RESEARCH ARTICLE

WHAT IS THE FUTURE OF CRNO LAKE ON TRESKAVICA MT. IN BOSNIA AND HERZEGOVINA?

Mirza Čelebičić[1,4]*, Sabina Trakić[2], Emina Sarač-Mehić[3], Adi Habul[4], Mahir Gajević[2]

[1]Department of Biology, Faculty of Science, University of Tuzla, Tuzla, Bosnia and Herzegovina
[2]Department of Biology, Faculty of Science, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
[3]Centar Dr. Stjepan Bolkay, Klinčići bb, Olovo, Bosnia and Herzegovina
[4]Environmental Fund of the Federation of BiH, Sarajevo, Bosnia and Herzegovina

***Corresponding author**:
Mirza Čelebičić MA
Address: Urfeta Vejzagića 4, 75000 Tuzla, Bosnia and Herzegovina
Phone: +387 62 072157
ORCID: 0000-0003-3403-931X
E-mail: mirzacelebicic24@gmail.com

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ABSTRACT

Crno jezero (1675 m a.s.l.) is an alpine lake on Treskavica Mt. in Bosnia and Herzegovina (BiH). We investigated the distribution and abundance of aquatic macrophytes in the lake after the standard BAS EN 15460:2009 and orthophotos that were taken by a drone at different heights (124, 80, 50, 20 m). Aquatic macrophytes were sampled on both the longitudinal and vertical profile of the lake, whereby the depth and temperature of water were measured by the Mares Quad dive computer. For the assessment of its ecological status, we used Macrophyte Nutrient Index for Ponds (M-NIP) and QGIS ver. 3.22.13. The most abundant macrophytes were: *Equisetum fluviatile, Potamogeton alpinus, P. perfoliatus and Carex rostrata*. By comparison of our results with the previous ones originating from 1954, we made a predictive model for the succession dynamics of macrophytic vegetation around the lake. In spite of that, calculated M-NIP classified the ecological status of Crno jezero as good. This research represents an original approach in the investigation of alpine lakes in BiH with the potential to be applied on a national scale as a contribution to global monitoring programs.

Keywords: Aquatic macrophytes, alpine lakes, Bosnia and Herzegovina, global changes, monitoring

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INTRODUCTION

Mountain ecosystems are proven sentinels of climate changes (Pepin et al. 2015; Zamora et al. 2016; Kang et al., 2019; Peñas et al., 2023), whereby the most apparent responses to changes in environmental parameters, such as acidification or nitrogen dynamics, are detectable in alpine lakes (Catalan et al., 1994; Camarero et al., 1995; Mosello et al., 2002; Beniston and Stoffel, 2013; Pulido et al., 2015; Peñas et al., 2023). However, the greatest ecological challenge for these delicate ecosystems is global warming (Schindler et al., 1996; Sommaruga-Wograth et al., 1997; Catalan et al., 2006; Trevisan et al., 2010; Pulido et al., 2015; Schmeller et al., 2018; Moser et al., 2019; Pastorino and Prearo, 2020; Gnjato et al., 2022; Lind et al., 2022). Since the rate of air warming rises with altitude (Pepin et al., 2015; Preston et al., 2016; Obertegger and Flaim, 2021), alpine lakes manifest steeper surface warming in comparison to the low-land lakes (Sadro et al., 2019; Moser et al., 2019; Obertegger and Flaim, 2021). This affects aquatic biota mainly through accentuated water stratification and periodicity of ice cover (Adrian et al., 2009; Moser et al., 2019; Obertegger and Flaim, 2021).

Due to their low accessibility, alpine lakes are less impacted by direct human activities (Kollmair et al., 2005; Peñas et al., 2023), which makes them a good reference point for monitoring of the ecological status of lentic ecosystems in general. Indirect human impact, however, relates mainly to the changes in biogeochemical cycles (Galloway et al., 2008; Kang et al., 2019) which alter their chemistry, nutrient supplies, and consequently, a bioproduction level (Saros et al., 2005; Vinnå et al., 2021; Oberteggerand Flaim, 2021; Gnjato et al., 2022). On the other hand, remote locations of alpine lakes led to poor knowledge of their biodiversity and ecological processes (Sommaruga, 2001; Tolotti et al., 2006). In Bosnia and Herzegovina (BiH) alpine lakes are many, but almost completely unexplored in terms of their macrophyte-based ecological status. By now, the objective of the research was the diversity of macrophytic communities or genera of special conservation interest (Milanović, 1954; Mišić, 1984; Redžić et al., 2013; Milanović et al., 2014). Our study aims to develop and test methods for monitoring of alpine lakes in BiH by selecting Lake Crno jezero as a case study.

MATERIALS AND METHODS

Lake Crno jezero is situated in a depression between the peaks Ljeljen (1974 m) and Ilijaš (1879 m) on Treskavica Mt. at an altitude of 1675 m a.s.l. (Fig. 1). The geological foundation here is mainly limestone, except for the lake's southern section where clastic formations - quartz sandstones occur (Hrvatović, 2006). The ratio between the mean and maximum depth for Crno jezero is 0.32, which is the threshold value between the funnel and convex-shaped basin of the lake. Indeed, the lake is funnel-shaped along its W-S-N axis and convex in the E, which has its consequences in terms of siltation dynamics, substrate type, water depth, and vegetation. Around the lake occurs rendzine, calcomelanosol, and ilimerized types of soil (Ćirić, 1980). According to some authors (Cvijić, 1900; Milojević, 1934; Bušatlija, 1977), this lake is glacial by its origin. However, Spahić (1984) stated the hypothesis that the origin of the lake was polygenetic. The lake is fed by precipitation and springs which are under the peaks Ljeljen and Ilijaš.

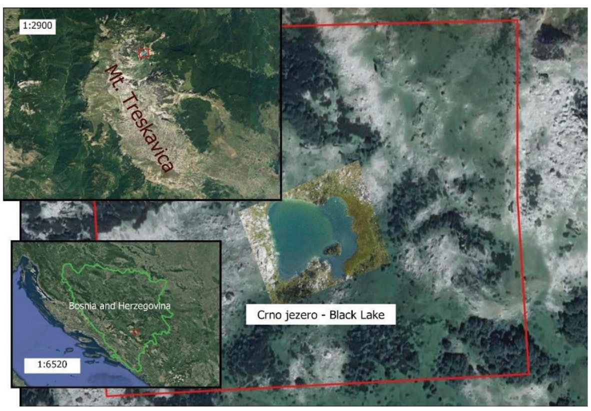

Figure 1 Physico-geographical position of Crno jezero in Bosnia and Herzegovina.

The climate at the lake is alpine with precipitation maximum in November and December (Fig. 2). Due to large quantities of snow in winter and low temperatures in general, the snow cover lasts until May, and the water level of the lake oscillates about 30 cm (Spahić, 1984). According to historical records, the depth of the lake has dropped from 5.3 m (Protić, 1926) to 3.7 m (Spahić, 1984). The succession of open water into the wetland, running from the East to the West, was noted already decades ago (Spahić, 1984).

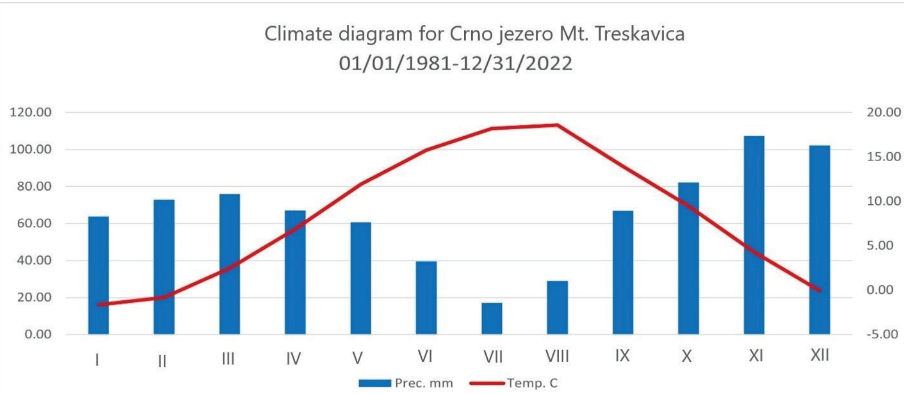

Figure 2 Climate diagram for Treskavica Mt.

The fieldwork was carried out in 2022 (October) and 2023 (June and August). Sampling, analysis, and processing of macrophytes was conducted according to the standards BAS EN 15460: 2009. The sampling of macrophytes was based on the obtained orthophotos of the lake that showed distinct vegetation belts. The abundance of submersed macrophytes was calculated based on orthophotos that were taken at 124, 80, 50, and 20 m by angle of -90 □MP 1 /2.0 FOV 84 F 2 8. The high-altitude diving was performed to delineate the thermal gradient of the lake using the Mares Quad dive computer. All methods were modified and adjusted to UAVs (Moreno, 2022). The ecological status of the lake was assessed according to The Macrophyte Nutrient Index for Ponds (Sager and Lachavanne, 2009). For spatial analysis, we used QGIS ver. 3. 2213 within the coordinate reference system ED50 / UTM zone 34N. The bathymetric map (Spahić, 2011) was overlaid with obtained orthophotos and processed in QGIS, with depths that were measured during diving and integrated into a digitized map. We used the available data from the literature and descriptive statistics to calculate standard deviation (σ) and Confidence Interval (CI) using the formulas: $\sigma = \sum\sqrt{(X-\bar{X})}/N$; $CI = \bar{X} \pm Z\times(\sigma/\sqrt{N})$, Z value fit CL 95% = 1.960. For the prediction of sedimentation dynamics, we used the linear function $Y = mX + b$ where the annual sedimentation rate was m-coefficient to the independent variable, and gross sedimentation was the dependent variable Y.

RESULTS

The temperature of the upper layers of water on a sunny summer day was +19°C. The reaction of the water in the lake was alkaline (pH = 8.7), electro-conductivity amounted 129.3 μS, and transparency of the lake was fully up to 3.7 m. However, macrophytes occurrence coincide with the thermocline at 3.2 m depth (+14°C). Here is noteworthy Lake Trnovačko in Montenegro (1517 m a.s.l.), which at 4 m depth had a temperature of +17.5°C (Blaženčić & Blaženčić, 2005), and the bottom was covered with Chara carpets. The fact that temperature is a limiting factor for macrophytes growth in shallow and fully transparent lakes was noticed earlier (Dale, 1986; Søndergaard et al., 2013).

According to the results, the most abundant macrophytes in Lake Crno jezero were *Equisetum fluviatile* L., *Potamogeton alpinus Hegetschw., P. perfoliatus* L. and *Carexrostrata*, which coincides with a list of the most common species in Dinaric lakes (Blaženčić & Blaženčić, 2005). In the riparian zone of Crno jezero occur: *C. goodenowü* Gay, *C. paniculata* L., *C. muricata* L., *C. flava* L., *C. oederi* Retz, *C. vesicaria* L., *Juncus articulatus* L., *J. alpinoarticulatus* Chaix, *Alchemilla xanthochlora* Rothm., *Geumrivale* L., *Filipendula ulmaria* (L.) Maxim., *Dactylorhiza cordigera* subsp. *bosniaca* Beck Soó and *Mentha longifolia* (L.) L. (Fig. 3).

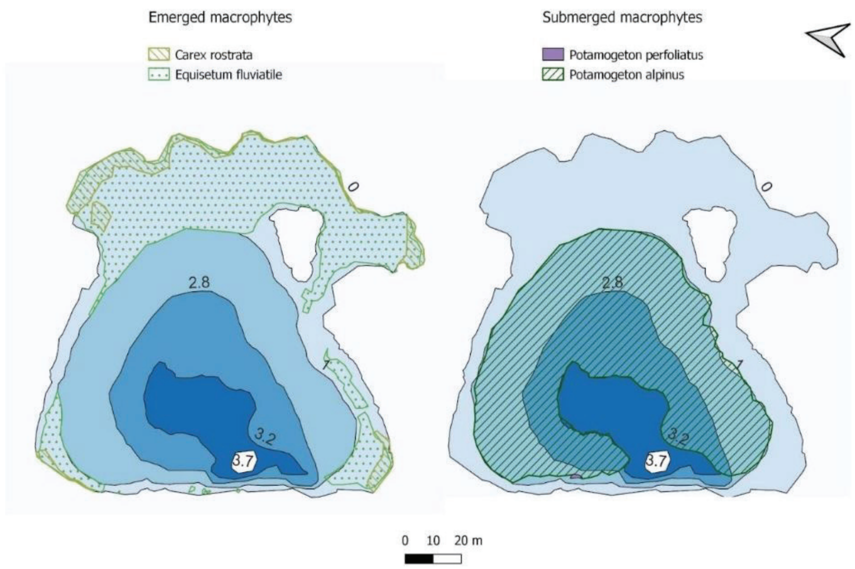

Figure 3 Distribution of macrophytes in Crno jezero

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DISCUSSION AND CONCLUSIONS

This kind of low species richness was found to be common for oligotrophic alpine lakes in the Dinarides with rather specialized species and aquatic plant communities (Radulović et al., 2010). Vegetation belts in and around the lake are clearly distinguished from each other and follow the ecological gradient of the water level and lake temperature (Fig. 4).

Figure 4 Lake Crno jezero in autumn (2022)

In 1954, Milanović reported that the Equisetum belt was 7 to 8 m wide, whereas today, according to our results, it has expanded to 19 m. The succession runs from the most shallow and convex section of the lake, in the East and continues to the West (Figure 5). In the SW, this process has led to formation of small peat bog fragments. The observed changes in the surface of the lake affect the ratio between volume and surface (Hutchinson, 1957; Obertegger and Flaim, 2021) which plays a crucial role in the dynamics of the warming (Poff, 2002; Lacoul and Freedman, 2006a; Lind *et al.*, 2022).

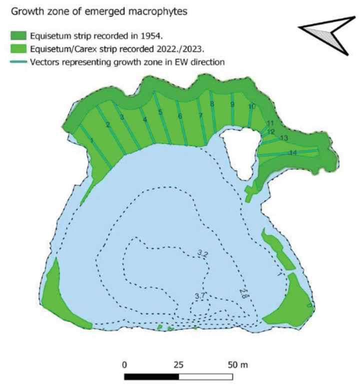

Figure 5 Widening of *Equisetum* belt through time

Studies have shown that the distribution of macrophytes is directly affected by lake bathymetry, due to the availability of light and the extent of littoral which is more prone to colonization of emergent plants (Horppila and Nurminen, 2003; Boon et al., 2019). Since emergent macrophytes increase the siltation rate and temperature in the shallows, the positive feedback loop establishes, and expansion of the emergent vegetation accelerates.

The sedimentation rate in alpine lakes is affected by parental rocks, climate, size and ecological status of the lake, bioproduction, catchment size and anthropogenic impacts. It varies between 100 µm and 23 mm per year (Anderson et al., 2011; Arnaud et al., 2016; Miller, 2023). In alpine lakes at Triglav Mt. (Slovenia), which is most similar to Crno jezero and for which we have available results, sedimentation rate was 0.45 ± 0.11 cm/year (Šmuc et al., 2013). This kind of sedimentation rate in Crno jezero would take 42.26 ± 14.80 (±35.0%) (p=0.05, confidence level 95 %) years for equalization/leveling of current isobaths 1 and 2.8 to 1 m. For isobaths 2.8 - 3.2 m, we expect this process to take 51.65 ± 18.09 (±35.0%) (p=0.05) years, and for isobaths 3.2 - 3.7 it would take 63.39 ± 22.20 (±35.0%) (p=0.05) years. Increasing the zone of the lake that is 1 meter deep or less, is a prerequisite for the spread of Equisetum zone. Current Equisetum zone (from 0-1 m depth) would probably convert to peat bog in the next 30.52 ±10.68 (CI 35 %) ($p=0.05$).

Moreover, we have analyzed changes of maximum depth of Crno jezero that can be traced back to 1926 when it was measured 5.3 m (Protić), while in 1984 it was measured 3.7 m (Spahić). In 2023, however, we measured a maximum depth to be 3.7 m. Since in the period between the last two measurements bathymetry of the lake has not been changed, we state the hypothesis that geological events in the past might have led to lake's perimeter reduction and expansion of an emergent macrophyte belt. According to Spahić (1984), the basin of Crno jezero is encircled by two faults. First one runs from the peak Veliki Lopoč (1776 m) to the SE shoreline of Crno jezero, while the second one runs from the peak Oblik (1877 m) to its SW shoreline.

It is noted that the earthquakes, landslides or avalanches can cause strong and sudden sediment input in small lake basins (Wilhelm et al., 2016; Brisset et al., 2017; Fouinat et al., 2018; Rapuc et al., 2018; Rapuc et al., 2022), or change its hydrological discharge without additional sedimentation. In the local language, Treskavica Mt. stands for the "shaking mountain" due to a high seismic activity in the area. As a matter of fact, this area represents one of nine seismogenic zones identified in Bosnia and Herzegovina (Ćatić, 2023). In 1962, an earthquake struck this area with a magnitude Mw= 5.9 and a focal depth at 15 km (Isik et al., 2022). We strongly believe that this kind of event might have created cracks in the parental rocks or fault sliding and lowered the water table of Crno jezero. We hypothesize, therefore, that the bathymetric changes noted in the period 1926-1984 were rather the result of a tectonic activity than of the sedimentation process.

However, according to the macrophytes assemblage, current ecological status of Crno jezero is assessed to be GOOD (Table 1).

Table 1 Assessment of ecological status for Crno jezero

Species	Indicator value	Weighting factor	Q - plant quantity index	IV*W*Q
Carex rostrata	1.79	1	8	14.32
Equisetum fluviatile	1.96	1	64	125.44
Potamogeton perfoliatus	0.67	8	1	5.36
Potamogeton alpinus	2.25	1	64	144
M-NIP Index		Class		EQR
2.01		II - Mesotrophic		0.34 (GOOD)

Small mountain lakes without a direct anthropogenic impact offer the possibility of the more reliable conclusions and understanding of changes in the ecosystem (EC, 2000; EEB, 2014), but the ongoing climate changes on a global scale might jeopardize their natural structure and processes in many ways. For example, increased temperature of water can "open the door" for the introduction of alien species (Holzapfel and Vinebrooke, 2005; Obertegger and Flaim, 2021). Such was the case with the previously non-vegetated and remote Himalayan lakes that were lately invaded by Ranunculus trichophyllus (Lacoul and Freedman, 2006b; Lind et al., 2022). Radulović et al. (2010) have shown that the natural climate stressors in alpine lakes can either select or deselect particular species. Hellmann et al. (2008) believe that a climate change will challenge the definition of invasive species itself, because some previously non-invasive species might become invasive (Lind et al., 2022). These findings were confirmed by our study, for we have, for the first time, recorded Potamogeton perfoliatus in Crno jezero (NW section) and associated its occurrence with a couple of ducks which have most probably introduced it from the 0.76 km distant Veliko jezero (Great Lake). Here, it co-dominates with P. alpinus in the middle of the lake.

Currently, overgrowth of the littoral zone in Crno jezero by Equisetum belt has reached 1-meter isobath, which represents 11 m widening compared to 1954. However, there is no data on its depth in 1954, making it impossible to predict the succession trend for the entire lake, but indicating that continuous monitoring in future is required.

Furthermore, our study represents the initial step toward incorporation of the small alpine lakes into the national legislation of Bosnia and Herzegovina in terms of the assessment of ecological status. This is a critical moment, considering the fact how fast the climate changes take their toll and how little we know about the biodiversity supported by the alpine lakes in the Dinarides.

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

CONTRIBUTIONS

Concept and Design: MČ, ST; Supervision:MČ, ST, MG; Fundings: MČ; Materials: MČ, ST, MG; Data collectionand Processing:MČ, ST, ESM, MG; Analysis and Interpretation: MČ, ST, ESM, AH; Literature review: MČ, ST, ESM; Writing and Critical review: MČ, ST, ESM, AH.

REFERENCES

Anderson RS, Jimenez-Moreno G, Carrión JS, Pérez-Martínez C. 2011. Post-glacial history of alpine vegetation, fire, and climate from Laguna de Río Seco, Sierra Nevada, southern Spain. Quaternary Sci Rev, 30, 1615-29. doi: http://dx.doi.org/10.1016/j.quascirev.2011.03.005

Arnaud F, Poulenard J, Giguet-Covex C, Wilhelm B, Révillon S, Jenny J-P, et al. 2016. Erosion under climate and human pressures: An alpine lake sediment perspective. Quaternary Sci Rev, 152, 1-18. doi: https://doi:10.1016/j.quascirev.2016.09.018

Beniston M, Stoffel M. 2013. Assessing the impacts of climatic change on mountain water resources. Sci Total Environ, 493, 1129-37. https://doi.org/10.1016/j.scitotenv.2013.11.122

Boon P, Argillier C, Boggero A, Ciampittiello M, England J, Peterlin M, et al. 2019.Developing a standard approach for assessing the hydromorphology of lakes in Europe. Aquat Conserv, 29. doi: https://doi.org/10.1002/aqc.3015

Blaženčić J, Blaženčić Ž. 2005. Macrophytes of the lakes Trnovačko jezero, Veliko Stabanjsko jezero, and Malo Stabanjsko jezero on Mt. Volujak (Montenegro). Arch Biol Sci, 57(3), 213-22.

Brisset E, Guiter F, Miramont C, Troussier T, Sabatier P, Poher Y, et al. 2017. The overlooked human influence in historic and prehistoric floods in the European Alps. Geology, 45, 347-50.

Bušatlija I. 1977. Visokeplanine. In Geologija Bosne i Hercegovine Knj. III Kenozojske periode (pp. 241-246). Geoinžinjering.

Catalan J, Camarero L, Felip M, Pla S, Ventura M, Buchaca T, et al. 2006. High mountain lakes: extreme habitats and witnesses of environmental changes. Limnetica, 25, 551-84.

Catalan J, Camarero L, Gacia E, Ballesteros E, Felip M. 1994. Nitrogen in the Pyrenean lakes (Spain). Hydrobiologia, 274, 17-27.

Cvijić J. 1900. Glacijalne i morfološke studije o planinama Bosne i Hercegovine i Crne Gore.Glas SKA LVII, 1-169.

Ćatić S. 2023. Temporal and spatial analysis of earthquake in Stolac on April 22nd, 2022. Glasnik Rudarsko-geološko-građevinskog fakulteta, 10, 101-10. doi:https://doi.org/10.51558/2303-5161.2022.10.10.101

Ćirić M. 1980. Pedologija. Univerzitet u Sarajevu, Šumarski fakultet.

Dale HM. 1986. Temperature and light: The determining factors in maximum depth distribution of aquatic macrophytes in Ontario, Canada. Hydrobiologia, 133, 73-7. doi: https://doi.org/10.1007/BF00010804

European Commission. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Offic J Europ Comm, L 327(1).

European Environmental Bureau, European Commission, Lithuanian Presidency, & Freshwater Habitats Trust. 2014. Report of the Workshop on the Protection and Management of Small Water Bodies. Freshwater Habitats Trust.

Fouinat L, Sabatier P, David F, Montet X, Schoeneich P, Chaumillon E, et al. 2018. Wet avalanches: long-term evolution in the Western Alps under climate and human forcing. Clim Past, 14(9), 1299-313. doi: https://doi.org/10.5194/cp-14-1299-2018

Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai Z, Freney JR, et al. 2008. Transformation of the nitrogen cycle:

recent trends, questions, and potential solutions. Science, 320, 889-92.

Gnjato S, Narancic B, Antoniades D, Pienitz R, Biskaborn BK, Gnjato R, et al. 2022. Surface sediment diatom assemblages from four alpine lakes in the Zelengora Mountains (Bosnia and Herzegovina): A Pilot Study. Bot Serb, 46(1), 61-70. doi: https://doi.org/10.2298/BOTSERB2201061G

Hellmann JJ, Byers JE, Bierwagen BG, Dukes JS. 2008. Five potential consequences of climate change for invasive species. Conserv Biol, 22(3), 534-43.

Holzapfel AM, Vinebrooke RD. 2005. Environmental warming increases invasion potential of alpine lake communities by imported species. Glob Chang Biol, 11, 2009-15.

Horppila J, Nurminen L. 2003. Effects of submerged macrophytes on sediment resuspension and internal phosphorus loading in Lake Hiidenvesi (Southern Finland). Water Res, 37, 4468–74.

Hrvatović H. 2006. Geological guidebook through Bosnia and Herzegovina (Separate Monograph of Herald Geological, volume 25). Sarajevo: Geological Survey Sarajevo.

Hutchinson GE.1967. A Treatise on Limnology. Vol. II: Introduction to Lake Biology and the Limnoplankton. John Wiley & Sons.

Işık E, Hadzima-Nyarko M, Bilgin H, Ademović N, Büyüksaraç A, Harirchian E, et al. 2022. A Comparative Study of the Effects of Earthquakes in Different Countries on Target Displacement in Mid-Rise Regular RC Structures. Appl Sci, 12(23), 12495. doi: https://doi.org/10.3390/app122312495

Kang W, Chen G, Wang J, Huang L, Wang L, Li R, et al. 2019. Assessing the impact of long-term changes in climate and atmospheric deposition on a shallow alpine lake from southeast Tibet. Sci Total Environ, 650, 714-24.

Kollmair M, Gurung GS, Hurni K, Maselli D. 2005. Mountains: special places to be protected? An analysis of worldwide nature conservation efforts in mountains. Int J Biodivers Sci Manag, 1(4), 181-9. doi: https://doi.org/10.1080/17451590509618091

Lacoul P, Freedman B. 2006a. Environmental influences on aquatic plants in freshwater ecosystems. Environ Rev, 14, 89-136.

Lacoul P, Freedman B. 2006b. Relationships between aquatic plants and environmental factors along a steep Himalayan altitudinal gradient. Aquat Bot, 84, 3-16.

Lind L, Eckstein RL, Relyea RA. 2022. Direct and indirect effects of climate change on distribution and community composition of macrophytes in lentic systems. Biolog Rev, 97, 1677-90. doi: https://doi.org/10.1111/brv.12858

Milanović Đ. 2014.PrilogpoznavanjurasprostranjenjanekihrijetkihvrstaizrodaCarex L. u Bosni i Hercegovini. Glasnik šumarskog fakulteta Univerziteta u Banjoj Luci, br. 21, 05-23. doi: https://doi.org/10.7251/GSF1421005M

Milanović S. 1954. Prilog poznavanju makrofitske vegetacije i zarastanja planinskih jezera na Treskavici. Godišnjak Biološkog instituta u Sarajevu, 7(1-2), 247-54.

Mišić Lj. 1984. Vegetacija livada i pašnjaka na planini Treskavici. Doktorska disertacija. Univerzitet u Sarajevu, Prirodno-matematički fakultet.

Miller L. 2023. Using Cesium-137 to Determine Sedimentation Patterns in Two Proglacial Lakes - Lago Argentino, Argentina, and Lake Josephine, Montana, USA. Geology Honors Projects, 25. https://digitalcommons.macalester.edu/geology_honors/25 (accessed 10.06.24.)

Milojević BŽ. 1934. Treskavica. GZM, knj. XLVI, 65-71.

Moser KA, Baron JS, Brahney J, Oleksy IA, Saros JE, Hundey EJ, et al. 2019. Mountain lakes: eyes on global environmental change. Glob Planet Change, 178,77-95.

Moreno JL, Ortega J, Moreno M, Ballesteros R. 2022. Using an unmanned aerial vehicle (UAV) for lake management: ecological status, lake regime shift and stratification processes in a small Mediterranean karstic lake. Limnetica, 41(1), 1.

Obertegger U, Flaim G. 2021. A 40-year perspective of an alpine lake: Is everything the same?. Limnologica, 91, 125929.

Pastorino P, Prearo M. 2020. High-mountain lakes, indicators of global change: Ecological characterization and environmental pressures. Diversity, 12,260.

Peñas FJ, Álvarez-Cabria M, Sáinz-Bariáin M, Mata-Campo MP, Pérez-Haase A, Ventura M, et al. 2023. An evaluation of freshwater monitoring programs in ILTER nodes and mountain national parks: Identifying key variables to monitor global change effects. Biodivers Conserv, 32(1), 65-94. doi: https://doi.org/10.1007/s10531-022-02466-x

Pepin N, Bradley RS, Diaz HF, Bara¨er M, Caceres EB, Forsythe N, et al. 2015. Elevation-dependent warming in mountain regions of the world. Nat Clim Chang, 5, 424-30.

Poff NL. 2002. Ecological response to and management of increased flooding caused by climate change. Philos Trans R Soc Lond, 360, 1497-510.

Preston DL, Caine N, McKnight DM, Williams MW, Hell K, Miller MP, et al. 2016. Climate regulates alpine lake ice cover phenology and aquatic ecosystem structure: Climate and alpine lakes. Geophys Res Lett, 43, 5353-60.

Protić Dj. 1926. Hidrobiološke i plankton studije na jezerima Bosne i Hercegovine, III dio. GZM Sarajevo, 47-78.

Pulido C, Riera JL, Ballesteros E, Chappuis E, Gacia E. 2015. Predicting aquatic macrophyte occurrence in soft-water oligotrophic lakes (Pyrenees mountain range). Limnology, 74(1), 143-54. doi: https://doi.org/10.4081/jlimnol.2014.965

Rapuc W, Sabatier P, Andrič M, Crouzet C, Arnaud F, Chapron E, et al. 2018. 6600 years of earthquake record in the Julian Alps (Lake Bohinj, Slovenia). Sedimentology, 65, 1777-99.

Rapuc W, Arnaud F, Sabatier P, Anselmetti F, Piccin A, Peruzza L, et al. 2022. Instant sedimentation in a deep Alpine lake (Iseo, Italy) controlled by climate, human and geodynamic forcing. Sedimentology, 69. doi: https://doi.org/10.1111/sed.12972

Sadro S, Melack JM, Sickman JO, Skeen K. 2019. Climate warming response of mountain lakes affected by variations in snow. Limnol Oceanogr Lett, 4, 9-17.

Sager M, Lachavanne JB. 2009. The M-NIP: A macrophyte-based Nutrient Index for Ponds. Hydrobiologia, 634, 43-63. doi: https://doi.org/10.1007/s10750-009-9899-1

Saros JE, Interlandi SJ, DoyleS, Michel TJ, Williamson CE. 2005. Are the deep chlorophyll maxima in Alpine lakes primarily induced by nutrient availability, not UV avoidance?. Arctic, Antarctic Alpine Res, 37, 557-63.

Schindler DW, Curtis PJ, Parker BR, Stainton MP. 1996. Consequences of climate warming and lake acidification for UV-B penetration in North American boreal lakes. Nature, 379, 705-8.

Schmeller DS, Loyau A, Bao K, Bracke W, Chatzinotas A, De Vleeschouwer F, et al. 2018. People, pollution and pathogens – Global change impacts in mountain freshwater ecosystems. Sci Total Environ, 622-763. doi: https://doi.org/10.1016/j.scitotenv.2017.12.006

Sommaruga-Wograth S, Koinig KA, Schmidt R, Sommaruga R, Tessadri R, Psenner R. 1997. Temperature effects on the acidity of remote alpine lakes. Nature, 387, 64-7.

Sommaruga R. 2001. The role of solar UV radiation in the ecology of alpine lakes. J Photochem Photobiol B, 62, 35-42.

Søndergaard M, Phillips G, Hellsten S, Kolada A, Ecke F, Mäemets H, et al. 2013. Maximum growing depth of submerged macrophytes in European lakes. Hydrobiologia, 704, 165-77.

Spahić M. 1984. Planinska jezera Bosne i Hercegovine - postanak i razvoj. Doktorska disertacija, Univerzitet u Sarajevu, Prirodno-matematički fakultet.

Spahić M. 2011. Prirodna jezera u Bosni i Hercegovini.Tuzla.

Šmuc A, Skaberne D, Muri G, Vreča P, Jaćimović R, Čermelj B, et al. 2013. Influence of geomorphic setting on sedimentation of two adjacent alpine lakes, Triglav Lakes Valley (Julian Alps, NW Slovenia). Geophysical Res Abst, 15, EGU2013-7231.

Tolotti M, Manca M, Angeli N, Morabito G, Thaler B, Rott E et al. 2006. Phytoplankton and zooplankton associations in a set of Alpine high-altitude lakes: geographic distribution and ecology. Hydrobiologia, 562, 99-122.

Trevisan R, Poggi C, Squartini A. 2010. Factors affecting diatom dynamics in the alpine lakes of Colbricon (Northern Italy): a 10-year survey. Limnology, 69, 199-208.

Vinnå LR, Medhaug I, Schmid M, Bouffard D. 2021.The vulnerability of lakes to climate change along an altitudinal gradient. Commun Earth Environ, 2, 35.

Wilhelm B, Nomade J, Crouzet C, Litty C, Sabatier P, Belle S, et al. 2016. Quantified sensitivity of small lake sediments to record historic earthquakes: implications for paleoseismology. J Geophys Res Earth Surf, 121, 2-16.

Zamora R, Pérez-Luque AJ, Bonet FJ, Barea-Azcón JM, Aspizua R. (Eds.). 2016. Global of Change Impacts in Sierra Nevada: Challenges for Conservation. Consejería de Medio Ambiente y Ordenación del Territorio. Junta de Andalucía.

KAKVA JE BUDUĆNOST CRNOG JEZERA NA PLANINI TRESKAVICI U BOSNI I HERCEGOVINI?

SAŽETAK

Crno jezero (1675 m) je alpsko jezero na planini Treskavici u Bosni i Hercegovini (BiH). U radu je analizirana distribucija i abundanca akvatičnih makrofita u Crnom jezeru prema standardu BAS EN 15460:2009 te na osnovu orto-fotografija snimljenih pomoću drona pri različitim visinama (124, 80, 50, 20 m). Uzorkovanje akvatičnih makrofita u jezeru je realizirano na longitudinalnom i vertikalnom transektu, prilikom čega je, pomoću ronilačkog uređaja Mares Quad, izmjerena dubina i temperatura vode. Ekološki status Crnog jezera je procjenjen na osnovu indeksa - Macrophyte Nutrient Index for Ponds (M-NIP) i primjenom QGIS ver. 3.22.13. Najzastupljenije vrste akvatičnih makrofita u jezeru su: *Equisetum fluviatile, Potamogeton alpinus, P. perfoliatus* and *Carex rostrata*. Usporedbom naših sa rezultatima ranijih istraživanja iz 1954. godine, izradili smo prediktivni model sukcesijske dinamike za makrofitsku vegetaciju oko Crnog jezera. Uprkos tome, izračunata vrijednosti M-NIP indeksa klasificira Crno jezero kao jezero dobrog ekološkog statusa. Prikazano istraživanje predstavlja originalni multidisciplinarni pristup istraživanjima alpskih jezera BiH sa potencijalnom mogućnošću primjene na nacionalnom nivou, a kao doprinos programima globalnog monitoringa.

Ključne riječi: Monitoring, globalne promjene, vodeni makrofiti, alpska jezera, Bosna i Hercegovina