

Original Research

DIATOMS FROM LUDAŠ LAKE AND THEIR APPLICATION IN BIOINDICATION

DOI: 10.5937/EcoTER26187J

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Abstract

*The main objectives of this study were to investigate the diversity and composition of the epiphytic diatom community in Ludaš Lake and to assess its ecological status using diatom indices. In total, 57 diatom taxa were recorded across three sampling sites during May and September 2025 (46 taxa in May and 37 in September). The dominant taxa at the studied sites included *Fragilaria mesolepta*, *Halamphora veneta*, *Nitzschia acidoclinata*, *Nitzschia amphibia*, and *Pseudostaurosira brevistriata*, with maximum relative abundances ranging from 19.23% to 50.11%. According to Serbian legislation, the ecological status based on phytobenthos was classified as moderate (class III, site L1) and good (class II, sites L2 and L3) in May. In contrast, in September, the status was moderate (class III, sites L1 and L2) and bad (class V, site L3). These findings highlight the need for continuous monitoring that integrates physical, chemical, and biological parameters in order to effectively assess the condition of aquatic ecosystems and detect various forms of pollution.*

Keywords: ecological status, phytobenthos, limnology.

INTRODUCTION

Several groups of organisms are widely used to assess the ecological status of aquatic environments, including fish, macroinvertebrates, macrophytes, phytoplankton and diatoms. Among these, benthic diatoms offer distinct advantages over other groups, making them especially valuable for routine environmental monitoring [1]. Diatoms are recognized as one of the most diverse and informative group of organisms used to assess the ecological status of water bodies under the European Water Framework Directive. Their high species diversity, combined with extensive ecological knowledge, enables their effective use as reliable bioindicators [2]. Diatoms are ubiquitous, easy to sample, and often abundant in different habitats, on hard substrates or in high-velocity rivers where macroinvertebrates, macrophytes, and phytoplankton (typically used in lowland ecosystems) may be absent. In addition, their rapid growth rates enable benthic diatoms to respond quickly to short-term hydrological changes, unlike other bioindicators (for example macroinvertebrates) [1]. However, their morphological and taxonomic identification remains challenging and requires specialized

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expertise [3]. Diatoms have been used less frequently in lake monitoring than in river water quality assessments, although some diatom indices have been developed specifically for lakes [4]. However, several studies have demonstrated the strong potential of epiphytic diatoms for evaluating lakes water quality [5,6].

Ludaš Lake, together with its surrounding complex of wet habitats, represents the only example of shallow, semi-static steppe lakes in our country. It was designated as a Special Nature Reserve in 2006. The protected area covers 846.33 hectares, while its buffer (protective) zone extends over 2,002 hectares. The site is managed under three levels of protection: I, II, and III. In 2008, the “Ludaš” Visitor Center was constructed on the edge of the reserve [7].

The main objectives of this study were: (i) to explore diversity and composition of epiphytic diatom community of Ludaš Lake, and (ii) to estimate the ecological status using diatom indices.

MATERIALS AND METHODS

Sampling

Diatom samples were collected at three sampling points (L1-L3) in Ludaš Lake during May and September 2025. L1 sampling site was located in the southern part of the lake, L2 situated near the Ludaš-Palić canal, and L3 positioned closed to the "Ludaš" Visitor Center. Epiphytic diatoms were sampled by scraping biofilm from older reed stems (*Phragmites australis* (Cav.) Trin. ex Steudel) that had been submerged for an extended period. The collected material was preserved with formaldehyde to a final concentration of approximately 4% [8]. At each sampling event, physicochemical parameters were measured *in situ*. Water temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were recorded using Eutech Instruments OaktonR7 probes, while dissolved oxygen concentration and oxygen saturation were determined with an EcoSense ODO200 instrument.

Laboratory work and microscopic analyses

Qualitative and quantitative analysis of diatoms require laboratory processing of samples, including the removal of all cellular organic material, followed by the preparation of permanent slides. Sample processing was carried out using a standard method [8], which involves treatment with hydrochloric acid and potassium permanganate. This procedure yields cleaned material containing the siliceous cell walls (frustules) of diatoms, which were subsequently mounted in Naphrax medium to produce permanent slides. Slides prepared in this manner enable detailed observation of the structures and ornamentation of the silicified cell walls, which represent key taxonomic features for accurate diatom identification and community analysis.

Qualitative analysis was performed using a Zeiss AxioImager M1 light microscope equipped with an AxioCam MRc5 camera and AxioVision 4.9.1 software. Identification was conducted using relevant taxonomic literature [9–11]. Quantitative analysis was carried out on the same microscope by counting 400 valves per slide.

Ecological status assessment based on phytobenthos

Results of the qualitative analysis were used to calculate diatom indices in the OMNIDIA software package [12]. This software provides values for a total of 18 diatom indices which indicate appropriate water quality. According to the scale proposed by Prygiel and Coste [13], diatom index values between 0 and 4.99 correspond to water quality class V (labeled with red color), 5.00–8.99 to class IV (orange), 9.00–12.99 to class III (yellow), 13.00–16.99 to class II (green), and 17.00–20.00 to class I (blue).

In accordance with the *National Rulebook on Parameters of the Ecological and Chemical Status of Surface Waters and Parameters of the Chemical and Quantitative Status of Groundwaters* [14], the first step in assessing water quality is the classification of the water body type. Based on this framework, Ludaš Lake is categorized as a shallow lake situated below 200 m above sea level.

For phytobenthos (epiphytic diatoms), the ecological status of Ludaš Lake is assessed using the IPS diatom index, as prescribed by the National Rulebook.

RESULTS AND DISCUSSION

The values of the measured physicochemical parameters are presented in Table 1. In May, site L1 was characterized by the lowest recorded water temperature, pH, and dissolved oxygen concentration, as well as the highest total dissolved solids (TDS) values. According to Anderson *et al.* [15], seasonal shifts in diatom communities are primarily driven by nutrient availability, while temperature exerts an indirect influence on these changes.

Table 1 Values of physicochemical parameters measured at the sampling sites of Ludaš Lake (L1-L3) in May and September 2025

	May			September		
	L1	L2	L3	L1	L2	L3
T (°C)	17.6	19.3	19.4	20.8	19.5	20.8
pH	7.66	8.15	8.55	9.58	7.87	9.27
EC (µS/cm)	1489	916	921	2150	1099	1468
TDS (ppm)	1044	646	646	1503	769	1029
O ₂ (mg/l)	6.8	10.8	15.5	17.9	9.6	12.4
O ₂ (%)	71	117.2	165.3	199.8	103.9	133.9

A total of 57 diatom taxa were recorded across three sampling sites in Ludaš Lake during May and September 2025 (46 taxa in May and 37 in September). The highest number of taxa (33) was observed at site L1 in September, while the lowest (10) was recorded at site L3 during the same month (Figure 1).

Köster and Pienitz [16] investigated diatom seasonality at a monthly scale in Bates Pond and found that temperature and lake circulation accounted for most of the observed variation in diatom assemblages. In the present study, the genus *Nitzschia* was particularly prominent, with 13 taxa identified.

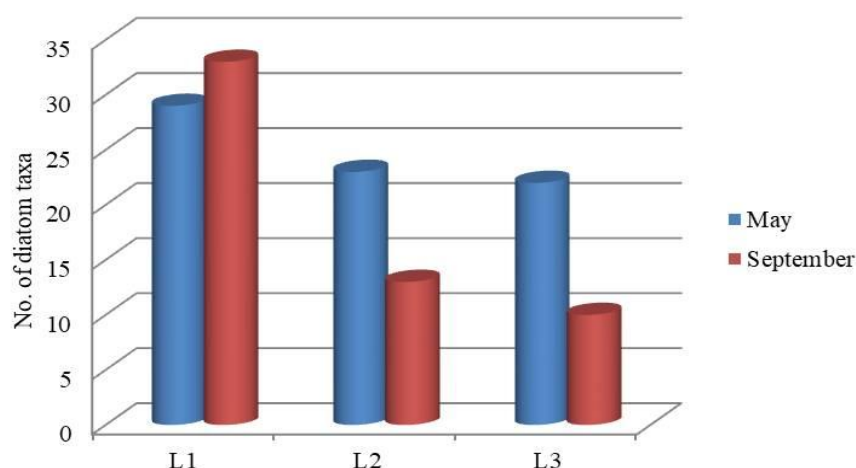


Figure 1 Number of diatom taxa per site in May and September 2025 at three sampling sites of Ludaš Lake (L1-L3)

The dominant taxa at the studied sites were *Fragilaria mesolepta* Rabenhorst, *Halamphora veneta* (Kützing) Levkov, *Nitzschia acidoclinata* Lange-Bertalot, *Nitzschia amphibia* Grunow, and *Pseudostaurosira brevistriata* (Grunow in Van Heurck) Williams & Round, with maximum relative abundances ranging from 19.23% to 50.11% (Figure 2). *P. brevistriata* was the dominant taxon at two sites (L1 and L2) in September, whereas the other dominant taxa each prevailed at only one site during a single sampling period. However, several of these taxa (*Halamphora veneta*, *Nitzschia acidoclinata*, and *N. amphibia*) can also be considered common, as they were recorded at all sites in both sampling months. *P. brevistriata* is typically found in calcium-rich lakes and running waters and exhibits a broad trophic tolerance, ranging from oligotrophic to eutrophic conditions, as well as a wide range of electrolyte contents [9]. It is noteworthy that *F. mesolepta* was recorded exclusively at site L2 in May, where it reached a high relative abundance (50.11%) (Figure 2). Although this species is widely distributed in standing and flowing freshwater habitats with moderate to high trophic levels, it is rarely observed in such high abundances [9]. In total, six common species were identified: *Cyclotella meneghiniana* Kützing, *Gomphonema parvulum* (Kützing) Kützing, *Halamphora veneta* (Kützing) Levkov, *Nitzschia acidoclinata* Lange-Bertalot, *Nitzschia amphibia* Grunow, and *Staurosira venter* (Ehrenberg) Cleve & Møller.

Based on Table 2, the ecological status of Ludaš Lake assessed by diatoms ranges from high to bad, depending on the sampling site, sampling month and diatom index. These findings are consistent with previous research conducted in 2022 [17]. A high ecological status was recorded only at a single site during one sampling month and was supported by the values of only two diatom indices. Diatom indices that testify to the presence of nutrients in aquatic ecosystems (Rott TI, TDIL, TDI) indicate a bad ecological status in at least one site, mostly in September (Table 2).

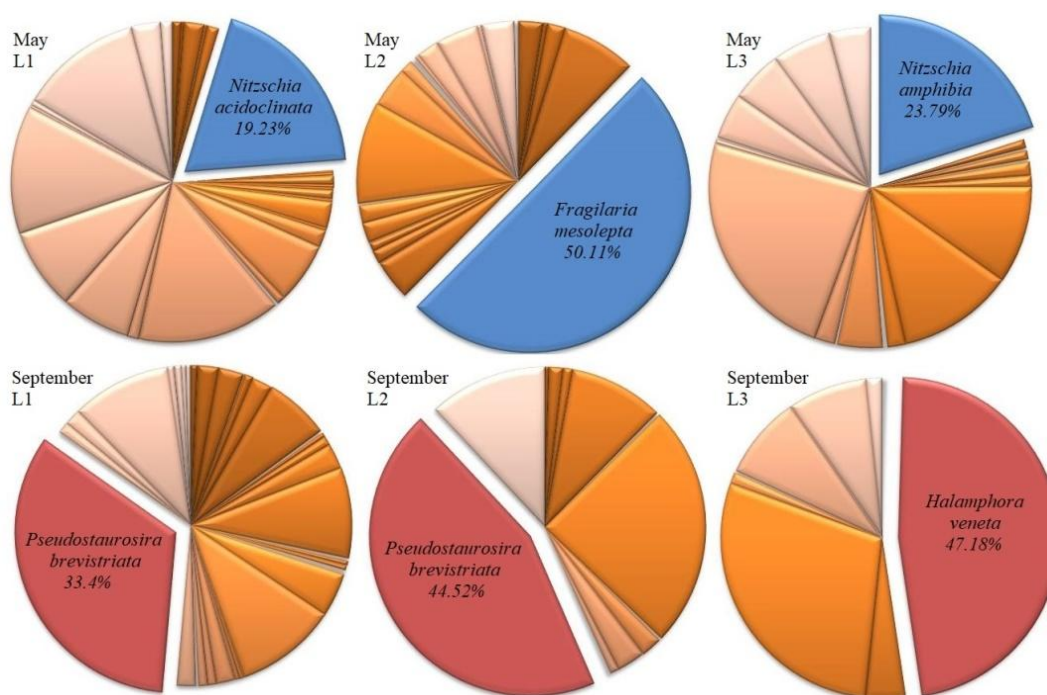


Figure 2 Percentage representation of dominant diatom taxa at each sampling site of Ludaš Lake (L1-L3) in May and September 2025

Table 2 Ecological status of Ludaš Lake based on the diatom indices values at investigated sampling sites (L1-L3) during two sampling seasons (May and September); class boundaries according to Prygiel and Coste [13]. Blue color – high ecological status, green – good, yellow – moderate, orange – poor, red – bad

	May			September		
	L1	L2	L3	L1	L2	L3
Biological Diatom Index (IBD)	11.3	13.6	13	11.3	11.7	7.5
Specific Pollution Sensitivity Index (IPS)	9.7	13	10.5	8.5	8.2	4.4
Generic Diatom Index (IDG)	6.3	9.8	10.2	8.2	10.6	5
Descy Diatom Index (Descy)	10.5	17.2	9.4	9.9	12.7	6.3
Sládeček Diatom Index (Sla.)	9.5	11.5	12.4	9.6	9.7	9.2
Index of Saprobity-Eutrophication (IDSE)	11.5	12.1	12.5	11.4	10.9	7.2
Artois-Picardie Diatom Index (IDAP)	5	8	9.3	4.8	1.8	2.9
Diatom-based Eutrophication/Pollution Index (EPID)	9.7	14.3	11.5	9.2	8.6	7.1
Lobo Index (Lobo)	12	14.7	17.9	11.9	5.6	11.4
Hürlimann Diatom Index (Hurl.)	7.2	12.2	6.2	8.9	12.7	5
Austrian Trophic Index (Rott TI)	5.7	6.4	4.9	4.7	5	2.3
Rott Saprobic Index (Rott SI)	13.6	15.4	12.9	14.4	13.8	8.1
Trophic Diatom Index for Lakes (TDIL)	9.2	10.7	12	9.4	8.3	4.5
Commission for Economical Community metric (CEE)	7.7	14.6	12.8	7.7	7	8
Watanabe's Index (WAT)	9.4	10.5	14.1	9.8	10.4	10.6
Trophic Diatom Index (TDI)	6.4	12.1	7.9	8.4	10.3	3.3
Pampean Diatom Index (IDP)	8.1	8.2	10.6	6.8	6.4	5.3
Schreiner's Index (SHE)	13.4	15.6	14.9	12.7	11.9	9.6

Considering that the ecological status class boundaries defined in the Serbian legislation [14] differ from those proposed by Prygiel and Coste [13], IPS index values are separated and marked by appropriate color (Table 3), as it is the only index considered relevant for shallow lakes located below 200 m a.s.l., a category that includes Ludaš Lake according to the

national Rulebook. In spring, IPS index values classified the ecological status as moderate (Class III at site L1) and good (Class II at sites L2 and L3) according to the national Rulebook [14]. In September, water quality at site L1 remained unchanged, whereas conditions at sites L2 and L3 deteriorated by one and three quality classes, respectively (Table 3). Compared with the ecological status recorded in 2022, the present results indicate an improvement in water quality at some sites, including improvements of up to two quality classes during spring [17].

Table 3 Ecological status of Ludaš Lake based on phyto**benthos** at investigated sampling sites (L1-L3) during two sampling seasons (May and September); class boundaries according to Serbian legislation ("Official Gazette of the RS", no. 74/11). Green color – good ecological status, yellow – moderate, orange – poor, red – bad

	May			September		
	L1	L2	L3	L1	L2	L3
IPS	9.7	13	10.5	8.5	8.2	4.4

CONCLUSION

This study identified 57 diatom taxa across three sampling sites in Ludaš Lake during May and September 2025, with 46 taxa recorded in May and 37 in September. The results indicate an improvement in water quality at certain sites compared with the ecological status recorded in 2022, highlighting the importance of continuous biomonitoring.

ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for financial support according to the contract with registration Nos. 451-03-33/2026-03/200178 and 451-03-34/2026-03/200178.

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