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Diatom communities of high-altitude creeks in Bosnia and Herzegovina

by

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Abstract

Diatoms from two high-altitude creeks in Bosnia and Herzegovina were studied from June 2005 to May 2007. Along with diatoms, water temperature, pH, conductivity and nutrients were also monitored, indicating stable physical and chemical conditions, low organic loading and oligotrophy. A total of 130 diatom taxa (species and subspecies) were recorded. Mostly oligotrophic and oligo-mesotrophic indicators were recorded in the creeks. The most abundant genera were *Eunotia* (15), *Pinnularia* (13), *Gomphonema* (10) and *Navicula* (9). The following taxa were recorded in all samples: *Cymbopleura naviculiformis* (Auerswald ex Heiberg) Krammer, *Decussiphycus hexagonus* (Torka) Guiry & Gandhi, *Eunotia arcus* Ehrenberg, *Frustulia vulgaris* (Thwaites) De Toni, *Pinnularia borealis* Ehrenberg and *Pinnularia viridis* (Nitzsch) Ehrenberg. Five new diatom taxa for Bosnia and Herzegovina were recorded. According to the German Red List, the largest number of taxa (34 for creek 1 and 27 for creek 2) were identified as declining taxa and 12 taxa as endangered ones (three for creek 1 and nine for creek 2). The high species richness and the presence of diatom taxa included on the German Red List underline the importance of protecting and preserving this important biotope.

Key words: diatoms, high-altitude creeks, ecology, threats, bioindication, Bosnia and Herzegovina

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1. Introduction

Mountain areas are an important source of water, energy and biodiversity, and as such belong to endangered ecosystems as a result of strong anthropogenic impact. They are widely valued for their geodiversity, species richness, high endemism, and association with various essential ecosystem services. The title of this paper uses the term high-altitude creeks, which implies wetlands. Wetlands are areas where water is the primary factor controlling the environment, flora and fauna (Kapetanović 2007; Kapetanović, Hafner 2007). Assessing the biodiversity of these habitats is important for determining their sensitivity and possible conservation measures (Kapetanović et al. 2011).

This paper reports on research at two high-altitude creeks on Mount Ozren near Sarajevo, at the weekend resort of Čavljak, with a focus on diatoms. Sampling sites are located in the Čavljak area (43°54′50″N; 18°27′30″E) at an altitude of 1300 m, with a southeastern exposure within the heath vegetation (*Callunetum vulgaris illyricum*). According to the EUNIS (European Nature Information System) database, such habitats can be classified as wetland ecosystems with extreme environmental conditions. The primary and, for many organisms, insurmountable parameter is lower pH, followed by a lack of nutrients and significant changes in temperature (Krivograd Klemenčić, Vrhošek 2003). The need for biodiversity research in these habitats is now underscored by the fact that these small, oligotrophic and mountain habitats of glacial relic origin are very sensitive to anthropogenic impacts and have become threatened in recent decades (Kapetanović et al. 2011). Diatoms are considered the dominant components of the algal flora in high mountain creeks (Negro et al. 2003; Kapetanović et al. 2011) and can be used as good indicators of the quality status of pristine areas (Kapetanović et al. 2011). These ecosystems in the territory of Bosnia and Herzegovina occupy a very small area. Since they represent remnants of vegetation from a time of much colder climate, they are classified as glacial relicts. Diatoms of high altitude ecosystems in Bosnia and Herzegovina are poorly investigated. To date, studies have been carried out around Mount Zvijezda (Kapetanović et al. 2011), partially in the Vranica mountains (Barudanović et al. 2017), and on the Blidinje plateau (Hafner et al. 2015). Kapetanović et al. (2011) described two diatom species new to science – *Sellaphora bosniaca* Kapetanović and Jahn sp. nov. and *Sellaphora hafnerae* Kapetanović and Jahn sp. nov. – from wetland ecosystems located in the protected landscape of Bijambare (Mount Zvijezda). In addition, a large number of species new to the algal flora of Bosnia and Herzegovina were identified. The results of the conducted research allow us to conclude that high-altitude creeks are unique ecosystems with great conservation potential.

The purpose of this study was to present the composition and seasonal dynamics of diatom taxa in two high-altitude creeks on Mount Ozren.

2. Materials and methods

Samples of mosses and sediments were collected from two high-altitude creeks between June 2005 and May 2007 for analysis of epiphytic and epipsammic diatoms. The collected material was fixed with 4% formaldehyde. Samples were cleaned with 30% H_2O_2 and permanent slides were mounted in Naphrax. Identification of taxa was carried out using a Zeiss DIC microscope (Zeiss, Germany) and an AXIOCAM MRc camera (Zeiss, Germany), and a SEM (Philips SEM: 515, Eindhoven, the Netherlands) at the Berlin-Dahlem Botanical Garden and Botanical Museum (BGBM) and the University of Mostar.

Identification was based on scientific literature and identification keys, i.e. Krammer & Lange-Bertalot (2000; 2004), Krammer (2000; 2003), Lange-Bertalot et al. (2003) and Werum & Lange-Bertalot (2004). Nomenclature and classification of taxa follow AlgaeBase (Guiry, Guiry 2023).

Data on the ecology and threats to diatoms are given according to the Germany Red List (Lange Bertalot, Steindorf 1996).

Saprobic data are provided according to Wegl (1983), Sladečèk (1973) and Rott et al. (1997), while trophic status and geochemical preferences according to Rott et al. (1999).

Ecological data on each species preferences in terms of habitat, temperature, salinity, pH, oxygenation, organic pollution, nutrition type, and trophic state are given according to the database (Barinova et al. 2006, 2019).

Biogeographic data are presented according to Krammer & Lange-Bertalot (1986–1991).

Conductivity, pH, and temperature were measured in the field at each sampling site using a portable pH-009 (III) pH and temperature meter (ATC probe, Thermo Scientific Orion) and an Ec 138-2 conductivity tester (ATC probe, Thermo Scientific Orion). The concentration of nutrients was analyzed by standard spectrophotometric methods (APHA AWWA WEF 1995) using a Perkin-Elmer lambda 15

UV/VIS spectrophotometer (Perkin-Elmer, USA) at the Laboratory for Oceanology of the Institute for Marine and Coastal Research (Dubrovnik, Croatia).

Calculations of similarity were performed as network analyses in JASP based the bootnet package in R. Network graphs and Pearson correlation coefficients produced by JASP are based on the R Statistical package (Love et al. 2019).

2.1. Sampling sites

The studied high-altitude creeks are located in the area of the Čavljak weekend resort near Sarajevo (Bukovik vertical profile of 1530 m) in Bosnia and Herzegovina. The area belongs to the Illyrian province and the Euro-Siberian-Boreo-American region (Redžić 2007). The dominant biome is dark coniferous forests of spruce and fir with occasional white pine (*Abieti–Piceetum illyricum* and *Piceo–Pinetum sylvestris* communities). Significant areas of these forests have now been transformed into secondary forms of vegetation – mountain meadows, thicket vegetation with birch (*Betuletum verrucosae*) and aspen (*Populetum tremulae*), and mountain meadows of the endemic Balkan association Pančićion and acidophilic meadows of *Nardetum strictae*. *Callunetum vulgaris illyricum* mountain heaths currently occur in many areas as a progradational–degradation stage (Redžić 2007). The basic characteristics of the creeks in the Čavljak locality are given by a peat bog community composed of *Sphagnum* mosses from *Sphagnion fusci* (order *Sphagnetalia fusci*), which have their southern limit of distribution in this area. The identified mosses for creek 1 are: *Sphagnum subsecundum* Pees, *Calliergonella cuspidata* (L.) Loeske, *Philonotis marchica* (Willd.) Brid, *Aulacomnium palustre* (L.) Schwägr, and for creek 2: *Calliergonella cuspidata* (L.) Loeske and *Aulacomnium palustre* (L.) Schwägr. Soils on which peatland vegetation develops are classified as acrohistosol (mires). Slightly less moist soils of the hydromorphic black soil type are covered with communities of *Molinetum coeruleae illyricum* and *Descampsietum caespitosae* (Redžić 1999). All these wetlands are refugia that provide shelter for many glacial relict plants and animals (Redžić 1999).

The climate of the Čavljak area is moderately continental, with a strong impact of certain variants of mountain climate. The mean temperature in the growing season (April–September) varies from 9°C to 14.6°C, while the mean January temperature is –1.9°C. Annual precipitation amounts to an average of 1082 mm.

3. Results

3.1. Physical and chemical conditions

The average water temperature during the study period was 9.9°C for creek 1 and 13.3°C for creek 2. The pH values of water ranged from 6.86 to 6.98 for creek 1 and from 6.77 to 7.96 for creek 2. Values of specific electric conductivity ranged from 0.31 to 13.78 μScm^{-1} for creek 1 and from 1.97 to 10.31 μScm^{-1} for creek 2. The results for nutrients are shown in Table 1. The results obtained indicate that there were no significant differences in all the parameters analyzed for the two creeks. Both creeks can be classified as oligotrophic, with stable physical and chemical conditions and low organic loading.

Table 1

Nutrients in 12 samples of water collected from high-altitude creeks (mg L^{-1}).

Date	Creek	Nitrates	Nitrite	Phosphate	Silicate
June 2005	1	0.07	0.01	0.02	3.076
	2	0.13	0.01	0.01	4.403
January 2006	1	0.08	0.01	0.02	6.242
	2	0.17	0.01	0.02	4.782
May 2006	1	0.08	0.01	0.02	0.433
	2	0.15	0.01	0.01	4.013
July 2006	1	0.08	0.01	0.02	6.885
	2	0.21	0.01	0.02	3.599
October 2006	1	0.09	0.01	0.01	7.168
	2	0.21	0.01	0.02	9.252
May 2007	1	0.07	0.02	0.8	5.107
	2	0.15	0.02	0.05	3.911

3.2. Diatom analysis

During the study period, a total of 130 taxa (from 40 genera) were identified in 12 samples (Table 2). The most abundant genera were: *Eunotia* (15), *Pinnularia* (13), *Gomphonema* (10) and *Navicula* (9). The following taxa were present regularly in all samples: *Cymbopleura naviculiformis* (Auerswald ex Heiberg) Krammer, *Decussiphycus hexagonus* (Torka) Guiry & Gandhi, *Eunotia arcus* Ehrenberg, *Frustulia vulgaris* (Thwaites) De Toni, *Pinnularia borealis* Ehrenberg and *Pinnularia viridis* (Nitzsch) Ehrenberg. The following taxa were present in all samples collected from creek 1: *Cymbopleura naviculiformis* (Auerswald ex Heiberg) Krammer, *Decussiphycus hexagonus* (Torka) Guiry & Gandhi, *Diploneis oblongella* (Nägeli ex Kützing) Cleve-Euler 1922, *Frustulia vulgaris* (Thwaites) De Toni, *Meridion circulare* (Greville) C.Agardh, *Meridion* *constrictum* Ralfs, *Pinnularia borealis* Ehrenberg, *Pinnularia viridis* (Nitzsch) Ehrenberg and *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg. Taxa of the genus *Surirella* were not recorded in creek 2 (Table 2). The following taxa were present in all samples collected from creek 2: *Cymbopleura naviculiformis* (Auerswald ex Heiberg) Krammer, *Decussiphycus hexagonus* (Torka) Guiry & Gandhi, *Diploneis oblongella* (Nägeli ex Kützing) Cleve-Euler, *Frustulia vulgaris* (Thwaites) De Toni, *Eunotia bilunaris* (Ehrenberg) Schaarschmidt, *Pinnularia borealis* Ehrenberg and *Pinnularia viridis* (Nitzsch) Ehrenberg.

The largest number of taxa (37 and 39) in the creeks were identified in May 2007 and the lowest in May 2006 for creek 2 and in June 2006 for creek 1 (18 and 25, respectively). In January 2006, 34 diatoms were identified under the snow.

Five new taxa were recorded for Bosnia and Herzegovina: *Aulacoseira alpigena* (Grunow) Krammer, *Decussiphycus hexagonus* (Torka) Guiry & Gandhi, *Diploneis fontium* E.Reichardt & Lange-Bertalot *Stauroneis kriegeri* R.M.Patrick and *Pinnularia abaujensis* var. *linearis* (Hustedt) R.M.Patrick).

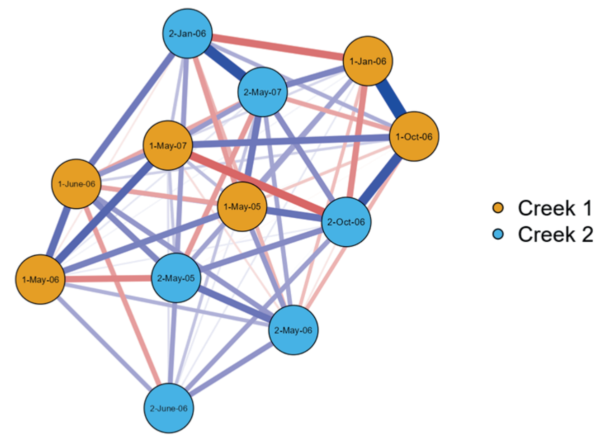

Figure 1

JASP network plot of similarity (R-statistics, $p < 0.05$) between diatom communities in 12 samples from the two creeks. The line thickness between the sites reflects the correlation value; blue color indicates positive correlation, red indicates negative correlation.

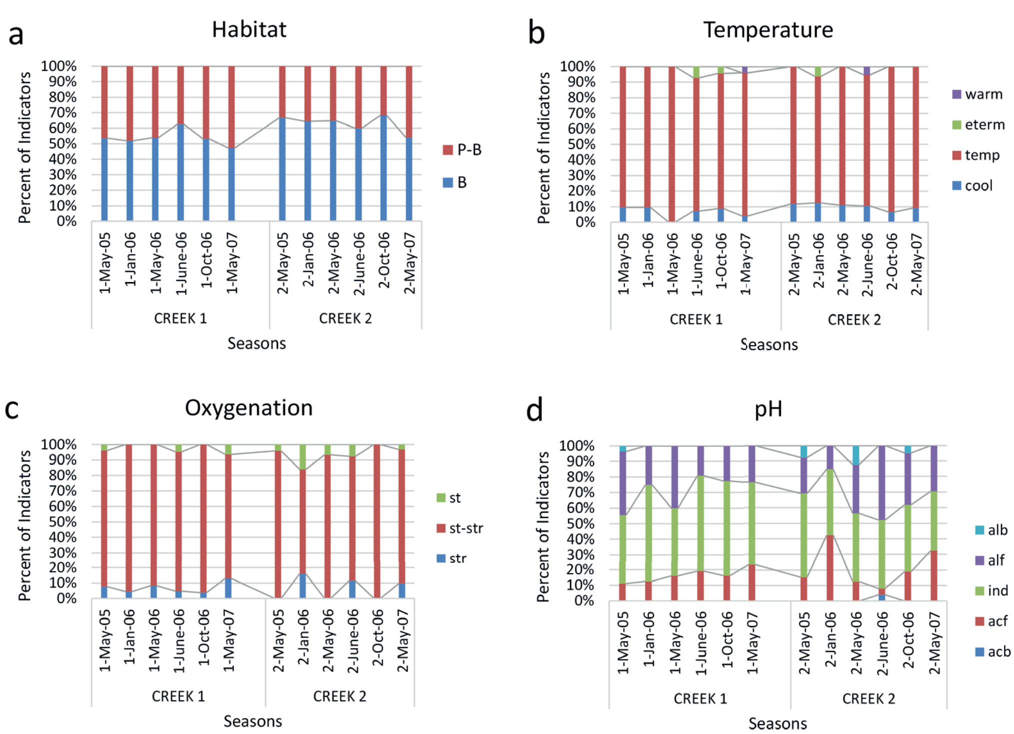

Figure 2

Distribution of bioindicators of habitat preferences, temperature, oxygenation, and pH in the creeks (Barinova et al. 2006; 2019). Abbreviations for ecological indicator groups: (a) Habitat preferences (Hab): B – benthic; P-B – planktic-benthic; P – planktic. (b) Water temperature (T): cool-loving species; temp, temperate – temperate water inhabitants; eterm – eurythermic species, warm – warm water inhabitants. (c) Streaming and oxygenation (Oxy): aer – aerophiles; str – streaming water inhabitants; st-str – low streaming water inhabitants; st – lentic water inhabitants. (d) Water pH (pH): acf – acidophilic species; ind – indifferent; alf – alkaliphilic species; alb – alkalibiontes.

Table 2

List of the identified diatoms with their ecological data (Lange Bertalot, Steindorf 1996), endangered status (Lange Bertalot, Steindorf, 1996), geochemical preferences (Rott et al. 1999), saprobic (Wegl 1983; Sladečèk 1973; Rott et al. 1997) and trophic status (Rott et al. 1999) in the creeks at the weekend resort Čavljak on Mt. Ozren, Bosnia and Herzegovina. Abbreviations: Status D = category on the German Red List according to Lange-Bertalot and Steindorf (1996): *, ** = not endangered taxon, D = insufficient data, V = almost endangered, G = dependent on conservation, R = questionable, 0 = extinct, 1 = critical, 2 = endangered, 3 = sensitive, o = Central European taxa, not found in Germany, but believed to occur there due to ecology. Ecology D = ecological data for diatoms according to Lange-Bertalot and Steindorfu (1996): eu = mesotrophic to eutrophic water, tol = oligotrophic to eutrophic water, o = oligotrophic water (no specific parameters), od= oligotrophic water (carbonate water), oc = oligotrophic water (acidic water, with varying content of humic acids), hal = halophilic, ae = aerophilic. Saprobic values: Sap. according to Rott et al. (1997) – A, Sladaček (1986) – B and Wegl – C (1983). Trophic values – Tro. and geochemical preferences – Geo. according to Rott et al. (1999): ACB – acidobiont, ACF – acidophile, CN – circumneutral, ALK – alkaliphile, ALB – alkalibiont, IND – indifferent.

Valid taxon name	Status D	Ecology D	Geo. A	Sap. A	Tro. A	Sap. B	Sap. C
Achnanthes sp.							
Achnanthidium affine (Grunow) Czarnecki 1994							
Achnanthidium minutissimum (Kützing) Czarnecki 1994							
Amphora ovalis (Kützing) Kützing 1844	**	tol	ALF	2.1	2.8		1.5
Amphora pediculus (Kützing) Grunow 1875	**	tol	ALF	2.1	2.8		1.5
Amphora sp.							
Aneumastus stroesei (Østrup) D.G.Mann 1990							
Aneumastus tusculus (Ehrenberg) D.G.Mann & A.J.Stickle 1990							
Aulacoseira alpigena (Grunow) Krammer 1991							
Caloneis silicula (Ehrenberg) Cleve 1894	*		ALF	1.2	2.5	1.5	1.8
Caloneis ventricosa var. *truncatula* (Grunow) Meister 1912							
Cavinula cocconeiformis (W.Gregory ex Greville) D.G.Mann & A.J.Stickle 1990	G						
Cocconeis pediculus Ehrenberg 1838	**	eu	ALF	2	2.6	1.75	1.7
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow 1895	**	tol	ALF		2.3		
Coscinodiscus sp.							
Cymbella affinis Kützing 1844	*		CN	1.2	0.7	1.6	1.3
Cymbella cymbiformis C.Agardh 1830			CN	1.1	1.1		
Cymbella gracilis (Ehrenberg) Kützing 1844	3	od	ACF	1	0.6	0.2	1
Cymbella lanceolata (C.Agardh) C.Agardh 1830							
Cymbella sp.							
Cymbella turgidula Grunow 1875							
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer 2003	V	eu	ALF	1.6		2	1.1
Decussiphycus hexagonus (Torka) Guiry & Gandhi							
Diatoma vulgaris Bory 1824							
Diploneis fontium E.Reichardt & Lange-Bertalot 2004							
Diploneis oblongella (Nägeli ex Kützing) Cleve-Euler 1922	V						
Diploneis ovalis (Hilse) Cleve 1891	V	oc	ALF	1	1	2	1.4
Encyonema hebridicum Grunow ex Cleve 1891							
Encyonema minutum (Hilse) D.G.Mann 1990							
Encyonema silesiacum (Bleisch) D.G.Mann 1990							
Encyonema ventricosum (C.Agardh) Grunow 1875							
Encyonopsis microcephala (Grunow) Krammer 1997							
Eunotia arcus Ehrenberg 1837	2	od	ACF	1	1.1		1.1
Eunotia bidens Ehrenberg 1843	G	oc	ACF	1	0.6		
Eunotia bilunaris (Ehrenberg) Schaarschmidt 1880							
Eunotia boreotenuis Nörpel-Schempp & Lange-Bertalot 1996							
Eunotia exigua (Brébisson ex Kützing) Rabenhorst 1864							
Eunotia inflata (Grunow) Norpel-Schempp & Lange-Bertalot 1996							
Eunotia lunaris (Ehrenberg) Grunow 1877						0.55	1.2
Eunotia minor (Kützing) Grunow 1881							
Eunotia naegelii Migula							
Eunotia paludosa Grunow 1862	V	od					
Eunotia parallela Ehrenberg 1843	o	od	ACF				1
Eunotia praerupta Ehrenberg 1843	3		ACF	1	0.9		
Eunotia sudetica O.Müller 1898	2	od	ACF	1	0.6		1
Eunotia tenella (Grunow) Hustedt 1913	V	od	ACF	1			
Eunotia valida Hustedt 1930	G	od	ACF	1	0.7		1
Fragilaria capucina Desmazières 1830							
Fragilaria exigua Grunow 1878							
Fragilaria radians (Kützing) D.M.Williams & Round 1988							
Fragilaria rumpens (Kützing) G.W.F.Carlson 1913							
Fragilariforma mesolepta (Rabenhorst) Kharitonov 2005							
Fragilariforma virescens (Ralfs) D.M.Williams & Round 1988	V	o	CN	1.2	1.4	0.2	1
Fragilariforma virescens var. *capitata* (Østrup) Czarnecki 1994							

Valid taxon name	Status D	Ecology D	Geo. A	Sap. A	Tro. A	Sap. B	Sap. C
Fragilariforma virescens var. *elliptica* (Hustedt) Aboal 2003							
Frustulia saxonica Rabenhorst 1853							
Frustulia vulgaris (Thwaites) De Toni 1891							
Gomphonella calcarea (Cleve) R.Jahn & N.Abarca 2019							
Gomphonella olivacea (Hornemann) Rabenhorst 1853	**	eu	ALF		2.9	1.85	2
Gomphonema agnitum Hustedt 1965	*					1.15	2.1
Gomphonema auritum A.Braun ex Kützing 1849							
Gomphonema gracile Ehrenberg 1838	D						
Gomphonema micropus Kützing 1844							
Gomphonema minutum (C.Agardh) C.Agardh 1831							
Gomphonema parvulum (Kützing) Kützing 1849	**	tol	ALB	2.6	3.6	1.95	2.1
Gomphonema pumilum (Grunow) E.Reichardt & Lange-Bertalot 1991						1.15	
Gomphonema vibrio var. *bohemicum* (Reichelt & Fricke) R.Ross 1986	3	od	ALF	1	0.6		
Halamphora veneta (Kützing) Levkov 2009							
Hantzschia amphioxys (Ehrenberg) Grunow 1880	**	ae	ALF	1.8	3.6	2.9	2.7
Iconella biseriata (Brébisson) Ruck & Nakov 2016							
Iconella linearis (W.Smith) Ruck & Nakov 2016							
Iconella tenera (W.Gregory) Ruck & Nakov 2016							
Lindavia glomerata (H.Bachmann) Adesalu & Julius 2017	D					1	1
Luticola mutica (Kützing) D.G.Mann 1990							
Meridion circulare (Greville) C.Agardh 1831							
Meridion constrictum Ralfs 1843	**	eu	ALF	1.9	2.5	0.65	1,1
Navicula capitatoradiata H.Germain ex Gasse 1986							
Navicula cari Ehrenberg 1836	**	eu	ALF	1.6	2.6		
Navicula cryptocephala Kützing 1844							
Navicula cryptotenella Lange-Bertalot 1985							
Navicula exilis Kützing 1844							
Navicula gregaria Donkin 1861							
Navicula oblonga (Kützing) Kützing 1844	V	tol	ALF	1.4	2.7	1.5	1,5
Navicula tenella Brébisson ex Kützing 1849							
Navicula sp.							
Neidium affine (Ehrenberg) Pfitzer 1871	V						
Neidium affine var. *amphirhynchus* (Ehrenberg) Cleve 1894							
Neidium bisulcatum (Lagerstedt) Cleve 1894	3	od	CN	1	0.6		
Neidium iridis (Ehrenberg) Cleve 1894	G	o	CN	1	1.3		1.4
Neidium productum (W.Smith) Cleve 1894	G	od	CN				1.5
Neidium sp.							
Nitzschia hantzschiana Rabenhorst 1860	*	tol	ACF	1.6	2	1.15	1.2
Nitzschia linearis W.Smith 1853			ALB	1.9	3.4	1.5	1.5
Nitzschia paleacea (Grunow) Grunow 1881							
Nitzschia sinuata (Thwaites) Grunow 1880	V		ALF		1.8		
Nitzschia sp.							
Nitzschia sublinearis Hustedt 1930							
Nitzschia umbonata (Ehrenberg) Lange-Bertalot 1978	**	eu	ALF	3.8	3.8	2.2	2.6
Pinnularia abaujensis var. *linearis* (Hustedt) R.M.Patrick 1966			ACF	1	0.3		
Pinnularia borealis Ehrenberg 1843	**	ae	ACF	1.4	1.9	0.4	1
Pinnularia brebissonii (Kützing) Rabenhorst 1864							
Pinnularia brevicostata Cleve 1891	R	od	ACF		0.3		
Pinnularia interrupta W.Smith 1853			CN	1.2	0.7		1.5
Pinnularia lata (Brébisson) W.Smith 1853	V	o	ACF		0.6		
Pinnularia microstauron (Ehrenberg) Cleve 1891	*	eu	CN	2.1	2.1	2.2	
Pinnularia polyonca (Brébisson) W.Smith 1856							
Pinnularia rupestris Hantzsch 1861	G						
Pinnularia silvatica J.B.Petersen 1935							
Pinnularia stomatophora (Grunow) Cleve 1895							
Pinnularia sudetica Hilse 1861							
Pinnularia viridis (Nitzsch) Ehrenberg 1843			CN	1.2	1.3	2.1	1.7
Placoneis exigua (W.Gregory) Mereschkovsky 1903							
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot 1999	**	tol	ALF	2.3	3.3	0.75	2
Psammothidium helveticum (Hustedt) Bukhtiyarova & Round 1996							
Rhopalodia gibba (Ehrenberg) O.Müller 1895	**	eu	CN	2.5	1.7	0.2	1
Rhopalodia sp.							
Sellaphora pupula (Kützing) Mereschkovsky 1902	**	eu				2.2	1.9
Sellaphora wummensis J.R.Johansen 2004	**	eu					
Stauroneis anceps Ehrenberg 1843	V	tol	CN	1.2	1.8	2	1.4
Stauroneis anceps var. *linearis* (Ehrenberg) J.-J.Brun 1880							
Stauroneis kriegeri R.M.Patrick 1945							
Stauroneis phoenicenteron (Nitzsch) Ehrenberg 1843	V						
Stauroneis smithii Grunow 1860	*	eu	ALF	1.5	3.3		
Staurosira venter (Ehrenberg) Cleve & J.D.Möller 1879							
Surirella angusta Kützing 1844	*	eu	ALF	2.2	3.7	2.25	
Surirella grunowii Kulikovskiy, Lange-Bertalot & Witkovski 2010	*	hal					
Surirella minuta Brébisson ex Kützing, 1849							
Surirella sp.							
Synedra famelica Kützing 1844							

The sampled sites offer suitable habitats for species of conservation interest. About 60% of the recorded taxa are on the German Red List (Lange-Bertalot, Steindorf 1996). The largest number of taxa (34 for creek 1 and 27 for creek 2) are identified as declining taxa and 12 as endangered taxa (three for creek 1 and nine for creek 2; Table 2). The extremely rare taxon *Pinnularia brevicostata* Cleve was found in both creeks. Sixty-one percent of diatoms in the creeks indicate oligotrophic conditions (Wegl 1983) and 71% indicate oligo-beta mesosaprobic waters (Wegl 1983). A floristic comparison of the similarity of diatom communities from the creeks (12 samples) is presented in Figure 1. The JASP network plot shows that the creek communities were similar to each other, with no statistically significant seasonality ($p < 0.05$). The communities of January and October samples from creek 1 and January and May samples from creek 2 form the core of similarity. The correlation between all other communities from the sampling sites is positive.

Geochemical preferences (Rott et al. 1999) show that 40% of the taxa in creek 1 and 22% of the taxa in creek 2 were circumneutral (Table 3). Thirty-four percent of the taxa in creek 2 and 30% of the taxa in creek 1 were alkaliphilic. Twenty-eight percent of the taxa in creek 2 and 25% in creek 1 were acidophilic. As can be seen in Table 2 by saprobic status, the creeks belong to classes 2 and 3 (Wegl 1983; Slâdeček 1973) and to classes 1, 2 and 3, with most taxa in class 3 (Rott et al. 1999).

Bioindication results for the creeks are presented in Figures 2 and 3 and Tables 2 and 3, with the percentage of indicator taxa from each ecological group. Distribution of bioindicators of habitat preferences, temperature, oxygenation, and pH in the creeks are shown in Figure 2.

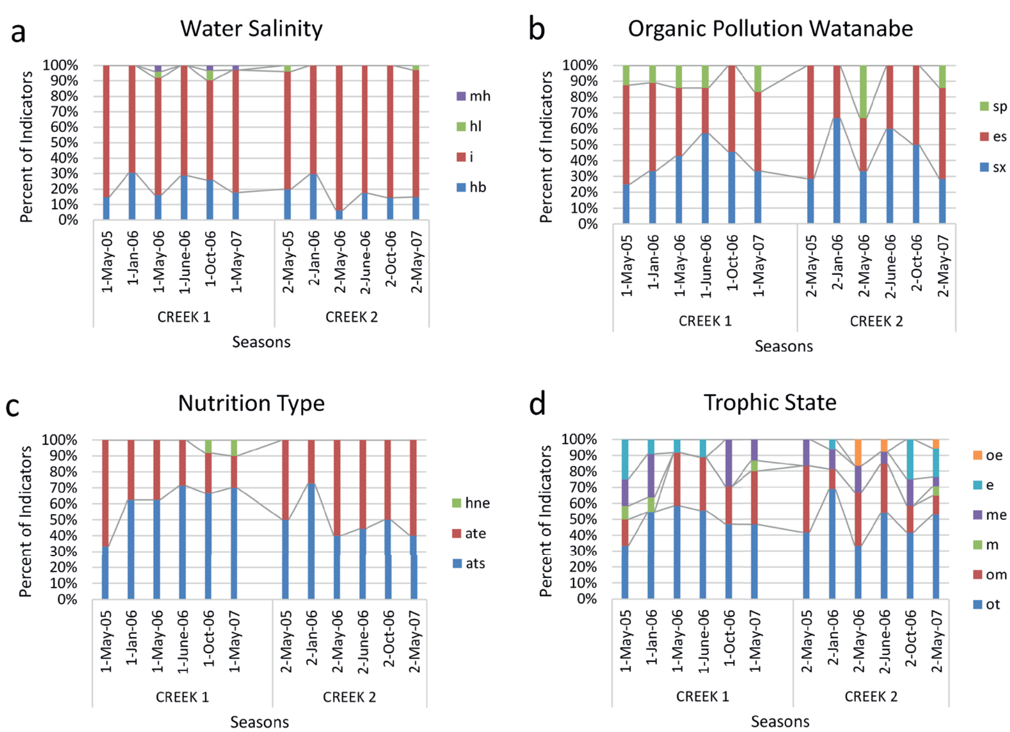

Figure 3

Distribution of bioindicators of salinity preferences, organic pollution according to Watanabe, nutrition type, and trophic state of the creeks (Barinova et al. 2006, 2019). Abbreviations for ecological indicator groups: (a) Water salinity (Sal): hb – halophobe; i – oligohalobious-indifferent; hl – oligohalobious-halophilous; mh – mesohalobious. (b) Organic pollution, Watanabe (D): sx – saproxenes; es – eurysaprobes; sp – saprophiles. (c) Nutrition type as nitrogen uptake metabolism (Aut-Het): ats – nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen; ate – nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen; hne – facultatively nitrogen-heterotrophic taxa that need periodically elevated concentrations of organically bound nitrogen; hce – nitrogen-heterotrophic taxa that need elevated concentrations of organically bound nitrogen. (d) Trophic state (Tro): ot – oligotrophic; o-m – oligo-mesotrophic; m – mesotrophic; me – meso-eutrophic; e – eutrophic; o-e – oligo- to eutrophic.

Table 3

List of identified diatoms with their seasonality and ecology according to Barinova et al. (2006; 2019) in the creeks at the weekend resort Čavljak on Mt. Ozren, Bosnia and Herzegovina. Abbreviations: Habitat preferences (Hab): B – benthic; P-B – planktic-benthic; P – planktic. Water temperature (T): cool – cool-loving species; temp – temperate temperature water inhabitants; eterm – eurythermic species; warm – warm water inhabitants. Streaming and Oxygenation (Oxy): aer – aerophiles; str – streaming waters inhabitant; st-str – low streaming waters inhabitant; st – standing water inhabitant. Water pH (pH): acf – acidophilic species; ind – indifferent; alf – alkaliphilic species; alb – alkalibionts. Water salinity (Sal): hb – halophobe; i – oligohalobious-indifferent; hl – oligohalobious-halophilous; mh – mesohalobious. Organic pollution, Watanabe (D): sx – saproxenes; es – eurysaprobes; sp – saprophiles. Nutrition type as nitrogen uptake metabolism (Aut-Het): ats – nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen; ate – nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen; hne – facultatively nitrogen-heterotrophic taxa, requiring periodically elevated concentrations of organically bound nitrogen; hce – nitrogen-heterotrophic taxa, requiring elevated concentrations of organically bound nitrogen. Trophic state (Tro): ot – oligotrophic; o-m – oligo-mesotrophic; m – mesotrophic; me – meso-eutrophic; e – eutrophic; o-e – oligo- to eutrophic.

Valid taxon name	Creek 1						Creek 2																
	6 May 2005	6 January 2006	6 May 2006	6 June 2006	6 October 2006	7 May 2007	6 May 2005	6 January 2006	6 May 2006	6 June 2006	6 October 2006	7 May 2007	Hab	T	Oxy	Hal	pH	D-Wat	S-Sla	Sap	Aut-Het	Tro
Achnanthes sp.											1											
Achnanthidium affine (Grunow) Czarnecki 1994	1												B		str	i	alf	es	1.1	o	ate	
Achnanthidium minutissimum (Kützing) Czarnecki 1994				1									P-B	eterm	st-str	i	ind	es	0.95	b	ate	e
Amphora ovalis (Kützing) Kützing 1844											1		B	temp	st-str	i	alf	sx	1.5	b	ate	e
Amphora pediculus (Kützing) Grunow 1875	1					1	1			1			B	temp	st	i	alf	es	1.7	b	ate	me
Amphora sp.			1																			
Aneumastus stroesei (Østrup) D.G.Mann 1990	1						1		1		1		B		st-str	i	alb		1.0	o	ats	me
Aneumastus tusculus (Ehrenberg) D.G.Mann & A.J.Stickle 1990									1	1			P-B		st	i	alb		0.9	b	ate	o-e
Aulacoseira alpigena (Grunow) Krammer 1991												1	P-B	temp	st-str	i	alf	sp	0.8	x-b	ate	ot
Caloneis silicula (Ehrenberg) Cleve 1894				1		1							B	warm	st	i	ind	sp	1.3	o	ats	om
Caloneis ventricosa var. *truncatula* (Grunow) Meister 1912								1					B		st-str	i	alf		1.3	b	ats	me
Cavinula cocconeiformis (W.Gregory ex Greville) D.G.Mann & A.J.Stickle 1990		1			1	1	1	1					P-B	temp	st-str	i	ind	es	0.4	x-o	ats	om
Cocconeis pediculus Ehrenberg 1838					1								B	temp	st-str	i	alf	sx	1.8	a-b	ate	me
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow 1895							1						B						1.3	o		om
Coscinodiscus sp.	1							1														
Cymbella affinis Kützing 1844	1												B	temp	st-str	i	alf	sx	1.1	b	ats	e
Cymbella cymbiformis C.Agardh 1830			1						1				B	temp	st-str	i	alf	sx	2.0	b	ats	om
Cymbella gracilis (Ehrenberg) Kützing 1844				1	1					1	1		B		st-str	hb	ind	sx	0.3	o	ats	om
Cymbella lanceolata (C.Agardh) C.Agardh 1830	1		1								1	1	B	temp	st-str	i	alf	es	2.5	b-a	ate	e
Cymbella sp.												1										
Cymbella turgidula Grunow 1875				1			1						B		st-str		ind					
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer 2003	1	1	1	1	1	1	1	1	1	1	1	1	B	temp	st-str	i	ind					
Decussiphycus hexagonus (Torka) Guiry & Gandhi	1	1	1	1	1	1	1	1	1	1	1	1	B						4.0	p		
Diatoma vulgaris Bory 1824	1										1		P-B	temp	st-str	i	alf		2.4	b-a		
Diploneis fontium E.Reichardt & Lange-Bertalot 2004								1				1	B						1.0	o	ate	ot
Diploneis oblongella (Nägeli ex Kützing) Cleve-Euler 1922	1	1	1	1	1	1	1	1	1	1	1	1	B		st-str	i	ind					
Diploneis ovalis (Hilse) Cleve 1891	1											1	B		st-str	i	alf		0.9	x-b	ate	m
Encyonema hebridicum Grunow ex Cleve 1891						1		1				1	P-B	temp	str	i	acf	sx	0.3	x		
Encyonema minutum (Hilse) D.G.Mann 1990										1			B	temp	st-str	i	ind	sx	1.5	o-b	ats	
Encyonema silesiacum (Bleisch) D.G.Mann 1990					1		1	1		1			B	temp	st-str	i	ind					
Encyonema ventricosum (C.Agardh) Grunow 1875								1	1	1	1	1	B		st-str	i	ind				ate	
Encyonopsis microcephala (Grunow) Krammer 1997									1				B	temp	st-str	i	alf					
Eunotia arcus Ehrenberg 1837					1	1		1			1		B	temp	st-str	i	acf	sx	0.4	x-o	ats	ot
Eunotia bidens Ehrenberg 1843		1			1		1	1					P-B,aer	cool	st-str	hb	acf		1.0	o		ot
Eunotia bilunaris (Ehrenberg) Schaarschmidt 1880			1	1		1	1	1	1	1	1	1	B	temp	st-str	i	acf					
Eunotia boreotenuis Nörpel-Schempp & Lange-Bertalot 1996								1					B			hb			1.0	o		ot
Eunotia exigua (Brébisson ex Kützing) Rabenhorst 1864										1			P-B,aer	temp	st-str	hb	acb		1.0	o		ot
Eunotia inflata (Grunow) Norpel-Schempp & Lange-Bertalot 1996		1		1	1	1		1	1	1		1	P-B,aer	cool		hb	acf					
Eunotia lunaris (Ehrenberg) Grunow 1877								1					B									
Eunotia minor (Kützing) Grunow 1881		1		1		1	1	1				1	B	temp	st-str	hb	acf					
Eunotia naegelii Migula								1					P-B	temp	str	hb	acf	sx	0.5	x-o	ate	ot
Eunotia paludosa Grunow 1862	1		1	1	1			1		1		1	B		str	hb	acf	sx	0.5	x-o	ats	ot
Eunotia parallela Ehrenberg 1843								1				1	P-B		str	i	acf		1.0	o		
Eunotia praerupta Ehrenberg 1843	1									1	1	1	P-B	cool	st-str	hb	acf		0.3	x		
Eunotia sudetica O.Müller 1898												1	P-B		st-str	i	acf					
Eunotia tenella (Grunow) Hustedt 1913			1		1	1		1			1		B	temp	st-str	hb	acf					
Eunotia valida Hustedt 1930								1					P-B			hb	acf		1.0	o		ot
Fragilaria capucina Desmazières 1830						1							P-B	temp	st-str	i	ind					
Fragilaria exigua Grunow 1878		1											B		str	hb	ind					
Fragilaria radians (Kützing) D.M.Williams & Round 1988										1			P-B	warm	st-str	i	alf					
Fragilaria rumpens (Kützing) G.W.F.Carlson 1913								1					P-B	eterm	st-str	i	ind		2.0	b	ats	e
Fragilariforma mesolepta (Rabenhorst) Kharitonov 2005										1			P-B		st-str	i	alf		1.0	o		ot
Fragilariforma virescens (Ralfs) D.M.Williams & Round 1988				1	1	1							P-B	temp	st-str	hb	ind		1.0	o		ot

Valid taxon name	Creek 1						Creek 2															
	6 May 2005	6 January 2006	6 May 2006	6 June 2006	6 October 2006	7 May 2007	6 May 2005	6 January 2006	6 May 2006	6 June 2006	6 October 2006	7 May 2007	Hab	T	Oxy	Hal	pH	D-Wat	S-Sla	Sap	Aut-Het	Tro
Fragilariforma virescens var. *capitata* (Østrup) Czarnecki 1994			1		1	1							P-B			hb	ind	es	1.0	x-o	ats	om
Fragilariforma virescens var. *elliptica* (Hustedt) Aboal 2003							1						P-B						0.4	x-o	ate	ot
Frustulia saxonica Rabenhorst 1853	1												B	temp	st-str	hb	acf				ate	
Frustulia vulgaris (Thwaites) De Toni 1891	1	1	1	1	1	1	1	1	1	1	1	1	P-B	temp	st-str	i	alf		1.0	o		
Gomphonella calcarea (Cleve) R.Jahn & N.Abarca 2019				1					1				B		st-str	i	alf					
Gomphonella olivacea (Hornemann) Rabenhorst 1853		1								1		1	B	temp	st-str	i	alf		2.3	b	ate	om
Gomphonema agnitum Hustedt 1965			1	1		1		1				1	B					es	0.9	x-b	ats	ot
Gomphonema auritum A.Braun ex Kützing 1849					1			1					B			i	ind	es	1.5	o-b	ats	me
Gomphonema gracile Ehrenberg 1838										1			B	temp	st-str	i	alf					
Gomphonema micropus Kützing 1844	1	1											B	temp	st-str	i	ind		1.1			
Gomphonema minutum (C.Agardh) C.Agardh 1831					1					1			B	temp		i	alf					
Gomphonema parvulum (Kützing) Kützing 1849		1								1		1	B	temp	st-str	i	ind		0.7	o-x	ats	ot
Gomphonema pumilum (Grunow) E.Reichardt & Lange-Bertalot 1991										1			B	temp		i	alf					
Gomphonema vibrio var. *bohemicum* (Reichelt & Fricke) R.Ross 1986							1						B			hb	ind	es				
Halamphora veneta (Kützing) Levkov 2009			1				1						B	temp	st-str	hl	alf					
Hantzschia amphioxys (Ehrenberg) Grunow 1880					1						1		B,aer	temp	st-str	i	ind		3.0	a		me
Iconella biseriata (Brébisson) Ruck & Nakov 2016						1							P-B	temp	st-str	i	alf	es	1.0	o		m
Iconella linearis (W.Smith) Ruck & Nakov 2016			1		1								P-B		st-str	i	ind					
Iconella tenera (W.Gregory) Ruck & Nakov 2016												1	P-B	temp	st	i	alf		0.2	x	ats	ot
Lindavia glomerata (H.Bachmann) Adesalu & Julius 2017												1	P	temp		hb	acf		1.2	o		
Luticola mutica (Kützing) D.G.Mann 1990												1	B,S	temp	st-str	hl	ind		1.9	o-a	ats	e
Meridion circulare (Greville) C.Agardh 1831	1	1	1	1	1	1	1					1	P-B	temp	st-str	i	ind					
Meridion constrictum Ralfs 1843	1	1	1	1	1	1	1						P-B	temp	st-str	hb	ind					
Navicula capitatoradiata H.Germain ex Gasse 1986			1		1	1							P-B	temp	st-str	mh	alf					
Navicula cari Ehrenberg 1836												1	P-B		st-str	i	ind		1.0	o		
Navicula cryptocephala Kützing 1844	1	1			1				1	1		1	P-B	temp	st-str	i	ind		2.4	b-a		
Navicula cryptotenella Lange-Bertalot 1985	1												P-B	temp	st-str	i	ind					
Navicula exilis Kützing 1844							1						B									
Navicula gregaria Donkin 1861											1		P-B	temp	st-str	i	alf					
Navicula oblonga (Kützing) Kützing 1844			1	1		1	1	1	1				B		st-str	i	alf	sx	1.5	o-b	ate	om
Navicula tenella Brébisson ex Kützing 1849		1											B				ind	es	1.0	o	ats	e
Navicula sp.	1		1																			
Neidium affine (Ehrenberg) Pfitzer 1871												1	B	temp	st-str	i	ind					
Neidium affine var. *amphirhynchus* (Ehrenberg) Cleve 1894							1						B			hb	alb					
Neidium bisulcatum (Lagerstedt) Cleve 1894							1			1	1		B		st-str	i	ind		1.0	o		
Neidium iridis (Ehrenberg) Cleve 1894		1											B	temp	st-str	hb	ind					
Neidium productum (W.Smith) Cleve 1894						1							P-B	temp	st-str	i	ind					
Neidium sp.								1														
Nitzschia hantzschiana Rabenhorst 1860	1		1										P-B	temp	st-str	i	alf	sp	1.8	b	ate	om
Nitzschia linearis W.Smith 1853					1			1					B	temp	st-str	i	alf					
Nitzschia paleacea (Grunow) Grunow 1881												1	P-B	temp	st-str	i	alf	es	2.0	b	ate	o-e
Nitzschia sinuata (Thwaites) Grunow 1880	1										1	1	B		st-str	i	alf		1.9	o-a	ate	e
Nitzschia sp.	1																					
Nitzschia sublinearis Hustedt 1930	1											1	P-B			i	alf					
Nitzschia umbonata (Ehrenberg) Lange-Bertalot 1978						1							P-B		st-str	i	ind	sp	2.0	b	hne	me
Pinnularia abaujensis var. *linearis* (Hustedt) R.M.Patrick 1966				1		1							B	temp	st-str	i	ind					
Pinnularia borealis Ehrenberg 1843	1	1	1	1	1	1	1	1	1	1	1	1	B,aer		st-str,aer	i	ind		1.0	o		ot
Pinnularia brebissonii (Kützing) Rabenhorst 1864	1						1						B	temp	st-str	i	ind		1.0	o		
Pinnularia brevicostata Cleve 1891	1						1						P-B	cool	st-str	i	ind					
Pinnularia interrupta W.Smith 1853			1										B		st-str	i	ind					
Pinnularia lata (Brébisson) W.Smith 1853						1							P-B		str	i	acf		0.3	x		
Pinnularia microstauron (Ehrenberg) Cleve 1891		1	1		1	1		1			1	1	P-B	temp	st-str	i	ind		0.3	x	ats	ot
Pinnularia polyonca (Brébisson) W.Smith 1856			1			1							B		str	i	acf		1.0	o		ot
Pinnularia rupestris Hantzsch 1861										1			B	temp	str	i	acf					
Pinnularia silvatica J.B.Petersen 1935	1	1			1		1				1			temp				es	1.0	o	ats	ot
Pinnularia stomatophora (Grunow) Cleve 1895												1	B		st-str	i	acf					
Pinnularia sudetica Hilse 1861							1					1	B		st-str	i	acf		1.0	o		
Pinnularia viridis (Nitzsch) Ehrenberg 1843	1	1	1	1	1	1	1	1	1	1	1	1	P-B	temp	st-str	i	ind		0.9	x-b		ot
Placoneis exigua (W.Gregory) Mereschkovsky 1903						1							B		str	i	ind	es	1.4	o-b		
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot 1999						1							P-B	temp	st-str	i	alf	sx	1.0	o	ats	om
Psammothidium helveticum (Hustedt) Bukhtiyarova & Round 1996		1											B	temp	st-str	hb	alf	es	2.4	b-a	ate	m
Rhopalodia gibba (Ehrenberg) O.Müller 1895	1	1			1		1			1	1	1	P-B	temp	st-str	i	alf	es	1.4	x-o	ate	om
Rhopalodia sp.	1							1	1			1										
Sellaphora pupula (Kützing) Mereschkovsky 1902					1								B	eterm	st-str	hl	ind	sx	1.9	o-a	ate	me
Sellaphora wummensis J.R.Johansen 2004					1								B			hl	ind	es	1.9	o-a	hne	me
Stauroneis anceps Ehrenberg 1843							1						P-B	temp	st-str	i	ind	sx	1.3	o	ats	om
Stauroneis anceps var. *linearis* (Ehrenberg) J.-J.Brun 1880			1	1	1		1			1			B		st-str	i	alf					
Stauroneis kriegeri R.M.Patrick 1945								1					B		st-str	i	ind	sx	1.0	o		
Stauroneis phoenicenteron (Nitzsch) Ehrenberg 1843	1	1	1	1	1	1			1			1	P-B	temp	st-str	i	ind					
Stauroneis smithii Grunow 1860										1			P-B		st-str	i	alf		1.0	o		om
Staurosira venter (Ehrenberg) Cleve & J.D.Möller 1879			1										P-B	temp	st-str	i	alf		1.0	o		ot
Surirella angusta Kützing 1844		1	1	1		1							P-B	temp	st-str	i	alf					
Surirella grunowii Kulikovskiy, Lange-Bertalot & Witkovski 2010						1							B			i	ind					
Surirella minuta Brébisson ex Kützing, 1849		1				1							B	temp	st-str	i	alf					
Surirella sp.				1		1																
Synedra famelica Kützing 1844										1			P-B		str	i	alf		1.5	o-b		ot

The percentage of benthic and planktic-benthic species were similar and dominated in both creeks with no planktic species recorded (Fig. 2a). The largest number of species were inhabitants of waters with moderate temperature.

Most species were temperate temperature water indicators (Fig. 2b). Indicators of oxygen content in the water showed increased presence in the sections of the creeks with low water flow (Fig. 2c). At the same time, indifferent and alkaliphilic indicators were represented in the creeks (Fig. 2d).

The distribution of bioindicators of salinity preferences, organic pollution according to Watanabe, nutrition type, and trophic state of the creeks are shown in Figure 3 and Table 3. The distribution of species indicators of chloride concentration reflects low increasing water salinity (Fig. 3a) with halophobe and oligohalobious-indifferent species. Increasing organic pollution in the creeks can be indicated by the presence of eurysaprobic indicators in the diatom communities (Fig. 3b). Diatoms in the creeks were represented by two dominant ecological groups of the type of nutrition: nitrogen-autotrophic taxa (tolerating very small concentrations of organically bound nitrogen) and nitrogen-autotrophic taxa (tolerating elevated concentrations of organically bound nitrogen; Fig. 3c). Figure 3d shows the main groups of trophic indicators. Mostly oligotrophic and oligo-mesotrophic indicators were recorded in the creeks.

4. Discussion

High mountain streams, such as those discussed in this work, are extremely oligotrophic ecosystems where the geology of the substrate is an important environmental factor in shaping diatom communities. Due to the low nutrient content, moderate to slow water flow and constant temperature, these high-altitude creeks can be considered suitable for a wide range of species. According to research on algae in areas around the mountain creeks (Paulíčková et al. 2003; Kapetanović T. 2007), the number of algae varies depending on physical and chemical conditions, habitats, especially pH values and conductivity. The pH and conductivity values in the studied creeks were low, indicating soft, fresh water with neutral pH and low ion concentrations. In general, lower conductivity values are reported for creeks at higher altitudes, on more sloping terrain, with faster water flow.

The water quality of the creeks was very good, with chemical and environmental conditions typical of mountain creeks in pristine areas. All samples collected from creek 1 had lower water temperatures (9.9°C on average) compared to creek 2, which is not located near the springs and have a thick layer of mosses. These results are consistent with research on algae conducted in the subalpine belt of Mt. Vranica and Blidinje plateau in Bosnia and Herzegovina (Kapetanović et al. 2011; Hafner et al. 2015).

Previous studies show that the composition of algal floras in fens is closely related to the variability of environmental variables, especially pH and conductivity (Kapetanović et al. 2011; Poulíčkova et al. 2003; Novákova 2003). The basic measurements in the present study confirmed the previous conclusions. In general, the most stable parameters measured in the creeks are pH and conductivity, while N-NO_3 and P-PO_4 can be used only with limitations (Kapetanović et al. 2011; Novákova 2003).

The biodiversity of diatoms in the Čavljak creeks is relatively high with 130 taxa. In a recent study of wet habitats on the Vranica mountains (Kapetanović and Hafner 2007), 221 taxa were identified based on 72 samples and 24 sampling sites. The largest number of taxa at a single sampling site was 60. Our study showed even higher biodiversity. As in the present study, *Eunotia* (29), *Navicula* (26) and *Cymbella* (22) were the dominant genera on the Vranica mountains. In their study in different lentic and acidic habitats in Carolina (USA), Gaiser and Johansen (2000) found that *Eunotia, Pinnularia, Frustulia* and *Neidium* were the dominant genera. Şahin et al. (2019) reported 85 diatom taxa from high mountain habitats in Turkey with the prevalence of *Pinnularia* (15), *Eunotia* (6), and *Gomphonema*. At Lake Nesamovite in the Carpathian National Nature Park, preferences of climatic and environmental conditions were obtain for *Eunotia*, *Pinnularia* and *Neidium* from 125 identified diatom taxa (Tsarenko et al. 2021; Barinova et al. 2006; Barinova et al. 2019) The diatom flora of Pamir habitats contain more than 550 taxa, of which *Pinnularia* dominates with 39 taxa (Niyatbekov et al. 2018). This draws attention to at least two genera of diatoms, *Pinnularia* and *Eunotia*, the prevalence of which in the flora may serve as an indicator of high-altitude, undisturbed habitats.

Eunotia and *Pinnularia* species are important indicators of high ecological quality and are strongly associated with naturally acidic, oligotrophic or dystrophic habitats. Some species, especially *Eunotia* species, are excellent indicators of different degrees of anthropogenic acidification (Cantonati et al. 2017). Species from the genera *Eunotia* and *Pinnularia* in Bosnia and Herzegovina are reported from different microhabitats, but no comprehensive checklist is available.

The most common taxa in the Čavljak creeks are also reported to be the most common in other studies of wet habitats in Bosnia and Herzegovina (Kapetanović et al. 2011; Kapetanović and Hafner 2007). Our results also showed no significant seasonality, which confirms previous studies in similar habitats (Kapetanović et al. 2011; Redžić 2007). The only difference was in the total number of species and it was most likely due to the "late spring", as diatom populations were not well developed. In general, the May samples were the richest in diatoms species. The significant decrease in the diversity of diatoms in summer and autumn 2007 was most likely caused by unusually dry weather conditions. Nováková (2003) observed among other algal species that the abundance of *Eunotia arcus* (syn. *Eunotia glacialis)* decreased in summer, which would correspond to the psychrophilic character of the species. In the Bijambare fen, it was also most abundant in the colder months (Kapetanović et al. 2011), which is consistent with our results.

The most abundant taxa are oligotrophic or oligo-mesotrophic species. Taxa from genera such as *Pinnularia* and *Eunotia* are expected to be the most abundant, as *Pinnularia* taxa can be found in a wide range of aquatic habitats, but are indicative of acidic, oligotrophic freshwater, while *Eunotia* taxa are strong indicators of acidic, oligotrophic freshwater rich in oxygen and deficient in organic nitrogen compounds (Van Dam et al. 1994).

According to the German Red List (Lange-Bertalot, Steindorf 1996), more than 60% of the taxa are assigned a conservation status category. Almost 30% belong to the endangered category. Some of them, e.g. *Decussata hexagona* (represented in all samples), considered extremely rare in Germany, appears to be more common in Balkan mountain habitats, where it has been reported from mire habitats (Levkov et al. 2005; Edlund et al. 2006). Five new diatoms taxa have been reported for the flora of Bosnia and Herzegovina. These data have been previously described and used in the preparation of a biodiversity report for Bosnia and Herzegovina (Redžić et al. 2008; Hafner et al. 2008).

Freshwater oligotrophic habitats, such as the studied creeks, are considered endangered due to various anthropogenic impacts. The importance of such habitats has been recognized by EU authorities and they are listed as important habitats for protection (NATURA 2000). Based on this study and literature data from previous studies, it can be concluded that these mountain creeks are exceptionally suitable habitats for a large number of rare and endangered diatom taxa. More than 60% of the recorded diatoms listed on the Red List (Lange-Bertalot, Steindorf 1996) have a certain category of vulnerability. This study showed the presence of a large number of endangered species, but also pronounced negative anthropogenic effects. Unfortunately, Bosnia and Herzegovina does not have a complete Red List of diatom taxa, and we can only illustrate the status of the studied flora by comparing it with other published European data. The German Red List, although compiled for the local diatom flora and updated in 2022, is the only currently available international reference for classifying diatoms based on their vulnerability.

Bosnia and Herzegovina has many pristine oligotrophic areas and there is a need for their detailed analysis and research. These activities should be reflected in the establishment of monitoring and prevention of further degradation of mountain creeks through more active and stronger protection. In order to protect these unique and extremely valuable ecosystems in the future, certain restoration and conservation measures should be undertaken.

Conclusions

A total of 130 diatoms taxa were recorded in the surveyed creeks, characterized by stable physical and chemical conditions, with oligotrophic taxa accounting for 61% of all identified taxa, which underlines the importance of preserving the creeks as specific aquatic ecosystems. The high species richness and the presence of diatom taxa included on the German Red List also underline the importance of protecting and preserving this important biotope. This paper contributes to completing the list of diatoms of Bosnia and Herzegovina and better understanding of their diversity. It should also contribute to the protection of these habitats. Further research on high-altitude creeks will contribute to the collection of useful information for their long-term monitoring and management, as well as for conservation.

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