

STRUCTURE AND ENVIRONMENTAL DETERMINANTS OF BENTHIC ALGAL COMMUNITIES IN THE HIGH-MOUNTAIN LAKES AND PONDS ECOSYSTEMS OF KAÇKAR MOUNTAINS NATIONAL PARK, N.E. TURKEY

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ABSTRACT

In August 2023, the composition, diversity, and relationships with environmental factors of benthic algae in the three lakes and two ponds located in the Kaçkar Mountains National Park were investigated. The surveyed flora comprised 139 species across five taxonomic groups: Bacillariophyta (75 species), Charophyta (35), Cyanobacteria (17), Chlorophyta (8), and Euglenozoa (4). The most species-rich genera were *Pinnularia* (13), followed by *Eunotia* (10), *Cosmarium* (10), *Staurastrum* (7), and *Closterium* (6). Physico-chemical analyses indicated that the waters were fresh, slightly acidic, low in salinity, and free from organic pollution, which was corroborated by bioindicator species. This study provides baseline data on the composition of benthic algae and highlights the lack of significant anthropogenic impact on these habitats.

ZUZAMMENFASSUNG: Struktur und Umweltdeterminanten benthischer Algengemeinschaften in den Hochgebirgsseen und Teichökosystemen des Nationalparks Kaçkar-Gebirge, N.O. Turkey.

Im August 2023 wurden Zusammensetzung, Diversität und Wechselwirkungen der benthischen Algen in drei Seen und zwei Teichen des Nationalparks Kaçkar-Gebirge mit Umweltfaktoren untersucht. Die erfasste Flora umfasste 139 Arten aus fünf taxonomischen Gruppen: Bacillariophyta (75 Arten), Charophyta (35), Cyanobakterien (17), Chlorophyta (8) und Euglenozoa (4). Die artenreichsten Gattungen waren *Pinnularia* (13), gefolgt von *Eunotia* (10), *Cosmarium* (10), *Staurastrum* (7) und *Closterium* (6). Physikalisch-chemische Analysen ergaben, dass die Gewässer süß, leicht sauer, salzarm und frei von organischen Schadstoffen waren. Dies wurde durch Bioindikatorarten bestätigt. Diese Studie liefert Basisdaten zur Zusammensetzung der benthischen Algen und hebt hervor, dass diese Lebensräume nicht signifikant vom Menschen beeinflusst werden.

REZUMAT: Structura și determinanții de mediu ai comunităților de alge bentonice din ecosistemele de lacuri și iazuri înalte de munte din Parcul Național Munții Kaçkar, N.E. Turciei.

În august 2023, au fost investigate compoziția, diversitatea și relațiile cu factorii de mediu ale algelor bentonice din cele trei lacuri și două iazuri situate în Parcul Național Munții Kaçkar. Flora studiată a cuprins 139 de specii din cinci grupe taxonomice: Bacillariophyta (75 de specii), Charophyta (35), Cyanobacteria (17), Chlorophyta (8) și Euglenozoa (4). Genurile cele mai bogate în specii au fost *Pinnularia* (13), urmate de *Eunotia* (10), *Cosmarium* (10), *Staurastrum* (7) și *Closterium* (6). Analizele fizico-chimice au indicat că apele erau proaspete, ușor acide, cu salinitate scăzută și lipsite de poluare organică, fapt coroborat de speciile bioindicatoare. Acest studiu oferă date de referință privind compoziția algelor bentonice și evidențiază lipsa unui impact antropic semnificativ asupra acestor habitate.

INTRODUCTION

Due to the rapid evolution of algal taxonomy, the revision of species, the description of new species, and the application of next-generation sequencing approaches to ecological monitoring studies, the establishment of taxonomic floras of local areas is of significant importance, as an accurately determined biodiversity structure provides a basis for verifying species distribution and richness, assessing changes in the flora due to anthropogenic pressures and climate change, harmonising current and future monitoring data, and comparing data obtained from modern metabarcoding approaches (Alers-Garcia et al., 2021; Bishop et al., 2017).

High-mountain lakes and ponds constitute particularly vulnerable freshwater ecosystems due to their relative isolation, water oligotrophic status, extreme seasonality, and rapid hydrological responsiveness. These systems function as sentinel habitats, where benthic algal communities rapidly reflect environmental perturbations, thereby providing early indicators of ecosystem health and resilience. Their sensitivity underscores the ecological and conservation significance of alpine aquatic habitats, particularly in regions subject to accelerated climate warming and diffuse anthropogenic influence (Pastesino and Prearo, 2020).

Kaçkar Mountains National Park, located in Turkey's Eastern Black Sea region, encompasses nearly 100 glacial lakes with highly varying morphometry and hydrology (GDNCNP, 2006). Previous studies by Şahin and Barinova (2025a, 2025b, 2024) characterized benthic algal assemblages in 14 lakes and one pond, documenting 228 taxa across five most important phyla (Bacillariophyta, Charophyta, Cyanobacteria, Chlorophyta, and Euglenozoa). These scientific investigations emphasized the ecological prominence of diatoms and desmids and added 12 species previously unrecorded in the Turkish freshwater flora (Şahin, 2023, 2022a).

Despite these scientific contributions, comprehensive knowledge of algal diversity in alpine lakes and ponds of Turkey remains rather fragmented, needing supplementary efforts in this respect. Existing studies are often spatially limited or taxonomically constrained, impeding the establishment of robust baselines necessary for long-term monitoring, ecological assessment, and conservation planning. Protected high-mountain ecosystems such as Kaçkar Mountains National Park provide unique opportunities to disentangle natural ecological variability from anthropogenic influences, offering benchmarks for evaluating climate-driven ecological change.

Benthic algal community structure is predominantly governed by water physical and chemical parameters, including pH, conductivity, nutrient concentrations, water temperature, and last but not least the habitat substrate composition. Quantifying the relative influence of these main variables is essential for mechanistic understanding of species-environment relationships and for informing ecological status assessments (Yang et al., 2018; Schneider et al., 2013).

The present research addresses these knowledge gaps by examining benthic algal assemblages in three previously unstudied lakes and two ponds within Kaçkar Mountains National Park. By integrating taxonomic identification with comprehensive physicochemical measurements, the research aims to (i) document species composition and richness, (ii) identify environmental determinants of community structure, and (iii) floristic data to support long-term ecological monitoring and conservation efforts in sensitive alpine freshwater ecosystems.

MATERIAL AND METHODS

Study area description

Kaçkar Mountains National Park is situated in the northeastern sector of Turkey and encompasses an area of around 51,550 ha. The park extends between 40°57'49''-40°42'10''N and 41°14'45''-40°51'27''E, forming the northeastern edge of the Eastern Black Sea Mountain Belt. This mountainous region reaches nearly 600 km in length and 200 km in width (Fig. 1) (GDNCNP, 2006). The geological framework of the park is mainly composed of granitic and volcanic lithologies, originating from Late Cretaceous to Eocene magmatic activity (Eyüpoğlu et al., 2019). The Kaçkar region is one of the few areas in Turkey where both remnants of Pleistocene glaciation and ongoing glacial dynamics are visible. Its geomorphology reveal nine pronounced glacial valleys, cirques, hanging valleys, moraine-dammed lakes and extensive moraine deposits, reflecting a complex glacial history (Kurdoğlu, 2002). Climatically, the area is governed by the Eastern Black Sea regime, characterized by cool summers, relatively mild winters and a consistently high annual precipitation distributed across all seasons (Erinç, 1969). In the lower elevations of the park, winter temperatures typically vary between 0 and 4°C, while summer temperatures exceed 18°C. At elevations above 3,000 m, thermal conditions become markedly colder, with winter values reaching approximately -6°C and summer temperatures stabilizing between 6 and 9°C. Annual rainfall averages around 2,000 mm (GDNCNP, 2006). The park harbors four primary soil categories: alpine meadow soils, lime-free brown forest soils, red-yellow soils and grey-brown soils (GDNCNP, 2006). Floristically, the region is positioned within the Colchic section of the Euro-Siberian phytogeographical province (Davis et al., 1965). Additionally, the area forms one of the three major avian migration corridors in Turkey, underscoring its biodiversity importance (Gürpınar, 1987).



Figure 1: The locations of Kaçkar Mountains National Park, lakes and ponds.

Description of studied lakes and ponds

The studied lakes and ponds are located in the south-western part of the Kaçkar Mountains National Park. The names, geographical coordinates, altitudes above sea level and surface area measurements of the lakes and ponds where epipelagic, epilithic, and epiphytic algae samples were collected are given in table 1, and their photographs are shown in figure 2.



Figure 2: The habitat views of Kaçkar Mountains National Park lakes and ponds: (a) Çermeşk Lake, (b) Karagöl Lake, (c) Adsız Lake, (d) Pond-1, (e) Pond-2. (photos Bülent Şahin).

Field investigation

A total of fourteen benthic algal samples were collected from the researched habitats during August 2023. Epipelagic material was obtained from the surface layer of the sediment in all sites except Lake Karagöl, using a glass tube measuring one meter in length and 0.8 centimeter in diameter. Epilithic samples were gathered by brushing stones that had been randomly selected from the shoreline of Adsız Lake with a soft toothbrush. Epiphytic algae were extracted by squeezing macrophytes (*Potamogeton* sp. and *Juncus* sp.) collected from Pond-2 (Sladeckova, 1962; Round, 1953). All samples were transferred into 100-ml plastic containers and preserved with 4% formaldehyde. In situ measurements of water temperature, dissolved oxygen, electrical conductivity, and pH were performed using a Thermo Orion-4-Star pH meter (Hampton, NH, USA; Marshall Scientific) and a YSI-55 dissolved oxygen meter (Letchworth, Hertfordshire, UK; Xylem Analytics). Water samples were collected only from the lakes for additional chemical analyses, which were conducted at the Quality Control Laboratory of the 22nd Regional Directorate of the General Directorate of State Hydraulic Works.

Laboratory analyses

In the laboratory, permanent slides were prepared for diatom identification. A portion of each sample was treated with 37% hydrogen peroxide and heated to remove organic material, followed by repeated rinsing with distilled water. The cleaned suspension was spread onto cover-slips, dried at room temperature, and mounted in Naphrax® (Chippenham, UK). Temporary slides were used for the examination of non-diatom algae. All algal specimens were observed and photographed using a Leica DM 2500 light microscope and Leica DFC 290 camera (Wetzlar, Germany; Leica Microsystems).

Table 1: Geographic coordinates, altitude and surface area information of the studied lakes and ponds.

Lakes and ponds	Geographic coordinates		Altitude (m)	Area (m ²)
Çermeş Lake (ÇL)	40°44'54.30''N	40°52'08.58''E	2810	51.362
Karagöl Lake (KL)	40°44'34.24''N	40°52'04.74''E	3010	49.405
Adsız Lake (AL)	40°44'21.50''N	40°51'50.44''E	3089	16.640
Pond-1 (P-1)	40°44'59.24''N	40°52'10.89''E	2800	242
Pond-2 (P-2)	40°44'55.26''N	40°51'55.26''E	3041	638

Data analysis

Taxonomic identifications were made using standard monographs and floras, including Prescott (1962), Patrick and Reimer (1975, 1966), Ruzicka (1977), Croasdale and Flint (1988, 1986), Krammer and Lange-Bertalot (1991a, 1991b, 1988, 1986), Gabor (1995), Lenzenweger (1999, 1997, 1996), John et al. (2003), Komarek and Anagnostidis (2005, 1998), Kadlubowska (2009), Brook and Williamson (2010), Coesel and Meesters (2013, 2007), and Cantonati et al. (2017). The taxonomic status and valid names of the species were verified through the AlgaeBase database (Guiry and Guiry, 2025). IUCN and red list categories were identified for diatoms only (Hofmann et al., 2018).

Ecological preference assessments were conducted using the bioindicator system proposed by Barinova (2025). Network analyses were performed with the JASP botnet package to explore significant relationships among taxa and environmental parameters (Love et al., 2019). Similarity among samples was evaluated using Bray-Curtis cluster analysis implemented in BioDiversity Pro 2.0 (McAleece et al., 1997).

The frequency of each algal taxon was determined according to its occurrence across the studied lakes and categorized into five classes: very rare (VR, 1-20%), rare (R, 21-40%), common (C, 41-60%), frequent (F, 61-80%), and very frequent (VF, 81-100%) (Koçataş, 1992).

RESULTS AND DISCUSSION

Physical and chemical properties of the waters

The physicochemical analysis results of the lakes and ponds are presented in table 2. It can thus be concluded that, in consideration of these values, the studied waters are to be regarded as fresh, exhibiting low salinity, a slightly acidic pH, and being uncontaminated by organic pollutants.

Table 2: The physical and chemical properties in the lakes and ponds of the Kaçkar Mountains National Park in 2023.

Lakes and ponds parameters	Çermeşk Lake (ÇL)	Karagöl Lake (KL)	Adsız Lake (AL)	Pond-1 (P-1)	Pond-2 (P-2)
Water Temperature (°C)	17	15.5	10	18	16
DO (mg L ⁻¹)	8.70	8.50	8.20	8.60	8.40
pH	6.09	5.53	5.30	6.20	5.50
Conductivity (µS cm ⁻¹)	49.8	56.6	51.7	50	55
TDS (mg L ⁻¹)	17.50	20.46	18.20	–	–
Total Hardness (mg L ⁻¹)	32.00	19.00	25.80	–	–
Potassium (mg L ⁻¹)	0.47	0.37	0.35	–	–
Calcium (mg L ⁻¹)	10	7.2	9.2	–	–
Magnesium (mg L ⁻¹)	1.68	0.19	0.67	–	–
Ammonium (mg L ⁻¹)	0.07	0.01	0.01	–	–
Chlorine (mg L ⁻¹)	1.12	1.04	1.02	–	–
Nitrate (mg L ⁻¹)	0.001	0.001	0.001	–	–
Nitrite (mg L ⁻¹)	0.001	0.007	0.008	–	–
Phosphate (mg L ⁻¹)	0.017	0.012	0.053	–	–

Floristic composition and diversity of algae

The examination of epipellic, epilithic and epiphytic communities revealed a total of 139 algal taxa distributed across the divisions Cyanobacteria, Bacillariophyta, Charophyta, Chlorophyta and Euglenozoa. Among these groups, Bacillariophyta constituted the most taxon-rich division with 75 species, followed by Charophyta with 35 species. Cyanobacteria (17 species), Chlorophyta (8 species) and Euglenozoa (4 species) contributed comparatively fewer representatives to the overall flora. Within the genera, *Pinnularia* (13 species), *Eunotia* (10 species), *Cosmarium* (10 species), *Staurostrum* (7 species) and *Closterium* (6 species) were the most diverse, whereas the remaining genera were represented by no more than four taxa. Çermeşk Lake hosted the richest assemblage, containing 74 species. Additionally, two desmid taxa – indicated by an asterisk (*) in table 3 – were documented as new records for the algal flora of Turkey. Table 3 includes the complete list of identified species, their habitat affiliations, occurrence frequencies and distributions across the sampled lakes and ponds (Figs. 3-9).

Table 3: Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Cyanobacteria									
<i>Ammatoidea normanii</i> West & G. S. West 1897	2	VR	–	–	0	0	1	0	0
<i>Cyanothece aeruginosa</i> (Nägeli) Komárek 1976	1	VR	–	–	0	1	0	0	0
<i>Johannesbaptistia pellucida</i> (Dickie) W. R. Taylor & Drouet 1938	2	VR	–	–	0	0	1	0	0

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Cyanobacteria									
<i>Kamptonema formosum</i> (Bory ex Gomont) Strunecký, Komárek & J. Smarda 2014	1	VR	–	–	1	0	0	0	0
<i>Komvophoron crassum</i> (Vozzhennikova) Anagnostidis & Komárek 1988	1	VR	–	–	0	1	0	0	0
<i>Komvophoron minutum</i> (Skuja) Anagnostidis & Komárek 1988	1	VR	–	–	0	0	0	1	0
<i>Komvophoron schmidlei</i> (Jaag) Anagnostidis & Komárek 1988	1	VR	–	–	0	0	0	1	0
<i>Merismopedia elegans</i> A. Braun ex Kützing 1849	1	VR	–	–	1	0	0	0	0
<i>Merismopedia glauca</i> (Ehrenberg) Kützing 1845	2	VR	–	–	1	0	1	0	0
<i>Merismopedia</i> sp.	1	VR	–	–	1	0	0	0	0
<i>Microcoleus amoenus</i> (Gomont) Strunecky, Komárek & J. R. Johansen 2013	1	VR	–	–	1	0	0	0	0
<i>Oscillatoria</i> sp.	1	VR	–	–	1	0	0	0	0
<i>Oscillatoria princeps</i> Vaucher ex Gomont 1892	1	VR	–	–	1	0	0	0	0
<i>Oscillatoria tenuis</i> C. Agardh ex Gomont 1892	1,2,3	F	–	–	1	0	1	1	1
<i>Phormidium ambiguum</i> Gomont 1892	3	VR	–	–	0	0	1	0	0
<i>Potamolinea aerugineocaerulea</i> (Gomont) M. D. Martins & L. H. Z. Branco 2016	2	VR	–	–	0	0	1	0	0
<i>Stigonema ocellatum</i> Thuret ex Bornet & Flahault 1886	3	VR	–	–	0	0	0	0	1

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Bacillariophyta									
<i>Achnanthyidium minutissimum</i> (Kützing) Czarnecki 1994	1	VR	LC	9	1	0	0	0	0
<i>Amphora ovalis</i> (Kützing) Kützing 1844	1.2	R	LC	9	1	0	1	0	0
<i>Aulacoseira distans</i> (Ehrenberg) Simonsen 1979	1	VR	EN	5	0	0	0	0	1
<i>Aulacoseira lacustris</i> f. <i>tenuior</i> Houk, Klee & Passauer 2007	1.2	R	–	–	0	1	1	0	0
<i>Aulacoseira valida</i> (Grunow) Krammer 1991	1	R	EN	5	1	0	0	0	1
<i>Brachysira brebissonii</i> R. Ross 1986	1	VR	EN	4	0	1	0	0	0
<i>Caloneis schumanniana</i> (Grunow) Cleve 1894	1	VR	EN	4, 5	1	0	0	0	0
<i>Caloneis silicula</i> (Ehrenberg) Cleve 1894	1	R	LC	9	1	0	0	1	0
<i>Cavinula lapidosa</i> (Krasske) Lange-Bertalot 1996	1	VR	–	–	0	0	0	0	1
<i>Cyclotella bodanica</i> var. <i>lemanica</i> (O. Müller ex Schroter) Bachmann 1903	1	VR	NE	0; 10	1	0	0	0	0
<i>Cyclotella distinguenda</i> Hustedt 1928	1	VR	LC	9	0	0	0	1	0
<i>Cyclotella striata</i> (Kützing) Grunow 1880	1.2	R	LC	9	1	0	1	0	0
<i>Cymbella cistula</i> (Ehrenberg) O. Kirchner 1878	1.2	R	DD	8	1	0	1	0	0
<i>Cymbella cymbiformis</i> C. Agardh 1830	3	VR	EN	4	0	0	0	0	1
<i>Cymbopleura cuspidata</i> (Kützing) Krammer 2003	1.3	R	EN	5	0	0	0	1	1
<i>Cymbopleura naviculiformis</i> (Auerswald ex Heiberg) Krammer 2003	1.3	C	LC	9	1	0	0	1	1
<i>Diatoma moniliformis</i> (Kützing) D. M. Williams 2012	1	VR	LC	9	0	0	0	0	1

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Bacillariophyta									
<i>Didymosphenia geminata</i> (Lyngbye) Mart. Schmidt 1899	1.2	R	LC	9	1	0	1	0	0
<i>Diploneis elliptica</i> (Kützing) Cleve 1894	1	VR	NT	7	1	0	0	0	0
<i>Encyonema minutum</i> (Hilse) D. G. Mann 1990	1,2,3	VF	LC	9	1	1	1	1	1
<i>Encyonema silesiacum</i> (Bleisch) D. G. Mann 1990	1	R	LC	9	1	0	0	0	1
<i>Epithemia gibba</i> (Ehrenberg) Kützing 1844	1.3	C	NE	0, 10	1	0	0	1	1
<i>Eunotia boreoalpina</i> Lange-Bertalot & Nörpel-Schempp 1998	1.3	C	NE	0	1	0	0	1	1
<i>Eunotia cristagalli</i> Cleve 1891	1	C	NE	0, 10	1	0	0	1	1
<i>Eunotia diodon</i> Ehrenberg 1837	1.3	C	NE	0-10	0	1	0	1	1
<i>Eunotia flexuosa</i> (Brébisson ex Kützing) Kützing 1849	3	VR	CR	3	0	0	0	0	1
<i>Eunotia glacialis</i> F.Meister 1912	1	VR	EN	4, 5	0	0	0	0	1
<i>Eunotia hexaglyphis</i> Ehrenberg 1854	1	VR	CR	2, 3	0	0	0	0	1
<i>Eunotia islandica</i> Østrup 1918	1	VR	DD	8	0	0	0	0	1
<i>Eunotia mucophila</i> (Lange-Bertalot, Nörpel-Schempp & Alles) Lange-Bertalot 2007	1.3	C	EN	5	1	0	0	1	1
<i>Eunotia paludosa</i> Grunow 1862	1	R	NT	7	1	0	0	0	1
<i>Eunotia praerupta</i> Ehrenberg 1843	1,2,3	C	CR	3	0	0	1	1	1
<i>Fragilaria capucina</i> Desmazières 1830	1	VR	LC	9	1	0	0	0	0
<i>Fragilaria radians</i> (Kützing) D. M. Williams & Round 1987	1	VR	LC	9	1	0	0	0	0

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Bacillariophyta									
<i>Frustulia amphipleuroides</i> (Grunow) Cleve-Euler 1934	1	VR	–	–	1	0	0	0	0
<i>Frustulia crassinervia</i> (Brébisson ex W. Smith) Lange-Bertalot & Krammer 1996	1	C	NT	7	1	0	0	1	1
<i>Frustulia rhomboides</i> (Ehrenberg) De Toni 1891	1	VR	NE	0, 10	1	0	0	0	0
<i>Gomphonella olivacea</i> (Hornemann) Rabenhorst 1853	1	VR	LC	9	1	0	0	0	0
<i>Gomphonema hebridense</i> W. Gregory 1854	1	VR	NT	7	0	0	0	0	1
<i>Gomphonema parvulum</i> (Kützing) Kützing 1849	1.2	VF	LC	9	1	1	1	1	1
<i>Gomphonema truncatum</i> Ehrenberg 1832	1.2	C	LC	9	1	0	1	1	0
<i>Hannaea arcus</i> (Ehrenberg) R. M. Patrick 1966	1	VR	NT	7	1	0	0	0	0
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow 1880	1	VR	LC	9	1	0	0	0	0
<i>Iconella biseriata</i> (Brébisson) Ruck & Nakov 2016	1	VR	LC	9	1	0	0	0	0
<i>Iconella linearis</i> (W. Smith) Ruck & Nakov 2016	1	R	LC	9	1	0	0	0	1
<i>Iconella tenera</i> (W. Gregory) Ruck & Nakov 2016	1.3	C	NT	7	1	0	0	1	1
<i>Meridion circulare</i> (Greville) C. Agardh 1831	1	VR	LC	9	1	0	0	0	0
<i>Navicula cryptocephala</i> Kützing 1844	1	VR	LC	9	1	0	0	0	0
<i>Navicula cryptotenella</i> Lange-Bertalot 1985	1	VR	LC	9	0	0	0	0	1
<i>Navicula radiosa</i> Kützing 1844	1	VR	LC	9	1	0	0	0	0

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Bacillariophyta									
<i>Navicymbula pusilla</i> (Grunow) Krammer 2003	1	VR	–	–	0	0	0	1	0
<i>Neidium ampliatus</i> (Ehrenberg) Krammer 1985	1.3	R	NT	7	0	0	0	1	1
<i>Neidium dubium</i> (Ehrenberg) Cleve 1894	1	VR	LC	9	1	0	0	0	0
<i>Neidium iridis</i> (Ehrenberg) Cleve 1894	1	VR	CR	3	1	0	0	0	0
<i>Neidium productum</i> (W. Smith) Cleve 1894	1.3	R	EN	5	0	0	0	1	1
<i>Orthoseira dendroteres</i> (Ehrenberg) Genkal & Kulikovskiy 2010	1.2	C	–	–	1	0	1	0	1
<i>Pinnularia abaujensis</i> var. <i>linearis</i> (Hustedt) R. M. Patrick 1966	3	VR	NE	0, 10	0	0	0	0	1
<i>Pinnularia aestuarii</i> Cleve 1895	1	VR	NE	0, 10	0	0	0	0	1
<i>Pinnularia borealis</i> Ehrenberg 1843	1.3	C	LC	9	0	1	0	1	1
<i>Pinnularia hemiptera</i> (Kützing) Rabenhorst 1853	1	VR	NE	0, 10	0	0	0	0	1
<i>Pinnularia interrupta</i> W. Smith 1853	1	C	NE	0, 10	1	0	0	1	1
<i>Pinnularia major</i> (Kützing) Rabenhorst 1853	1	C	NE	0, 10	1	0	0	1	1
<i>Pinnularia microstauron</i> (Ehrenberg) Cleve 1891	1	C	NT	7	0	1	0	1	1
<i>Pinnularia platycephala</i> (Ehrenberg) Cleve 1891	1	VR	EN	4, 5	0	1	0	0	0
<i>Pinnularia rupestris</i> Hantzsch 1861	1	VR	EN	5	0	0	0	0	1
<i>Pinnularia</i> sp.	1	VR	-	–	–	0	0	1	0
<i>Pinnularia subrupestris</i> Krammer 1992	1	VR	EN	5	0	0	0	0	1
<i>Pinnularia sudetica</i> Hilse 1861	1	VR	DD	8	0	0	0	1	0

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Bacillariophyta									
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg 1843	1.3	C	DD	8	1	0	0	1	1
<i>Sellaphora pupula</i> (Kützing) Mereschkovsky 1902	1	C	DD	8	0	1	0	1	1
<i>Stauroneis anceps</i> Ehrenberg 1843	1.3	C	NT	7	1	0	0	1	1
<i>Surirella angusta</i> Kützing 1844	1	VR	LC	9	1	0	0	0	0
<i>Surirella robusta</i> Ehrenberg 1841	1	VR	EN	4, 5	0	1	0	0	0
<i>Tabellaria flocculosa</i> (Roth) Kützing 1844	1.2	C	LC	9	1	0	1	0	1
<i>Ulnaria acus</i> (Kützing) Aboal 2003	2	VR	LC	9	0	0	1	0	0
Charophyta									
<i>Actinotaenium spinospermum</i> (Joshua) Kouwets & Coesel 1984	1	VR	–	–	1	0	0	0	0
<i>Closterium diana</i> var. <i>brevius</i> (Petkoff) Willi Krieger 1935	1	VR	–	–	0	0	0	0	1
<i>Closterium incurvum</i> Brébisson 1856	1.3	R	–	–	0	0	0	1	1
<i>Closterium lunula</i> Ehrenberg & Hemprich ex Ralfs 1848	3	VR	–	–	0	0	0	0	1
<i>Closterium parvulum</i> Nägeli 1849	1	VR	–	–	1	0	0	0	0
<i>Closterium pritchardianum</i> W. Archer 1862	1	R	–	–	1	0	0	0	1
<i>Closterium tumidulum</i> F. Gay 1884	1	VR	–	–	1	0	0	0	0
<i>Cosmarium abbreviatum</i> Raciborski 1885	1	VR	–	–	0	0	0	1	0
<i>Cosmarium crenatum</i> var. <i>bicrenatum</i> Nordstedt 1872	1	VR	–	–	1	0	0	0	0
<i>Cosmarium impressulum</i> var. <i>suborthogonum</i> (Raciborski) Taft 1945	2	VR	–	–	0	0	1	0	0
<i>Cosmarium laeve</i> Rabenhorst 1868	2	VR	–	–	0	0	1	0	0

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Charophyta									
<i>Cosmarium laeve</i> var. <i>octangulare</i> (Wille) West & G.S.West 1908	1	VR	–	–	1	0	0	0	0
<i>Cosmarium notabile</i> var. <i>transiens</i> Insam & Willi Krieger 1936	1	VR	–	–	0	0	0	0	1
<i>Cosmarium pygmaeum</i> W. Archer 1864	1	VR	–	–	0	0	0	1	0
<i>Cosmarium regnellii</i> var. <i>pseudoregnellii</i> (Messikommer) Willi Krieger 1944	1	VR	–	–	1	0	0	0	0
<i>Cosmarium subcostatum</i> var. <i>minus</i> (West & G. S. West) Kurt Förster 1981	1.2	C	–	–	1	0	1	1	0
<i>Cosmarium subcrenatum</i> Hantzsch 1868	1	R	–	–	0	0	0	1	1
<i>Euastrum ansatum</i> var. <i>pyxidatum</i> Delponte 1873	1	R	–	–	1	0	0	0	1
<i>Euastrum denticulatum</i> F. Gay 1884	1.3	R	–	–	0	0	0	1	1
<i>Euastrum oblongum</i> Greville ex Ralfs 1848	1	C	–	–	1	0	0	1	1
<i>Micrasterias thomasi</i> var. <i>notata</i> (Nordstedt) Grönblad 1920	1	R	–	–	1	0	0	0	1
<i>Penium margaritaceum</i> Brébisson ex Ralfs 1848	1	VR	–	–	1	0	0	0	0
<i>Penium spirostriolatum</i> J. Barker 1869	1.3	VR	–	–	0	0	0	1	1
<i>*Pleurotaenium crenulatum</i> (Ehrenberg ex Ralfs) Rabenhorst 1868	1	VR	–	–	0	0	0	1	0
<i>Spirogyra</i> sp.	1	VR	–	–	1	0	0	0	0
<i>Spirogyra weberi</i> Kützing 1843	1,2,3	C	–	–	1	0	1	0	1
<i>Staurostrum dilatatum</i> Ehrenberg ex Ralfs 1848	1	VR	–	–	1	0	0	0	0
<i>Staurostrum dispar</i> Brébisson 1856	1	VR	–	–	1	0	0	0	0

Table 3 (continued): Distribution of species content with frequency, IUCN and red list categories in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

Species	H	F	IUCN	Red List	CL	KL	AL	P-1	P-2
Charophyta									
<i>Staurostrum gracile</i> Ralfs ex Ralfs 1848	1	VR	–	–	1	0	0	0	0
* <i>Staurostrum kouwetsii</i> Coesel 1996	1	VR	–	–	0	0	0	0	1
<i>Staurostrum oxyacanthum</i> var. <i>polyacanthum</i> Nordstedt 1885	1	VR	–	–	1	0	0	0	0
<i>Staurostrum polymorphum</i> Brébisson 1848	1	VR	–	–	1	0	0	0	0
<i>Staurostrum punctulatum</i> Brébisson 1848	1.2	R	–	–	1	0	1	0	0
<i>Tetmemorus laevis</i> Ralfs ex Ralfs 1848	1	VR	–	–	0	0	0	1	0
<i>Zygnema</i> sp.	2	VR	–	–	0	0	1	0	0
Chlorophyta									
<i>Bulbochaete</i> sp.	2	VR	–	–	0	0	1	0	0
<i>Desmodesmus armatus</i> var. <i>longispina</i> (Chodat) E. Hegewald 2000	1	VR	–	–	1	0	0	0	0
<i>Microspora loefgrenii</i> (Nordstedt) Lagerheim 1887	1	R	–	–	0	0	0	1	1
<i>Oedogonium</i> sp.1	2	VR	–	–	0	0	1	0	1
<i>Oedogonium</i> sp.2	1.3	R	–	–	0	0	0	1	1
<i>Palmodictyon viride</i> Kützinger 1845	2	VR	–	–	0	0	1	0	0
<i>Pseudopediastrium boryanum</i> (Turpin) E. Hegewald 2005	1.2	R	–	–	0	0	1	1	0
<i>Stauridium tetras</i> (Ehrenberg) E. Hegewald 2005	1	VR	–	–	0	0	0	1	0
Euglenozoa									
<i>Trachelomonas bacillifera</i> var. <i>minima</i> Playfair 1915	1	VR	–	–	1	0	0	0	0
<i>Trachelomonas curta</i> A. M. Cunha 1913	1	VR	–	–	0	0	0	0	1
<i>Trachelomonas</i> sp.	1	C	–	–	1	0	0	1	1
<i>Trachelomonas volvocina</i> (Ehrenberg) Ehrenberg 1834	1.3	C	–	–	0	1	0	1	1

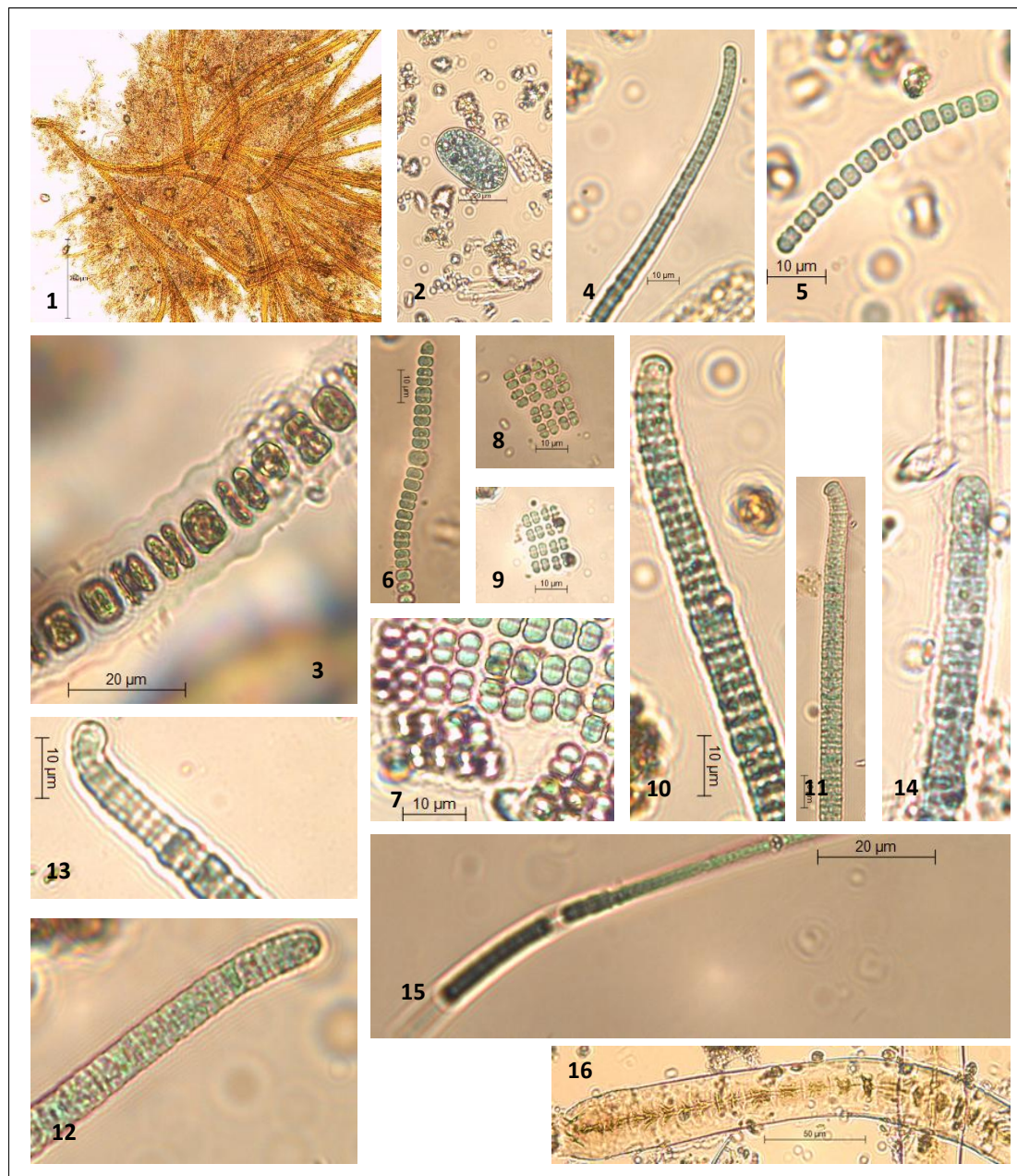


Figure 3: Species of Cyanobacteria from studied habitats:

- (1) *Ammatoidea normanii*, (2) *Cyanothece aeruginosa*, (3) *Johannesbaptistia pellucida*,
 (4) *Kamptonema formosum*, (5) *Komvophoron crassum*, (6) *K. schmidlei*,
 (7) *Merismopedia elegans*, (8) *M. glauca*, (9) *Merismopedia* sp., (10) *Microcoleus amoenus*,
 (11) *Oscillatoria princeps*, (12) *O. tenuis*, (13) *Oscillatoria* sp., (14) *Phormidium ambiguum*,
 (15) *Potamolinea aerugineocaerulea*, (16) *Stigonema ocellatum*.
 (scale bar: 10, 20, 50, 200 μm).

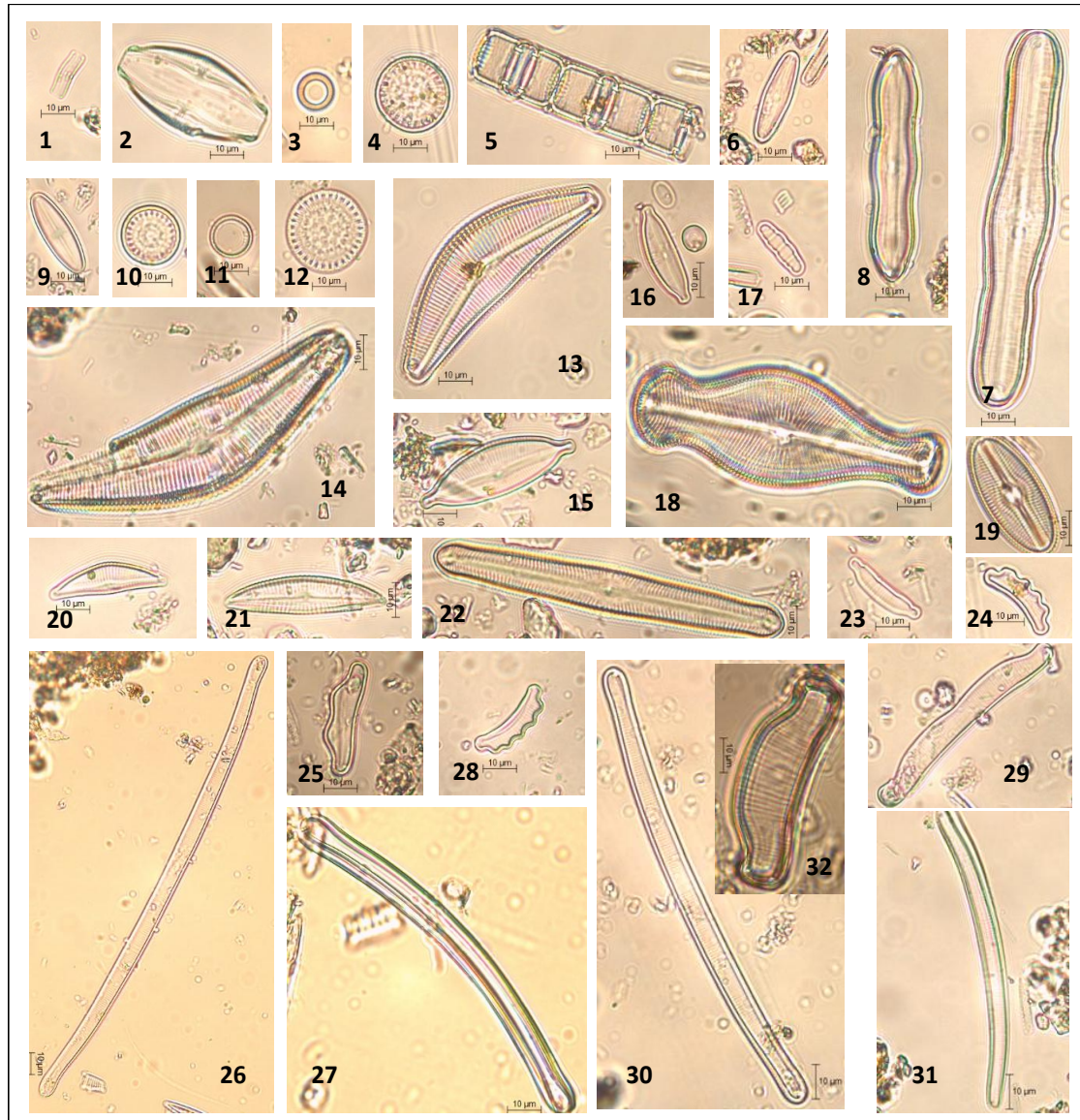


Figure 4: Species of diatoms from studied habitats:

- (1) *Achnantheidium minutissimum*, (2) *Amphora ovalis*, (3) *Aulacoseira distans*,
 (4) *A. lacustris* f. *tenuior*, (5) *A. valida*, (6) *Brachysira brebissonii*,
 (7) *Caloneis schumanniana*, (8) *C. silicula*, (9) *Cavinula lapidosa*,
 (10) *Cyclotella bodanica* var. *lemanica*, (11) *C. distinguenda*, (12) *C. striata*,
 (13) *Cymbella cistula*, (14) *C. cymbiformis*, (15) *Cymbopleura cuspidata*,
 (16) *C. naviculiformis*, (17) *Diatoma moniliformis*, (18) *Didymosphenia geminata*,
 (19) *Diploneis elliptica*, (20) *Encyonema minutum*, (21) *E. silesiacum*,
 (22) *Epithemia gibba*, (23) *Eunotia boreoalpina*, (24) *E. cristagalli*, (25) *E. diodon*,
 (26) *E. flexuosa*, (27) *E. glacialis*, (28) *E. hexaglyphis*, (29) *E. islandica*,
 (30) *E. mucophila*, (31) *E. paludosa*, (32) *E. praerupta*.
 (scale bar: 10 µm).

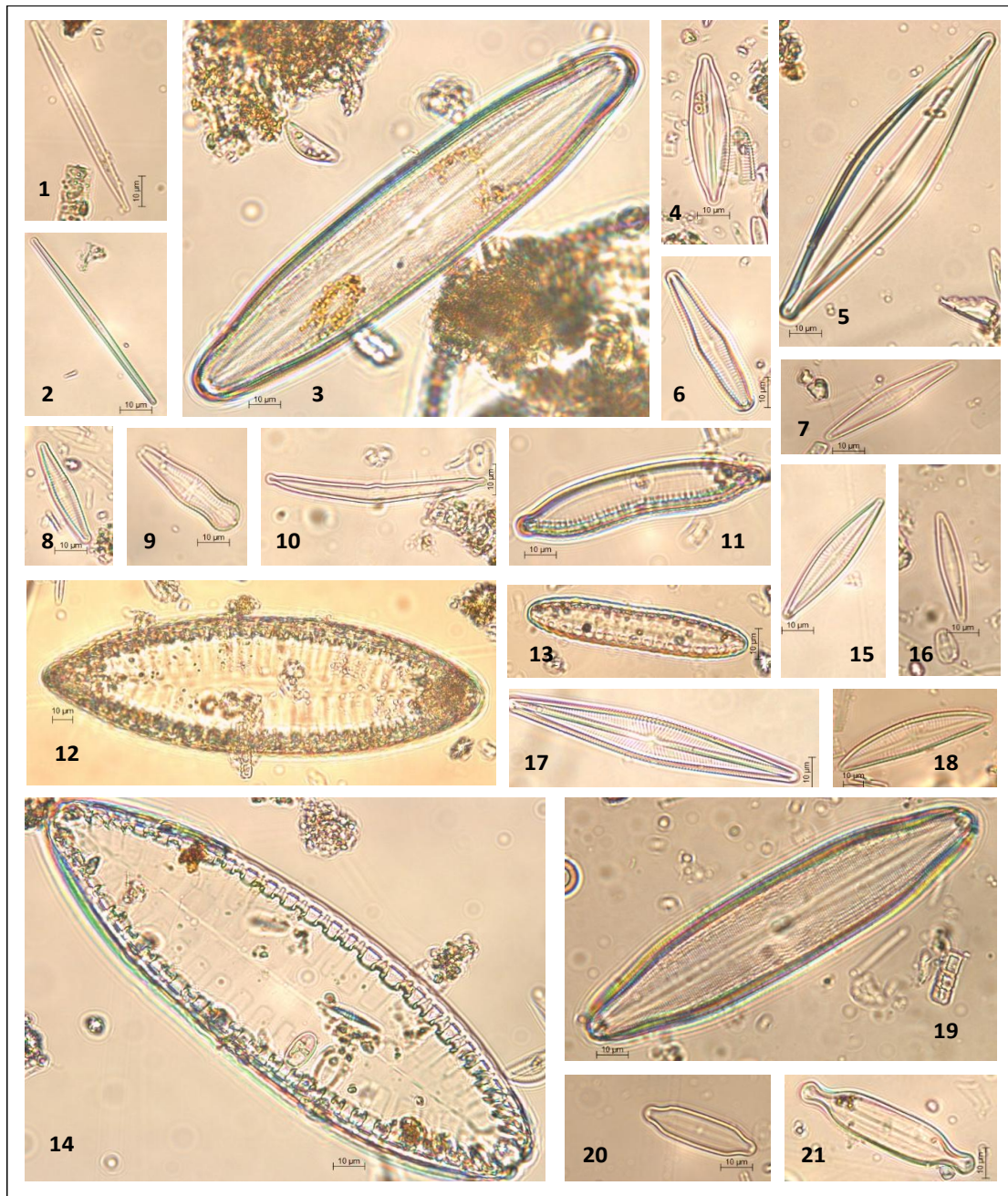


Figure 5: Species of diatoms from studied habitats: (1) *Fragilaria capucina*, (2) *F. radians*, (3) *Frutulia amphipleuroides*, (4) *F. crassinervia*, (5) *F. rhomboides*, (6) *Gomphonella olivacea*, (7) *Gomphonema hebridense*, (8) *G. parvulum*, (9) *G. truncatum*, (10) *Hannaea arcus*, (11) *Hantzschia amphioxys*, (12) *Iconella biseriata*, (13) *I. linearis*, (14) *I. tenera*, (15) *Navicula cryptocephala*, (16) *N. cryptotenella*, (17) *N. radiosa*, (18) *Navicymbula pusilla*, (19) *Neidium ampliatus*, (20) *N. dubium*, (21) *N. productum* (scale bar: 10 µm).

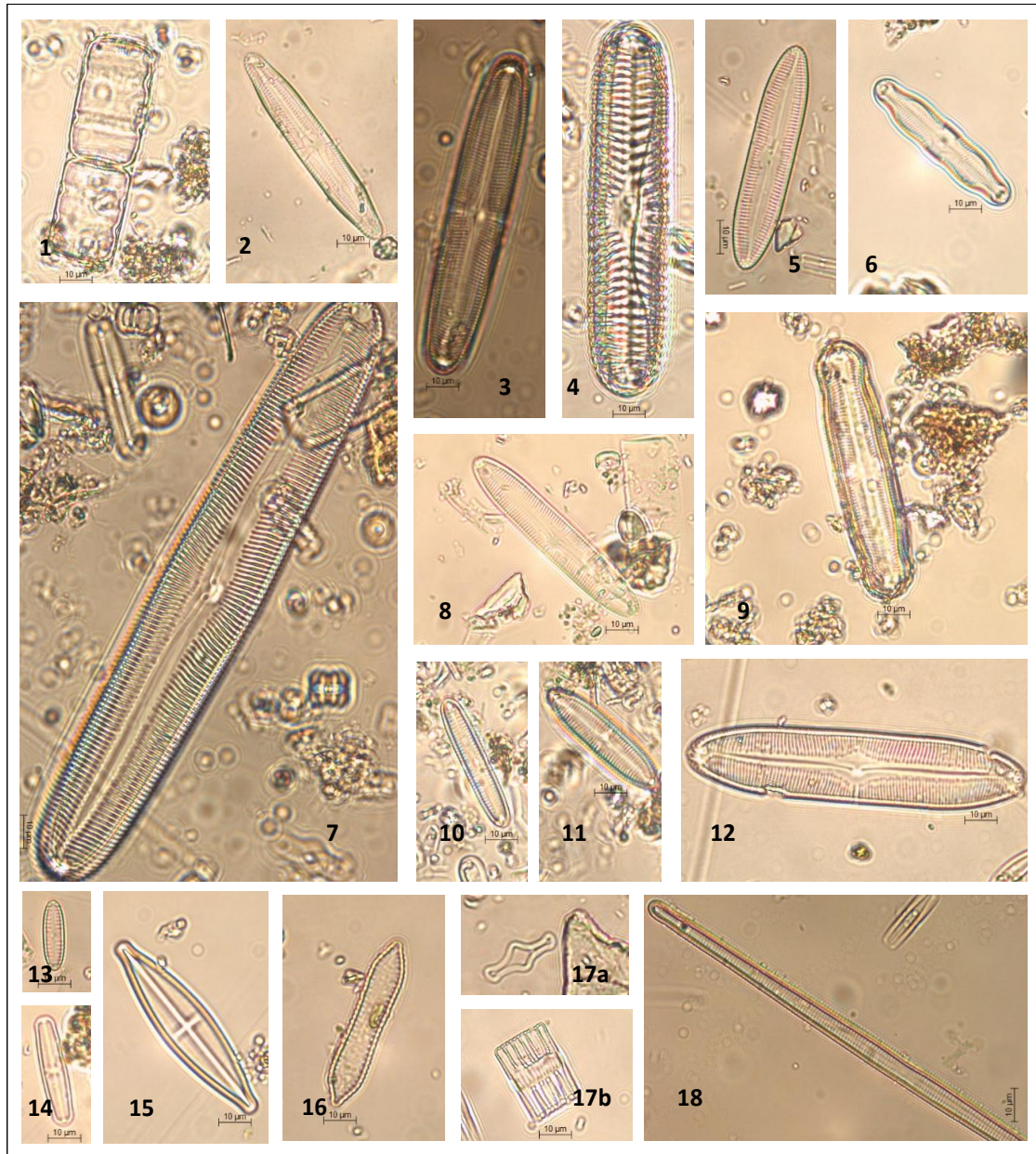


Figure 6: Species of diatoms from studied habitats: (1) *Orthoseira dendroteres*, (2) *Pinnularia abaujensis* var. *linearis*, (3) *P. aestuarii*, (4) *P. borealis*, (5) *P. hemiptera*, (6) *P. interrupta*, (7) *P. major*, (8) *P. microstauron*, (9) *P. platycephala*, (10) *P. rupestris*, (11) *P. subrupestris*, (12) *P. viridis*, (13) *P. sp.*, (14) *Sellaphora pupula*, (15) *Stauroneis anceps*, (16) *Surirella angusta*, (17a,b) *Tabellaria flocculosa*, (18) *Ulnaria acus* (scale bar: 10 µm).

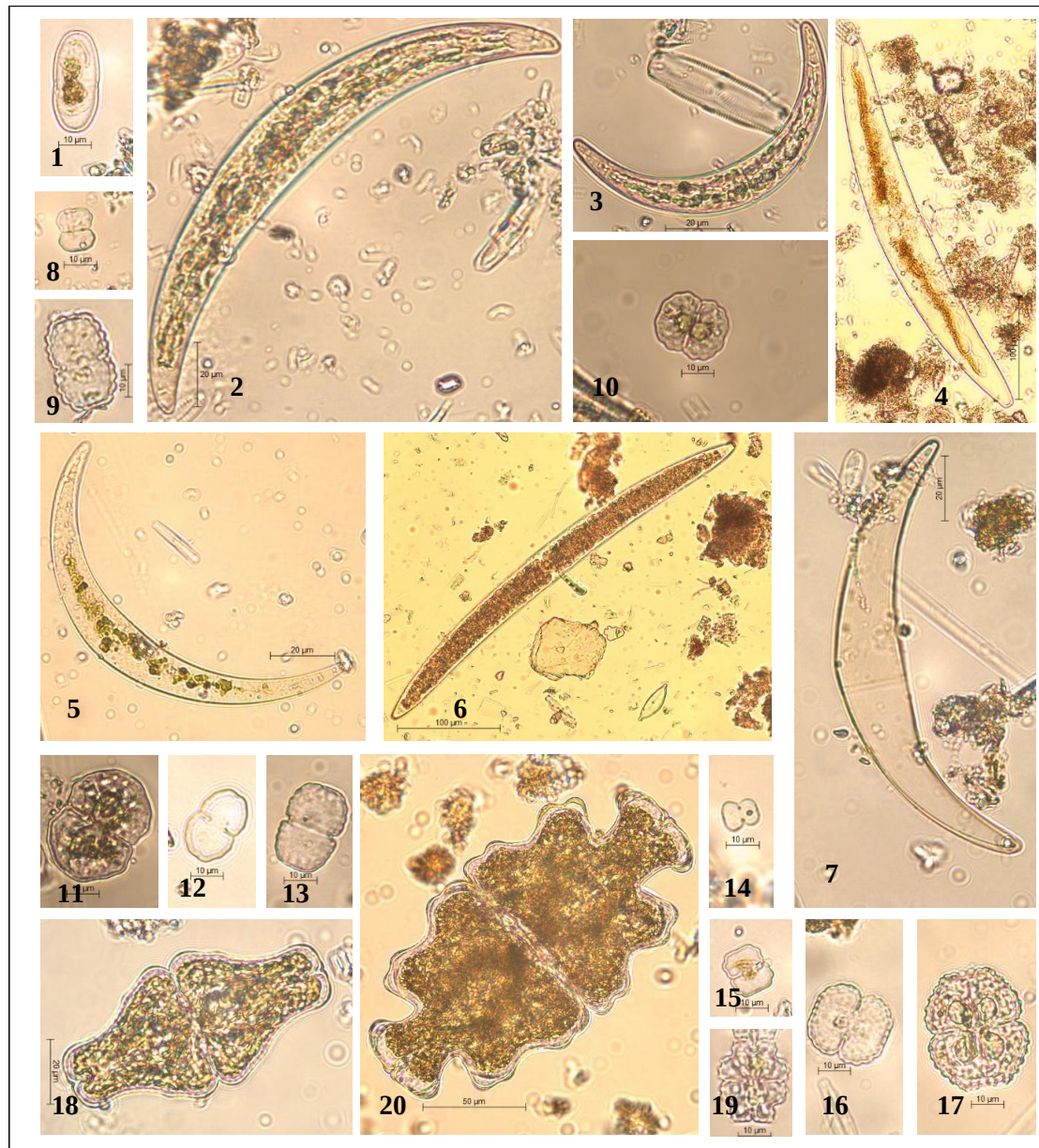


Figure 7: Charophyte species from studied habitats: (1) *Actinotaenium spinospermum*, (2) *Closterium diana* var. *brevius*, (3) *Cl. incurvum*, (4) *Cl. lunula*, (5) *Cl. parvulum*, (6) *Cl. pritchardianum*, (7) *Cl. tumidulum*, (8) *Cosmarium abbreviatum*, (9) *C. crenatum* var. *bicrenatum*, (10) *C. impressulum* var. *suborthogonum*, (11) *C. laeve*, (12) *C. laeve* var. *octangulare*, (13) *C. notabile* var. *transiens*, (14) *C. pygmaeum*, (15) *C. regnellii* var. *pseudoregnellii*, (16) *C. subcostatum* var. *minus*, (17) *C. subcrenatum*, (18) *Euastrum ansatum* var. *pyxidatum*, (19) *E. denticulatum*, (20) *E. oblongum* (scale bar: 10, 20, 50 μm).

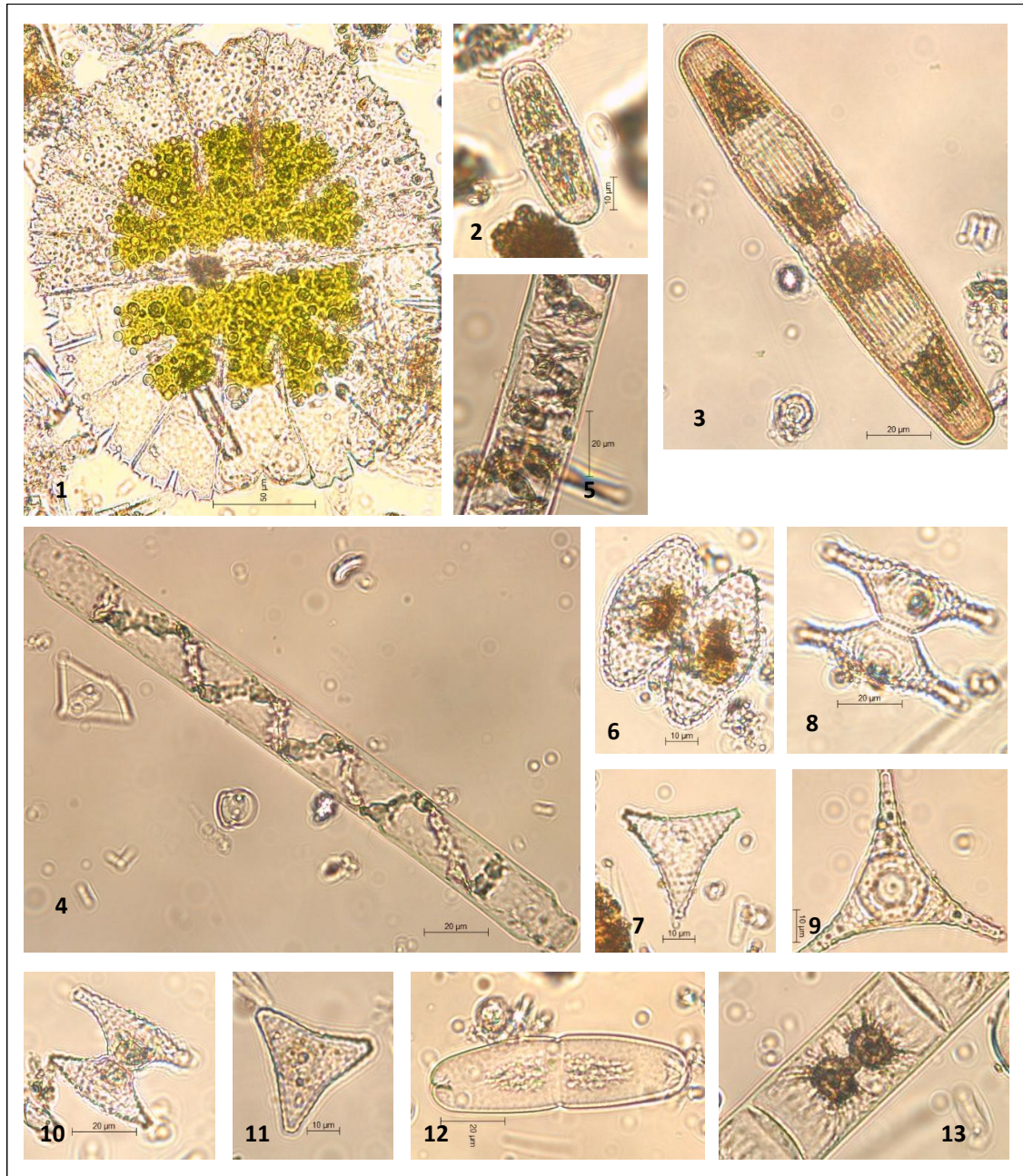


Figure 8: Charophyte species from studied habitats:

- (1) *Micrasterias thomasi* var. *notata*, (2) *Penium margaritaceum*, (3) *P. spirostriolatum*,
 (4) *Spirogyra weberi*, (5) *S. sp.*, (6) *Staurostrum dilatatum*, (7) *S. dispar*, (8) *S. gracile*,
 (9) *S. oxyacanthum* var. *polyacanthum*, (10) *S. polymorphum*, (11) *S. punctulatum*,
 (12) *Tetmemorus laevis*, (13) *Zygnema* sp.
 (scale bar: 10, 20, 50 µm).

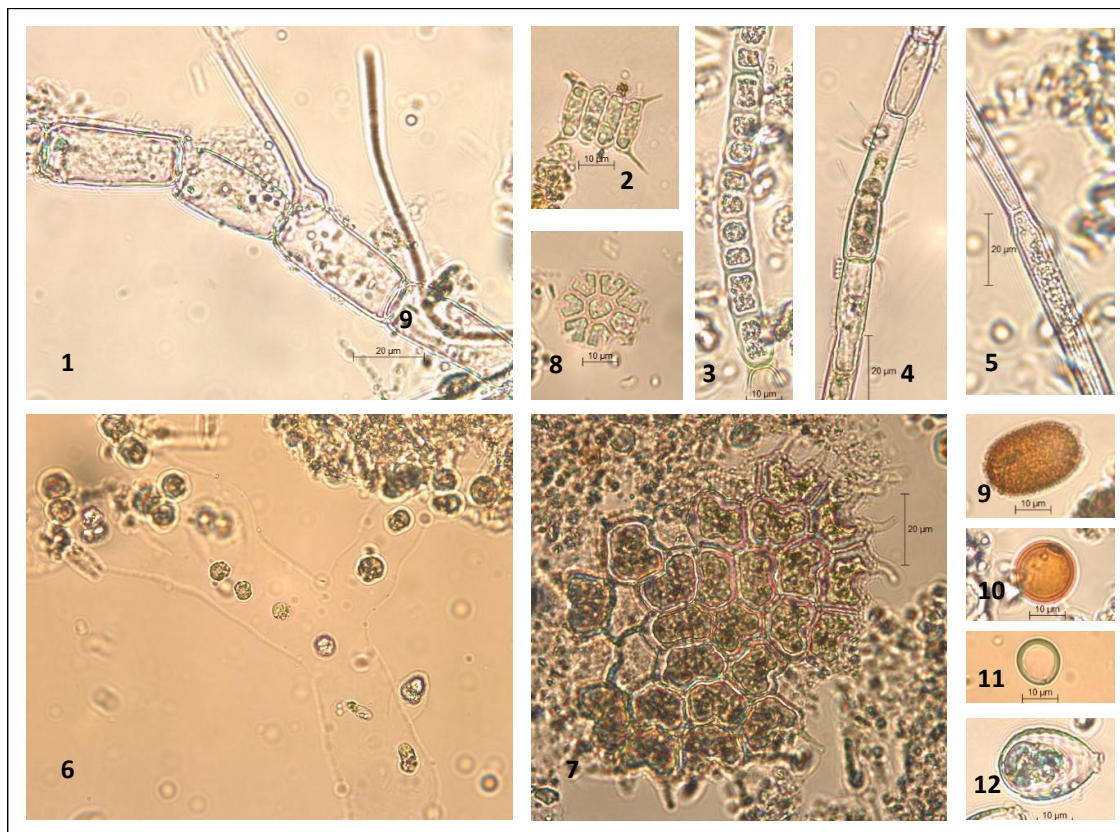


Figure 9: Green and Euglenoid species from studied habitats:

- (1) *Bulbochaete* sp., (2) *Desmodesmus armatus* var. *longispina*, (3) *Microspora loefgrenii*, (4) *Oedogonium* sp.1, (5) *O.* sp.2, (6) *Palmodictyon viride*, (7) *Pseudopediastrum boryanum*, (8) *Stauridium tetras*, (9) *Trachelomonas bacillifera* var. *minima*, (10) *T. curta*, (11) *T. volvocina*, (12) *T. sp.* (scale bar: 10, 20 µm).

Bioindicators

The distribution of taxa among algal divisions, the presence of species in various threat categories and the patterns observed in environmental, taxonomic and bioindicator characteristics are summarised in tables 3 and 4. Bacillariophyta emerged as the dominant division in terms of species richness within all investigated water bodies. Some taxa classified within threatened categories were also recorded. Temperate-water benthic species formed the bulk of the communities, followed by taxa with planktonic–benthic habits. Regarding oxygen conditions, indicators of moderately oxygenated waters were prevalent. For salinity-related groups, oligohalobe–indifferent species were predominant. All pH indicator categories were represented, although species tolerant of a wide pH range occurred most frequently. The assemblages were largely composed of taxa associated with unpolluted waters. Autotrophic and oligotrophic species were also prominent within the flora. Furthermore, several species corresponding to Class II water quality categories were noteworthy for assessing the ecological condition of the lakes and ponds.

Table 4: Ecological preferences of algae and cyanobacteria species in studied lakes and ponds of the Kaçkar Mountains National Park in 2023.

[illegible]

<i>Oscillatoria princeps</i> Vaucher ex Gomont 1892	P-B, S	–	st-str	–	ind	6.0-10.5	–	–	–	–	–
<i>Oscillatoria tenuis</i> C. Agardh ex Gomont 1892	P-B, S	–	st-str	hl	–	–	–	–	–	–	–
<i>Phormidium ambiguum</i> Gomont 1892	B, S	eter m	st-str	i	ind	6,0-8,2	–	–	–	–	–
<i>Potamolinea aerugineocaerulea</i> (Gomont) M. D. Martins & L. H. Z. Branco 2016	P-B, S	–	st-str	–	alf	8.0-8.6	–	–	–	–	me
<i>Stigonema ocellatum</i> Thuret ex Bornet & Flahault 1886	B	–	–	–	–	–	–	–	–	–	–
Bacillariophyta											
<i>Achnantheidium minutissimum</i> Czarnecki 1994	P-B	eter m	st-str	i	ind	4.3-9.2	es	0.95	b	ate	e
<i>Amphora ovalis</i> (Kützing) Kützing 1844	B	temp	st-str	i	alf	6.2-9.0	sx	1.5	b	ate	e
<i>Aulacoseira distans</i> (Ehrenberg) Simonsen 1979	P-B	cool	str	i	acf	4.5-7.8	sp	0.4	o	ats	ot
<i>Aulacoseira lacustris</i> f. <i>tenuior</i> Houk, Klee & Passauer 2007	–	–	–	–	–	5.7	–	–	–	–	–
<i>Aulacoseira valida</i> (Grunow) Krammer 1991	P-B	–	–	i	alf	–	es	1.3	o	ate	om
<i>Brachysira brebissonii</i> R. Ross 1986	P-B	temp	st-str	hb	acf	4.6-7.8	sx	0.4	o	ats	ot
<i>Caloneis schumanniana</i> (Grunow) Cleve 1894	P-B	–	st-str	i	ind	–	es	0.9	o	ats	m
<i>Caloneis silicula</i> (Ehrenberg) Cleve 1894	B	war m	st	i	ind	6.3-9.0	sp	1.3	o	ats	om
<i>Cavinula lapidosa</i> (Krasske) Lange-Bertalot 1996	B	–	st-str	hb	acf	–	–	1.0	o	ats	–

<i>Cyclotella bodanica</i> var. <i>lemanica</i> Bachmann 1903	P	–	–	i	ind	6.72 – 7.97	–	v	–	–	–
<i>Cyclotella distinguenda</i> Hustedt 1928	P	–	str	hl	alf	8.2	–	1.3	o	–	om
<i>Cyclotella striata</i> (Kützing) Grunow 1880	P-B	–	st-str	mh	alf	6.9- 7.4	es	2.0	b	ats	–
<i>Cymbella cistula</i> (Ehrenberg) O. Kirchner 1878	B	–	st-str	i	alf	7.0- 8.0	sx	1.2	b	ats	e
<i>Cymbella cymbiformis</i> C. Agardh 1830	B	temp	st-str	i	alf	6.2- 9.0	sx	2.0	b	ats	om
<i>Cymbopleura cuspidata</i> (Kützing) Krammer 2003	P-B	temp	st-str	i	alf	5.7- 7.5	–	–	–	–	–
<i>Cymbopleura naviculiformis</i> (Auerswald ex Heiberg) Krammer 2003	B	temp	st-str	i	ind	7.8- 6.94	–	–	–	–	–
<i>Diatoma moniliformis</i> (Kützing) D.M. Williams 2012	P-B	temp	st-str	i	alf	8.0- 8.5	v	0.4	x-o	–	–
<i>Didymosphenia geminata</i> Mart. Schmidt 1899	B	–	st-str	i	ind	–	–	2.0	b	–	–
<i>Diploneis elliptica</i> (Kützing) Cleve 1894	B	temp	str	i	alf	8.2	es	–	–	–	–
<i>Encyonema minutum</i> (Hilse) D. G. Mann 1990	B	temp	st-str	i	ind	4.9- 8.9	sx	1.5	o-b	ats	–
<i>Encyonema silesiacum</i> (Bleisch) D. G. Mann 1990	B	temp	st-str	i	ind	6.2- 8.6	v	–	–	–	–
<i>Epithemia gibba</i> (Ehrenberg) Kützing 1844	P-B	temp	st-str	i	alf	6.2- 9.0	es	1.4	x-o	ate	om
<i>Eunotia boreoalpina</i> Lange-Bertalot & Nörpel-Schempp 1998	B	–	–	hb	–	–	–	–	–	–	–

<i>Eunotia cristagalli</i> Cleve 1891	P-B	–	st-str	i	acf	–	–	1.0	o	–	ot
<i>Eunotia diodon</i> Ehrenberg 1837	B	cool	st-str	i	acf	6.75	–	–	–	–	–
<i>Eunotia flexuosa</i> (Brébisson ex Kützing) Kützing 1849	B	temp	st-str	i	acf	4.5-7.8	–	0.4	x-o	–	–
<i>Eunotia glacialis</i> F. Meister 1912	B	–	str	hb	acf	–	–	0.6	o-x	–	–
<i>Eunotia hexaglyphis</i> Ehrenberg 1854	B	temp	–	hb	acf	5.79 - 6.66	–	1.0	o	ats	ot
<i>Eunotia islandica</i> Østrup 1918	B	–	–	i	acf	–	–	0.4	x-o	–	ot
<i>Eunotia mucophila</i> Lange-Bertalot 2007	P-B	temp	st-str	hb	acf	5.25 -6.4	–	–	–	–	–
<i>Eunotia paludosa</i> Grunow 1862	B	-	str	hb	acf	6.0-6.48	sx	0.5	x-o	ats	ot
<i>Eunotia praeupta</i> Ehrenberg 1843	P-B	cool	st-str	hb	acf	6.68 -8.0	–	0.3	x	–	–
<i>Fragilaria capucina</i> Desmazières 1830	P-B	temp	st-str	i	ind	6.4-8.9	–	–	–	–	–
<i>Fragilaria radians</i> (Kützing) D. M. Williams & Round 1987	P-B	war m	st-str	i	alf	7.0-7.5	–	–	–	–	–
<i>Frustulia amphipleuroides</i> (Grunow) Cleve-Euler 1934	B	–	st-str	hb	acf	6.6-8.0	–	1.8	o-a	–	om
<i>Frustulia crassinervia</i> (Brébisson ex W. Smith) Lange-Bertalot & Krammer 1996	B	–	str	hb	acf	4.7-7.2	sx	0.5	x-o	ats	ot
<i>Frustulia rhomboides</i> (Ehrenberg) De Toni 1891	B	temp	st-str	hb	acf	4.6-6.8	es	1.0	o	–	–
<i>Gomphonella olivacea</i> (Hornemann) Rabenhorst 1853	B	temp	st-str	i	alf	6.5-8.8	–	2.3	b	ate	om

<i>Gomphonema hebridense</i> W. Gregory 1854	B	–	–	–	acf	6.1	–	1.0	o	–	–
<i>Gomphonema parvulum</i> (Kützing) Kützing 1849	B	temp	st-str	i	ind	4.5-8.6	–	0.7	o-x	ats	ot
<i>Gomphonema truncatum</i> Ehrenberg 1832	B	temp	st-str	i	ind	7.19	–	2.0	b	–	–
<i>Hannaea arcus</i> (Ehrenberg) R. M. Patrick 1966	B	temp	str	i	alf	5.7-7.5	–	–	–	–	–
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow 1880	B,ae r	temp	st-str	i	ind	6.3-9.5	–	3.0	a	–	me
<i>Iconella biseriata</i> (Brébisson) Ruck & Nakov 2016	P-B	temp	st-str	i	alf	7-9	es	1.0	o	–	m
<i>Iconella linearis</i> (W. Smith) Ruck & Nakov 2016	P-B	–	st-str	i	ind	4.6-9.0	–	–	–	–	–
<i>Iconella tenera</i> Ruck & Nakov 2016	P-B	temp	st	i	alf	5.7-7.5	–	0.2	x	ats	ot
<i>Meridion circulare</i> (Greville) C. Agardh 1831	P-B	temp	st-str	i	ind	6.6-8.3	–	–	–	–	–
<i>Navicula cryptocephala</i> Kützing 1844	P-B	temp	st-str	i	ind	6.5-8.4	–	2.4	b-a	–	–
<i>Navicula cryptotenella</i> Lange-Bertalot 1985	P-B	temp	st-str	i	ind	6.5-8.7	–	–	–	–	–
<i>Navicula radiosa</i> Kützing 1844	B	temp	st-str	i	ind	5-9	sx	–	–	–	–
<i>Navicymbula pusilla</i> (Grunow) Krammer 2003	B	–	-	mh	alf	–	–	–	–	–	–
<i>Neidium ampliatus</i> (Ehrenberg) Krammer 1985	B	temp	st	i	ind	5.2-8.6	–	–	–	–	–
<i>Neidium dubium</i> (Ehrenberg) Cleve 1894	B	–	str	i	alf	–	–	–	–	–	–
<i>Neidium iridis</i> (Ehrenberg) Cleve 1894	B	temp	st-str	hb	ind	5.1-8.9	–	–	–	–	–

<i>Neidium productum</i> Cleve 1894	P-B	temp	st-str	i	ind	–	–	–	–	–	–
<i>Orthoseira dendroteres</i> (Ehrenberg) Genkal & Kulikovskiy 2010	B, aer	–	–	i	–	–	es	1.8	o-a	–	–
<i>Pinnularia abaujensis</i> var. <i>linearis</i> R. M. Patrick 1966	B	temp	st-str	i	ind	7.20	–	–	–	–	–
<i>Pinnularia aestuarii</i> Cleve 1895	B	–	–	mh	alf	–	–	–	–	–	–
<i>Pinnularia borealis</i> Ehrenberg 1843	B, aer	–	st- str,a er	i	ind	7.8	–	1.0	o	–	ot
<i>Pinnularia hemiptera</i> (Kützing) Rabenhorst 1853	B	–	str	i	ind	–	–	–	–	–	–
<i>Pinnularia interrupta</i> W. Smith 1853	B	–	st-str	i	ind	6.0- 8.0	–	–	–	–	–
<i>Pinnularia major</i> (Kützing) Rabenhorst 1853	B	temp	st-str	i	ind	6.38 -7.1	–	1.0	o	ats	m
<i>Pinnularia microstauron</i> (Ehrenberg) Cleve 1891	P-B	temp	st-str	i	ind	4.5- 8.7	–	0.3	x	ats	ot
<i>Pinnularia platycephala</i> Cleve 1891	B	–	–	i	–	–	–	0.4	x-o	–	–
<i>Pinnularia rupestris</i> Hantzsch 1861	B	temp	str	i	acf	5.39	–	–	–	–	–
<i>Pinnularia</i> sp.	–	–	–	–	–	4.5- 7.8	–	–	–	–	–
<i>Pinnularia subrupestris</i> Krammer 1992	B	–	–	hb	acf	–	–	0.4	x-o	–	–
<i>Pinnularia sudetica</i> Hilse 1861	B	–	st-str	i	acf	–	–	1.0	o	–	–
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg 1843	P-B	temp	st-str	i	ind	5.24 -7.1	–	0.9	x-b	–	ot

<i>Sellaphora pupula</i> (Kützing) Mereschkovsky 1902	B	eter m	st-str	hl	ind	5.2-9.0	sx	1.9	o-a	ate	me
<i>Stauroneis anceps</i> Ehrenberg 1843	P-B	temp	st-str	i	ind	4.8-8.2	sx	1.3	o	ats	om
<i>Surirella angusta</i> Kützing 1844	P-B	temp	st-str	i	alf	6.9-8.9	–	–	–	–	–
<i>Surirella robusta</i> Ehrenberg 1841	P-B	temp	st-str	I	ind	7.6-9.5	–	2.1	b	ate	e
<i>Tabellaria flocculosa</i> (Roth) Kützing 1844	P-B	eter m	st-str	i	acf	4.5-8.0	–	3.0	a	–	–
<i>Ulnaria acus</i> Aboal 2003	P-B	war m	st-str	i	alf	6.8-8.0	es	1.85	o-a	ate	me
Charophyta											
<i>Actinotaenium spinospermum</i> (Joshua) Kouwets & Coesel 1984	B	–	–	–	acf	–	–	–	–	–	m
<i>Closterium diana</i> var. <i>brevius</i> (Petkoff) Willi Krieger 1935	–	–	–	–	–	–	–	–	–	–	–
<i>Closterium incurvum</i> Brébisson 1856	B	–	–	–	ind	–	–	1.8	o-a	–	me
<i>Closterium lunula</i> Ehrenberg & Hemprich ex Ralfs 1848	B	–	–	–	ind	7.8	–	0.8	x-b	–	m
<i>Closterium parvulum</i> Nägeli 1849	P-B	–	–	i	ind	–	–	2.0	b	–	m
<i>Closterium pritchardianum</i> W. Archer 1862	P-B	–	–	–	ind	–	–	–	–	–	m
<i>Closterium tumidulum</i> F. Gay 1884	P-B	–	–	–	acf	–	–	–	–	–	o-e
<i>Cosmarium abbreviatum</i> Raciborski 1885	P-B	–	–	–	ind	–	–	–	–	–	me
<i>Cosmarium crenatum</i> var. <i>bicrenatum</i> Nordstedt 1872	B	–	aer	–	acf	–	–	–	–	–	m
<i>Cosmarium impressulum</i> var. <i>suborthogonum</i> Taft 1945	B	–	–	–	ind	–	–	1.6	b-o	–	m

<i>Cosmarium laeve</i> Rabenhorst 1868	P-B	–	st-str	hb	ind	–	–	1.9	o-a	–	me
<i>Cosmarium laeve</i> var. <i>octangulare</i> (Wille) West & G. S. West 1908	P-B	–	–	–	ind	–	–	1.9	o-a	–	me
<i>Cosmarium</i> <i>notabile</i> var. <i>transiens</i> Insam & Krieger 1936	B, aer	–	–	–	acf	–	–	–	–	–	m
<i>Cosmarium</i> <i>pygmaeum</i> W. Archer 1864	P-B	–	st-str	–	acf	–	–	–	–	–	om
<i>Cosmarium</i> <i>regnellii</i> var. <i>pseudoregnellii</i> (Messikommer) Willi Krieger 1944	B	–	–	–	acf	–	–	–	–	–	m
<i>Cosmarium</i> <i>subcostatum</i> var. <i>minus</i> (West & G. S. West) Kurt Förster 1981	B	–	–	–	ind	–	–	–	–	–	m
<i>Cosmarium</i> <i>subcrenatum</i> Hantzsch 1868	B, aer	–	aer	–	acf	8.2	–	1.1	o	–	m
<i>Euastrum</i> <i>ansatum</i> var. <i>pyxidatum</i> Delponte 1873	P-B	–	–	–	ind	–	–	0.5	x-o	–	m
<i>Euastrum</i> <i>denticulatum</i> F. Gay 1884	P-B	–	–	–	acf	–	–	0.5	x-o	–	m
<i>Euastrum</i> <i>oblongum</i> Greville ex Ralfs 1848	B	–	–	–	acf	–	–	0.5	x-o	–	ot
<i>Micrasterias</i> <i>thomasiana</i> var. <i>notata</i> (Nordstedt) Grönblad 1920	B	–	–	–	acf	–	–	0.3	x	–	–
<i>Penium</i> <i>margaritaceum</i> Brébisson ex Ralfs 1848	B	–	–	–	ind	–	–	0.4	x-o	–	om
<i>Penium</i> <i>spirostriolatum</i> J. Barker 1869	B	–	–	–	acf	–	–	–	–	–	–

<i>*Pleurotaenium crenulatum</i> (Ehrenberg ex Ralfs) Rabenhorst 1868	B	–	–	–	acf	–	–	0.8	x-b	–	–
<i>Spirogyra</i> sp.	P-B	–	–	–	alf	7.8	–	–	–	–	–
<i>Spirogyra weberi</i> Kützing 1843	P-B	–	–	–	–	–	–	2.1	b	–	–
<i>Staurostrum dilatatum</i> Ehrenberg ex Ralfs 1848	P	–	–	–	–	–	–	–	–	–	m
<i>Staurostrum dispar</i> Brébisson 1856	B	–	–	–	ind	–	–	–	–	–	m
<i>Staurostrum gracile</i> Ralfs ex Ralfs 1848	P-B	–	st	i	acf	–	–	–	–	–	m
<i>*Staurostrum kouwetsii</i> Coesel 1996	B	–	–	–	acf	–	–	–	–	–	m
<i>Staurostrum oxyacanthum</i> var. <i>polyacanthum</i> Nordstedt 1885	P	–	–	hb	acf	–	–	–	–	–	m
<i>Staurostrum polymorphum</i> Brébisson 1848	P-B	–	–	i	ind	–	–	1.8	o-a	–	me
<i>Staurostrum punctulatum</i> Brébisson 1848	P-B	–	st-str	i	ind	6.4-7.6	–	–	–	–	ot
<i>Tetmemorus laevis</i> Ralfs ex Ralfs 1848	B, aer	–	aer	–	ind	–	–	0.5	x-o	–	om
<i>Zygnema</i> sp.	P-B	–	–	–	alb	5.7-8.4	–	1.0	x-b	–	–
Chlorophyta											
<i>Bulbochaete</i> sp.	B	–	–	–	–	7.5	–	1.2	o	–	e
<i>Desmodesmus armatus</i> var. <i>longispina</i> (Chodat) E. Hegewald 2000	P	–	st-str	–	alb	8.2-11	–	2.2	b	–	e
<i>Microspora loefgrenii</i> (Nordstedt) Lagerheim 1887	B	–	–	–	–	–	–	1.6	b-o	–	–
<i>Oedogonium</i> sp.1	B	–	–	–	alb	7.7-8.3	–	–	–	–	–

<i>Oedogonium</i> sp.2	–	–	–	–	–	–	–	–	–	–	–
<i>Palmodictyon viride</i> Kützing 1845	–	–	–	–	–	–	–	2.1	b	–	–
<i>Pseudopediastrium boryanum</i> (Turpin) E. Hegewald 2005	P-B	–	st-str	i	ind	8.1	–	2.1	b	–	e
<i>Stauridium tetras</i> (Ehrenberg) E. Hegewald 2005	P-B	–	st-str	i	ind	8.3	–	–	–	–	om
Euglenozoa											
<i>Trachelomonas bacillifera</i> var. <i>minima</i> Playfair 1915	–	–	–	–	–	–	–	2.3	b	–	–
<i>Trachelomonas curta</i> A. M. Cunha 1913	P	–	–	–	–	–	–	2.1	b	–	–
<i>Trachelomonas</i> sp.	P	–	–	–	–	6.9-8.8	–	2.3	b	–	-
<i>Trachelomonas volvocina</i> Ehrenberg 1834	P-B	eterm	st-str	i	ind	4.4-8.4	–	2.0	b	–	–

Although biodiversity reflects the overall structural characteristics of the investigated communities (Fig. 10a), the ecological preferences of the species forming these communities provide important clues about the environmental factors shaping them. Figures 10a and 10b illustrate how indicator groups are distributed across the nine major environmental variables considered in this study. In the waters of Kaçkar Mountains National Park, benthic algae constitute the dominant ecological group, followed by species with planktonic-benthic tendencies. Planktonic taxa were also recorded in Lake Çermek and in ponds 1 and 2 (Fig. 10b). Temperate-adapted organisms account for a large portion of the algal flora (Fig. 10c). The communities primarily consist of taxa typical of still-water environments such as small lakes, as well as species that tolerate weakly flowing habitats with moderate oxygen concentrations (Fig. 10d). Salinity plays a key role in regulating algal productivity by contributing to the total ionic balance of the water, species indifferent to salinity dominated the flora of the studied lakes (Fig. 10e). The results of the pH bioindication show that indifferent species are prevalent in the algal flora. These were followed by acidophiles and alkaliphiles. Alkalibionte species were identified in Çermek and Adsız lakes and pond-2 (Fig. 10f).

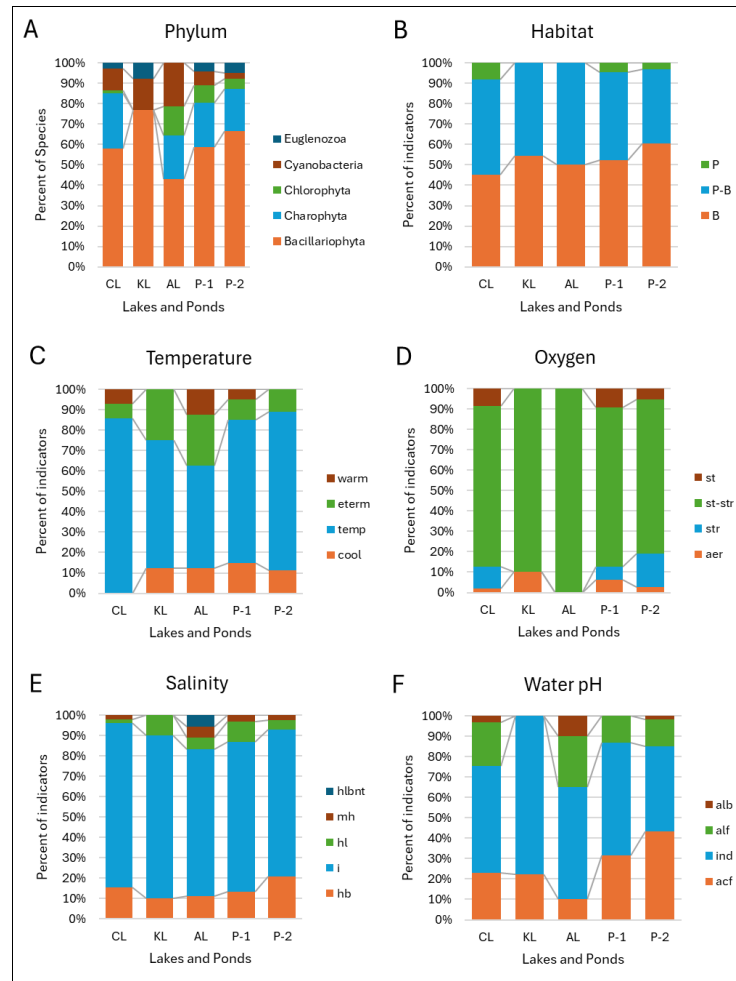


Figure 10: Distribution of species numbers in taxonomic phyla and bioindicators abundances of benthic algae in studied lakes and ponds of the Kaçkar Mountains National Park: (a) Number of species. Abbreviations of ecological groups: (b) Habitat (P: planktonic, P-B: plankto-benthic, B: benthic), (c) Temperature preferences (temp-temperate, eterm-eurythermic, warm-warm water), (d) Oxygenation and water moving (Oxygen) (aer-aerophiles, str-streaming water, st-str-low streaming water, st-standing), (e) Salinity ecological groups (salinity) (hb: oligohalobes-halophobes, i: oligohalobes-indifferent, hl: halophiles, mh: mesohalobes), (f) pH preferences groups (pH) (alb: alkalibiontes, alf: alkaliphiles, ind: indifferent, acf: acidophiles).

In the aquatic environments examined, species from the sx and es ecological groups – both characteristic of unpolluted and transparent waters – were frequently recorded (Barinova, 2025). Additionally, representatives of the sp group were observed in CL, P-1 and P-2 (Fig. 11a). Light availability and temperature constitute the two principal climatic drivers regulating algal photosynthesis, and photosynthetic taxa were present across all surveyed sites (Fig. 11b). Organic matter concentration is recognised as a central determinant of a waterbody's trophic state (Barinova, 2025). Within the identified algal assemblages, oligotraphentic species were the most prevalent, followed by meso-traphentic taxa, which occurred at all sampling locations but in relatively limited numbers. Oligo-mesotraphentic forms were restricted to three sites

(Çermeşk Lake and ponds 1 and 2), whereas mesotraphentic taxa were documented in four water bodies (Çermeşk and Adsız Lakes and ponds 1 and 2). Notably, eutraphentic species were recorded at four stations and occurred at comparatively high densities in Adsız Lake only. The detection of oligotraphentic taxa also represents an important ecological finding (Fig. 11c). Bioindication-based assessments concerning organic pollution levels are summarised in figure 11d (Barinova, 2025). According to these results, Class 2 indicators formed a substantial portion of the algal community in all studied waters, while Class 3 indicators constituted the second most abundant group. Class 1 followed in third place, and Class 4 taxa – although less common – were identified in ÇL, AL and P-2. Overall, each water body contained representatives of all recorded classes, whereas Class 5 indicators were absent.

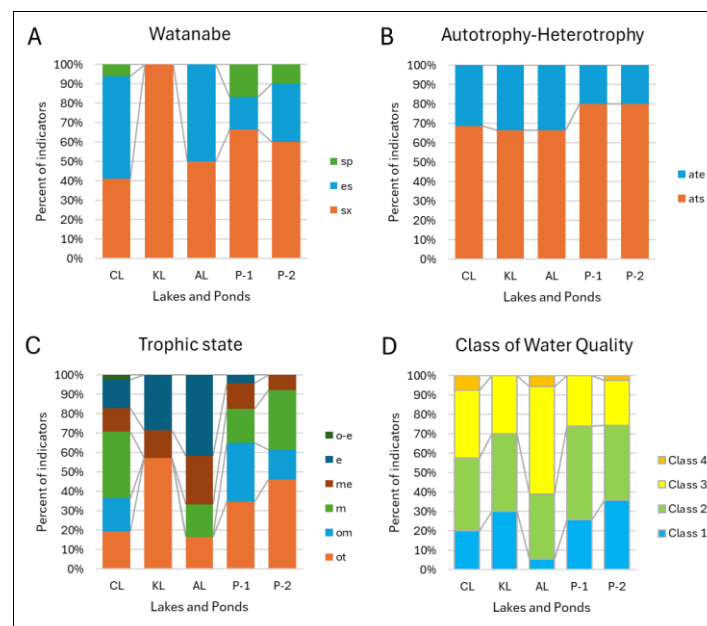


Figure 11: (a) Organic pollution indicators (sx: saproxenes; es: eury saprobes; sp: saprophiles), (b) Nitrogen uptake metabolism (autotrophy-heterotrophy ats: nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen; ate-nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen), (c) Trophic state indicators (Trophic state) (ot: oligotraphentic, om: oligo-mesotraphentic, m: mesotraphentic, me: meso-eutraphentic, e: eutraphentic, o-e: hyper-eutraphentic), (d) Class of Water Quality based on species-specific index saprobity S (Tab. 4).

Comparative Analysis

Using comparative assessment of floristic data provides a useful framework for interpreting how environmental gradients shape algal communities in high-altitude aquatic ecosystems. This analytical approach also supports the categorization of floras based on shared taxonomic traits and biogeographic patterns.

There are two applications of comparative analysis in floristic and ecological studies. The first is used to statistically compare the presence or absence of species or their abundance in floristic lists, as we did use the data in table 3. This allows us to see the degree of overlap in species composition in the studied water bodies, thereby identifying the most similar ones. The

second approach is based on a statistical comparison of taxonomic groups and ecological preference groups together as a characteristic of community characteristics in each water body. In this case, communities most similar in terms of phylum composition and their ecological adaptations are identified, suggesting similarities not only in species composition but also in their habitats. The second approach to statistical analysis of communities in the studied lakes and ponds was based on the data in table 5. Thus, quantitative assessment of the species richness of phyla and the ecological properties of each community of lakes and ponds using the JASP program revealed two distinct clusters. Cluster 1 united only lakes (CL and AL) with a similarity of 61%. Cluster 2 demonstrated significant similarity between the communities of two ponds (P-1 and P-2), which exhibited a higher degree of mutual overlap (67%), while KL showed only limited similarity with the remaining water bodies (Fig. 12).

Employing a comparative evaluation of floristic data (Tab. 3) provides a useful framework for interpreting how environmental gradients shape algal assemblages in high-mountain aquatic ecosystems. This analytical perspective also supports the categorization of floras based on shared taxonomic features and biogeographical patterns.

The quantitative assessment of species richness and ecological properties of each lake and pond community (Tab. 5) with JASP program indicated two different clusters. Cluster 1 combine the lakes only (CL and AL) with similarity 61%. Cluster 2 demonstrated a notable floristic affinity of communities of two ponds (P-1 and P-2) exhibit a higher degree of mutual resemblance (67%), whereas KL showed limited similarity to the remaining sites (Fig. 12).

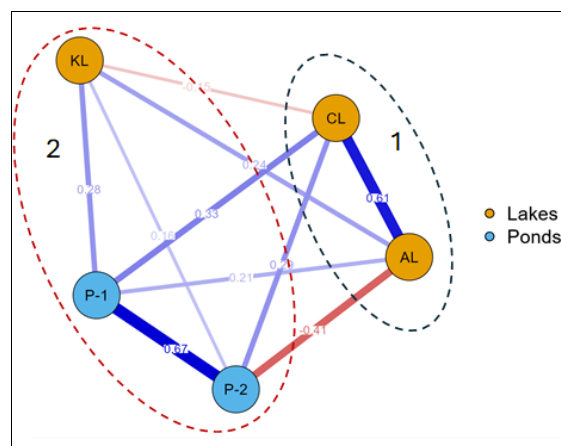


Figure 12: JASP network plot correlations of species (Tab. 3) and ecological indicators (Tab. 4) numbers in Kaçkar Mountains National Park waters. The thickness of the lines is proportional to the strength of the connection, indicated by the numbers. Blue lines are positive correlation, red lines are negative correlation. Clusters outlined by dashed lines and numbered.

Cluster analysis using the Bray-Curtis index and the single-linkage algorithm distinguished three principal assemblage groups based on the table 3. These groupings were identified for the total species dataset at a 50% similarity threshold (Fig. 13a) and for phylum-level and indicators content based on table 5 at a 70% similarity threshold (Fig. 13b). The first cluster encompassed P-1, P-2 and CL, revealing marked homogeneity among these sites. AL formed a separate second cluster, while KL was isolated as the third group.

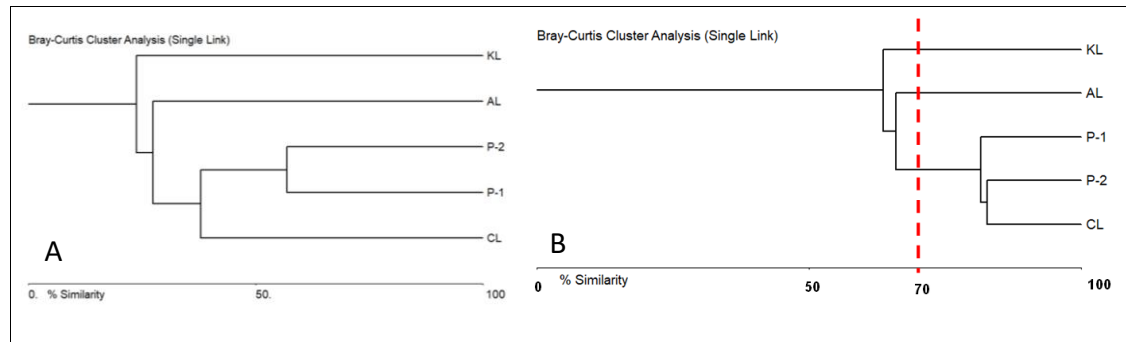


Figure 13: (A) Bray-Curtis cluster analysis of algae list similarity of species in the studied waters based on table 3 and (B) similarity of species in phyla and indicators the studied waters based on table 5 in Kaçkar Mountains National Park.

Table 5: Summarised taxonomic, threat categories, ecological properties of algae and cyanobacteria species in the studied lakes and ponds of Kaçkar Mountains National Park in 2023.

Phylum	CL	KL	AL	P-1	P-2
Bacillariophyta	43	10	12	27	42
Charophyta	20	0	6	10	13
Chlorophyta	1	0	4	4	3
Cyanobacteria	8	2	6	3	2
Euglenozoa	2	1	0	2	3
Total No of Species	74	13	28	46	63
IUCN categories					
EX	0	0	0	0	0
CR	1	0	1	1	3
EN	3	3	0	3	9
VU	0	0	0	0	0
NT	6	1	0	5	7
LC	22	3	8	7	9
DD	2	1	1	3	3
NE	7	1	0	6	9

Table 5 (continued): Summarised taxonomic, threat categories, ecological properties of algae and cyanobacteria species in studied lakes and ponds of Kaçkar Mountains National Park in 2023.

Habitat					
B	33	6	13	23	37
P-B	34	5	13	19	22
P	6	0	0	2	2
Temperature					
cool	0	1	1	3	3
temp	24	5	4	14	21
eterm	2	2	2	2	3
warm	2	0	1	1	0
Oxygen					
aer	1	1	0	2	1
str	5	0	0	2	6
st-str	37	9	16	25	28
st	4	0	0	3	2
Salinity					
hb	8	1	2	4	9
i	41	8	13	22	31
hl	1	1	1	3	2
mh	1	0	1	1	1
hlbnt	0	0	1	0	0
Water pH					
acf	15	2	2	12	23
ind	34	7	11	21	22
alf	14	0	5	5	7
alb	2	0	2	0	1
Watanabe					
sx	7	3	3	4	6
es	9	0	3	1	3
sp	1	0	0	1	1
Autotrophy-Heterotrophy					
ats	11	4	4	8	12
ate	5	2	2	2	3
Trophic state					
ot	8	4	2	8	12
om	7	0	0	7	4
m	14	0	2	4	8
me	5	1	3	3	2

Table 5 (continued): Summarised taxonomic, threat categories, ecological properties of algae and cyanobacteria species in studied lakes and ponds of Kaçkar Mountains National Park in 2023.

Trophic state					
e	6	2	5	1	0
o-e	1	0	0	0	0
Class of Water Quality					
Class 1	8	3	1	7	14
Class 2	15	4	6	13	15
Class 3	14	3	10	7	9
Class 4	3	0	1	0	1

Species in threat categories

When we analysed the levels of endemism and rarity of the diatom species identified in Kaçkar Mountains National Park, as well as the threats to their extinction, we determined that 96 species are under threat categories of IUCN (Fig. 14). Four of these species (*Eunotia flexuosa*, *E. hexaglyphis*, *E. praerupta*, and *Neidium iridis*) are considered to be critically threatened (CR). Examining the known ecological preferences of these species revealed that they inhabit waters with moderate temperatures (temp), high oxygen content (st-str), fresh water (hb), low pH (acf) and low organic matter saturation (x, x-o, o). *Eunotia hexaglyphis* is characterised by an autotrophic feeding pattern (ats) and inhabits oligotrophic water bodies (ot) (Tab. 4). This species was previously identified as a new record for the Turkish Freshwater Algal Flora in a study conducted on Koçdüzü Büyük Lake (Şahin, 2021). Taking these findings into account, we can conclude that high mountain lakes are under threat.

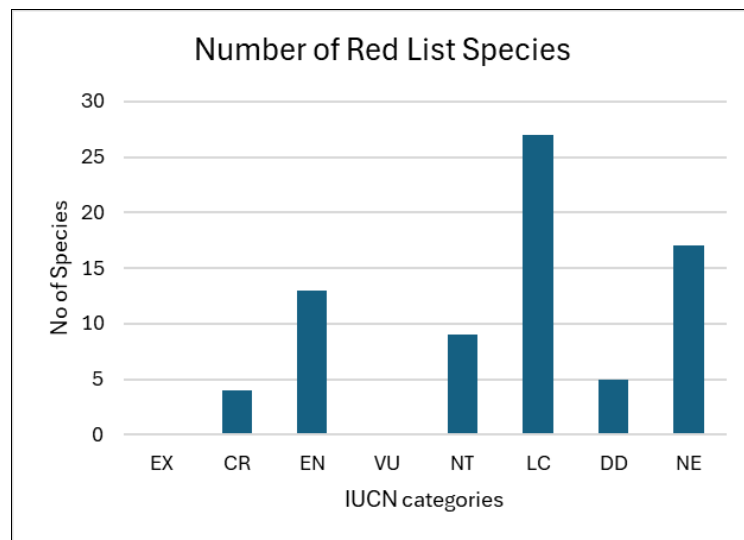


Figure 14: Distribution of the number of diatom species in the flora of the studied water bodies of the Kaçkar Mountains National Park according to IUCN Threat Categories.

The rank of IUCN categories on the x-axis corresponds to decreasing threat.

DISCUSSIONS

This study investigated the benthic algal communities of three high-mountain lakes and two ponds located within Kaçkar Mountains National Park, with a particular focus on their relationships with environmental variables. The algal assemblages were dominated by the genera *Pinnularia*, *Eunotia*, *Cosmarium*, *Staurostrum*, and *Closterium*, while *Encyonema minutum* and *Gomphonema parvulum* were identified as the most prevalent species. The overall floristic structure closely resembles that of previously documented benthic algal communities in lakes of the same region (Şahin and Barinova, 2025a, 2025b, 2024), a similarity likely attributable to shared soil properties, macroclimatic conditions, and limnological characteristics.

The genus *Pinnularia*, which typically inhabits oligotrophic freshwater environments with low electrolyte concentrations and acidic pH, is represented by 13 species in the studied ecosystems, constituting the most diverse genus in the dataset (Tab. 3) (Krammer, 2000). The physicochemical parameters further indicate that the waters provide optimal conditions for members of this genus (Tab. 2).

According to AlgaeBase, *Eunotia* comprises 1,065 species globally (Guiry and Guiry, 2025). Although predominantly distributed in the northern hemisphere, the genus is also present in tropical regions (Joh, 2011). Species of *Eunotia*, widely recognised as indicators of ecological quality, typically inhabit benthic and periphytic freshwater environments characterised by low to moderate electrolyte concentrations and acidic to neutral pH (Cantonati et al., 2017; Hofmann et al., 2013; Wojtal et al., 1999). Ortiz-Lerin and Cambra (2007) emphasised the importance of pH and electrolyte levels for the distribution of this genus, while noting that water temperature plays a less significant role. Several species are also acknowledged as effective indicators of anthropogenic acidification (Cantonati et al., 2017). In Turkey, *Eunotia* is not widely distributed; 51 species have been recorded nationwide, 24 of which occur in high-mountain lakes of the eastern Black Sea region (Gönülol and Şahin, 2024; Taşkın et al., 2023, 2019). In the present study, 10 species were identified, primarily from Pond-2 (Tab. 3), whose physicochemical characteristics (pH 5.50; conductivity 55 $\mu\text{S cm}^{-1}$) represent favourable ecological conditions for this genus (Tab. 2).

In the context of global climate change, several studies propose that species native to temperate latitudes may increasingly colonise Arctic aquatic ecosystems. Bessudova et al. (2021) suggest that rising diatom diversity and altered community structure may serve as early indicators of climatic shifts, and that similarities between temperate and Arctic floras are likely to intensify. The predominance of *Pinnularia* and *Eunotia* species in both the present study and in comparative Arctic floras reinforces this hypothesis. Moreover, a progressive increase in species richness of these genera toward higher latitudes may represent a valuable metric for assessing climate-driven changes in Arctic freshwater ecosystems.

The prominence of the genera *Cosmarium*, *Staurostrum*, and *Closterium*, which together account for 16.54% of the recorded flora, is consistent with earlier studies from the region (Şahin and Barinova, 2025a). Previous research (Stamenkovic et al., 2008; Coesel, 1996) highlights the prevalence of these genera in freshwater coastal habitats of northern regions, whereas *Pleurotaenium*, represented by a single species in this study, is typically associated with high-mountain northern environments. Additionally, the presence of *Tetmemorus leavis* indicates glacial influence on the lakes (Stamenkovic et al., 2008). Reports by John et al. (2003) and Wehr and Sheath (2003) observe that these genera commonly occur in acidic, oligotrophic waters, while Sigeo (2005) notes their favourable growth in soft-water lakes. The physicochemical results obtained in this study support these ecological characterisations (Tab. 2).

Encyonema minutum is a cosmopolitan species frequently associated with oligotrophic to oligo-mesotrophic waters with moderate electrolyte levels (Cantonati et al., 2017; Krammer and Lange-Bertalot, 1986; Patrick and Reimer, 1975). *Gomphonema parvulum*, although often linked to nutrient-rich environments (Patrick and Reimer, 1975), is also recognised as a cosmopolitan taxon capable of inhabiting diverse water types (Krammer and Lange-Bertalot, 1986). Cantonati et al. (2017) note its occurrence in oligosaprobic to mesosaprobic freshwater systems. The physicochemical characteristics of the study sites are consistent with the ecological requirements of these species (Tab. 2). *Oscillatoria tenuis*, identified at a frequent (F) level, is similarly cosmopolitan and commonly occurs in benthic and metaphytic freshwater habitats (Komarek and Anagnostidis, 2005).

A notable finding of the present study is also the presence of eutraphentic species in the composition of trophic indicators in the studied waters (Fig. 11c). It is hypothesised that this phenomenon is attributable to the transformation of lake and pond ecosystems in response to environmental variables (e.g. shortening ice cover duration, increasing acidification and salinity) and biological processes.

Bioindicator analysis reveals that the majority of species recorded from the lakes and ponds are benthic autotrophs that prefer temperate, well-oxygenated, low-salinity waters with indifferent pH and high clarity, corresponding to water-quality classes 2 and 4. These communities predominantly characterise oligotrophic and mesotrophic trophic states.

The study also demonstrated a pronounced individuality in the diatom communities of the investigated lakes and ponds. For the first time in Kaçkar Mountains National Park, a preliminary assessment of threatened diatom species was conducted, identifying 96 taxa fitting IUCN categories. These species generally favour moderate temperatures and slightly acidic to neutral environments devoid of organic pollution. Consequently, the lake communities characterised by pristine, pH-neutral freshwater conditions appear to be the most vulnerable within the park.

CONCLUSIONS

This research provides a detailed assessment of the benthic algal flora and ecological conditions of three lakes and two ponds situated within Kaçkar Mountains National Park. The algological and physicochemical analyses reveal that these aquatic ecosystems largely maintain their pristine and undisturbed character. The research represents a significant step toward establishing a comprehensive database on the algal biodiversity of the park. Given its relatively intact nature, the park represents an important reference site for examining how high-mountain freshwater ecosystems may respond to global climate change and local anthropogenic pressures. To strengthen this foundation, it is crucial to expand similar investigations to the remaining water bodies within the park. Continued research will not only improve knowledge of algal diversity but also clarify how these communities adapt to the challenging environmental conditions characteristic of high-altitude habitats.

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