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Surface sediment diatom assemblages from four alpine lakes in the Zelengora Mountains (Bosnia and Herzegovina): A Pilot Study

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ABSTRACT:
This pilot study presents surface sediment diatom assemblages in four alpine lakes in the Zelengora Mountains. The four lakes are distributed across an alpine treeline, spanning temperate mixed forest and treeless alpine tundra zones, thus offering an excellent opportunity to study the interaction of physicochemical properties and biotic communities in different alpine lake settings. A total of 52 taxa from 28 genera were identified, with only one taxon (*Staurosirella neopinnata*) present in every lake. In the Orlovačko, Donje Bare and Crno lakes, the diatom assemblages were mainly comprised of benthic and tychoplanktonic species, as opposed to the Kotlaničko Lake where the planktonic *Lindavia radiosa* was the most abundant species. Our results identified water turbidity, macrophytes and pH to be the prevailing environmental factors which influence the diatom assemblage composition in the studied lakes. The results of this study also represent a starting point in establishing biomonitoring programmes for the sustainable management of these alpine aquatic ecosystems in a rapidly changing environment.

Keywords:
biomonitoring, Bacillariophyceae,
lake water hydrochemistry,
Balkan Peninsula

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INTRODUCTION

One of the most important ecological features of mountain landscapes are alpine lakes, most of which are of glacial origin (Moser *et al.* 2019). These lakes are often remote, have small surface areas and are particularly sensitive to environmental changes (Trevisan *et al.* 2010). They act as sentinels because they reflect the impact of climate change on their catchments and aquatic ecosystem structures (Catalan *et al.* 2006; Pastorino & Prearo 2020). Alpine lakes often have low nutrient and ionic concentrations due to low catchment soil development and vegetation cover, which makes them a habitat where a limited number of species can survive (Feret *et al.* 2017). They are also more likely to record climate change related to precipitation and air temperature fluctuations, and are sensitive to changes in dissolved organic carbon and nitrogen inputs (Moser *et al.* 2019; Biskaborn *et al.* 2021). Recent increases in air temperature and modifications in snow and ice cover over various mountain regions (Falasco *et al.* 2012; Wang *et al.* 2018) have modified the functioning, diversity and productivity of alpine lakes (Vinnå *et al.* 2021). One way to understand how these lakes respond to climate change is to examine the dynamics of diatom assemblage shifts in lake sediments and to use this information in building diatom-based biomonitoring programmes.

Diatoms (Bacillariophyceae) are unicellular siliceous algae which are common in aquatic environments world-

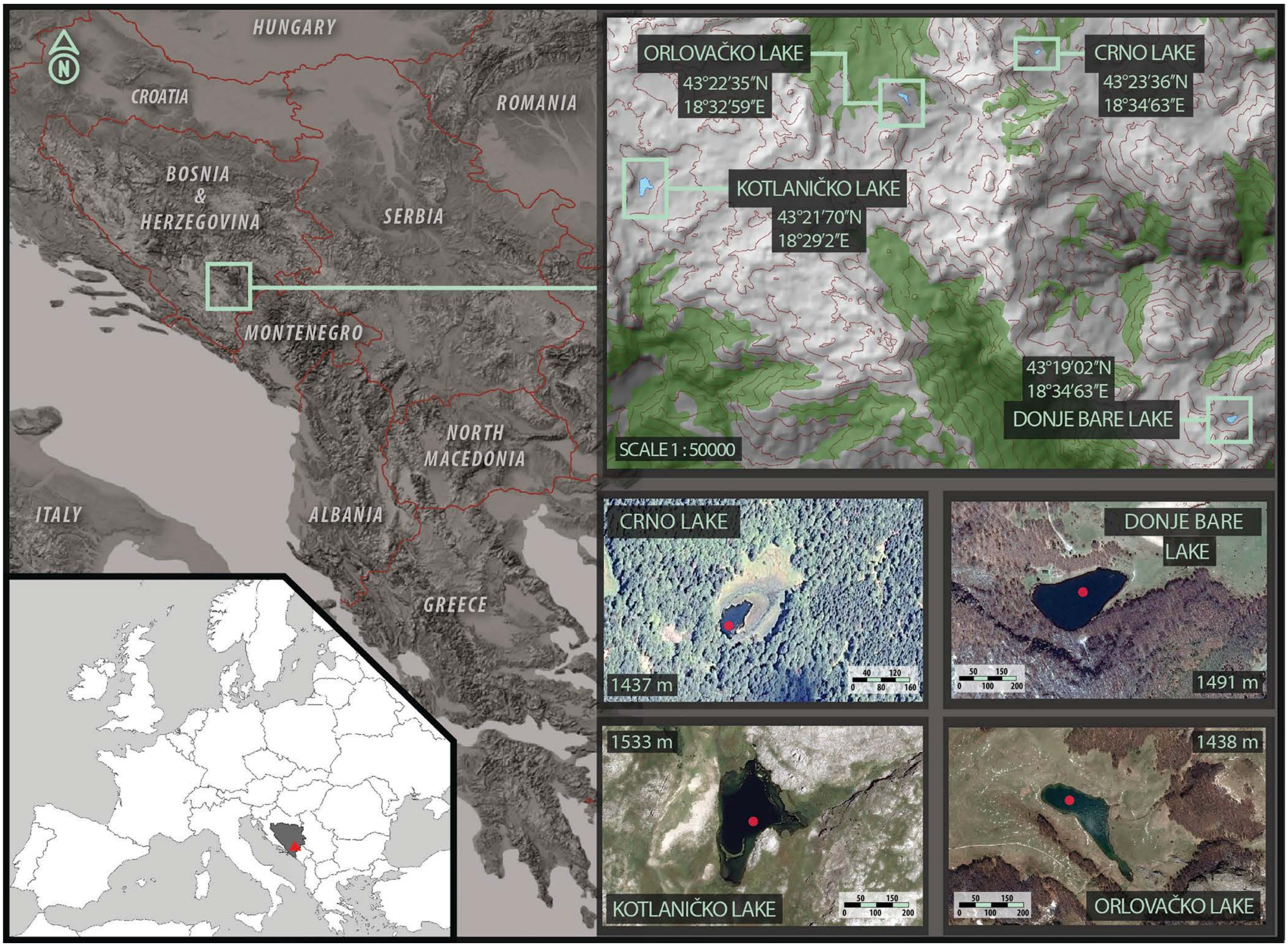

Fig. 1. Geographical location, satellite photographs and altitude of the study lakes. The red dots on the aerial photographs mark the sampling location (Image source: Google Earth - https://earth.google.com/web/).

wide (Smol & Stoermer 2010). As primary producers, they play a crucial role in aquatic ecosystem health. Diatoms are among the most commonly used bioindicators due to their short life cycles and rapid responses to changes in physical and chemical water variables (i.e. temperature, nutrients, pH, salinity, etc.; Pienitz *et al.* 2006). Moreover, diatoms from surface sediments are particularly suitable for applied biomonitoring as they integrate recent seasonal and annual limnological dynamics (Jacques *et al.* 2016).

The Dinaric Alps form a mountain range in the western part of the Balkan Peninsula (Southeastern Europe; Fig. 1) characterized by a particular set of geologic, bioclimatic and hydrologic conditions (Žebre & Stepišnik 2016). The region is highly biodiverse and encompasses unique floral richness, with a large number of endemic species along with numerous alpine lakes (Redzic 2011). Studies of the regional diatom flora are scarce; to date only one study of the diatom flora of alpine lakes in Bosnia & Herzegovina has been published (Hafner & Jasprica 2013). On the other hand, numerous studies of diatom floras in European alpine lakes have been conducted in recent years (Levkov *et al.* 2005; Štefková 2006; Buczkó 2016; Feret *et al.* 2017; Rivera-Rondón & Catalan 2017; Rott & Kofler 2019; Tsarenko *et al.* 2021). In order to establish biomonitoring programmes, the first step is to provide detailed ecological information about diatom assemblage compositions within a range of lacustrine settings. Hence, the main objective of this study is to determine the diatom species composition in summer in surface sediments and the prevailing environmental factors influencing their distribution in four alpine lakes of the Zelengora Mountains.

MATERIALS AND METHODS

Study region. The Zelengora Mountains are located in southeastern Bosnia & Herzegovina (N 43°20', E 18°33') approximately 100 km east of the Adriatic Sea coast (Fig. 1), and are the hydrological divide between the watersheds of the Black and Adriatic Seas (Tošić & Crnogorac 2008). The mountain range is composed largely of Mesozoic limestone overlying carbonaceous flysch, sandy clay and sandy limestone bedrock formations. The region is characterized by a large number of lakes, streams and rivers which are remnants of periglacial landscapes from the last glaciation ca. 11700 years ago (BP; Milivojević 2007; Hughes *et al.* 2011). These shallow (i.e. < 10 m) lakes are embedded in impermeable flysch sediments and are mostly replenished by underground karstic springs and precipitation.

The region is exposed to marine air masses originating from the Mediterranean Sea. The regional climate is characterized by cold, wet winters and warm, dry summers. According to the 1961–2016 averages from the nearest meteorological station Čemerno (WMO Index Number: 14656; Fig. 2) ca. 15 km away from the central part of the Zelengora Mountains at an altitude of 1304 m above sea level (a.s.l.), the average annual temperature and precipitation are 6.3°C and 1800 mm, respectively (Popov *et al.* 2019). The mean temperature of the coldest month (January) is -2.8°C, while the mean temperature of the warmest month (August) is 15.7°C. The highest mean precipitation was recorded in November (239 mm) and the lowest in July (65 mm).

The study area covers two distinct altitudinal and vegetation zones. The temperate mixed forests up to 1500 m a.s.l. are composed of *Picea abies* (L.) H. Karst., *Fagus sylvatica* L., *Abies alba* Mill. and *Pinus sylvestris* L. Alpine tundra, while the area above 1500 m a.s.l. is composed of alpine grasslands (*Seslerion juncifoliae* Horvat 1930, *Oxytropidion dinaricae* Lakušić 1966, *Seslerion comosae* Horvat 1936, *Ranunculion crenati* Lakušić 1968 and *Jasionion* orbiculatae Lakušić 1964) (Milanović *et al.* 2015).

The Kotlaničko (KO; N 43°21'70", E 18°29'2"; 1533 m a.s.l.), Orlovačko (OR; N 43°22'35", E 18°32'59"; 1438 m a.s.l.) and Crno lakes (CJ; N 43°23'36", E 18°34'63"; 1437 m a.s.l.) are located in the central sector of the Zelengora Mountains, whereas the Donje Bare Lake (DB; N 43°19'02", E 18°37'53"; 1491 m a.s.l.) is in the southeastern sector (Table 1; Fig. 1). They are situated in remote, high-altitude regions and have moderate anthropogenic activities in their catchments, consisting mainly of pastures (OR and DB) and alpine tourism (KO and CJ). The lakes are shallow (max. depth 9 m), oligotrophic to mesotrophic (Dekić *et al.* 2016, 2020; Gnjato *et al.* 2018, 2019) and are ice-covered during winter.

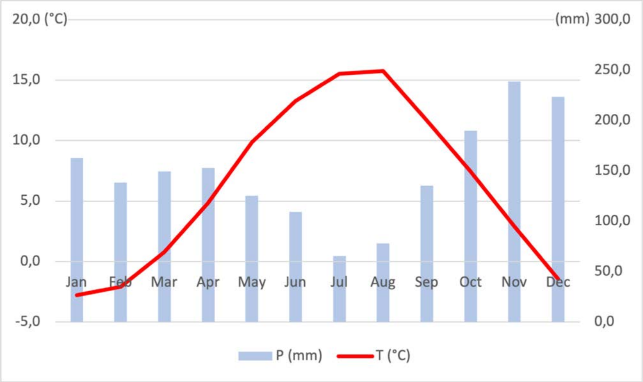

Fig. 2. Mean monthly air temperatures (T) and precipitation (P) at the Čemerno station for the period 1961–2016 (Popov *et al.* 2019).

The Kotlaničko (KO) Lake is located in the alpine tundra zone and is the largest (6.4 ha) and deepest (9 m) of the four lakes. The lake receives water from nearby springs located along its western shoreline. The lake surface outflow stretches approximately 100 m to the east before it becomes subterranean. The lake's littoral zone is covered with macrophytes. Arctic char (*Salvelinus alpinus* Linnaeus 1758) and an endemic amphibian genus of newts (*Triturus*) are among the lake's fauna (Gafić & Džeko 2008).

The Orlovačko (OR) Lake receives water from three springs on its northwestern shoreline, and its outflow to the southeast disappears through permeable karst. Its maximum depth is 6 m and it has a surface area of 2.1 ha. The lake's littoral zone is also covered with macrophytes (*Myriophyllum spicatum* Brown and Brown 1984 and *Juncus* spp.). River trout (*Salmo trutta fario* Linnaeus 1758) is the only fish species present.

The Donje Bare (DB) Lake receives water from several springs located on its western shoreline and has a surface outflow on its eastern side. It is the second largest lake (2.2 ha), with a maximum depth of 4 m. The only fish spe-

Table 1. Physico-chemical properties of lakes and water. The parentheses contain the results for the bottom water samples

Parameter	Kotlaničko	Orlovačko	Donje Bare	Crno
Area (ha)	6.4	2.1	2.2	0.7
Max. depth (m)	9	6	4	2
Secchi depth (m)	3.5	2	3	2
Ca^{++} (mg/l)	32.7 (33.0)	32.5 (32.7)	13.6 (13.1)	26.4 (31.1)
Na^{+} (mg/l)	0.70 (0.80)	0.78 (0.78)	0.52 (0.53)	0.76 (0.79)
K^{+} (mg/l)	0.88 (0.50)	0.27 (0.31)	0.34 (0.28)	0.26 (0.31)
Mg^{++} (mg/l)	0.70 (0.74)	1.62 (1.63)	3.74 (3.66)	11.2 (13.0)
Cl^{-} (mg/l)	1.19 (0.86)	0.76 (0.77)	0.95 (0.99)	0.85 (0.92)
SO_4^{--} (mg/l)	1.94 (1.92)	2.06 (2.04)	2.18 (2.38)	6.11 (8.0)
HCO_3^{-} (mg/l)	98.4 (101.4)	102.8 (103.1)	52.5 (52.0)	121.6 (139.3)

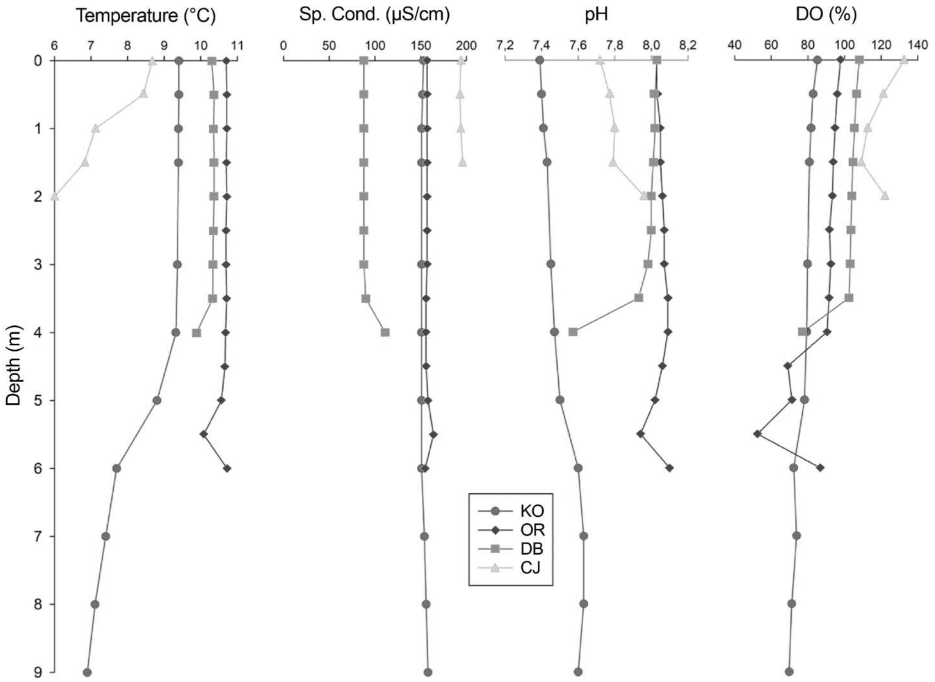

Fig. 3. Vertical profiles of lake water temperature, conductivity, pH and dissolved oxygen (DO) measured in situ.

cies present in the lake is rainbow trout (*Oncorhynchus mykiss* Walbaum 1792). The lake bottom is covered with thick layers of mud and macrophytes (*Potamogeton lucens* Linnaeus 1753).

The Crno (CJ) Lake is the smallest (0.7 ha) and shallowest (2 m). The lake receives water from one major and several smaller springs located on its southwestern shoreline, while its surface outflow is on the northeastern side. The bottom of the lake is covered with macrophytes. A significant part of the lake has turned into a wetland due to extensive macrophyte decomposition (Dekić *et al.* 2016). The lake is a natural habitat for river trout (*Salmo trutta fario* Linnaeus 1758).

Field sampling. Lake water measurements and surface sediment samples from the four lakes were collected during the field campaign at the end of May 2019. Deep parts of the lakes were chosen as sampling locations and one sampling was performed per lake. Surface sediments in the KO Lake were retrieved in the central part, approximately 70 m from the eastern shore of the lake, at 9 m depth. The sampling site in the OR Lake was approximately 80 m from the northwestern shore at 6 m depth, while in the DB Lake it was almost in the very central part at 4 m depth. The sampling site in the CJ Lake was approximately 25 m from the southern shore at 2 m depth.

Lake water and sediments were sampled from an inflatable boat (zodiac). Surface and bottom lake waters were collected with a handmade water sampling device (a vertical glass container which is pulled upwards to

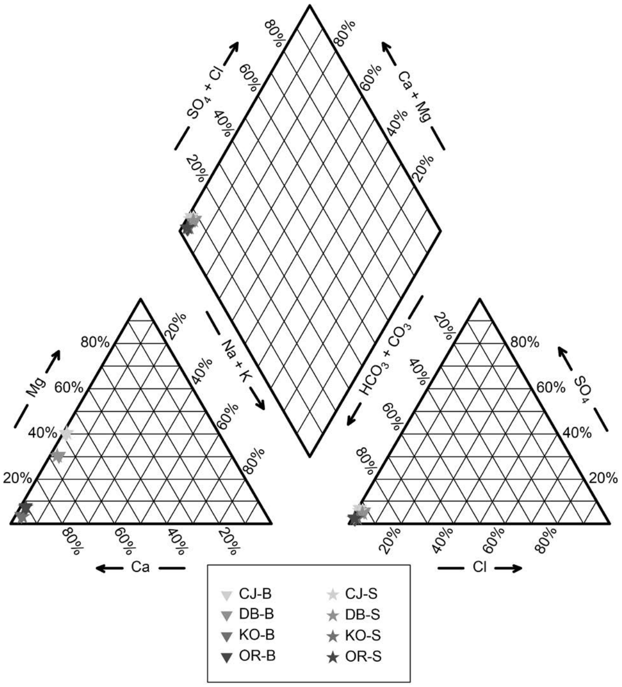

Fig. 4. Piper diagram showing the hydrochemical characteristics for all four study lakes. The trilinear diagrams illustrate the relative concentrations of cations (left diagram) and anions (right diagram) and combinations (middle diagram) in milli-equivalent percentages per liter (% meq/l). The acronyms stand for lakes CJ-Crno, DB-Donje Bare, KO-Kotlaničko, OR-Orlovačko; B = bottom and S = surface.

Table 2. Relative abundance (%) of diatom species from the four study lakes, the Shannon diversity index and species richness (summer aspect of communities).

Taxon	**KO**	**OR**	**CJ**	**DB**
Achnanthidium minutissimum (Kützing) Czarnecki	0.6	18.3	2.0	0.0
Achnanthidium sp. 1	0.0	0.0	0.3	0.0
Amphora copulata (Kützing) Schoeman & R.E.M.Archibald	0.6	0.0	0.7	0.0
Amphora pediculus (Kützing) Grunow	0.9	0.0	2.0	0.0
Aneumastus tusculus (Ehrenberg) D.G.Mann & A.J. Stickle	0.0	0.0	0.7	0.0
Asterionella formosa Hassall	3.4	0.0	0.0	0.0
Aulacoseira cf. *islandica* Müller	0.8	0.0	0.0	0.0
Cocconeis pediculus Ehrenberg	0.0	0.0	0.3	0.0
Cocconeis placentula Ehrenberg	0.0	15.7	0.0	0.0
Cymbella neocistula Krammer	0.0	1.0	0.0	0.6
Cymbopleura inaequalis (Ehrenberg) Krammer	0.6	0.0	0.0	0.0
Cymbopleura cf. *anglica* (Lagerstedt) Krammer	0.0	0.0	0.7	0.0
Denticula tenuis Kützing	0.3	0.0	0.0	0.0
Discostella stelligera (Cleve & Grunow) Houk & Klee	1.1	1.6	0.0	0.0
Encyonema minutum (Hilse)	0.6	0.0	0.0	0.0
Encyonema silesiacum (Bleisch)	0.0	0.3	0.0	0.0
Encyonopsis cf. *microcephala* (Grunow) Krammer	0.0	1.9	0.0	0.0
Encyonopsis sp. 1	0.0	0.0	0.7	0.0
Encyonopsis subminuta Krammer & Reichardt	0.0	2.6	0.0	0.0
Epithemia adnata (Kützing) Brébisson	0.0	5.9	0.0	0.0
Epithemia adnata var. *saxonica* (Kützing) Patrick in Patrick & Reimer	0.0	0.0	0.0	0.6
Epithemia sorex Kützing	0.0	3.3	0.0	0.0
Epithemia turgida (Ehrenberg) Kützing	0.0	1.3	0.0	0.0
Fragilaria capucina (Kützing) Lange-Bertalot	0.0	0.0	1.0	0.0
Fragilaria tenera (W. Smith) Lange-Bertalot	0.3	1.0	0.0	0.0
Fragilariforma virescens var. *exigua* (Grunow) Poulin	0.8	0.0	0.0	0.0
Geissleria schoenfeldii (Hustedt) Lange-Bertalot & Metzeltin	0.6	0.0	0.0	0.0
Gomphonema cf. *pumilum* (Grunow) Reichardt & Lange-Bertalot	0.0	40.8	0.0	3.6
Gomphonema minutum (C. Agardh) C. Agardh	0.0	2.0	0.0	0.0
Gyrosigma acuminatum (Kützing) Rabenhorst	0.3	0.0	0.0	0.0
Lindavia bodanica (Eulenst. ex Grunow) Nakov et al.	0.8	0.0	0.0	0.0
Lindavia radiosa (Grunow) De Toni & Forti	41.9	0.7	1.0	0.0
Navicula cf. *caterva* Hohn & Hellermann	0.0	0.3	0.0	0.0
Navicula cf. *cryptotenella* Lange-Bertalot	0.0	0.6	0.3	0.0
Navicula radiosa Kützing	0.6	0.0	0.0	1.0
Nitzschia regula Hustedt	0.3	0.0	0.0	0.0
Odontidium mesodon (Kützing) Kützing	0.0	0.6	0.0	0.0
Pinnularia neomajor Krammer	0.6	0.0	0.0	0.0
Planothidium lanceolatum (Brébisson *ex* Kützing) Lange-Bertalot	0.0	0.0	0.0	0.6
Platessa bahlsii Potapova	0.0	0.0	0.0	0.3
Platessa conspicua (Ant.Mayer) Lange-Bertalot	0.0	0.0	0.0	1.3
Pseudostaurosira brevistriata (Grunow) D.M.Williams & Round	0.0	0.0	13.1	0.0
Pseudostaurosira pseudoconstruens (Marciniak) D.M.Williams & Round	1.4	0.0	0.0	0.0
Rossithidium petersenii (Hustedt) Round & Bukhtiyarova	0.0	0.0	0.0	1.0
Sellaphora pupula (Kützing) Mereschkowsky	0.0	0.0	0.0	0.6
Sellaphora rectangularis (W. Gregory) Lange-Bertalot & Metzeltin	0.6	0.0	0.0	0.0
Sellaphora vitabunda (Hustedt) Lange-Bertalot	0.0	0.6	0.0	0.0
Staurosira brevistriata var. *papillosa* Cleve	4.3	0.0	0.0	0.0
Staurosira cf. *construens* Ehrenberg	6.6	0.0	3.6	58.6
Staurosirella cf. *frigida* Van de Vijver & Morales	0.0	0.0	3.6	0.0
Staurosira venter (Ehrenberg) Cleve & J.D.Möller	14.2	0.0	0.0	1.0
Staurosirella neopinnata E.A.Morales, C.E.Wetzel, Haworth & Ector	18.2	1.3	70.5	31.3
Shannon diversity index (N1)	2.0	1.9	1.2	1.1
Species richness (N0)	23.3	19.0	15.0	12.0

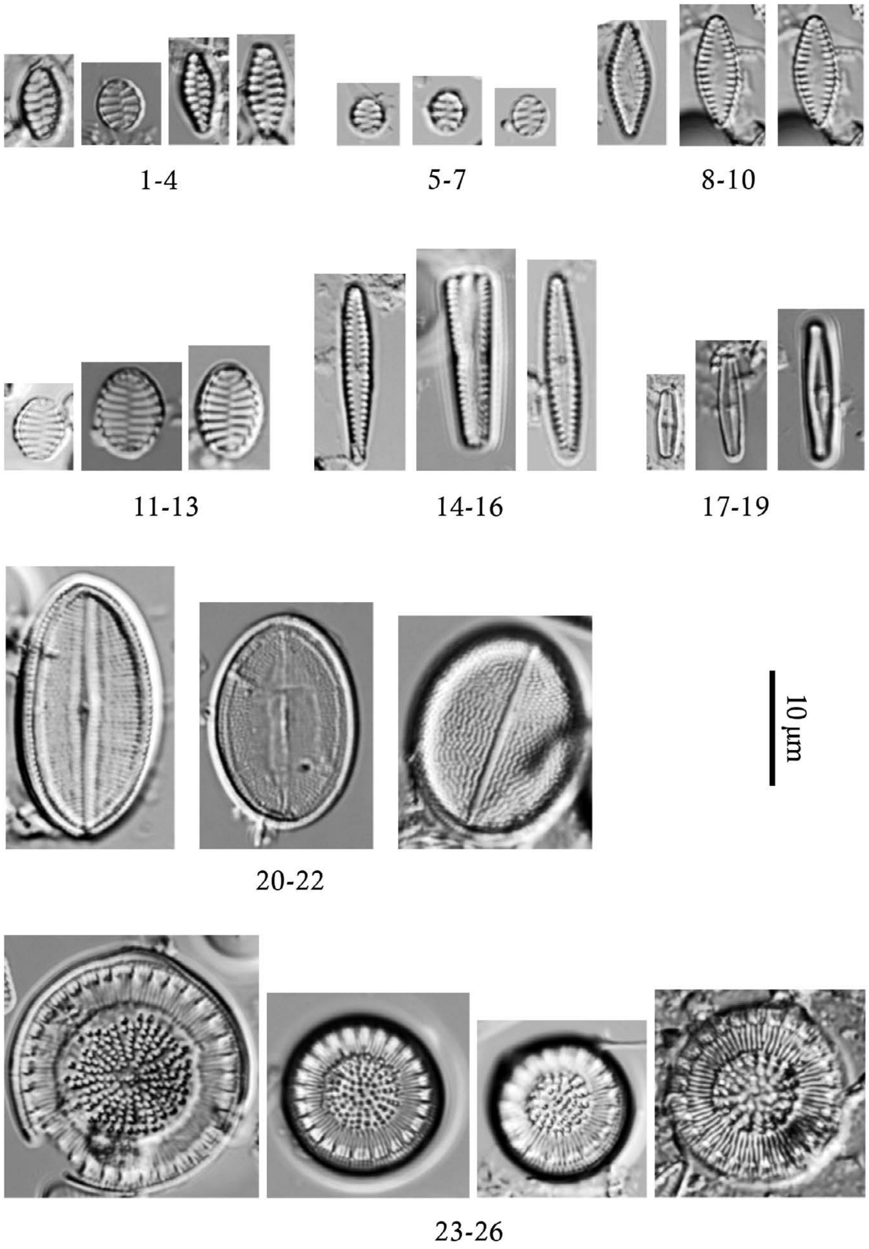

Fig. 5. Light micrographs of selected diatom species. 1–4: *Staurosirella neopinnata*. 5–7: *Staurosira* cf. *construens*. 8–10: *Pseudostaurosira brevistriata*. 11–13: *Staurosira venter* 14–*16: Gomphonema* cf. *pumilum. 17–19: Achnantidium minutissimum. 20–22: Cocconeis* placentula. 23–26: *Lindavia radiosa*.

close at specific water depths). Lake transparency and depth were measured with a calibrated Secchi disk rope. Surface sediments (i.e. the top 1 cm) were sampled with a 3.8 cm-diameter Mini-Glew gravity corer and placed in 120 ml Whirl-Pak bags. The water and sediment samples were placed in a cooler during transport and later stored at 4°C in the laboratory until analysis.

Hydrochemistry. In order to examine the relationship between the water chemistry and diatom assemblages in the lake surface sediments, water temperature, dissolved oxygen (DO), specific conductivity (SPC), and pH were measured in situ using a YSI probe (600 QS) at 0.5 meter intervals, and major ions (Ca^{2+}, Na^+, K^+, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-) from the lake surface and bottom waters were analysed in the laboratory. For major ion analyses, the water samples were filtered through cellulose-acetate filters (Whatman TM CA; pore size 0.4 µm), and for cation analyses the water samples were acidified with suprapure HNO_3 (65%) directly in the field. The anion and cation contents were determined by ion chromatography (IC, Dionex DX-320) and inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin- Elmer Optima 3000 XL), respectively, at the Alfred Wegener Institute in Potsdam (Germany).

Slide preparation and counting. For diatom analysis, the samples were freeze-dried and cleaned following the methods proposed by Scherer (1994). The siliceous material was then mounted onto glass microscope slides with the synthetic resin Naphrax. More than 300 valves were enumerated in each sample under oil immersion optics at 1000× magnification using a Zeiss Axioscop 2 light microscope. Identification was made to the lowest possible taxonomic level based on standard taxonomic guides (Krammer & Lange-Bertalot 1986, 1988, 1991a, b; Lange-Bertalot *et al.* 2017) and the relative abundance of each identified taxon was calculated as the percentage of the total number of valves counted per sample. In this pilot study, we counted 351 valves in the KO Lake, 305 valves in the OR Lake, 309 valves in the DB Lake and 305 valves in CJ Lake. The diatom species richness N0 and the exponential of the Shannon index N1 (Hill 1973) were estimated using valve count data rarefied to the minimum base sum (n=305). Rarefaction, richness, and the Shannon index were calculated using the 'vegan' package (Oksanen *et al.* 2020).

RESULTS

Lake water. The physico-chemical parameters of the lakes are given in Table 1 and the vertical profiles of the lake water temperature, specific conductivity, pH and dissolved oxygen (DO) are presented in Fig. 3. The lake depths and surface areas ranged from 2 m and 0.7 ha (i.e. CJ) to 9 m and 6.4 ha (i.e. KO), respectively. The pH values indicate slightly alkaline water in all of the lakes, and the generally low specific conductivity, and rather stable water temperatures indicate well mixed water columns. In the Piper plot (Fig. 4), all the samples are concentrated in the bottom left corner of the cation and anion diagrams, thus indicating calcium bicarbonate dominance, typical for hard water regions.

Diatoms. A total of 52 different diatom species from 28 genera were identified from the surface sediments (Table 2). Of these, 17 species exceeded 2% relative abundance in at least one lake (Table 2). The genera *Staurosira* and *Epithemia* had the largest number of species, 5 and 4 respectively (Table 2). The dominant species was *Staurosirella neopinnata* (Fig. 5; Images 1–4), which was present in all the lakes, ranging from 70.5% relative abundance in CJ to 1.3% in OR. *Achnanthidium minutissimum* (Fig. 5; Images 17–19) occurred in all the lakes with the exception of DB, with its highest relative abundance in OR (18.3%). *Staurosira* cf. *construens* (Fig. 5; Images 5–7) was present in all the lakes except for OR with the highest relative abundance in DB (58.6%). *Staurosira venter* (Fig. 5; Images 11–13) was common in KO and DB, *Gomphonema* cf. *pumilum* (Fig. 5; Images 14–16) in OR and DB, and *Lindavia radiosa* (Fig. 5; Images 23–26) in the KO and OR lakes. Other species such as *Cocconeis placentula* (Fig. 5; Images 20–22), *Epithemia sorex*, *Epithemia* cf. *adnata* and *Encyonopsis* cf. *microcephala* were common only in OR, whereas *Asterionella formosa* and *Pseudostaurosira brevistriata* (Fig. 5; Images 8–10) were present only in the KO and CJ lakes, respectively. Among the recorded species, only *Amphora pediculus*, *Navicula radiosa* and *Staurosirella neopinnata* were previously reported from a study of a small alpine lake in Bosnia & Herzegovina (Hafner & Jasprica 2013). The taxonomic richness and Shannon diversity index results indicated that the highest taxonomic richness was found in the KO and OR lakes, respectively, whereas the lowest values of these two parameters were found for the DB lake (Table 2).

DISCUSSION

Our pilot study contains a small number of samples due to logistical constraints in the field, thus, our results give only a rough estimate of the diatom spatial distribution in the Zelengora Mountains. The sedimentary diatom assemblages in the lakes were mostly, but not entirely, composed of epiphytic diatoms typical of circumneutral to alkaline environments (Štefková 2006), reflecting the presence of extensive macrophyte substrates in the littoral/benthic zone and calcium bicarbonate-dominated lake water chemistry.

The diatom assemblages in the KO lake surface sediments were mainly composed of planktonic and tychoplanktonic sedimentary diatom species (Table 2). The KO Lake was the only lake to be slightly stratified during sampling (Fig. 3), which may account for the abundance of planktonic species such as *Lindavia radiosa* in the surface sediments, as these species have been reported to be abundant in lake surface waters during longer periods of thermal stratification and prolonged ice-free seasons (Rühland *et al.* 2015). The conditions in these high elevation, remote lakes are linked to changes in air temperature and precipitation, mainly due to the absence of a dense catchment vegetation cover and other water sources apart from underground springs which are replenished by seasonal precipitation. The shifts in sedimentary diatom assemblages from the KO Lake may thus provide valuable information about regional climate and hydrological dynamics. The low abundance of benthic species in the KO lake surface sediments could be explained by low water transparency (Secchi depth = 3.5 m; Table 1) limiting the growth of benthic diatom species in the deeper parts of the lake (Hofmann *et al.* 2020). The 48% of sediment diatom valves composed of planktonic species perhaps reflects the increased near-surface biomass that can inhibit the transparency of the water column (Vogt *et al.* 2010), but might also be a result of the sedimentation of dead cells. Moreover, the KO Lake is located in the alpine tundra zone at the base of hill slopes exposed to wind erosion and thus receives greater sediment inputs from the surrounding unconsolidated fine-grained flysch sediments, contributing further to lake turbidity.

The surface sediment diatom assemblages from the OR Lake were dominated by benthic-epiphytic species (Table 2). The most abundant diatom genus was *Gomphonema*, in particular *G.* cf. *pumilum*, followed by *Achnanthidium minutissimum* and *Cocconeis placentula.* These species have been reported from calcium-rich, alkaline, and unpolluted waters, often in epiphytic microhabitats (Trevisan *et al.* 2010; Rivera-Rondón & Catalan 2017; Biskaborn *et al.* 2019). They are also known to flourish in shaded environments, which is consistent with the lake's low water transparency (Secchi depth = 2 m; Table 1). The alkaline environment (pH = 8.1; Fig. 3) and the lake's extensive macrophyte substrates appear to exert control over the assemblage composition. More detailed analyses of the lake-specific microalgae composition is needed to further assess the dominance of epiphytic diatoms in the lake's surface sediments.

The surface sediment diatom assemblages from the CJ Lake were dominated by tychoplanktonic diatom species (Table 2). The dominant species was *Staurosirella neopinnata*, followed by *Pseudostaurosira brevistriata* and *Staurosira* cf. *construens*. These oligohalobous, tychoplanktonic taxa are abundant in brackish and freshwater environments and are tolerant of a wide range of salinities (Hassan *et al.* 2006; Narancic *et al.* 2016; Morales *et al.* 2019). Significant water loss through evaporation and lake infilling by extensive macrophyte growth may have contributed to increases in lake salinity (Dekić *et al.* 2016).

Benthic species dominated the surface sediment diatom assemblages of the DB Lake. The dominant species were *Staurosira* cf. *construens*, *Staurosirella neopinnata* and *Gomphonema* cf. *pumilum*. The DB and CJ lakes are both located in forested catchments and have similar hydrochemical (Fig. 4) and physical properties (Table 1), dominant diatom species and overall low planktonic species in the diatom assemblages. The principal difference between the sedimentary diatom assemblages from the CJ and DB lakes may be related to the greater abundance of macrophytes in the former, which favours the growth of epiphytic diatoms, while the supersaturated dissolved oxygen levels in both lakes are largely due to the submerged macrophyte photosynthetic production of oxygen (Dekić *et al.* 2016). The reason why the diatom diversity and species richness in the DB Lake were the lowest in our dataset requires further investigation into the causes of the changes in aquatic biodiversity and their relationship with species richness and ecosystem function over longer time scales.

Our study showed that the diatom assemblages from the Zelengora Lakes displayed many similarities with other alpine (mostly oligotrophic) lakes across European mountain ranges. The greatest resemblance in terms of phisical properties (i.e. lake surface and depth) was found with the alpine lakes in the Retezat Mountains (southern Carpathians), while the similarity with the Zelengora lakes, in terms of diatom flora, refers to the presence of mainly small benthic *Staurosira* taxa (Buczkó 2016). The presence of *Staurosirella neopinnata* and *Staurosira construens* has also been confirmed in the Shara and Nidze Mountains (Levkov *et al.* 2005), the Pyrenees (Rivera-Rondón & Catalan 2017), the Tatra Mountains (Štefková 2006), the Rila Mountains (Ognjanova-Rumenova *et al.* 2011) and the Pirin Mountains (Stefanova *et al.* 2003). Furthermore, Levkov *et al.* (2005) and Rivera-Rondón & Catalan (2017) also reported the presence of *Gomphonema pumilum*, which is consistent with its dominant presence in the Orlovačko Lake. In addition, Buczkó (2016) reported *Gomphonema* taxa to be the fourth most common species in the Retezat Mountain lakes. One of the most common taxa in the Zelengora lakes was *Achnanthidium minutisimum*, which has also been reported in previous research of diatom floras from alpine oligotrophic lakes accross Europe (Levkov *et al.* 2005; Štefková 2006; Buczkó 2016; Rivera-Rondón & Catalan 2017; Ognjanova-Rumenova *et al.* 2019).

CONCLUSION

Our main finding reveals that water chemistry and environmental conditions are reflected in the sedimentary diatom assemblages indicating that diatom distributions are related to lake water depth/light availability, macrophytes and pH levels. Future research in this area of the Dinaric Alps should include a greater number of mountain lakes, thus providing deeper knowledge of the diatom spatial distribution in order to obtain a robust foundation for biomonitoring. This study is the first of its kind performed on surface sediment diatoms in this region, and as such represents a starting point for further investigations on diatom-environment relationships in the Zelengora Mountains and for building diatom-based biomonitoring programmes for the implementation of sustainable management plans.

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REZIME

Botanica
SERBICA

Zajednice bentosnih silikatnih algi četiri planinska jezera na Zelengori (Bosna i Hercegovina): Pilot studija

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Ova pilot studija prikazuje razlike između zajednica silikatnih algi u površinskim sedimentima u četiri planinska jezera na Zelengori. Četiri jezera nalaze se na gornjoj šumskoj granici, obuhvatajući zonu umerenih mešovitih šuma i zonu alpskih tundri bez drveća. Tako pružaju izvrsnu priliku za proučavanje interakcije fizičko-hemijskih svojstava i biotičkih zajednica u različitim okruženjima planinskih jezera. Ukupno su identifikovana 52 taksona iz 28 rodova, od kojih je samo jedan takson (*Staurosirella neopinnata*) prisutan u svakom jezeru. U jezerima Orlovačko, Donje Bare i Crno, zajednice silikatnih algi karakterisale su se uglavnom bentosnim i tihoplanktonskim vrstama, za razliku od Kotlaničkog jezera, gde je planktonska *Lindavia radiosa* bila najrasprostranjenija vrsta. Naši rezultati su ukazali na turbiditet, makrofite i pH kao preovlađujuće faktore životne sredine koji utiču na sastav silikatnih algi u proučavanim jezerima. Rezultati ove studije predstavljaju polaznu osnovu za uspostavljanje programa biomonitoringa za održivo upravljanje ovim planinskim vodenim ekosistemima u okruženju koje se ubrzano menja.

Ključne reči: biomonitoring, silikatne alge, hidrohemija jezerske vode, Balkansko poluostrvo