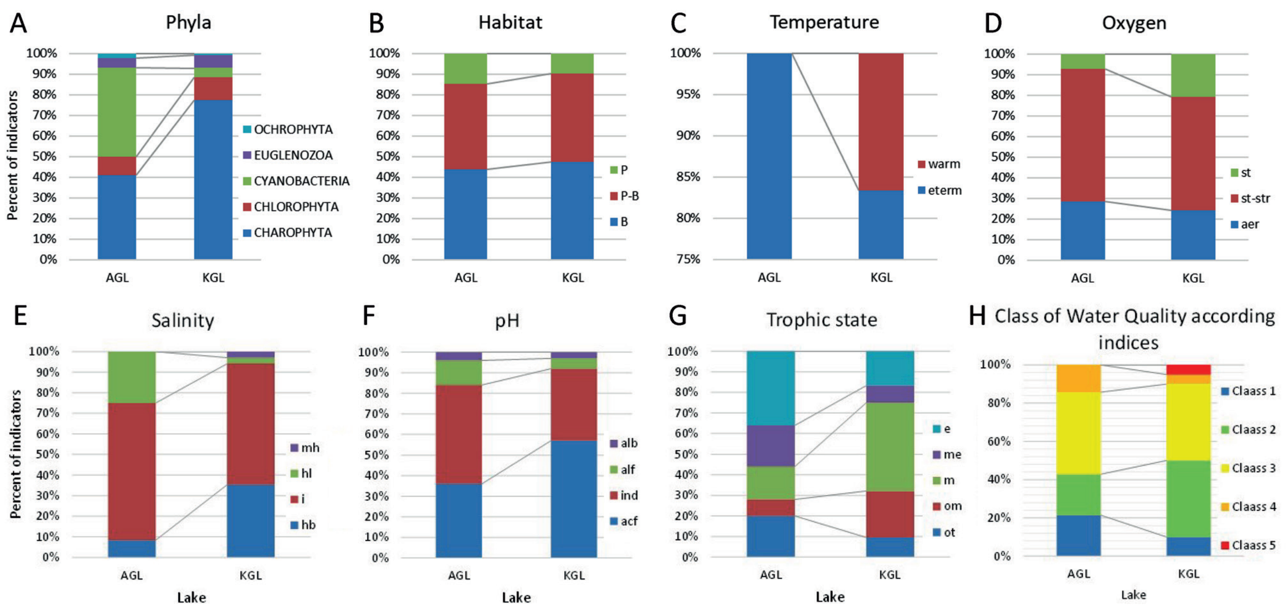


**Figure 2** Distribution of indicator species by phyla (A), habitat preferences (B), water temperature (C), oxygen (D), salinity (E), pH (F), trophic state (G) and classs of water quality (H) for benthic communities in the Avusor Great Lake and Koçdüzü Great Lake

of the Avusor Great Lake and Koçdüzü Great Lake. It was followed by indifferent (35.13 %) species. Additionally, alkaliphiles (5.26 %) and alkalibiontes (3.60 %) species were also seen in the algal flora of the both lakes. As a whole, indicator groups consisting of acidophiles and indifferent were comprised 90.98 % of the indicator species in all non-diatom algal flora (Fig. 2F). One of the factors that determine the trophic status of lakes is the amount of organic matter they contain (Van Dam et al. 1994). While mesotrophic species constituted the dominant group in the flora with 40.40 %, this was followed by oligo-mesotrophic (20.20 %) and eutrophic (20.20 %) species, respectively. While oligotrophic species are represented by 10.10 % in the flora, the rate of mesotrophic species is 9.09 %. It is noteworthy that mesotrophic species predominate in Koçdüzü Great Lake and eutrophic species dominate in Avusor Great Lake (Fig. 2G). While the indicators of Class 3 ranked first of the both lakes, Class 2 was second. Class 1 was represented in the Avusor Great Lake with more indicator species. It is noteworthy that indicator species of all classes are presented in the Koçdüzü Great Lake (Fig. 2H).

## DISCUSSION

In the Table 1 data give us the opportunity to say that the lakes do not experience eutrophication and acidification problems, which are the most important issues of glacial lakes (Bjork 1988, Lotter et al. 1999).

When the benthic algal floras were compared both of the lakes, it was determined that the species diversity and relative abundances of the lakes were different. In the benthic algal flora, Koçdüzü Lake is represented by 128 species, while the species diversity of Avusor Lake is very low (44 species). The number of common species in the flora of both lakes is 15 (9.55 %). The benthic algal flora of the Avusor Lake mostly consists of the members of Cyanobacteria (19 species) and Charophyta (18 species). With 99 species only Charophyta was dominated in the flora of Koçdüzü Lake (Table 2). This situation can be explained by the fact that the epiphytic samples taken from Koçdüzü Lake have a rich desmid diversity.

It is seen that the non-diatom taxonomic composition of both lakes is compatible with the lakes in Artabel Lakes Nature Park and Suntar-Khayat Ridge (Şahin et al. 2020a, Kopyrina et al. 2022). It is thought that similar water parameters, similar land structures, and similar macroclimatic conditions are effective in the formation of this situation. The Desmidiaceae and Closteriaceae families accounted for 64.33 % of the total flora. This is consistent with previous studies conducted in the region (Şahin 2000, 2001, Şahin et al. 2020b) and with literature that indicates these families are most diverse in the northern mountainous regions (Sterlyagova 2008, Stamenkovič et al. 2008, Šovran et al. 2013). On the orther hand, it was not also surprising that 53.50 % of the flora was represented by the genera *Cosmarium*, *Staurastrum*, *Closterium* and *Euastrum*. They, because, are inhabitants of littoral regions of clear waters in the northern regions (Stamenkovič et al. 2008, Şahin et al. 2020a,b). Also, *Pleurotaenium* and *Teilingia* genera, represented by one species each in the flora, are considered typical genera of the mountainous regions in the North (Coesel 1996).

The ecological needs and habits of species and taxonomic groups are effective in the biotic distribution of algae (Tsarenco et al. 2019).

The most striking feature of the detected flora is the dominance of Charophyta members (Table 1). When this result is compared with the flora of the lakes in the Artabel Lakes Nature Park (located at 2600-3000 m a.s.l), it will be seen that there is a similar situation (Şahin et al. 2020a). We can say that similar habitat and macro-climatic conditions are effective on the formation process of the flora structure. In addition, we can also state that the members of Charophyta are better adapted to arctic climatic conditions than the diatoms.

Although most of the desmid flora consists of cosmopolitan species (91.50 % of total desmids taxa number), there are species, which have holarctic, boreal, boreal-arctic, arctic-alpine and alpine characteristics in the flora (Coesel 1996, John et al. 2003, Lenzenweger1996, 1997, 1999, Kosteviciene et al. 2003, Sterlyagova 2008). This group consisting of species such as *Actinotaenium cucurbita*, *A. cucurbitinum*, *A. rufescens*, *Cosmarium amoenum*, *C. debaryi*, *C. sportella*, *Euastrum bidentatum*, *Penium polymorphum*, and *Tetmemorus leavis* informs us that lakes are affected by glaciers (Stamenkovič et al. 2008, Fuzinata et al. 2011a,b).

The saturation of dissolved organic matter in water is the important source that gives us information about the trophic status of lakes. However, we cannot ignore the contribution of the indicator species that form the basis of the trophic pyramid (Barinova 2017).

Considering these findings, we can say that the investigated lakes are of mesotrophic character. Such bioindicator desmid distribution was also observed in the region and Russia (Şahin et al. 2020b, Kopyrina et al. 2022). The fact that the species are cosmopolitan, as well as similar macro-climatic conditions, can an effect on the formation of this situation.

In the literature (Effiong & Inyang 2015) states that genera such as *Euglena*, *Oscillatoria* and *Phacus* are usually members of organically polluted waters. However, there is also literature information that members of these genera have wide ecological tolerance. *Euglena* members, for example, found in hard or soft waters of low pH (0.9) to high pH (over 8.0) (Prescott1962, Wehr & Sheath 2003).

## CONCLUSION

We implemented in the first time ecological assessment of water quality with bioindication methods in the Avusor Great Lake and Koçdüzü Great Lake. Bioindication of two lake water properties was doing with species-specific preferences of 157 indicator species of five taxonomic phyla of algae collected in summer of 2019 in 6 sampling points along the lake shore. The prevalence of charophyta species allowed us to implement few bioindication systems for conclusion about water properties. In indicator groups were prevaled bentic, eurythermic water inhabitants, which preferred middle oxygenated, acidophilic and indifferent water. Bioindication also showed that the water in both lakes as clear, Class 3 water quality and mesotrophic species predominated in the lakes. However, increasing human pressure, the effects of recreational use and changes in the ecosystem are causing the biota to change over time. We therefore believe that this study will be an important source of data for future lake monitoring.

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