

Original Research

DIATOM ASSEMBLAGES IN BIOFILMS OF FRUŠKA GORA WATERFALLS
(SERBIA)

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Abstract

The main aim of this study was to determine the diversity and composition of diatom species in the Dumbovački and Nadine kaskade waterfalls in Serbia. Diatoms are a group of microalgae that represent a dominant component of phytobenthos and play a fundamental ecological role in aquatic ecosystems. The measured physical and chemical parameters showed similar values at both study sites, i.e., the two waterfalls. A total of 33 diatom species were identified in the biofilms of the Dumbovački and Nadine kaskade waterfalls in June 2025. Amphora pediculus was the dominant diatom species in the biofilm of Nadine kaskade Waterfall, while it was subdominant in Dumbovački Waterfall, where Cocconeis euglypta was the dominant species.

Keywords: Dumbovački Waterfall, Nadine kaskade Waterfall, diatoms.

INTRODUCTION

Diatoms (Bacillariophyta) are among the most widespread groups of algae in freshwater ecosystems, inhabiting nearly all available habitats [1]. They represent a dominant component of phytobenthos and play a fundamental ecological role in aquatic ecosystems. The diversity and composition of diatom communities are strongly influenced by environmental variables such as temperature, light, moisture conditions, current velocity, salinity, pH, dissolved oxygen, and inorganic nutrient concentrations, as well as by anthropogenic factors including organic pollution, acidification, and eutrophication [1]. As primary producers, diatoms participate in the cycling of phosphorus, nitrogen, and silica [2]. In addition to aquatic environments, they colonize a wide variety of substrates outside water bodies, including soils, rocks, lichens, litter, vegetation, and bark. However, specific environmental conditions are required in these habitats, with light availability and moisture being particularly important factors [1]. Changes in the diversity and composition of diatom communities may reflect alterations in ecological conditions within a habitat and can therefore serve as indicators of changes in water quality [3]. Waterfalls typically contain a variety of microhabitats that

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provide favourable conditions for different groups of plants and microorganisms, including diatoms [4].

The aim of this study was to determine the diversity and composition of diatom species in the Dumbovački and Nadine kaskade waterfalls in Serbia. In addition, several physical and chemical parameters were measured.

MATERIALS AND METHODS

Study sites and water analysis

The Dumbovački Waterfall is situated in the forested area of the Fruška Gora National Park, located in the Vojvodina region of northern Serbia. Although the waterfall is not particularly rich in water, it is usually present during the summer months. The Dumbovački Waterfall is approximately 5 m high and is located on the Dumbovac Stream at an altitude of 275 m [5].

Nadine kaskade is a hidden and relatively lesser-known waterfall, also located within the forested area of Fruška Gora National Park. It is situated at the confluence of an unnamed tributary and the Srneći Stream, at an altitude of 302 m. The waterfall consists of several interconnected cascades formed along the steeper sections of the stream.

In the field, pH, water temperature (°C), electrical conductivity ($\mu\text{S}/\text{cm}$), total dissolved solids (ppt) and oxygen concentration (mg/l) and oxygen saturation (%) of the water samples were measured using Oakton[®] sensors (Eutech Instruments, Thermo Fisher Scientific, Waltham, MA, USA) and a YSI ProODO optical dissolved oxygen meter (YSI Inc., Yellow Springs, OH, USA).

Diatom sampling and laboratory work

Sampling was conducted in June in 2025 at two waterfalls (Figure 1). Biofilms were collected directly from the stone substrates (Figure 1), which were constantly moistened by water using scalpels, and were stored in Eppendorf tubes until transport to the laboratory. For detailed diatom analyses, the samples were treated using the KMnO_4 and HCl method [6], which removes organic material and enables observation of the silicified diatom cell walls that are essential for species identification. After that, permanent slides were prepared by air-drying the cleaned material onto coverslips and mounting them in the synthetic medium Naphrax[®].

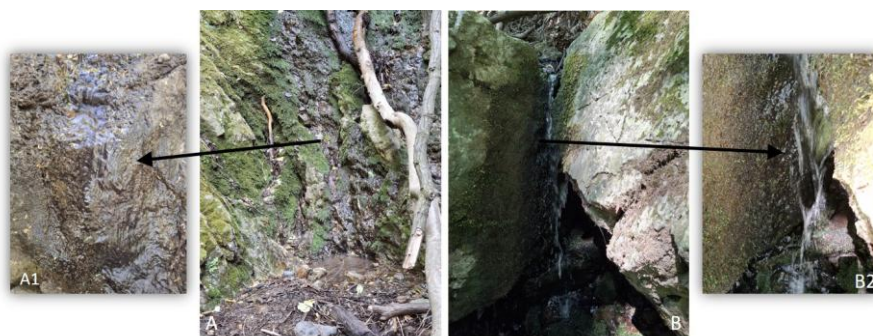


Figure 1 Dumbovački (A) and Nadine kaskade (B) waterfalls and sampling sites (A1, B2)

Diatom identification and microscopic analysis

A detailed qualitative analysis was performed, and all detected diatom taxa were identified using relevant taxonomic literature [7]. Permanent slides were examined using an AxioImager M1 light microscope equipped with an AxioCam MRc5 camera and AxioVision 4.9 software.

RESULTS AND DISCUSSION

The measured physicochemical parameters were similar at both locations, i.e., the waterfalls. The only notable difference was the higher oxygen concentration recorded at Dumbovački Waterfall (Table 1). In some Slovenian waterfalls, higher water temperature was associated with higher conductivity [3], which was not observed in our study. Previous studies have reported that conductivity increases by approximately 2–3% for every 1 °C rise in temperature [3].

Table 1 Physicochemical water parameters measured at the sampling sites of the two waterfalls in June in 2025

	Dumbovački Waterfall	Nadine kaskade Waterfall
pH	8.42	8.95
T (°C)	17.1	19
EC (μS/cm)	972	826
TDS (ppt)	0.6	0.5
O ₂ (mg/l)	9.07	6.45
O ₂ (%)	96.8	80

A total of 33 diatom species were identified in the biofilms of Dumbovački and Nadine Kaskade waterfalls in June 2025. At the individual site level, species richness differed slightly: 22 taxa were recorded at Dumbovački Waterfall and 19 at Nadine Kaskade Waterfall. All species belonged to 18 genera, with *Navicula*, *Amphora*, and *Gomphonema* representing the most species-rich genera (Figure 2). Compared with diatom diversity reported from several waterfalls in Slovenia (101 taxa), the diversity observed in this study can be considered relatively high [3].

Amphora pediculus (Kützing) Grunow was the dominant diatom species in the biofilm of Nadine Kaskade Waterfall, while it was subdominant at Dumbovački Waterfall, where *Cocconeis euglypta* Ehrenberg was dominant (Figure 3). This taxon has also been reported as one of the most frequently occurring diatom taxa in waterfalls of the Krka River [3]. Its tolerance range for nitrate is relatively wide; however, it is generally considered an indicator of mesotrophic conditions, although not a particularly reliable one [8]. The presence of some aerophytic species, such as *Humidophila contenta* (Grunow) R.L.Lowe, Kociolek, Johansen, Van de Vijver, Lange-Bertalot & Kopalová and *Aerophilina roeseana* (Rabenhorst) Danz, Van de Vijver & Kociolek, in Dumbovački Waterfall is noteworthy. Although waterfall biofilms often provide suitable habitats for aerophilic species, the sampled biofilm was continuously submerged. However, the hydrological conditions in the period prior to sampling are unknown and may have influenced species occurrence. The genus *Aerophilina* is typically aerophilous and is frequently found on wet rocks, in caves, in the splash zones of waterfalls, as well as on mosses and soils [9]. *A. roeseana* was originally described as *Melosira roeseana* from wet rocks in a waterfall in Germany in the 19th century [10].

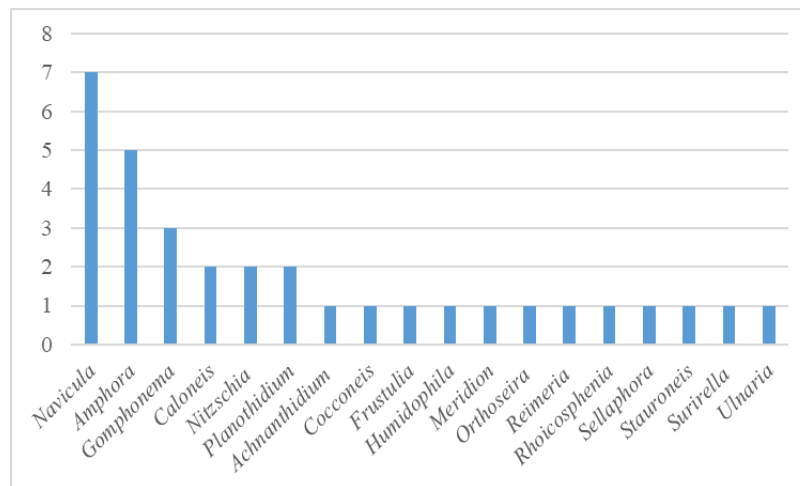


Figure 2 Number of species within the identified diatom genera in the biofilms of two waterfalls in June 2025

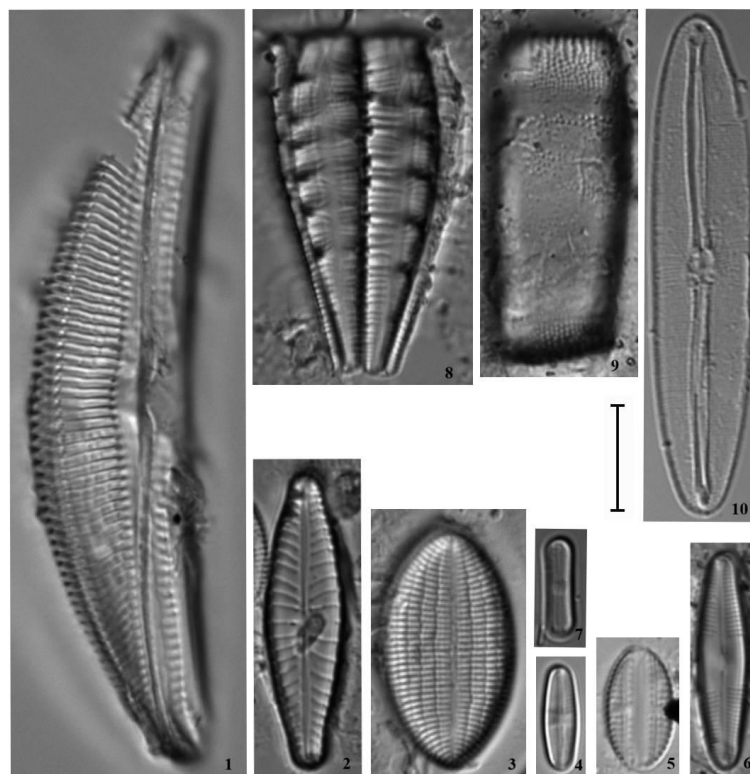


Figure 3 LM micrographs of selected diatoms identified in biofilms from two waterfalls in June 2025.

1 – *Amphora ovalis*, 2 – *Gomphonema micropus*, 3 – *Cocconeis euglypta*, 4 – *Sellaphora nigri*, 5 – *Amphora pediculus*, 6 – *Caloneis lancettula*, 7 – *Humidophila contenta*, 8 – *Meridion circulare*, 9 – *Aerophila roeseana*, 10 – *Frustulia vulgaris*. Scale bar 10 μ m

CONCLUSION

The diversity observed in this study can be considered relatively high for this type of aquatic ecosystem. *Navicula*, *Amphora*, and *Gomphonema* were the most species-rich genera. Investigating the diversity and composition of diatom communities, together with

measurements of physical and chemical parameters, represents an important first step in assessing potential anthropogenic impacts on these specific aquatic ecosystems.

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