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Full Paper

Algal flora of an extremophile ecosystem: Kaklik Cave (Denizli, Turkey)

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Abstract: Caves are specific ecosystems with both biotic and abiotic characteristics. Turkey has approximately 20,000 caves, and the biology of most of them has yet to be studied. Kaklik Cave is sinkhole-shaped and its entrance is quite large. A mineral-rich spring forms travertine as it enters the cave giving it unique characteristics. The study aims to determine the algal flora of Kaklik Cave. A total of eighty-six taxa were identified. Among them, twenty-one taxa were recorded for the first time as freshwater algal flora of Turkey. Also, the relationships among the most effective environmental parameters, the most frequently found algae taxa composition, and sampling sites were observed.

Keywords: Kaklik Cave, algal flora, mineral-rich spring, canonical correspondence analysis, Turkey

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INTRODUCTION

Caves are specific ecosystems with both biotic and abiotic characteristics. The formation and development characteristics of caves and their physicochemical conditions are the most critical factors determining their viability and diversity [1, 2].

The first written biospeleological report was related to a cave amphipod (probably Niphargus) by Trissino [3]. In terms of cave algae, studies in Hungary [4-6] and the US [7, 8] were among the first. In the years that followed, studies on algal flora of caves were conducted by many researchers [9-11]. There have also been studies on the relationship between cave algae and light [9, 12-14].

There are several studies on the fauna and flora of caves in Turkey [15-23]. In the first study on cave algae in Turkey Sen [16] investigated Cennet Cave (Mersin) and identified eleven cyanobacteria taxa. Selvi and Altuner [19] identified seventy-seven taxa from Ballica Cave (Tokat).

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Ulcay et al. [22] conducted an observational study in Kaklik Cave (Denizli) and identified seventeen taxa. Kulkoyluoglu et al. [23] reported sixty-seven taxa from seven different caves in the western Black Sea Region of Turkey.

It is estimated that there are more than 20,000 caves in Turkey. Among them, 1,500 have been examined by the General Directorate of Mineral Research and Exploration Institute and other cave-related organisations. Considering that Turkey is a cave-rich country, the number of biospeleological studies remains insufficient [24]. This study aims to determine the algal flora of the Kaklik Cave and its mineral-rich spring. There was also a monitoring study on the geomorphological features, environmental parameters and general biodiversity of the cave [22].

Kaklik Cave was chosen as the study area owing to its three main features: i) there is a mineral-rich spring; ii) as the water pours into the cave, it forms travertines and gives the cave unique characteristics; and iii) due to its sinkhole shape, the entrance is quite large and thus receives plenty of sunlight. The cave, which has an extremophile ecosystem, is home to many algae.

MATERIALS AND METHODS

Study Area

The cave coordinates are 37°51'20.86"N; 29°23'08.50"E. It is located in the western Anatolia region of Turkey. The cave was opened to tourism in 2002. If the entrance of the cave is considered to be 0 m, its deepest point is -14 m (vertical depth) [1, 25-27]. The cave has much potential for tourism because of the continuously growing travertines and its natural beauty. Moreover, the cave is in the hot-cave class with its large entrance and the presence of mineral-rich spring [1].

Sampling

Eighteen sampling sites were identified in the study area. Thirteen were inside the cave (sampling sites 1-13) (Figure 1) and the remainder were outside (sampling sites 14-18). Sampling was done monthly between May 2008 - June 2009 using forceps, a spatula and a plankton net (30 µm). Two separate samples were taken from each sampling site and placed in labelled 1.5-mL Eppendorf tubes. Formaldehyde solution (4%) was added to one while the other was used for direct observation.

Environmental Parameters

The substrate, habitat, light, depth, temperature and humidity values were revised from Ulcay et al. [22] and are given in Table 1 for the sampling sites.

Algological Analyses

The collected samples were examined in the laboratory under an Olympus BX 50 (phase-contrast) microscope and photographed using a Sony DSC-TX7 camera.

The identification of the taxa was made according to previous studies: Komárek and Anagnostidis [28, 29], John et al. [30] and Komárek [31] for cyanobacteria members; Krammer and Lange-Bertalot [32-35] for Bacillariophyta members; Pentecost [36], John et al. [30] and Wehr et al. [37] for Euglenophyta, Ochrophyta and Chlorophyta members. The nomenclature was checked on the AlgaeBase database [38]. New records were checked on Guiry and Guiry [38] and Gonulol [39].

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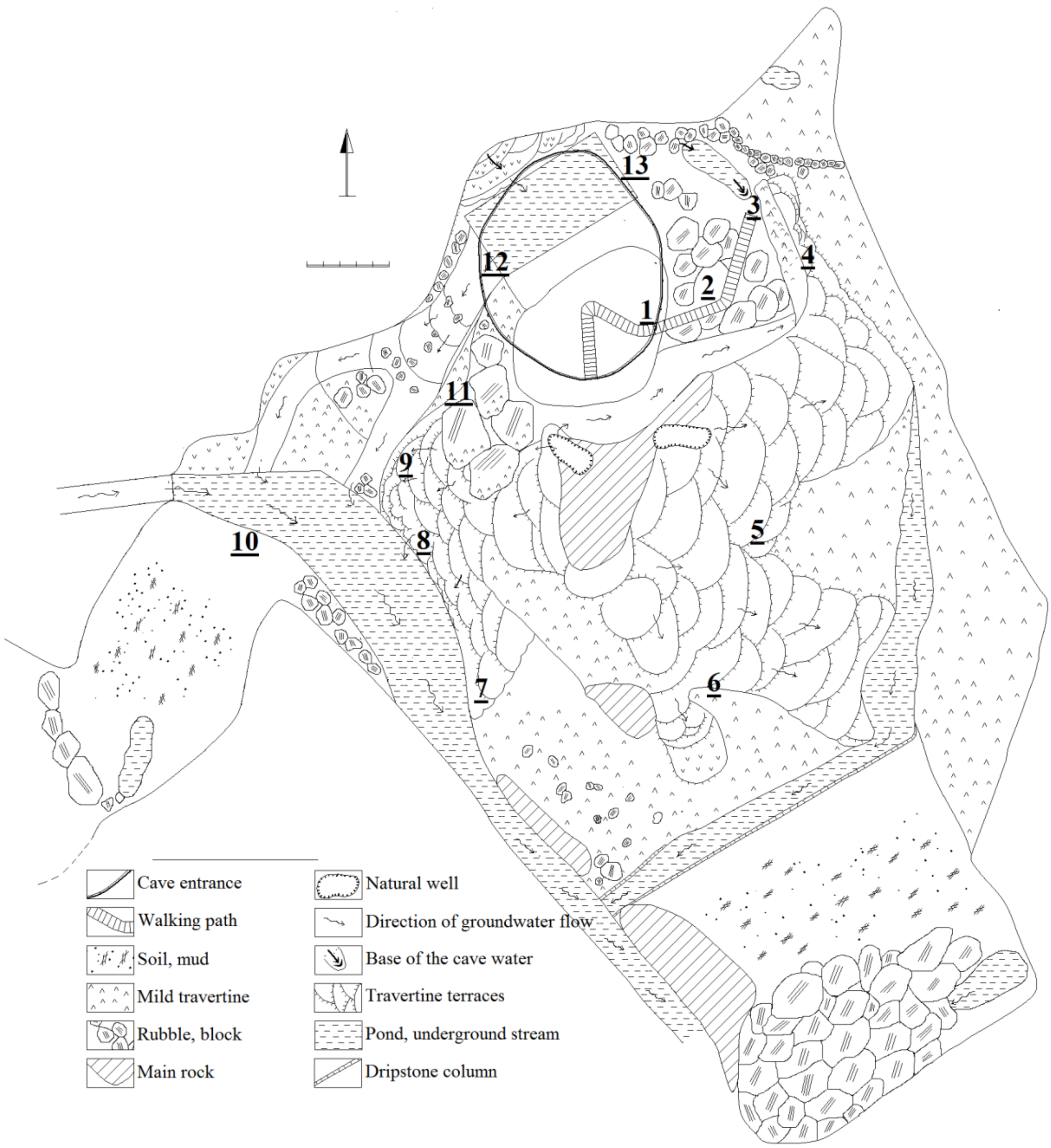

Figure 1. Schematic view of Kaklik Cave and location of sampling sites [22]. Scale: 5 m

Table 1. Specifications of sampling sites (revised from Ulcay et al. [22])

Sampling site	Substrate	Habitat	Light (Lux)	Depth (m)	T (˚C)	Humidity (%)
1	Soft limestone	Continuous water flow	350-400	-2.5	22	74
2	Hard limestone, waterhole	Continuous water flow	380	-3	22.3	72
3	Hard limestone	Continuous water flow	100	-6.7	23	72
4	Soft-soil wall	Humid	120	-10.8	23	75
5	Hard travertine	Continuous water flow	200	-12	23.4	78
6	Stone	Continuous water flow	200	-12.8	23.6	78

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Table 1. (Continued)

Sampling site	Substrate	Habitat	Light (Lux)	Depth (m)	T (°C)	Humidity (%)
7	Soft limestone	Slow flowing water	700	-10.5	24	78
8	Soft limestone	Slow flowing water, waterhole	500	-11.15	24.6	81
9	Hard limestone	Humid	1250	-11.5	24.8	83
10	Soft-soil wall	Humid	150	-12	24.1	84
11	Soft limestone	Slow-flowing water, waterhole	1500	-11.5	25.7	78
12	Pool	Fast-flowing water	1700-Sunlight	-8	24	76
13	Soil or limestone	Humid, small waterhole	Sunlight	-7.3	23.6	74
14	Concrete floor	Fast-flowing water	Sunlight	0	19	65
15	Concrete and marble floor	Fast-flowing water	Sunlight	0	19	65
16	Marble floor	Fast-flowing water	Sunlight	0	19	65
17	Rocks	Fast-flowing water spring	Sunlight	0	19	65
18	Waterhole	Stagnant water	Sunlight	0	19	65

Statistical Analysis

Canonical correspondence analysis (CCA) and detrended correspondence analysis (DCA) were conducted to determine the relationships between the most effective environmental parameters, the most frequent algae taxa composition, and the sampling sites using CANOCO 5.0 software for Windows [40]. Firstly, DCA was performed to test the suitability of the data. Also, the gradient lengths (Axis 1: 5.44; Axis 2: 6.00) were assessed through the DCA. All canonical axes were used to determine the significant environmental parameters (log (x + 1) transformed for the light) through a Monte Carlo test (499 permutations). The significant parameters (habitat, depth, and light) were used in the CCA analysis. In the CCA ordination algal flora, sampling sites and environmental parameters were used as explanatory variables. The significance of their effects was supported by a Monte Carlo permutation test (499 permutations, F–ratio = 2.2, P-value = 0.002).

RESULTS AND DISCUSSION

As a result of the study, a total of eighty-six taxa were identified (49 cyanobacteria, two Euglenophyta, 19 Bacillariophyta, two Ochrophyta, seven Chlorophyta and seven Charophyta). Among them, twenty-one taxa were recorded for the first time for freshwater algal flora of Turkey. Identified taxa and sampling sites are shown in Table 2. Photographs of some taxa are shown in Figures 2 and 3.

Kaklik Cave is an extremophile ecosystem with its mineral-rich spring, so species diversity is expected. Since the temperature of the mineral-rich spring is above 20 °C, the temperature inside the cave does not fall below 19 °C. Because the characteristics of the sampling sites are very different (Table 1, Figure 1), there is a difference in the species compositions (Table 2). As can be seen in Table 2, the highest taxa diversity was at sampling site 14 (26 taxa), and the poorest were at sampling sites 4 and 10 (2 taxa). Light and water parameters are important factors in the difference in taxa at the sampling sites (Table 1). As can be seen from the CCA analysis, most of the species show a positive correlation with light (Figure 4).

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Table 2. Algal flora of study area and sampling sites

Taxa	Sampling site
Cyanobacteria	
Anagnostidinema acutissimum (Kufferath) Strunecký, Bohunická, J.R.Johansen & J.Komárek	12,17
Anagnostidinema amphibium (C.Agardh ex Gomont) Strunecký, Bohunická, J.R.Johansen & J.Komárek	11
Anagnostidinema ionicum (Skuja) Strunecky et al.	14,17
Aphanothece elabens (Brébisson ex Meneghini) Elenkin	9
Limnospira maxima (Setchell & N.L.Gardner) Nowicka-Krawczyk, Muhlsteinová & Hauer *	13
Chroococcus minutus (Kutzing) Nägeli	13
Chroococcus westii Boyle-Petersen	13
Cyanobacterium crassiusculum (Skuja) Komárek, J.Kopecký & Cepák*	7, 11
Cyanothece aeruginosa (Nägeli) Komárek	7, 11, 14
Geitlerinema splendidum (Greville ex Gomont) Anagnostidis	1, 2
Gloeocapsa biformis Ercegovic	14,15
Gloeocapsa punctata Nägeli	14
Gloeothece fuscolutea (Nägeli ex Kutzing) Nägeli*	14, 15
Gomphosphaeria aponina Kutzing	12,13,14,15
Heteroleibleinia kossinskajae (Elenkin) Anagnostidis & Komárek	11, 13
Heteroleibleinia lachneri (Zimmermann) Anagnostidis & Komárek*	6
Heteroleibleinia pusilla (Hansgirg) Compère*	1,6,14,15,17,18
Heteroleibleinia rigidula (Kutzing ex Hansgirg) L.Hoffmann*	8, 11
Jaaginema geminatum (Schwabe ex Gomont) Anagnostidis & Komárek	1, 2, 3, 5,17
Jaaginema subtilissimum (Kutzing ex De Toni) Anagnostidis & Komárek	17
Kamptonema animale (C.Agardh ex Gomont) Strunecký, Komárek & J.Smarda	12,16
Kamptonema okenii (C.Agardh ex Gomont) Strunecký, Komárek & J.Smarda	9
Leibleinia epiphytica (Hieronymus) Compère	13,14
Leibleinia kryloviana (Popova & Degtereva) Anagnostidis &Komárek*	13
Leptolyngbya foveolara (Gomont) Anagnostidis & Komárek	12,14
Leptolyngbya margaritata (Kufferath) Anagnostidis *	7
Leptolyngbya perforans (Geitler) Anagnostidis & Komárek*	3
Limnoraphis hieronymusii (Lemmermann) J.Komárek, E.Zapomelová, J.Smarda, J.Kopecký, E.Rejmánková, J.Woodhouse, B.A.Neilan & J.Komárková	13
Lyngbya calcarea (Tilden) Symoens*	2,3,5,6,14
Merismopedia glauca (*Ehrenberg) Kutzing*	14,15
Microcoleus autumnalis (Gomont) Strunecky, Komárek & J.R.Johansen	7,8,11,14,15,16,17,18
Oscillatoria limosa C.Agardh ex Gomont	1,12,14
Oscillatoria engelmanniana Gaidukov*	7, 8, 9, 10, 11
Oscillatoria jenensis G.Schmid*	1,12,14
Oscillatoria nitida Schkorbatov	1,7,17
Oscillatoria princeps Vaucher ex Gomont	1,2,3,12,14,15
Oscillatoria tenuis C.Agardh ex Gomont	2,17,18
Phormidium subfuscum Kutzing ex Gomont	13
Phormidium incrustatum Gomont ex Gomont*	1, 2, 3, 5, 6
Planktothrix agardhii (Gomont) Anagnostidis & Komárek	14, 17
Planktothrix isothrix (Skuja) Komárek & Komárková*	5, 6
Plectonema tomasinianum Gomont ex Gomont *	13
Potamolinea aerugineocaerulea (Gomont) M.D.Martins & L.H.Z.Branco	12
Pseudanabaena lonchoides Anagnostidis	16
Pseudanabaena minima (G.S.An) Anagnostidis	16
Spirulina major Kutzing ex Gomont	15
Spirulina subsalsa Oerstedt ex Gomont	9,16
Spirulina subtilissima Kutzing ex Gomont	14
Symphyonema sinense C.-C.Jao*	6

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Table 2. (Continued)

Taxa	Sampling site
Euglenophyta	
Euglenaformis proxima (P.A.Dangeard) M.S.Bennett & Triemer	7
Phacus curvicauda Svirenko	7
Bacillariophyta	
Amphora ovalis (Kutzing) Kutzing	13
*Cymbella subturgidula Krammer**	14, 15
Diploneis ovalis (Hilse) Cleve	1, 4, 10
Diploneis puella (Schumann) Cleve	4
Epithemia argus (Ehrenberg) Kutzing	7
Epithemia gibba (Ehrenberg) Kutzing	7, 14
Fragilaria sp. 1	13, 14
Fragilaria sp. 2	7, 8, 11,15,16,18
Frustulia rhomboides (Ehrenberg) De Toni	14, 17
Gomphonema sp. 1	11, 13
Gomphonema sp. 2	7, 8
Licmophora sp.	7,14,15,17
Meridion circulare (Greville) C. Agardh	7,8
Navicula peregrina (Ehrenberg) Kutzing	11
Navicula sp.	7, 8, 11,15,16
Pinnularia major (Kutzing) Rabenhorst	8, 11
Pinnularia nobilis (Ehrenberg) Ehrenberg	13
Pinnularia subcapitata W.Gregory	7, 9
Surirella sp.	1
Ochrophyta	
Vaucheria canalicularis (Linnaeus) T.A.Christensen*	13
Vaucheria sessilis (Vaucher) De Candolle	13
Chlorophyta	
Cladophora fracta (O.F.Muller ex Vahl) Kutzing	13
Cladophora glomerata (Linnaeus) Kutzing	7, 8, 13
Desmodesmus communis (E.H.Hegewald) E.H.Hegewald	8, 11, 12, 14
Oedogonium sp.	7, 13, 18
Sphaerocystis schroeteri Chodat	1
Stigeoclonium longipilum Kutzing*	1
Tetradesmus obliquus (Turpin) M.J.Wynne	15
Charophyta	
Chara contraria A.Braun ex Kutzing*	18
Cosmarium granatum Brébisson ex Ralfs	11, 13, 14, 15, 18
Mougeotia sp.	15
Spirogyra sp. 1	15
Spirogyra sp. 2	13
Spirogyra decimina (O.F.Muller) Dumortier	13, 14, 15, 16
Staurastrum hirsutum Ehrenberg ex Ralfs*	14, 15

* As a new record for freshwater algal flora of Turkey

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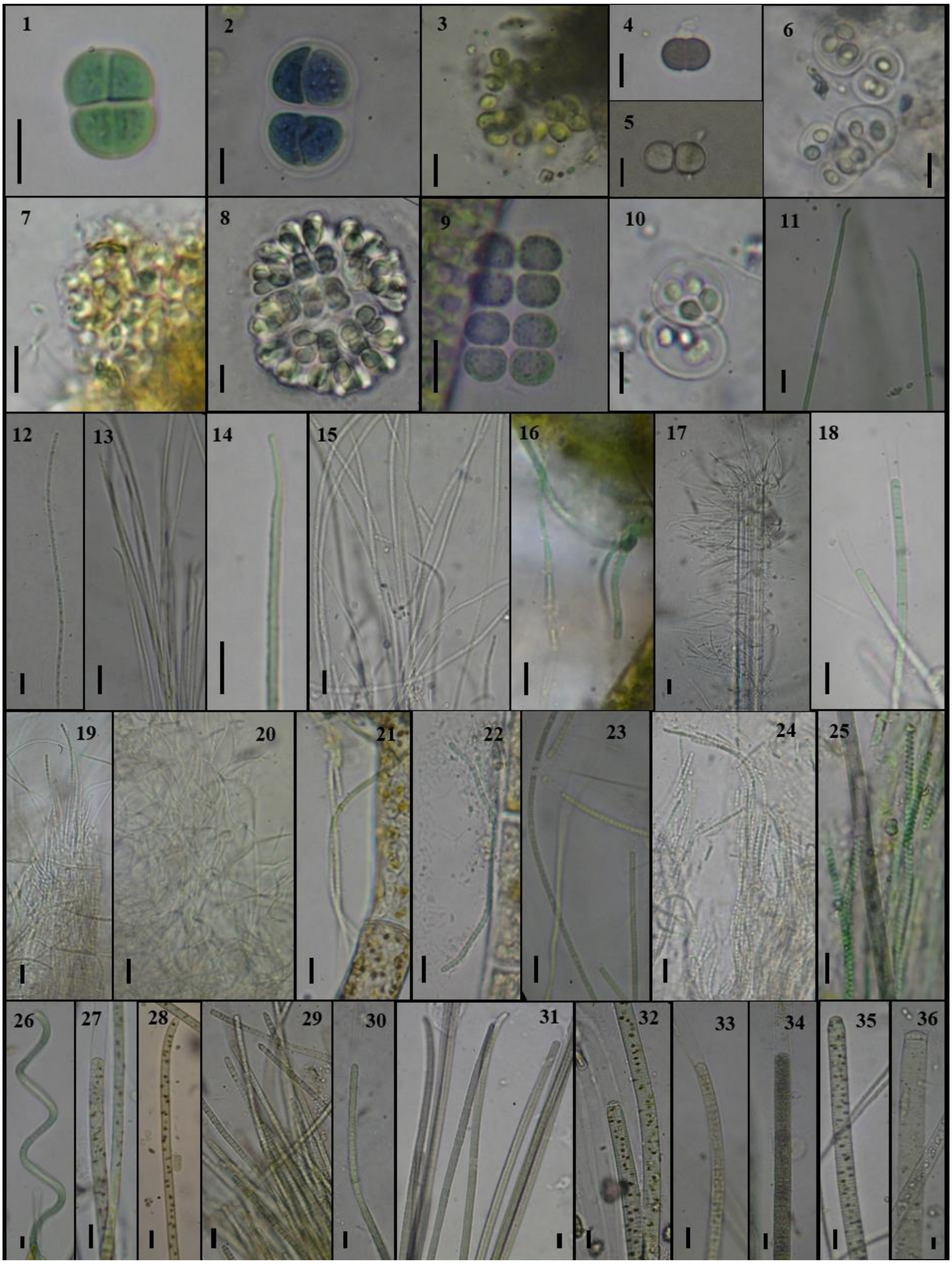

Figure 2. General views of some cyanobacteria taxa in the study area: 1.*Chroococcus minutus*, 2.*Chroococcus westii*, 3.*Aphanothece elabens*, 4.*Cyanobacterium crassiusculum*, 5.*Cyanothece aeruginosa*, 6.*Gloeothece fuscolutea*, 7.*Gloeocapsa biformis*, 8.*Gomphosphaeria aponina*, 9.*Merismopedia glauca*, 10.*Gloeocapsa punctate*, 11.*Anagnostidinema acutissimum*, 12.*Anagnostidinema amphibium*, 13.*Anagnostidinema ionicum*, 14.*Geitlerinema splendidum*, 15.*Heteroleibleinia kossinskajae*, 16.*Heteroleibleinia lachneri*, 17.*Heteroleibleinia pusilla*, 18.*Heteroleibleinia rigidula*, 19.*Jaaginema geminatum*, 20.*Jaaginema subtilissimum*, 21.*Leibleinia epiphytica*, 22.*Leibleinia kryloviana*, 23.*Leptolyngbya foveolarum*, 24.*Pseudanabaena lonchoides*, 25.*Spirulina subsalsa*, 26.*Limnospira maxima*, 27.*Potamolinea aerugineocaerulea*, 28.*Kamptonema animale*, 29.*Microcoleus autumnalis*, 30.*Phormidium incrustatum*, 31.*Kamptonema okenii*, 32.*Phormidium subfuscum*, 33.*Lyngbya calcarea*, 34.*Limnoraphis hieronymusii*, 35.*Oscillatoria engelmanniana*, 36.*Oscillatoria limosa*. Scales: 10 µm

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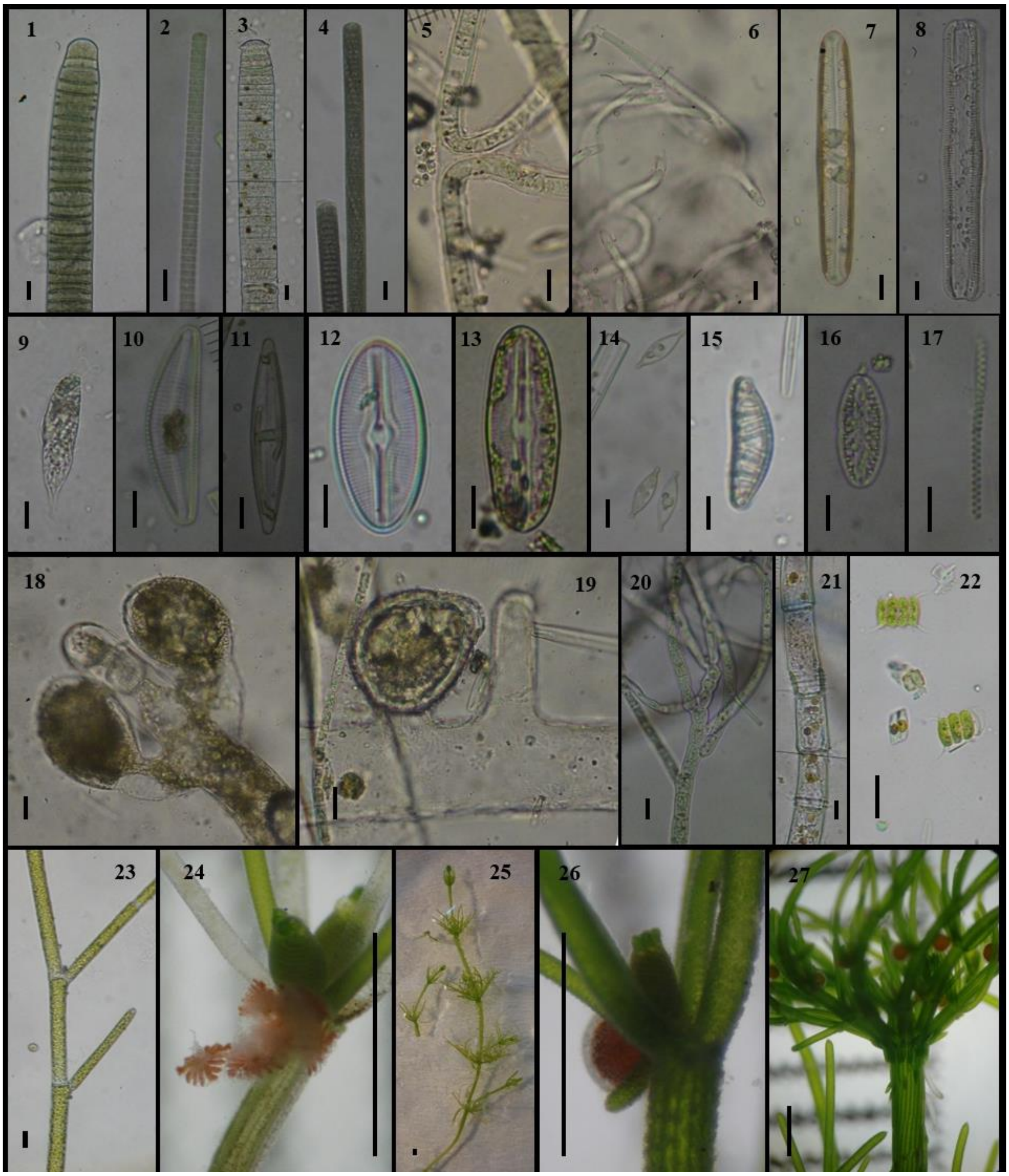

Figure 3. General views of some algae taxa in the study area: 1.*Oscillatoria jenensis,* 2.*Oscillatoria nitida,* 3.*Oscillatoria princeps,* 4.*Oscillatoria tenuis,* 5.*Plectonema tomasinianum,* 6.*Symphyonema sinense,* 7.*Pinnularia major,* 8.*Epithemia gibba,* 9.*Euglenaformis proxima,* 10.*Cymbella subturgidula*, 11.*Frustulia rhomboides*, 12.*Diploneis ovalis*, 13.*Diploneis puella,* 14.*Navicula* sp., 15.*Epithemia argus,* 16.*Surirella* sp., 17.*Spirulina subtilissima,* 18.*Vaucheria canalicularis,* 19.*Vaucheria sessilis,* 20.*Stigeoclonium longipilum,* 21.*Oedogonium* sp., 22.*Desmodesmus communis,* 23.*Cladophora fracta,* 24-27.*Chara contraria.* Scales: 10 µm (1-22), 25 µm (23), 1 mm (24-27)

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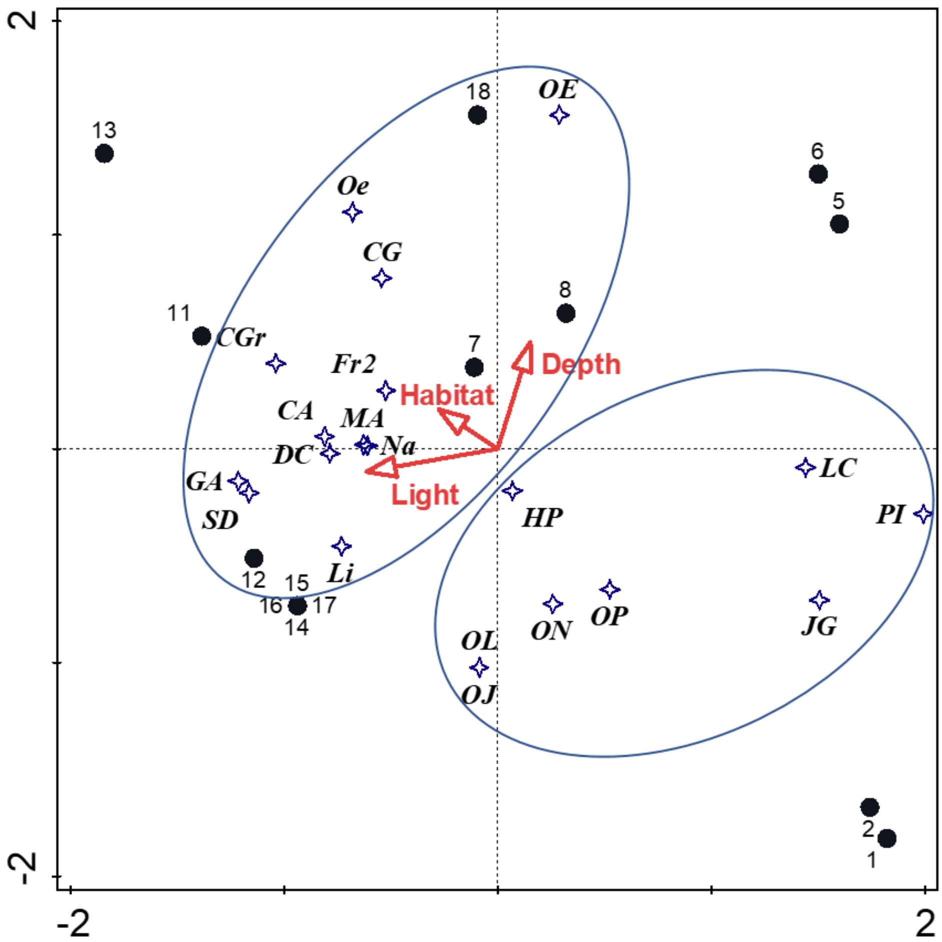

Figure 4. CCA ordination diagram showing the most frequent algal taxa compositions, sampling sites, and the most effective environmental parameters of the study area: Four-point stars= taxa [(OE) *Oscillatoria engelmanniana*, (Oe) *Oedogonium* sp., (CG) *Cladophora glomerata*, (CGr) *Cosmarium granatum*, (Fr2) *Fragilaria* sp. 2, (CA) *Cyanothece aeruginosa*, (MA) *Microcoleus autumnalis*, (Na) *Navicula* sp., (DC) *Desmodesmus communis*, (GA) *Gomphosphaeria aponina*, (SD) *Spirogyra decimina*, (Li) *Licmophora* sp., (HP) *Heteroleibleinia pusilla*, (LC) *Lyngbya calcarea*, (PI) *Phormidium incrustatum*, (JG) *Jaaginema geminatum*, (OP) *Oscillatoria princeps*, (ON) *Oscillatoria nitida*, (OL) *Oscillatoria limosa*, (OJ) *Oscillatoria jenensis*]; Black circles= sampling sites; Vectors= environmental variables

According to the CCA analysis, light as a single factor contributes 44.1% to the distribution of the species in this study. It was also reported that the most important factor affecting taxa diversity and distribution was light in the studies of cave algae [12, 41, 42]. Pentecost and Zhaohui [12] reported the light intensity relationship for the algal flora of Scoska Cave. Komaromy [41] found that light and temperature conditions were decisive in the distribution of the algal species in Ordoglyuk Cave sections. However, according to Komaromy [41], some algal species could live in the moist and nutritious cave soil for a long time in complete darkness. Vinogradova et al. [42] confirmed the importance of light to species richness of algae and reported that many areas differed in the taxonomic composition of algae in Sefunim Cave: the Oscillatoriales members preferred the entrance to the cave while Chroococcales members preferred the interior; Xanthophyta disappeared towards the interior of the cave and Chlorophyta followed Diatomae in terms of species richness [41]. In the present study the distribution of the Chroococcales and Oscillatoriales members in the cave shows similar results to those from Vinogradova et al. [42].

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There have been many studies on the algal flora of caves around the world. The results of previous studies [4-8, 10, 12, 13, 16, 19, 22, 23, 41-50] are compared with this study and shown in Table 3. Cyanobacteria are the dominant group among the algae divisions.

Table 3. Taxa numbers of some algal biospeleological studies in the world and comparison with this study

Author's name	Name of Cave	Cyanobacteria	Euglenophyta	Dinophyta	Bacillariophyta	Ochrophyta	Rhodophyta	Chlorophyta	Total Taxa Number
Palik [4]	Baradla Peace(Beke)	68	2	-	8	-	1	11	90
	Abaliget	52	2	-	18	-	1	18	93
	Palvolgy	21	-	-	7	-	-	13	41
	Kolyuk	19	-	-	2	-	-	7	28
Claus [6]	Baradla	17	-	-	5	-	-	9	31
Kol [5]	Ice-Cave	8	-	-	1	2	-	12	23
Jones [7]	Mammoth	11	1	-	2	-	1	10	25
Nagy [8]	Crysta	2	-	1	1	-	1	2	7
Landingham [42]	Mammoth		-	-	16	-	-	-	16
Hajdu [43]	Matyas Mount	7	-	-	2	-	-	1(?)	10
Palik [44]	Matyas Mount	5	-	-	4	-	-	12	21
Williams [45]	Galler	15	-	-	5	-	-	19	39
Komaromy [46]	Ordoglyuk	4	-	-	9	3		5	21
Dayner and Johansen [47]	Seneca	?	-	-	14	-	-	?	25
Pentecost and Zhaohui [12]	Scoska	3	-	-	-	-	-	1	4
Smith and Olson [13]	Mammoth	14	-	-	6	-	-	6	28
Vinogradova et al. [41]	Sefunim	45	-	-	7	2	-	15	69
Lamprinou et al. [48]	Leontari	22	-	-	-	-	-	-	22
Martinez and Asencio [10]	Gelada	22	-	-	-	-	-	-	22
Czerwik-Marcinkowska and Mrozińska [49]	25 caves	33	-	2	10	7	-	30	82
Popovic et al. [50]	3 caves	44	-	-	5	-	-	10	59
Sen [16]	Cennet	11	-	-	-	-	-	-	11
Selvi and Altuner [19]	Ballica	56	-	-	18	-	-	3	77
Ulcay et al. [22]	Kaklik	4	1	-	3	1	-	8	17
Kulkoyluoglu et al. [23]	Kizilcik	7	2	-	14	-	-	5	28
	Fakilli	8	-	-	4	-	-	2	14
	Gokgol	2	1	-	1	-	-	1	5
	Sogutlu	1	-	-	1	-	-	1	3
	Cehennem Agzi	1	-	-	2	-	-	-	3
	Çayirkoyu	1	-	-	-	-	-	-	1
	Cumayani	2	-	-	1	-	-	-	3
This Study*	**Kaklik**	**42**	**2**	**-**	**17**	**2**	**-**	**6+3****	**72**

* The table does not include taxa identified from sampling sites 14-18.
**Chlorophyta+Charophyta

According to AlgaeBase [38], *Gloeocapsa biformis* is a marine/terrestrial taxon. However, in the literature it has been reported that it is aerophytic and epilithic in calcareous environments in the Alps [28]. In addition, Martinez and Asencio [10] reported this taxon as common and epilithic in Gelada Cave. It was sampled as aerophytic from the upper part of the algae mats (sampling sites

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14 and 15) in the present study. *Gloeocapsa punctata* was sampled as aerophytic from the cave walls [12, 42]. In contrast, it was collected from outside the cave (sampling site 14) in this study.

Artificial lighting has been used in historical caves and those popular with tourists. This artificial light causes the development of algae and damages prehistoric wall paintings. The algae developed in this manner are called "Lampflora" or "Lampenflora," and are investigated as a unique study topic [9, 13, 14]. As mentioned above, the Kaklik Cave was opened to tourism in 2002 [24] and the artificial light source added to sampling site no. 9 caused results similar to those in the literature [22].

As a result of this analysis, it was found that the total algal variation is 3.09069 and all the applied parameters explain 49.73% of the species data variation. Despite this, none of the environmental parameters is significant for differentiation in the data set (Figure 4). Ordination data distinguish two main groups of taxa: (1) taxa such as *Cyanothece aeruginosa*, *Microcoleus autumnalis* and *Desmodesmus communis* from ten sampling sites of the study area (nos. 7, 8, 11-18) give positive correlation with the environmental parameters; (2) taxa such as *Heteroleibleinia pusilla*, *Oscillatoria princeps* and *Oscillatoria nitida* from four sampling sites of the Kaklik Cave (nos. 1, 2, 5 and 6) give negative correlation with the environmental parameters. It is noteworthy that the entire negatively related group consist of filamentous cyanobacteria members. Also, the four Oscillatoria taxa (*Oscillatoria princeps*, *O. nitida*, *O. limosa* and *O. jenensis*) have similar ecological requirements (from sampling sites 1, 2 and 14), while *O. engelmanniana* (from sampling sites 7-11) stands out with quite different demands. *Lyngbya calcarea* and *Phormidium incrustatum* differ significantly from the other taxa by preferring calcareous substrate and their light requirements are much lower than other taxa (Figure 4) [51, 52]. According to the literature, *P. incrustatum* also prefers calcareous substrate [51-53].

Microcoleus autumnalis is the most frequent taxon (from eight sampling sites) in this study. According to the results of the CCA analysis, this taxon has a significant positive correlation with light and habitat. When the light demand of the taxon was examined, it is seen that it was spread both in semi-shaded stations 7 and 8 and in stations 17 and 18 under direct sunlight. Also, looking at the habitat requirement of *M. autumnalis*, it is seen that the common feature of all the stations where it was distributed is flowing water. According to Komárek and Anagnostidis [29] *M. autumnalis* (as *Phormidium autumnale*) is periphytic on submersed substrates and it is cosmopolitan. In the present study, the taxon forms dark blue-green thin layers at these eight sampling sites where the water flows continuously. In addition, *M. autumnalis* filaments show morphological variety at the apex. Similarly, John et al. [30] reported that when phosphorus is limited, *M. autumnalis* could have morphological variations, especially at its apex.

CONCLUSIONS

Biological and geological features of caves, whose formations last for millions of years, are significant. Thus, caves must be preserved and their biological importance revealed. The author believes that the biospeleological studies of the caves of Turkey should increase and the biological significance of caves should be emphasised. Mineral-rich springs and cave algal flora are among the less-studied topics in Turkey. The results of this study emphasise the need to investigate a topic that has not been studied enough in Turkey.

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