Journal of Advances in Biology & Biotechnology

Volume 26, Issue 1, Page 42-53, 2023; Article no.JABB.97117
ISSN: 2394-1081

Diversity of Cyanobacteria and Microalgae in the Shallow Mountain Lake Paučko, Konjuh Mountain

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Authors' contributions

This work was carried out in collaboration among all authors. Authors JK, SH, SB and SS designed the study, performed the field sampling, laboratory analysis of biological samples, statistical analysis, managed the literature searches and wrote the manuscript. Author ASM managed the physical and chemical analysis of water. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JABB/2023/v26i1616

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97117

Original Research Article

Received: 04/01/2023
Accepted: 09/03/2023
Published: 14/03/2023

ABSTRACT

Shallow mountain lakes are highly sensitive to eutrophication. Cyanobacteria and microalgae in planktonic communities are the main producers in lake ecosystems, but stability of its communities is impacted by numerous factors. The aim of this study is to analyze seasonal diversity and community structure of cyanobacteria and microalgae in plankton and periphyton of the lake Paučko, physical and chemical properties of water and evaluate trophic status. The mountain lake Paučko is the shallow natural lake in Protected landscape Konjuh in northeastern Bosnia and Herzegovina. Sampling of net – phytoplankton, periphyton and water for physical and chemical analysis was caried in two seasons in 2018. Light microscopes and immersion objective

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(magnification 1000x) were used for the identification and quantification of microalgae. Non metric multimensional scaling and Simper analysis were used to describe communities in periphytic and planktic samples. In total, 70 taxa were identified. The most numerous were Bacillariophyta with 52, and Chlorophyta with 7 taxa. Seasonal dynamics in plankton communities were observed in the direction of shift of abundant *Cyclotella meneghiniana*, *Dinobryon divergens*, *Peridinum cinctum* and *Ankistrodesmus fusiformus* in spring season to *Rabdoderma lineare* and *Pantocsekiella comensis* in summer sampling season. Physical and chemical analysis of water revealed high values of total phosphorus, which correspond to the evaluated meso to eutrophic status of the lake calculated by Rott Trophic Index. The lake Paučko is under high pressure caused by the influx and retention of nutrients, which makes it susceptible to eutrophication. The results of the study provide the first insight into the diversity of cyanobacteria and microalgae for this lake and can be useful in planning of restoration measures in the context of ecological monitoring.

Keywords: Cyanobacteria; microalgae; diversity; trophic status; phytoplankton; periphyton; mountain shallow lake.

1. INTRODUCTION

Microalgae are unicellular photosynthetic microorganisms, that may exist independently or in colonies, able to uptake CO_2 from both the atmosphere and flue gas emissions, converting it into biomass or other organic compounds, living in saline or freshwater environments [1]. Microalgae are usually characterized by a short generation time, and respond rapidly to environmental changes, what makes them a good indicator of the water quality [2]. Microalgae also include microscopic cyanobacteria. Cyanobacteria are a very diverse group of prokaryotic organisms that were historically considered as "blue-green algae". In contrast to other prokaryotes (bacteria and archaea), they perform oxygenic photosynthesis and possess chlorophyll-a [3]. Cyanobacteria are among the most abundant and potent primary producers on Earth, occurred in different aquatic and terrestrial habitats [4], whilst diazotrophic cyanobacteria are major players in global nitrogen fixation [5]. Many of cyanobacteria produce unique secondary metabolites, such as toxins [6], and cause blooms, which results from an overabundance of planktic forms, having a large negative impact [7]. Cyanobacteria and microalgae are often used in the evaluation of ecological status of freshwaters. The Water Framework Directive 2000/60/EC obliges monitoring of lakes including biological elements as indicators, but smaller lakes are not an integral part of monitoring. Small mountain lakes can have exceptional conservation value, but are highly susceptible to eutrophication.

The Paučko lake is a small mountain water body, located in Protected Landscape Konjuh and recognized as an area of natural, landscape and hydrological value in northeastern Bosnia and Herzegovina. The lake is not on the list of monitoring stations due to its small size, and recent studies of macrophytes point to the problem of accelerated overgrowth of the lake with aquatic vegetation of weed taxa *Myriophyllum spicatum* which threatens the disappearance of endangered species in lake [8]. On the other hand, there is a lack of published data on algal research of the lake Paučko on the Konjuh Mt. Algological research on Mt. Konjuh was carried out on springs and streams [9,10], whilst researches on the lakes and rivers of northeastern Bosnia and Herzegovina have been more frequent in the last few years [11,12]. Cyanobacteria and microalgae can reflect changes in the environment and indicates changes and the state of the ecosystem.

Due to the need to preserve a small mountain lake, the aim of this work is to investigate the structure and ecological characterization of the planktic and periphytic communities of cyanobacteria and microalgae, along with the physical and chemical analysis and the evaluation of the ecological status of the lake.

2. MATERIALS AND METHODS

2.1 Study Area

The lake Paučko is a small lake located at 711 m a.s.l. in the catchment area of the Drinjača River in the Protected Landscape Konjuh, northeastern Bosnia and Herzegovina (N 44°14´01.61˝, E 18°36´05.51˝). The maximum length of the lake is 150 meters, and the width is about 100 meters, the maximum depth is 5 meters. The catchment area of the lake is 35.6 ha. The Paučko Lake is fed by an underground water source and a stream into which water gravitates from the basin of the surrounding area. Water from the lake flows into a smaller stream. The area is characterized by moderate-continental [13]. Due to torrential flows, the lake is subject to the natural process of filling with sediment.

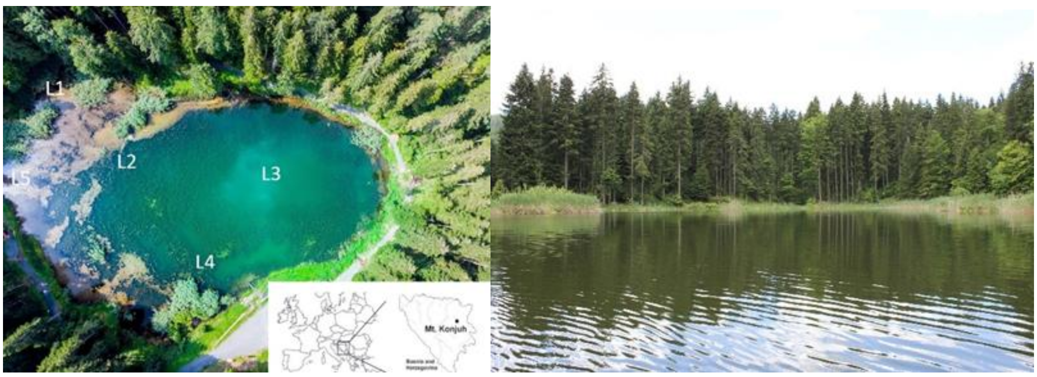
2.2 Methods

Sampling was carried out at 5 locations (L1-L5) in May (marked with a) and August (marked with b) in 2018 (Fig. 1). These months were selected based on their hydrologic conditions, where May is typical for higher water precipitation and spring season. In situ measurements of water temperature, pH, conductivity, oxygen concentration and saturation were done with a multimeter HQ 40d, 30d flexy multi, HACH. Physical and chemical analysis of the following parameters were done in the laboratory according to standardized methodology [14]: turbidity, biological oxygen demand (BOD_5), dichromate chemical oxygen demand (COD dichromate), permanganate chemical oxygen demand (COD permanganate), total nitrogen (TN), nitrate ($N\text{-}NO_3^-$), nitrite ($N\text{-}NO_2^-$), ammonium ($N\text{-}NH_4^+$), total phosphorus (TP), orto-phosphate ($P\text{-}PO4_3^-$), total suspended solids (TSS), alkalinity, total hardness, ions of calcium (Ca^{2+}), magnesium (Mg^{2+}), sulphates (SO_4^{2-}), and chloride (Cl^-).

Samples 1 and 5 are phytobenthic samples taken at the inlet and outlet streams of the lake, respectively, using the method BAS EN15708:2011. Phytoplankton samples 2, 3, and 4 were taken using a phytoplankton net with mesh spacing of 25 µm for qualitative analysis, following the methodology described in EN 16698:2015. Samples were preserved with a buffered 4% formaldehyde solution. Non-diatom species were identified in fresh samples, whilst diatoms were acid cleaned [15], and mounted in Naphrax (Brunel Microscopes Ltd., U.K.). Quantitative analysis of phytoplankton samples was determined via relative abundance using a six-step scale (1, 2, 3, 5, 7, 9). Light microscopes (Motic) and immersion objective (magnification 1000x) were used for the identification and quantification of microalgae. Identification of cyanobacteria and microalgae was performed using literature [16-27].

The saprobic status of the lake (Saprobic Index) was calculated on the basis of a list of indicator organisms according to Wegl [28], using the Pantle-Buck Index [29]. Ecological status is determined according to guidelines Official Gazette of Republika Srpska 42/01 [30]. Additionally, the diatom trophic index (TI) by Rott et al. [31] was used in the evaluation of trophic status of the lake ecosystem.

Statistical analysis was performed in package Primer 7.0 [32]. All data were transformed by using the square root function prior to statistical analyses. Non-metric multidimensional scaling (nMDS) and hierarchical group average clustering based on scale abundance were used for ordering locations. The ordination was conducted on the Bray-Curtis similarity matrix of species data. Simper analysis were conducted for determination of contribution of taxa to assemblages caused by different factors. Diversity of cyanobacteria and microalgae was calculated by using species richness (S) as the number of identified taxa, and the Shannon index of species diversity *H'*(ln).



a) b)

Fig. 1. Study area – Paučko Lake (a - photo by A. Čamdžić, b – photo by J. Kamberović, 2018)

3. RESULTS

3.1 Physical and Chemical Variables of the Lake Paučko

The physical and chemical variables measured at the sampling locations are shown in Table 1. The water temperature in the Lake (L2-L4) varied between the lowest measured in May (15.2 °C) to the highest measured in August (23.8 °C). The lake Paučko is a weakly alkaline to alkaline (pH varied among 8.48 – 9.11) shallow lake with moderate conductivity, good oxygen saturation, high alkalinity, mostly low content of total nitrogen and nitrogen oxides, sulphates and chlorides. However, high values of total phosphorus and orthophosphates were measured in both sampling series corresponding to the polytrophic status of the Lake. Inlet stream (L1) is characterized by the lower temperature and higher values of total nitrogen in comparison to the outlet stream (L5).

3.2 Cyanobacteria and Microalgae of the Lake Paučko

In total, 70 taxa were identified in both sampling series. The most numerous were Bacillariophyta with 52, and Chlorophyta with 7 taxa. Cyanobacteria, Pyrrophycophyta, Xanthophyta, Charophyta were represented with only a few taxa (Table 2). In the analysis of community of cyanobacteria and microalgae, more taxa were found in plankton samples of the lake in comparison to periphytic samples of inlet and outlet streams. The greatest number of taxa was found in the net-phytoplankton sample in the spring season (L2a – 28 taxa), and lowest number were identified in plankton sample L3b in summer season (8 taxa). The following taxa were identified with high abundance in at least one sample: *Rhabdoderma lineare*, *Achnanthidium minutissimum*, *Cyclotella meneghiniana*, *Cymbella dorsenotata*, *Encyonopsis microcephala*, *Odontidium mesodon*, *Planothidium lanceolatum* and *Staurosira construens*.

Hierarchical group average clustering and the non-metric MDS identified 3 assemblages (Fig. 2), mainly related to sample type: two groups of periphyton of inlet (L1a, L2b) and outlet stream (L5a, L5b), and one group of phytoplankton samples of both seasons of sampling (L3ab – L4ab). Simper analysis of samples according to sample type revealed 25.26% similarity among periphytic samples, and 43.6% similarity among phytoplankton samples. Periphytic samples were characterized by following taxa with cumulative contribution up to 70%: *Achnanthidium minutissimum*, *Cocconeis placentula*, *Gomphonema parvulum*, *Planothidium lanceolatum* and *Navicula tripunctata*. Crenophile diatom species *Odontidium mesodon* was dominant in spring season of inlet stream. In the outlet stream, in addition to the abundant *A. minutissimum* and *Encyonopsis microcephala*, common taxa for the plankton of the lake were found. Phytoplankton samples were characterized by following taxa with cumulative contribution up to 70%: *Cymbella dorsenotata*, *Cyclotella meneghiniana, Staurosira construens*, *Chroococcus dispersus*, *Peridinium cinctum*, *Cymbopleura inaequalis*, *Ankistrodesmus fusiformis*, *Pantocsekiella comensis*, *Encyonema minutum*, *Rhabdoderma lineare* and *Denticula tenuis*.

In the analysis of the seasonal aspect, the following species were represented in the spring, and less common in the summer*: Cyclotella meneghiniana*, *Peridinium cinctum*, *Dinobryon divergens*, *Ankistrodesmus fusiformis* and *Chroococcus dispersus*. On the contrary, summer samples are typical for more abundant cyanobacteria *Rhabdoderma lineare* and diatom *Cymbella dorsenotata* (Fig. 3). The frequent species *Staurosira contruens* remains more or less equally abundant in both sample series.

Shannon index of diversity varied from 1.86 to 3.15 indicating moderate to high diversity of taxa, with slightly higher average value in spring (*H´*= 2.77) in comparison with summer samples (*H´*=2.51).

In total, 45.7 % of microalgal taxa were indicators according to Rott et al. (1999). The trophic index (TI) indicates the meso to eutrophic and eutrophic status of the lake Lake Paučko. Saprobic index (SI) by Pantle – Buck (1955) included 48.57 indicator taxa and varied among 1.69-2.19, with an average of 1.91, corresponding mostly to the betamesosaprobic level, and indicating good ecological status (Table 3).

4. DISCUSSION

Shallow lakes are prone to eutrophication and often resistant to restoration. Biological monitoring and diversity studies of small lakes that are not an integral part of national monitoring in terms of early warning is desirable in order to avoid water blooms and the development of potential toxic cyanobacteria. Cyanobacteria, Bacillariophyta and Chlorophytaare were the most represented phytoplankton groups. Many species of planktic cyanobacteria are well known as bloom formers and toxin producers in freshwaters [33]. With the aim of analyzing the structure of the plankton community, it was determined that cyanobacterial taxa specific for toxic bloom such as *Dolichospermum circinalis, Aphanizomenon flos–aquae, Cylindrospermopsis raciborskii, Microcystis aeruginosa* were not found in Paučko Lake, and only frequent cynobacteria in planktic sample were *Rhabdoderma lineare* and *Chroococcus dispersus*. *Rhabdoderma lineare*, previous known as *Synechococcus linearis* is a freshwater, planktic cynobacteria typical for oligo- to mesotrophic water bodies and common in temperate zones [34], whilst *Chroococcus is* distributed over the world. Planktic samples were typical by dinophyte *Peridinium cinctum*, and chrysophyte *Dinobryon divergens*. *Peridinium cinctum* is a common generalist species in freshwater ecosystems, characterized as oxyphilic inhabiting shallow mesotrophic to eutrophic water bodies [35]. Although most species of the genus *Dynobrion* are specific to oligotrophic and water with neutral pH, *D. divergens* can occasionally be found in water with high phosphate concentrations [36], which is the case with Paučko Lake.

Analyzing the composition of diatoms, *Cyclotella meneghiniana*, *Staurosira construens* and *Cymbella dorsenotata* were most abundant, first species during the spring, and other two species independent of the sampling series. *C. meneghiniana* can causes diatom bloom, which has been observed in the shallow middle reaches of the Hunter River, Australia. Optimal conditions for bloom are water temperature in the range of 23°C to 28°C, long retention time in the extended period for at least 12 days [37]. In this study, the temperature in lake Paučko did not exceed 23.8°C and a higher abundance of C. *meneghiniana* was recorded in the spring period. Fragilarioids *Staurosira construens* is benthic/tychoplanktonic diatoms with a wide range of ecological preferences, capable of growing in shallow aquatic environments and littoral areas of flowing waters and deep lakes [38] with affinity for habitats covered with macrophytes [39], that are very abundant in Paučko lake. Diatom *Pantocsekiella comensis* is occurred frequently in summer season in planktic samples. Previous studies revealed that this species occurred at high abundance in the plankton communities of alkaline montane lakes with high surface temperatures (>18°C), lover concentration of phosphorous and higher values of Ca^{2+} [40]. Water temperature and weakly alkaline reaction could cause higher frequency of this taxa, despite the high phosphorous concentrations in the lake Paučko.

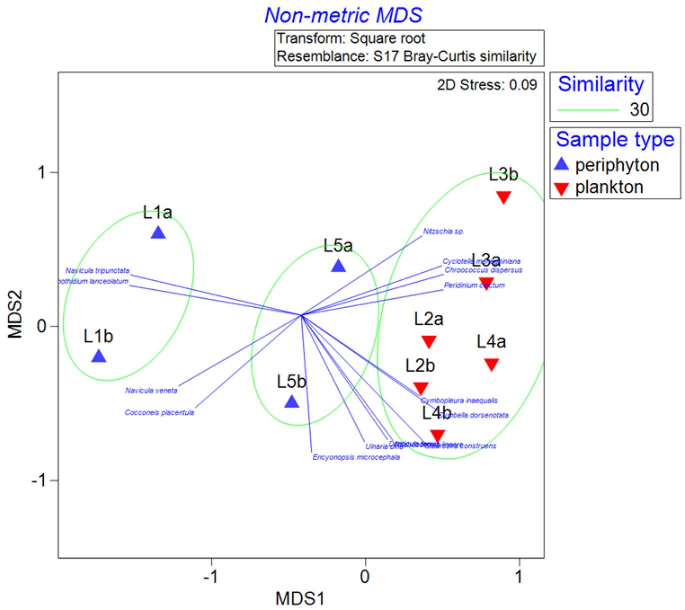


Fig. 2. Non-metric multidimensional scaling (nMDS) overlayed with clusters of group average clustering (30% of similarity) of locations based on Bray-Curtis matrix of similarities of microalgal assemblages in relation to sample type and Pearson correlation index of taxa (r>0.7)

Table 1. Physical and chemicals variables of water measured at the sampling locations on the lake Paučko

Location code	**L1a**	**L1b**	**L2a**	**L2b**	**L3a**	**L3b**	**L4a**	**L4b**	**L5a**	**L5b**
Temperature °C	10	14.1	16.8	21.9	17.9	23.7	15.2	23.8	18.4	19.2
pH	9.33	8.48	9.01	8.68	8.96	8.49	9.11	8.63	9.36	8.61
Cond (µS cm^{-1})	275	376	420	439	397	458	418	405	265	436
Turbidity (NTU)	2.13	1.49	2.71	5.6	2.86	3.87	3.34	3.92	3.54	4
Secchi depth (m)			2	1.3	2	1	1.2	1		
Oxygen (mgL^{-1})	10.07	9.41	8.46	12.04	10.51	6.79	11.37	11.03	10.67	9.66
O_2 saturation (%)	97.1	99.2	96.2	149.5	120.8	87.3	129.4	142.4	123.6	113.5
BOD_5 (mgL^{-1})	1.01	0.93	2.14	1.37	2.17	3.36	2.32	1.2	2.32	1.5
COD dichromate (mgL^{-1})	7.98	10.49	9.12	12.14	10.83	14.9	11.4	9.94	11.97	11.59
COD permanganate (mgL^{-1})	2.4	3.2	3.6	4.16	3.92	5.68	4.48	2.4	4.48	4
TN (mgL^{-1})	1.001	1.059	0.256	0.425	0.174	0.276	0.145	0.319	0.144	0.235
$N\text{-}NO_3^-$ (mgL^{-1})	0.99	1.05	0.24	0.33	0.16	0.21	0.13	0.27	0.13	0.19
$N\text{-}NO_2^-$ (mgL^{-1})	0.011	0.009	0.016	0.015	0.018	0.016	0.015	0.019	0.03	0.015
$N\text{-}NH_4^+$ (mgL^{-1})	0.02	0.01	0.03	0.08	0.03	0.05	0.04	0.03	0.03	0.03
$P\text{-}PO_4^{3-}$(mgL^{-1})	0.178	0.543	0.07	0.11	0.06	0.11	0.13	0.11	0.01	0.09
TP (mgL^{-1})	0.05	0.28	0.174	0.209	0.4	0.191	0.555	0.114	0.271	0.174
TSS (mgL^{-1})	10	0.5	10	3.8	6	2.8	8	12.4	9.8	2.6
Alkalinity (mg $CaCO_3$ L^{-1})	170	170	205	220	200	220	205	220	205	205
Total hardness (mg $CaCO_3$ L^{-1})	66	76	66	72	70	72	70	70	66	72
Ca^{2+} (mgL^{-1})	24.05	28.06	24.05	25.65	25.65	25.65	25.65	24.85	24.05	25.65
Mg^{2+} (mgL^{-1})	1.46	1.46	1.46	1.94	1.46	1.46	1.46	1.94	1.46	1.94
SO_4^{2-}(mgL^{-1})	3.6	4.7	5.3	6.2	5.9	6.9	5.3	6.6	5.4	6.4
Cl^- (mgL^{-1})	6.13	6.6	5.19	6.13	4.71	5.19	4.71	5.19	4.71	5.19

Table 2. The list of idientified cyanobacteria and microalge of the Paučko Lake

Locations/taxa	**L1a**	**L1b**	**L2a**	**L2b**	**L3a**	**L3b**	**L4a**	**L4b**	**L5a**	**L5b**	**Per. Fr.**	**Pl. Fr.**	**Spring Fr.**	**Summer Fr.**
Cyanobacteria														
Aphanocapsa sp.							3	2				2	1	1
Chroococcus dispersus (Keissler) Lemmermann			3	1	2	2	2					5	3	2
Rhabdoderma lineare Schmidle & Lauterborn			2	2			3	5				4	2	2
Spirulina major Kützing ex Gomont					1		1					2	2	
Pyrrophycophyta														
Dinococcus oedogonii (P.Richter) Fott				1			1					2	1	1
Peridinium cinctum (O.F.Müller) Ehrenberg			2	1	2	1	2					5	3	2
Chrysophyta														
Dinobryon divergens O.E.Imhof			2		3		2					3	3	
Xanthophyta														
Vaucheria sp.	3										1		1	
Bacillariophyta														
Achnanthidium affine (Grunow) Czarnecki										2	1			1
Achnanthidium minutissimum (Kützing) Czarnecki	1	2	2		2				5	7	4	2	4	2
Achnanthidium neomicrocephalum Lange-Bertalot & F.Staab			2				2	2	3		1	3	3	1
Amphipleura pellucida (Kützing) Kützing	1								1		2		2	
Amphora copulata (Kützing) Schoeman & R.E.M.Archibald	1								1		2		2	

Locations/taxa	**L1a**	**L1b**	**L2a**	**L2b**	**L3a**	**L3b**	**L4a**	**L4b**	**L5a**	**L5b**	**Per. Fr.**	**Pl. Fr.**	**Spring Fr.**	**Summer Fr.**
Amphora pediculus (Kützing) Grunow	1									1	2		1	1
Amphora stechlinensis Levkov & Metzeltin			1									1	1	
Brachysira neoexilis Lange-Bertalot				1						1	1	1		2
Cocconeis pediculus Ehrenberg								1				1		1
Cocconeis placentula Ehrenberg	2	1	1	2				1		2	3	3	2	4
Cocconeis pseudolineata (Geitler) Lange-Bertalot		3									1			1
Cyclotella meneghiniana Kützing			7	1	7	3	7		1		1	5	4	2
Cymbella dorsenotata Østrup			2	5	1	1	2	3	2	2	2	6	4	4
Cymbella excisa Kützing										3	1			1
Cymbella vulgata Krammer				2	1	1						3	1	2
Cymbopleura inaequalis (Ehrenberg) Kram			3	2	1		2	2	1		1	5	4	2
Denticula tenuis Kützing				1	1		1	1		1	1	4	2	3
Encyonema minutum (Hilse) D.G.Mann	1		1	2		2	2		3		2	4	4	2
Encyonopsis microcephala (Grunow) Krammer			1	1				2		5	1	3	1	3
Epithemia adnata (Kützing) Brébisson			1	1				1	1	1	2	3	2	3
Eucocconeis flexella (Kützing) Meister				1					1		1	1	1	1
Eunotia tenella (Grunow) Hustedt			1		1		1	1				4	3	1
Fragilaria acus (Kützing) Lange-Bertalot										1	1			1
Fragilaria gracilis Østrup								1				1		1
Gomphonema auritum A.Braun ex Kützing				1						3	1	1		2
Gomphonema parvulum (Kützing) Kützing	1								2	3	3		2	1
Gomphonema pumilum (Grunow) E.Reichardt & Lange-Bertalot		1									1			1
Gomphonema pumilum var. *elegans* E.Reichardt & Lange-Bertalot							1					1	1	
Gomphonema subclavatum (Grunow) Grunow				1								1		1
Gomphonema truncatum Ehrenberg								1		1	1	1		2
Gyrosigma acuminatum (Kützing) Rabenhorst				1								1		1
Halamphora veneta (Kützing) Levkov				1			1					2	1	1
Meridion circulare (Greville) C.Agardh	1										1		1	
Navicula oblonga (Kützing) Kützing				1								1		1
Navicula radiosa Kützing								1	1		1	1	1	1
Navicula sp.					1							1	1	
Navicula tripunctata (O.F.Müller) Bory	1	1									2		1	1
Navicula veneta Kützing		1								1	2			2
Nitzschia denticula Grunow			1									1	1	
Nitzschia lacuum Lange-Bertalot			1	1								2	1	1
Nitzschia linearis W.Smith	3										1		1	
Nitzschia sp.					1	1	1					3	2	1
Odontidium mesodon (Kützing) Kützing	5										1		1	
Pantocsekiella comensis (Grunow) K.T.Kiss & E.Ács			2		2	1		2		1	1	4	2	3
Pinnularia sp.			1									1	1	
Pinnularia subgibba Krammer		1									1			1
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	3	5									2		1	1
Rhopalodia gibba (Ehrenberg) Otto Müller			1					1				2	1	1

Locations/taxa	L1a	L1b	L2a	L2b	L3a	L3b	L4a	L4b	L5a	L5b	Per. Fr.	Pl. Fr.	Spring Fr.	Summer Fr.
Stauroneis smithii Grunow									1		1		1	
Staurosira construens Ehrenberg			3	3	2		5	5	1	1	2	5	4	3
Ulnaria capitata (Ehrenberg) Compère					1		1	1				3	2	1
Ulnaria ulna (Nitzsch) Compère			1	1			1	1	1	1	2	4	3	3
Chlorophyta														
Ankistrodesmus fusiformis Corda			3		3		3	2				4	3	1
Celochaete sp.			1									1	1	
Chaetomorpha linum (O.F.Müller) Kützing				2				2				2		2
Desmodesmus communis (E.Hegewald) E.Hegewald			1		1		1					3	3	
Pediastrum boryanum			1		1		1	1				4	3	1
Scenedesmus acuminatus (Lagerheim) Chodat			1				1					2	2	
Sphaerocystis schroeteri Chodat			2				1					2	2	
Charophyta – Zygnematophyceae														
Staurastrum polymorphum Brébisson				1								1		1
Closterium moniliferum Ehrenberg ex Ralfs				3								1		1
Klebsormidiaceae							1	1				2	1	1
Number of taxa	13	8	28	26	19	8	26	23	15	18	36	52	52	52

**L1, L5 – periphyton samples, L2, L3, L4 – plankton samples; Per. Fr. – frequency as number of periphyton samples, Pl. Fr. – frequency as number of phytoplankton samples*

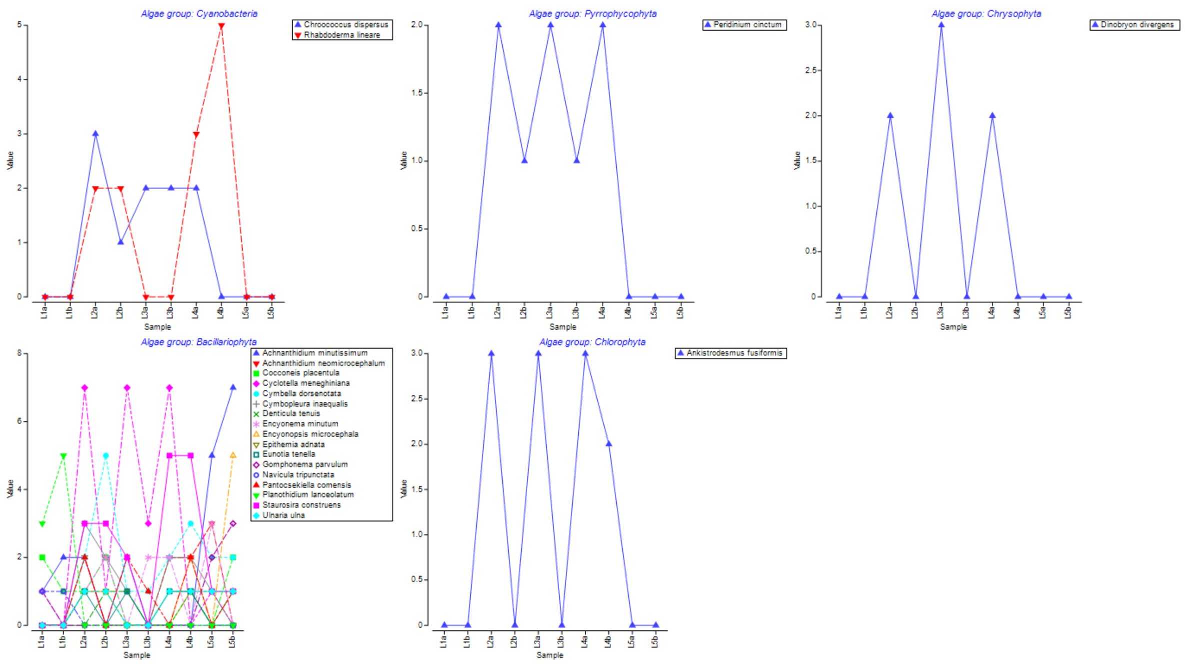


Fig. 3. Abundance of the most typical algal taxa per season fluctuation and sample locations according to the algal groups

Chlorophyte such as *Ankistrodesmus* can overgrow freshwaters under high nutrient enrichment, and sometimes cause oxygen depletion in ponds and sheltered lake coves [41], *A. fusiformus* is identified in spring season in Paučko lake with moderate abundance.

Analyzing planktonic diversity, Bacillariophyta dominated in all samples, especially in the spring season. Applying Shannon diversity index revealed moderately high values of taxa diversity, with higher values in spring compared to summer.

Seasonal dynamics in plankton communities were observed in the direction of shift of abundant *C. meneghiniana, D. divergens, P. cinctum* and *A. fusiformus* in spring season to the R. *lineare* and *Pantocsekiella comensis* in the summer. Applying the functional group model sensu Reynolds [42], revealed that seasonal dynamic follows the succession from group C, ecosystem eutrophic small- and medium sized lakes with species sensitive to the onset of stratification (centric diatoms *Cyclotella meneghiniana*), to the group K, shallow, nutrient-rich water columns (*Rhabdoderma* sp., syn. *Synechococcus* sp.). In temperate eutrophic systems, transition of functional groups is expected during the phytoplankton succession C-G-M-P, but other groups can also be dominant in the various sub-types of shallow lake [43], which in the case of lake Paučko is the group K in the summer period. The applied trophic index is in concordance with the qualitative description of functional groups and indicates the meso to eutrophic status of the lake.

The lake is located in a forest area and is occasionally used by the local community as a picnic spot. However, it is characterized by a very high values of total phosphorus and low values of total nitrogen, which points to the enrichment of the lake with phosphorus through the infiltration of the forest land and the long-term retention of phosphorus in the lake due to accelerated growth and decomposition of plant mass. High values of total phosphorus correspond to the evaluated eutrophic status using trophic index.

The lake Paučko is under high pressure caused by gradual shallowing. Shallow lakes usually have a small volume and weak capacity to dilute input nutrients, resulting in high sensitivity to anthropogenic forcing. One of the threats that disrupt the ecosystem structure of the lake Paučko is the influx of nutrients, mostly through surface flows which encourage the development of macrophyte vegetation that rapidly overgrows the lake and reduces the surface of the water mirror. Bearing in mind the high value of nutrients in the lake, there is a risk of water bloom in the future, which implies undertaking restoration measures. The special caution should be taken in restauration measures. As is known from Scheffer et al. [43], shallow lakes usually have two alternative stable equilibria, e.g. macrophyte-dominated versus turbid state. The Paučko lake is macrophyte dominated type, inhabited with aquatic submerged competitive macrophyte species *Myriophyllum spicatum,* that covers almost the entire bottom of the lake in the summer aspect [8]. Macrophytes can maintain clear water and nutrient retention in shallow lakes [44], and reduce the growth of the plankton communities. Although the lake is in the intensive process of becoming overgrown with macrophytic weed vegetation, the non-systematic removal of weed vegetation could result in the potential bloom development of cyanobacteria and microalgae. The restoration of the lake Paučko, with the aim of preventing water bloom should preferably go in the direction external load reductions.

Table 3. Diversity, trophic (TI) and saprobic (SI)/ecological status of the lake Paučko

Locations	*H´*	TI Rott	Trophic status	SI	Ecological status according to SI
L1a	2.37	2.023	Meso- to eutrophic	1.69	good
L1b	1.86	2.32	Meso- to eutrophic	1.95	good
L2a	3.15	2.49	Meso- to eutrophic	1.91	good
L2b	3.11	2.12	Meso- to eutrophic	1.86	good
L3a	2.73	2.56	Eutrophic	2.03	good
L3b	1.98	2.7	Eutrophic	2.19	good
L4a	3.05	2.54	Eutrophic	1.98	good
L4b	2.96	2.00	Mesotrophic	1.73	good
L5a	2.52	2.00	Mesotrophic	1.95	good
L5b	2.65	1.1	Oligo- to mesotrophic	1.86	good

** H´ - Shannon diversity index, TI Rott – Trophic Index Rott 1999, SI; Saprobic Index Pantle Buck, 1955*

5. CONCLUSION

The lake Paučko is a weakly alkaline to alkaline shallow lake with moderate conductivity, good oxygen saturation, high alkalinity, mostly low content of total nitrogen and nitrogen oxides, and high concentrations of total phosphorus. In total, 70 cyanobacterial and microalgal taxa were identified in planktic and periphytic samples. The most numerous were Bacillariophyta with 52 taxa. Non metric multidimensional scaling and hierarchical clustering classified samples into three groups, mostly based on sample type (planktic and periphytic) on 30% similarity. Simper analysis in planktic samples revealed most contributive taxa: *Cyclotella meneghiniana, Staurosira construens, Cymbella dorsenotata, Chroococcus dispersus, Peridinium cinctum, Cymbopleura inaequalis, Ankistrodesmus fusiformis, Pantocsekiella comensis, Encyonema minutum, Rhabdoderma lineare* and *Denticula tenuis*. Highest contribution to periphytic samples had *Achnanthidium minutissimum, Cocconeis placentula, Gomphonema parvulum, Planothidium lanceolatum* and *Navicula tripunctata*. Seasonal dynamics in plankton communities were observed in the direction of shift of abundant *C. meneghiniana, Dinobryon divergens, P. cinctum* and *A. fusiformus* in spring season to the R. *lineare* and *Pantocsekiella comensis* in summer season. The trophic index pointed to the meso to eutrophic and eutrophic status of the lake Paučko, and saprobic index to the beta-mesosaprobic status. Although located in an uninhabited mountainous area, the lake Paučko is under high pressure caused by the influx and retention of nutrients, especially phosphates, what makes it highly susceptible to eutrophication and potential algal bloom.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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