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ORIGINAL SCIENTIFIC PAPER

# Ecological Assessment of Macrozoobenthos in the Mountain Lake Šator (Bosansko Grahovo, Bosnia and Herzegovina)

## Ekološki uvjeti i makrozoobentos planinskog jezera Šator (Bosansko Grahovo, Bosna i Hercegovina)

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### ABSTRACT

Mountain lakes are sensitive ecosystems that serve as natural indicators of ecological change and conservation needs. This study presents the first ecological assessment of Lake Šator (Bosansko Grahovo, Bosnia and Herzegovina), a glacial lake situated at 1,488 m a.s.l. Field research in July and November 2021 included measurements of physicochemical parameters, water sampling, and analysis of littoral and sublittoral macrozoobenthos. The lake showed oligotrophic conditions with high oxygen saturation (101–134%), low organic load, and stable conductivity (208 µS/cm). Nitrate concentrations increased in November, reflecting seasonal dynamics. The macrozoobenthic community comprised 10 taxa in July (26 individuals) and 11 taxa in November (19 individuals). Characteristic taxa included *Sympetrum flaveolum, Asellus aquaticus*, *Erpobdella octoculata, Limnephilus rhombicus, Limnephilus flavicornis,* Tubificidae, and water mites (Hydracarina). Functional Feeding Groups analysis revealed dominance of predators (42–46%), followed by collectors, shredders, and scrapers, indicating a balanced trophic structure. Saprobic Index values (2.24 in July; 2.14 in November) correspond to □-mesosaprobic conditions, while the Shannon–Weaver Index indicated stable but seasonally variable diversity. These findings confirm the good ecological status of Lake Šator with preserved littoral dynamics. Given its sensitivity and limited prior research, the lake should be considered a priority for long-term monitoring and conservation in the Dinaric karst.

***Key words***: *natural high-mountain lakes, bioindicators, conservation, management, alien species*

## INTRODUCTION – *Uvod*

Natural mountain lakes represent specific ecosystems of great importance for the conservation of biological diversity and for monitoring ecological changes. Due to their geological origin, altitude, and hydromorphological characteristics, they are particularly sensitive to climate change and various anthropogenic pressures. Research on these lakes enables understanding of the relationships between physicochemical water characteristics and the structure of living communities, which is essential for their protection and sustainable use. Among biological elements, macrozoobenthos has a special role as an indicator of water quality, since its diversity reflects

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Figure 1. Location of Lake Šator at the foot of Mount Veliki Šator

*Slika 1. Položaj jezera Šator u podnožju planine Veliki Šator*

long-term changes in the ecosystem. In combination with physicochemical parameters, the analysis of these communities enables a comprehensive ecological assessment (Urbanič, 2014; Pastorino et al., 2020).

Macrozoobenthos in lakes shows pronounced trophic diversity, from filter-feeders of phytoplankton and bacteria (e.g., bivalves), through algivores and detritivores (snails, oligochaetes), to predators of benthic and planktonic organisms (damselflies, dipterans of the family Chaoboridae). Numerous species have developed adaptations to hypoxic and anoxic bottom conditions, including hemoglobin production (chironomids, snails) or anaerobic metabolism, while aquatic insects and pulmonate snails avoid low concentrations of dissolved oxygen by using atmospheric air (Strayer, 2009; Urbanič, 2014). In Bosnia and Herzegovina, natural lakes are mostly of the mountain type and associated with the Dinaric mountain system. Their origin is predominantly glacial or karstic, and more rarely tectonic. They are characterized by limited surface area (0.11% of all aquatic ecosystems in BiH), oligotrophic status, and high water transparency, which makes them important for the conservation of biological diversity and monitoring of climate change impacts (Gligić, 1955; Ržehak, 1957; Spahić, 2002). The largest natural lake in the country is Lake Blidinje, located in the Neretva sub-catchment, with a surface area of 2.5 km² and a maximum depth of 3 m. Glacial lakes formed by glacier retreat during the last ice age include Lake Šator, Lake Blidinje, and the Lake Zelengora complex (Orlovačko, Kotlaničko, Gornje, and Donje Bare). They are situated above 1,000 m a.s.l., characterized by seasonal ice cover and stable communities of planktonic and benthic organisms (Pastorino et al., 2020). Karst lakes, such as the Pliva Lakes in Jajce, were formed in typical karst depressions and fields. They are deeper and hydromorphologically more stable but sensitive to changes in surface and groundwater inflow as well as anthropogenic pressures (Spahić, 2002). Lake Prokoško on Vranica Mountain is an example of a combined glacial and tectonic origin, known for its relict and endemic amphibian species, including the Alpine newt *Triturus alpestris reiseri* (Werner, 1902), which has also been recorded in Lake Šator (Zimić & Lelo, 2020; Šunje et al., 2021).

Due to their sensitivity and biological value, natural lakes of Bosnia and Herzegovina serve as indicators of ecological processes in mountain ecosystems. Their preservation requires continuous monitoring and protection from anthropogenic pressures, including tourism, eutrophication, and changes in the hydrological regime. Lake Šator, located at the foot of Veliki Šator Mountain at 1,488 m a.s.l., is an ideal model for such research. It is of glacial origin, irregular in shape, 300–337 m long, up to 127 m wide, and has a depth of 5–8 m (Figure 1). It is characterized by high water transparency and seasonal freezing from December to April. Its plankton hosts numerous algae, protozoa, and crustaceans, while amphibians such as the common frog (*Rana temporaria* L.) and other species also inhabit the lake.

## MATERIALS AND METHODS – *Materijal i metode*

For the purpose of this study, field investigations were carried out in July and November 2021. In the field, physicochemical parameters were measured, water samples were collected (for laboratory analysis), and macrozoobenthos was sampled in the littoral and part of the sublittoral zone (Figure 2).

Figure 2. Location of the sampling site

*Slika 2. Položaj lokaliteta uzorkovanja*

The measurement of physicochemical parameters was carried out using a multiparameter probe (sonde) to determine water temperature, dissolved oxygen concentration, pH value (pH meter), and electrical conductivity, while in the laboratory, BOD□, COD, total nitrogen, nitrates, ammonia, phosphates, and total phosphorus were measured (Table 1).

Table 1. Methods of measuring chemical parameters in the laboratory

*Tabela 1. Metode mjerenja hemijskih parametara u laboratoriji*

| Parameter | Measurement method |
|---|---|
| $BOD_5$ (Biochemical Oxygen Demand) mg/L | Difference in dissolved oxygen concentration after 5 days of incubation |
| COD (Chemical Oxygen Demand) mg/L | Oxidation with potassium dichromate |
| Total nitrogen (TN mg/L) | Persulfate oxidation |
| Nitrates ($NO_3^-$) mg/L | Spectrophotometric method (sulfo-salicylic acid) |
| Ammonium ($NH_4^+$) mg/L | Spectrophotometric method (indophenol blue) |
| Orthophosphates mg/L | Spectrophotometric method with molybdate |
| Total phosphorus (TP mg/L) | Spectrophotometric method with molybdate after oxidative digestion |

## Sampling of macrozoobenthos

Sampling of macrozoobenthos in the littoral zone of the lake (25–35 cm depth) was conducted at representative microhabitats of different substrate types (muddy, sandy, and vegetation-covered parts). In the shallower littoral zones, organisms were collected by hand-scraping from stone substrates and macrophytes, while in deeper zones, a benthic hand net, adapted for bottom sampling, was used. The collected samples were washed through a sieve of appropriate mesh size, preserved in 70% ethanol, and subsequently stored and transported to the laboratory of the Department of Biology, Faculty of Science, University of Sarajevo, for further processing and identification.

Laboratory processing of samples involved rinsing and sorting of material under a stereomicroscope, separation of invertebrates, their identification to the lowest possible taxonomic level using appropriate identification keys (Studemann et al., 1992; Nilsson, 1996, 1997; Glöer, 2002; Waringer & Graf, 2011), and quantitative analysis (abundance and relative representation of taxa).

## Statistical analysis

For the purpose of statistical analysis of the macrozoobenthos community composition, the following indices were applied: Functional Feeding Groups (FFG) index, Saprobic Index (SI), and the Shannon-Weaver diversity index (H').

**Functional Feeding Groups (FFG) index:** The FFG index is based on the classification of macrozoobenthic invertebrates into functional groups according to their feeding mode, such as collectors, scrapers, filter-feeders, predators, and shredders (Moog, 1995). This index enables assessment of the functional structure of the community and provides insight into ecological processes in the ecosystem.

**Saprobic Index (SI):** The Saprobic Index is a biological indicator of water quality (Table 2) that describes the degree of organic pollution in a watercourse or lake. The index represents a numerical indicator of the actual ecological status of the water, obtained by combining ecological tolerance, indicator value, and abundance of aquatic organisms present in the sample. The Saprobic Index is strictly linked to the sample and its quantitative composition, and it is calculated using the following formula:

$$SI=\sum\frac{h\cdot s\cdot G}{s\cdot G}$$

where **SI** – Saprobic Index, **h** – relative abundance/number of individuals of the taxon, **s** – saprobic value of the taxon, and **G** – indicator weight of the taxon (Wegl, 1983).

Table 2. Saprobic zones and quality categories

*Tabela 2. Zone saprobnosti i kategorije kvaliteta*

| Saprobic zone | Main characteristics | Category |
|---|---|---|
| Oligosaprobic | Very clean water, minimal organic load | Class I |
| β-mesosaprobic | Slightly loaded waters, moderate degree of organic matter decomposition, good quality | Class II |
| α-mesosaprobic | Moderately to considerably loaded waters, pronounced decomposition of organic matter | Class III |
| polysaprobic | Heavily polluted waters, reductive conditions, high organic load | Class VI |

**Shannon–Weaver diversity index (H')** is a measure that combines the species richness and the evenness of their representation within the community. It is calculated based on the relative frequency of each species in the sample, using the formula:

$$H' = -\sum\left(\left(\frac{ni}{N}\right) log_2\left(\frac{ni}{N}\right)\right)$$

where **N** – total number of individuals in the sample; $\mathbf{n_i}$ – number of individuals of taxon *i* in the sample.

This diversity index (H') is used to assess species richness and the evenness of their representation within the community. All individuals in the sample must be identified at the same taxonomic level (most often at the species level, or at the family level when identification is more difficult). Wilhelm and Dorris (1966) applied this index in the assessment of water quality (Table 3).

Table 3. Water quality scale according to the Shannon-Weaver index values (after Wilhm and Dorris, 1966)

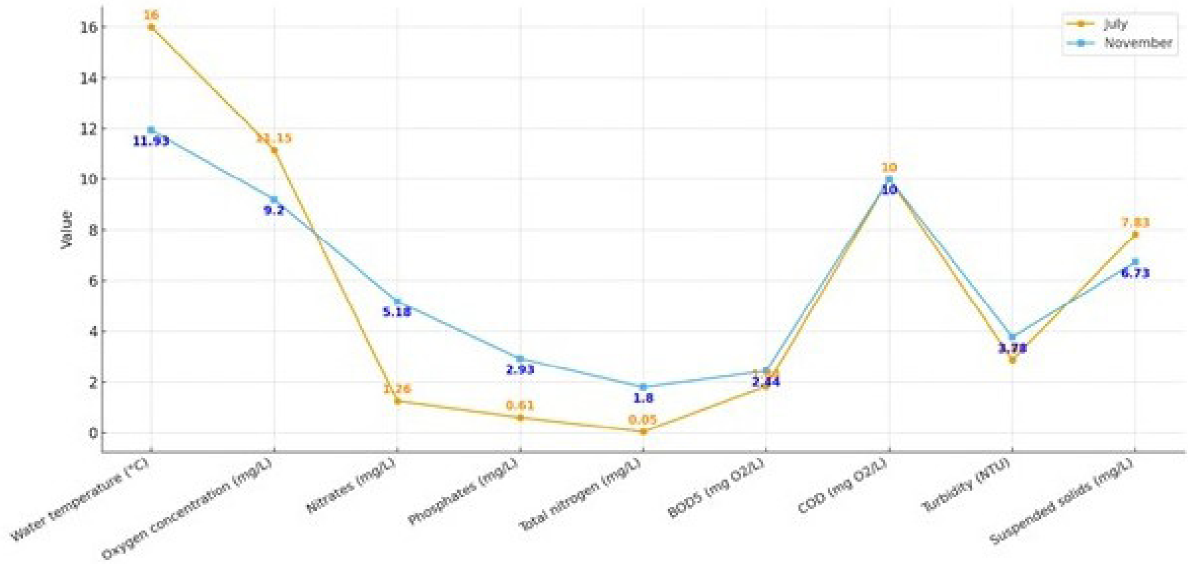
*Tabela 3. Skala kvaliteta vode prema vrijednosti Shannon-Weaver indeksa (prema Wilhm and Dorris, 1966)*

| Value of H' | Ecological interpretation | Quality category |
|---|---|---|
| H'<1 | Very low diversity; community poor in species, dominance of one or a few species. | IV–Polluted |
| H'=1–2 | Low to moderate diversity | III–Moderately polluted |
| H'=>2–3,5 | High diversity, stable community | II–Slightly polluted/good |
| H'>3,5 | Very high diversity | I–Clean water |

## RESULTS AND DISCUSSION – *Rezultati i diskusija*

For Lake Šator, it has been documented that the lake bottom is covered with aquatic plants of the genus *Potamogeton* L., which in the littoral form an "underwater meadow" and give the water a dark green shade. On the limestone shore, plant communities of *Festucion pungentis* Horvat 1930/1931 are present. The immediate catchment of Lake Šator belongs to beech-fir forests (*Abieti-Fagetum dinaricum*, Tregubov 1957), followed towards Veliki Šator Mountain by a belt of subalpine beech, and above it a belt of dwarf pine (*Pinion mugo* Pawłowski et al., 1928).

The physicochemical parameters of Lake Šator showed seasonal differences between July and November 2021 (Figure 1). In July, the water temperature was 16 °C, while in November it was 11.9 °C. The pH values were slightly alkaline in both periods (8.7–9.3). Dissolved oxygen concentration ranged from 9.2 to 11.1 mg/L, with high saturation levels (101–134%), indicating good aeration and photosynthetic activity. Electrolytic conductivity was stable (around 208 μS/cm). $BOD_5$ and COD values remained low, confirming a small organic load and high water quality. Nitrate concentrations were higher in November (5.2 mg/L) than in July (1.3 mg/L), while phosphorus and phosphates were recorded at very low concentrations. Sulphates, chlorides, and fluorides remained low and stable. Suspended matter and turbidity were somewhat higher in July, probably due to more intense biological processes and surface runoff. Overall, these parameters confirm oligotrophic conditions, high transparency, and good oxygen saturation.




Graph 1. Values of physicochemical water parameters of Lake Šator in July and November 2021

*Grafikon 1. Vrijednosti fizičko-hemijskih parametara vode jezera Šator u julu i novembru 2021. godine*

Overall, the analysed parameters confirm that Lake Šator is characterized by oligotrophic conditions, high transparency, and good oxygen saturation, which classifies it among mountain lakes with preserved ecological characteristics.

In July, macrozoobenthos samples from Lake Šator contained a total of 26 individuals belonging to 10 taxa (Table 4). The most numerous were larval stages of the dragonfly *Sympetrum flaveolum* (Linnaeus, 1758), while oligochaetes (Tubificidae), the isopod *Asellus aquaticus* (Linnaeus, 1758), larvae of Ephemeroptera (*Caenis* sp.), and caddisfly larvae *Limnephilus rhombicus* (Linnaeus, 1758) were each represented by three individuals. Aquatic mites (Hydracarina), the leech *Erpobdella octoculata* (Linnaeus, 1758), *Ischnura pumilio* (Charpentier, 1825), Chironomidae, and Tanypodinae were each represented by two individuals. In November, 19 individuals and 11 taxa were recorded. The most common were *Asellus aquaticus* and *Limnephilus rhombicus* (3 individuals each), while *Erpobdella octoculata*, Hydracarina, and Chironomidae were represented by two individuals each. In the November sample, species not observed in July were recorded – *Limnephilus flavicornis* (Fabricius, 1787) with two individuals, and one larva of Hydroptilidae. *Limnephilus rhombicus* is considered more tolerant and frequent in eutrophic ponds and lakes, whereas *L. flavicornis* prefers cleaner, colder, and more natural small aquatic ecosystems (Waringer & Graf, 2011). A single individual was recorded for *Sympetrum flaveolum*, *Ischnura pumilio*, and Tanypodinae. *Ischnura pumilio* is a damselfly species typical of shallow and pioneer aquatic habitats, tolerant to changes and often associated with young or unstable ecosystems (Nilsson, 1997). Overall, more individuals were recorded in July, whereas a higher number of taxa was observed in November, indicating seasonal changes in macrozoobenthic community structure.

The macrozoobenthic community of Lake Šator comprised four Functional Feeding Groups (FFG) (Table 4): collector-gatherers (CG – Tubificidae, *Asellus aquaticus*, Chironomidae), predators (PR – *Erpobdella octoculata*, Hydracarina, Tanypodinae, *Sympetrum flaveolum*, *Ischnura pumilio*), scrapers (SC – *Caenis* sp., Hydroptilidae gen. spec.), and shredders (SH – *Limnephilus rhombicus*, *Limnephilus flavicornis*).

Graph 2 shows the representation of Functional Feeding Groups (FFG) in the macrozoobenthic community of Lake Šator. Predators formed the most abundant group (37%), followed by collector-gatherers (28%) and shredders (26%), while scrapers (9%) were the least represented. This distribution indicates a well-developed trophic structure of the community, in which predators play a dominant role in regulating the abundance of other organisms. Collector-gatherers and shredders contribute to organic matter decomposition, while scrapers maintain the balance of periphytic communities. Within broad temperature ranges, such trophic relationships may be closely associated with the structure of invertebrate communities. Food source categories

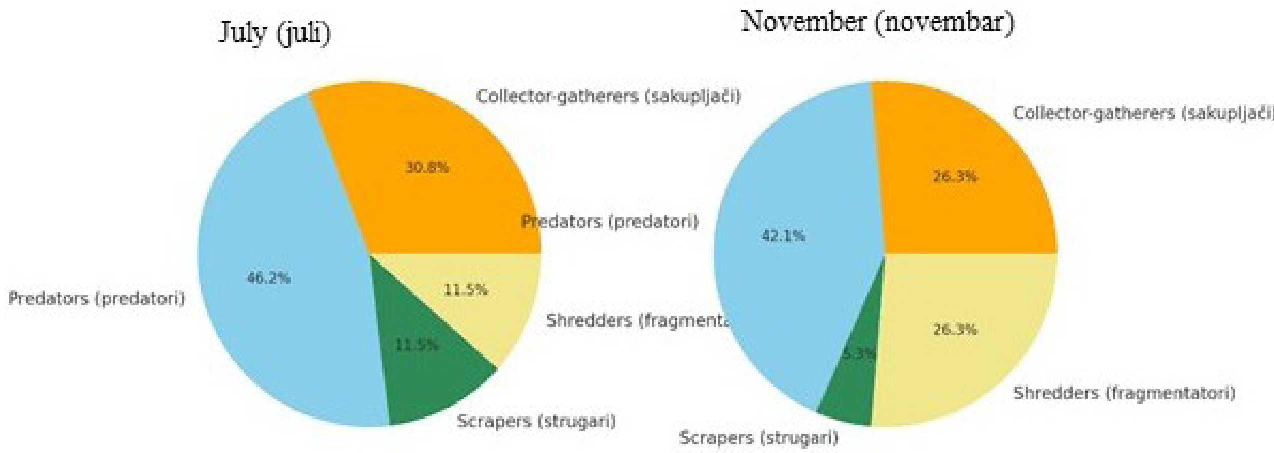
Table 4. Qualitative and quantitative composition of macrozoobenthos and functional feeding groups (FFG) in Lake Šator in July and November

*Tabela 4. Kvalitativni i kvantitativni sastav makrozoobentosa i funkcionalne grupe (FFG) u Šatorskom jezeru u julu i novembru*

| Takson | July | November | FFG | Functional group (description) |
|---|---|---|---|---|
| Tubificidae | 3 | 0 | CG | Collector-gatherers |
| *Erpobdella octoculata* | 2 | 2 | PR | Predators |
| *Asellus aquaticus* | 3 | 3 | CG | Collector-gatherers |
| Hydracarina | 2 | 2 | PR | Predators |
| *Caenis* sp. | 3 | 0 | SC | Scrapers |
| *Limnephilus rhombicus* | 3 | 3 | SH | Shredders |
| *Limnephilus flavicornis* | 0 | 2 | SH | Shredders |
| Hydroptilidae gen. spec. | 0 | 1 | SC | Scrapers |
| *Sympetrum flaveolum* | 4 | 2 | PR | Predators |
| *Ischnura pumilio* | 2 | 1 | PR | Predators |
| Chironomidae | 2 | 2 | CG | Collector-gatherers |
| Tanypodinae | 2 | 1 | PR | Predators |

often overlap, and differences are not always distinct. These divisions generally correspond to morpho-behavioural adaptations of invertebrates grouped into functional feeding guilds, which can approximately be differentiated on a microbial and/or biochemical basis. The distinction of food sources is based on particle size (detrital categories), the presence of chlorophyll (periphyton dominated by algae), and the high protein content of typical animal prey (Cummins & Klug, 1979).

Analysis of functional feeding groups (FFG) in macrozoobenthic communities represents an important approach in assessing the ecological conditions of lake ecosystems. Unlike a simple taxonomic list, the FFG approach provides insight into trophic interactions and the ecological roles of organisms. In lakes, collector-gatherers and shredders contribute to the decomposition and recycling of organic matter, scrapers maintain the balance of periphytic communities, while predators play a key role in regulating the abundance of other groups. In this way, FFG structure reflects the availability of energy resources and the stability of food webs. Disturbances in the participation of individual functional groups may indicate changes in water quality, increased nutrient input, or reduced transparency, which is particularly important in mountain lakes such as Šator. Therefore, the FFG index is increasingly used in biomonitoring, as it links abiotic factors with the trophic organization of the community and provides a clearer picture of the ecological status of lakes (Cummins & Klug, 1979; Moog, 1995). Predators dominated in both periods (46% in July and 42% in November), indicating a stable prey base in the benthos (insect larvae, small invertebrates). Their high proportion is associated with relatively clean, well-oxygenated water that supports diverse lower trophic levels. They were represented by taxa such as *Erpobdella octoculata*, Hydracarina, Tanypodinae, *Sympetrum flaveolum*, and *Ischnura pumilio* (previously recorded in the littoral of Lake Šator). These organisms feed on other invertebrates and play a key role in regulating community abundance. Their dominance in both seasons indicates a stable prey base and good ecological balance in the lake. Hydracarina parasitize Odonata larvae in Lake Šator (Kulijer et al., 2012; Zawal et al., 2017). Collector-gatherers (CG) were more frequent in July (31%) than in November (26%), associated with a greater input of fine detritus and organic material during the warmer period, when primary production increases and leaf litter enters from the shore. Tubificidae, *Asellus aquaticus*, and Chironomidae collect fine particulate organic matter (FPOM) from sediment and water. Their presence indicates a role in detritus recycling and contribution to organic matter cycling in the lake. Scrapers (SC) were more abundant in summer (12%) compared to autumn (5%), related to higher periphyton and algal development on substrates during longer daylight and warmer water. They were represented by taxa such as *Caenis* sp. and Hydroptilidae gen.




Graph 2. Proportion (%) of Functional Feeding Groups (FFG) in the zoobenthic community of Lake Šator. Abbreviations: CG–collector-gatherers, PR–predators, SC–scrapers, SH–shredders

*Grafikon 2. Udio (%) funkcionalnih skupina ishrane (FFG) u zajednici makrozoobentosa Šatorskog jezera. Skraćenice: CG–sakupljači, PR–predatori, SC–strugači, SH–usitnjivači*

spec., which feed on periphyton (algae and microorganisms) from the substrate. Their greater representation in July was associated with higher light energy and algal growth during the summer months. Shredders (SH) were more abundant in November (26%) than in July (12%), because leaf fall in autumn increases the input of coarse particulate organic matter (CPOM), which is the main resource for this group (e.g., Limnephilidae). Shredders (SH) such as preimaginal stages of caddisflies of the family Limnephilidae feed on CPOM, mainly fallen leaves and plant debris, which they shred and decompose, thereby enabling further decomposition and making food available to collector-gatherers.

The dominance of predatory taxa (mainly *Odonata*, *Trichoptera*, *Coleoptera,* and *Hirudinea*) within the littoral zoobenthos of Lake Šator indicates a stable and well-oxygenated ecosystem with balanced trophic interactions. Such community structure reflects a high ecological integrity, typical for oligotrophic to mesotrophic mountain lakes, where energy flow is slow, and benthic niches are well-defined. Predator prevalence suggests that lower trophic groups are sufficiently abundant to sustain higher trophic levels and that the ecosystem is not exposed to significant anthropogenic or organic stress**.** The littoral zone thus functions as a key stabilizing habitat, ensuring long-term ecological resilience of Lake Šator.

The values of the Saprobic Index in July (3.28) and November (3.22) indicate that, based on macrozoobenthos samples, the littoral of Lake Šator retains a β-mesosaprobic status, implying moderate organic load and generally good ecological water quality (Figure 3). It should be emphasized that this refers to the littoral, the most dynamic part of the lake, where conditions are variable due to constant input of organic matter from land, changes in light availability, and temperature fluctuations (Alcocer et al., 2022). The slightly higher value in July probably reflects stronger biological activity and a higher contribution of more tolerant groups (e.g., Tubificidae, Chironomidae), while the lower index in November is due to a greater presence of shredders (*Limnephilus*), related to the input of coarse organic matter (leaves) during autumn. These results are consistent with physicochemical parameters (stably high oxygenation, moderate nitrate increase in November) and the structure of functional feeding groups, confirming that the macrozoobenthic community reflects seasonal changes in resource availability but that the ecological status of the lake remains preserved.

The evident seasonal differences in water chemistry (temperature 16 → 11.9 °C; higher $NO_3^-$ in November; consistently high $O_2$ saturation 101–134%; low $BOD_5$/COD) point to oligotrophic lake conditions, with autumn circulation and groundwater inflow as key mechanisms for nitrate increase. Although the littoral saprobic index (2.24 in July; 2.14 in November) indicates a β-mesosaprobic signal, this is expected for a dynamic nearshore zone where CPOM (coarse particles) and FPOM (fine particles) enter impulsively from the shore. The FFG structure further supports this picture: in summer, collector-gatherers and scrapers (periphyton, FPOM) were more promi-

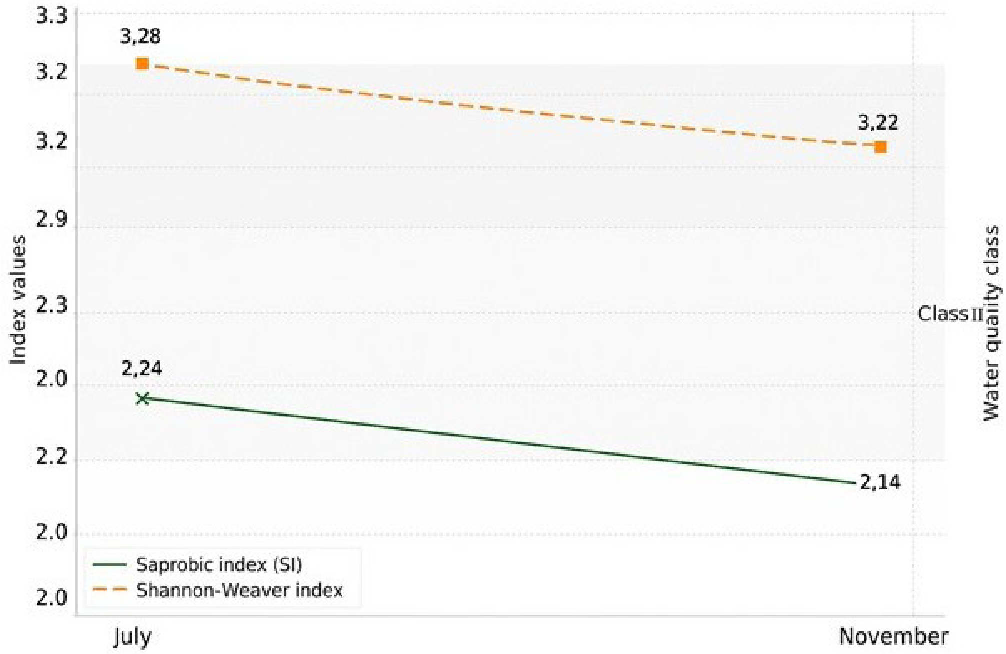



Figure 3. Values of the Saprobic Index and the Shannon-Weaver Index for the qualitative-quantitative composition of macrozoobenthos samples from Lake Šator, as well as the water quality categories (July and November 2021)

*Grafikon 3. Vrijednosti saprobnog indeksa i Shannon-Weaver indeksa za kvalitativno-kvantitativni sastav makrozoobentosa uzoraka iz jezera Šator, kao i kategorija kvaliteta vode (juli i novembar 2021)*

nent, in autumn shredders (leaves/CPOM), while the stable dominance of predators in both periods reflects good oxygenation and a reliable prey base. At the same time, functional overlap of certain taxa (e.g., Chironomidae, *Caenis*) emphasizes the advantage of the FFG approach over a purely taxonomic list, as it directly links resource availability with trophic roles (Cummins & Klug, 1979; Moog, 1995). Zoobenthos in lakes shows clear vertical zonation. The littoral zone, where macrophytes and sufficient dissolved oxygen are present, supports the highest species diversity and biomass. In this zone, various insects, snails, and other detritivores are most common, while macrophytes serve as substrate for attachment, refuge from predation, and a source of food. Thus, the littoral represents the most dynamic part of the macrozoobenthic community (Strayer, 2009; Trožić-Borovac et al., 2023). In contrast, the profundal zone is characterized by low oxygen or complete anoxia, which greatly limits species number. Under such conditions, only specialized taxa such as certain chironomids, oligochaetes, and ostracods survive, often with reduced diversity and biomass. Oxygen deficiency, lower organic matter input, and absence of macrophytes are key factors shaping the composition and abundance of zoobenthos in deeper parts of the lake (Strayer, 2009).

In a regional context, Lake Šator can be regarded as a "cold-water reference" with a narrower trophic range, whereas Lake Boračko at a lower altitude shows greater macrozoobenthic diversity amplitudes under anthropogenic pressures. Similar investigations were conducted in the littoral and limnion of Lake Boračko (Trožić-Borovac, 2007; Trožić-Borovac et al., 2023). Despite limited systematic data on lakes in Bosnia and Herzegovina, comparative insights show that Lake Boračko, due to its lower altitude and stronger anthropogenic pressures (recreation, shoreline modification, fish stocking), exhibits reduced macrozoobenthos diversity. However, Lake Boračko has also been confirmed as a habitat of the white-clawed crayfish *Austropotamobius pallipes* Fabricius, 1758, and a diverse assemblage of damselflies (Odonata), attesting to preserved heterogeneous microhabitats and high evolutionary value of this Dinaric karst site. This combination of reduced overall diversity along with the presence of sensitive and biogeographically important taxa highlights the need for targeted protection of the littoral and source-shore zones as key refugia.

Compared with Lake Šator, which has only been partially described in the literature and whose biological characteristics remain insufficiently studied, Lake Prokoško on Vranica is one of the most thoroughly investigated mountain lakes in Bosnia and Herzegovina, with its aquatic flora and fauna, vegetation, and peatland ecosystems well documented (Barudanović, 2003; Redžić, 2007; Mašić, 2020). This difference clearly underscores the need for continued and expanded biological research of Lake Šator to valorize its ecological values. At the same time, these ecosystems should be considered in the context of potential Natura 2000 sites, further emphasizing the necessity of establishing appropriate protection measures for these sensitive mountain lakes and their unique ecosystems. The fir forests (*Abieti-Fagetum dinaricum* Tregubov 1957) on Mount Šator, first surveyed in 1879 by forestry councillor Ritter von Guttenberg, were at that time among the most beautiful and best-preserved forest communities in Bosnia and Herzegovina, with significant ecological and economic potential and rich fauna including roe deer, hares, capercaillie, and wolves. Today, the forests of Mount Šator are considerably degraded due to decades of logging, with former continuous complexes of fir forests largely replaced by secondary beech and mixed stands. Although some relict fir (*Abies alba* Mill.) groups still persist, their area and ecological stability are greatly reduced. Anthropogenic pressures, primarily intensive timber exploitation and lack of sustainable management, have led to habitat fragmentation and loss of characteristic fauna. Compared to historical descriptions, the abundance and distribution of species such as capercaillie (*Tetrao urogallus* L.) are significantly reduced, while roe deer (*Capreolus capreolus* L.) and wolves (*Canis lupus* L.) are still present but in smaller numbers and subject to habitat changes (Avdibegović et al., 2017).

Secondary production of zoobenthos in most lakes is modest, and energy flow through this community is lower than through the microbial ones. However, in Lake Šator this component has a special importance as it represents a key link in matter cycling. Benthic animals in Lake Šator, as in other mountain lakes, consume phytoplankton, detritus, and organic remains, and their feeding intensity can directly affect the availability of resources and ecosystem stability. Considering the isolation and natural features of Lake Šator, local pressures (eutrophication, introduction of allochthonous species) could have a strong impact on the zoobenthos, where potential extinctions would be particularly significant as they would mean the loss of rare or endemic populations.

## CONCLUSIONS – *Zaključak*

Lake Šator, situated at higher elevations of the Dinaric mountain system, represents one of the few preserved natural glacial ecosystems in Bosnia and Herzegovina. Its location, surrounded by beech–fir and subalpine forests, together with a rich macrophyte belt in the littoral zone, testifies to its high natural value and habitat diversity.

The research results confirm that the lake is characterized by good ecological conditions, stable communities, and pronounced seasonal dynamics, in which macrozoobenthos plays a key role in matter cycling and maintaining ecological balance. Functional feeding groups clearly reflect resource availability and seasonal changes in the littoral, while the saprobic index indicates a preserved but dynamic littoral zone.

This study provides the first comprehensive picture of the ecological conditions and macrozoobenthic communities of Lake Šator, emphasizing its importance as a natural lake while at the same time highlighting the need for continuous monitoring and protection of this unique mountain ecosystem.

In conclusion, although Lake Šator is small in surface area and cannot serve as a complete reference profile, it possesses features that make it significant for inclusion in the *Natura 2000* network and for monitoring under the Water Framework Directive, with recommended protection measures such as prohibiting the introduction of alien species and regulating tourism activities.

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## SAŽETAK

Prirodna planinska jezera Bosne i Hercegovine predstavljaju rijetke, osjetljive i biološki vrijedne ekosisteme, koji služe kao indikatori klimatskih promjena i antropogenih pritisaka. Ovaj rad donosi prvu cjelovitu ekološku procjenu Šatorskog jezera, glečarskog porijekla, smještenog na 1.488 m n. v., u podnožju planine Veliki Šator. Terenska istraživanja provedena su u julu i novembru 2021. godine, s obuhvatom mjerenja fizičko-hemijskih parametara, uzorkovanja vode i analize makrozoobentosa litorala i sublitorala. Rezultati ukazuju na očuvane oligotrofne uvjete: visoku prozirnost i zasićenost kisikom (101–134%), niske vrijednosti $BPK_5$ i HPK, stabilnu elektrovodljivost (208 µS/cm) te niske koncentracije fosfora. U novembru je zabilježen porast nitrata, što odražava sezonske procese cirkulacije i dotok podzemnih voda. Makrozoobentosna zajednica sadržavala je 10 taksa u julu (26 jedinki) i 11 taksa u novembru (19 jedinki), uz sezonske razlike u brojnosti i sastavu. Najčešće zabilježene vrste bile su vilinski konjic *Sympetrum flaveolum*, izopodni račić *Asellus aquaticus*, pijavica *Erpobdella octoculata*, te tulari *Limnephilus rhombicus* i *Limnephilus flavicornis*. Pored njih, važnu ulogu imale su oligohete (Tubificidae), grinje (Hydracarina), preimaginalni stadiji efemeroptera (*Caenis sp.*) i larve trihoptera (Hydroptilidae). Analiza funkcionalnih grupa ishrane (FFG) pokazala je dominaciju predatora (42–46%), potom sakupljača, usitnjivača i strugača. Ovakva raspodjela svjedoči o stabilnoj trofičkoj mreži i dobroj oksigenaciji, dok sezonske razlike učešća sakupljača i usitnjivača odražavaju unos organske materije i fenološke promjene. Vrijednosti saprobnoga indeksa (2,24 u julu; 2,14 u novembru) potvrđuju β-mezosaprobni status litorala, što znači umjereno organsko opterećenje uz dobar ekološki kvalitet. Shannon–Weaver indeks ukazuje na stabilnu, iako sezonski varijabilnu, raznolikost. Zaključci istraživanja potvrđuju da Šatorsko jezero predstavlja značajan prirodni referentni lokalitet s očuvanim ekološkim karakteristikama i bogatim makrofitskim pojasom. Rezultati pružaju osnovu za dalji monitoring i naglašavaju potrebu za uspostavom zaštitnih mjera u okviru evropskih standarda (WFD, Natura 2000). S obzirom na nedostatak sistematskih podataka o jezerima BiH, Šatorsko jezero treba posmatrati zajedno s detaljnije istraženim jezerima, poput Prokoškog i Boračkog, uz naglašenu potrebu za nastavkom bioloških i ekoloških istraživanja.


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