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ALGAE IN THREE DIFFERENT WATERFALLS IN SLOVENIA – THE SAVICA WATERFALL, THE WATERFALLS OF THE KRKA RIVER AND A SMALL WATERFALL ON POHORJE

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Abstract. In 1998, 1999 and 2000, samples were taken seasonally in the Savica Waterfall, the waterfalls of the Krka River and a small waterfall on Pohorje, all three in Slovenia. The purpose of the investigation was to establish qualitative species structure and the abundance of the periphyton. In 1999 and 2000, some physical and chemical parameters were also measured. Altogether, 143 species and subspecies of algae were determined. Most of them belonged to Bacillariophyceae. 27 species and subspecies were new to Slovenia, most of them belonging to Bacillariophyceae, followed by Cyanophyceae. Most new species and subspecies belonged to *Nitzschia* (5) and *Navicula* (5) genera.

■ Algae, periphyton, waterfalls, Savica, Krka.

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Introduction

The biodiversity of algae in Slovenia is relatively high; more than 2000 different algae species has been recorded so far (Kosi and Vrhovšek 1996). The issue of endangered species is worrying due to lack of investigations. The endangered water ecosystems represent the main problem of endangered algae species. Drastic changes usually occur during the regulation of rivers and streams, when the basic ecological conditions are changed (the substrate, water current, light); the consequences are shown in the reduced diversity. Similar results can be seen in polluted waters, where the number of species is decreasing from the spring toward the outfall (Vrhovšek et al. 1983). The large part of Slovenian water-streams is already polluted (Vrhovšek et al. 1983; Vrhovšek et al. 1994; Krivograd 1997; Smolar 1997). Savica River is one of the very few unpolluted Slovenian rivers.

During floods, the water flow in streams never exceeds 3 m^3/s and in waterfalls the water flow rarely exceeds 6 m^3/s (Hynes 1979). The erosion of riverbed begins when the water flow is 2 m^3/s. If the water flow is very high (5 m^3/s and more), the association of algae is reduced to species, which are firmly attached to the substratum, like *Chamaesiphon fuscum*, *Ulothrix zonata* and *Lemanea fluviatilis* (Whitton 1975). According to the research of McIntire (1966), the predominant species at the 0,9 m^3/s water flow are genera *Stigeoclonium*, *Oedogonium* and *Tribonema*. Diatoms predominate at the 0.38 m^3/s water flow.

For our investigation, we chose three different waterfalls in Slovenia: the Savica Waterfall, the waterfalls of the Krka River and a small waterfall on Pohorje (Table 1). The Savica Waterfall is situated on the limestone ground in the Alps. The Krka River is the only Slovenian river with travertine barriers and with travertine waterfalls. The small waterfall on Pohorje is located on acid-silicate ground in the Lovrenška Jezera Forest Reserve.

The objective of the investigation was to establish the species structure and the abundance of periphyton in the Savica Waterfall, the waterfalls of the Krka River and the small waterfall on Pohorje, all three in Slovenia. Some physical and chemical parameters were also measured.

Materials and Methods

Samples of periphyton were taken seasonally in 1998, 1999 and 2000. The samples were brushed from the surface of stones and rocks and also squeezed out of water mosses. Five samples were taken in the Savica Waterfall and the waterfalls of the Krka River and four samples in the small waterfall on Pohorje. The dates of sampling are shown in Table 2.

The samples were immediately bottled and preserved in a 4 % solution of formaldehyde. All samples were also treated by concentrated HNO_3 to determine the species from the class Bacillariophyceae.

We determined the species and subspecies of the algae by a light microscope and following determination keys: Lazar (1960), Starmach (1966, 1972, 1980), Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b), Hindák et al. (1978), Hindák (1996), Cvijan and Blaženčić (1996). Abundance was estimated by the numbers 1, 3 and 5 (1-single, 3-customary, 5-dominant) (Grbović 1994).

In 1999 and 2000, various physical and chemical pa-

Table 1. Description of sampling points. For precise description of sampling points see Krivograd Klemenčič (2001).

Sampling point	Shadiness of the river bed	Water velocity	Width of the riverbed [m]	Trees and shrubs around the riverbed
Savica Waterfall	sunny	rapid	5	*Fagus sylvatica* *Picea abies*
Waterfalls of the Krka River	shady	rapid	50	*Corylus avellana* *Alnus glutinosa* *Carpinus betulus* *Acer campestre* *Salix* sp. *Quercus robur* *Cornus sanguinea* *Fraxinus ornus*
Small waterfall on Pohorje	sunny	rapid	1	*Picea abies*

Table 2. Dates of sampling and measuring of some physical and chemical parameters in the Savica Waterfall, the waterfalls of the Krka River and a small waterfall on Pohorje.

Sampling point	Date
Savica Waterfall	8. 8. 1998, 23. 5. 1999, 22. 8. 1999*, 2. 11. 1999*, 25. 3. 2000*
Waterfalls of the Krka River	20. 9. 1998, 24. 4. 1999, 27. 8. 1999*, 23. 10. 1999*, 13. 2. 2000*
Small waterfall on Pohorje	25. 7. 1998, 7. 8. 1999*, 16. 10. 1999*, 3. 6. 2000*

* On these days, some physical and chemical parameters were also determined.

Table 3. Fluctuation of some physical and chemical parameters in the Savica Waterfall, the waterfalls of the Krka River and the small waterfall on Pohorje in 1999 and 2000.

Sampling point	Temperature °C	Conductivity µS/cm	pH	Oxygen mg/l	Saturation %
Savica Waterfall	5.6–6.3	165.2–176.5	7.57–8.03	12.6–13.9	105–115
Waterfalls of the Krka River	7.9–14.5	394–480	7.90–8.10	10.2–16.0	101–118
Small waterfall on Pohorje	4.4–9.3	39.2–57.7	7.0–7.31	11.5–14.2	103–116

rameters were measured; these included temperature, conductivity, pH, dissolved oxygen and percentage saturation. The dates of measuring physical and chemical parameters are shown in Table 2.

Results and Discussion

Physical and Chemical Parameters

Fluctuation of some physical and chemical parameters in the Savica Waterfall, the waterfalls of the Krka River and the small waterfall on Pohorje in 1999 and 2000 are shown in Table 3. Changes in water temperature of the waterfalls of the Krka River and in the small waterfall on Pohorje during the year follow the temperature of the air. Water temperature of springs, which receive water from deeper layers, was more or less constant and oscillated around the average annual air temperature (Rejic 1988). Such a spring is also the Savica Waterfall with small temperature changes of water through the year. In the small waterfall on Pohorje, the conductivity in the time of measuring was low (39.2–57.7 S/cm), which can be explained by the acid-silicate ground. Physical and chemical results revealed that the temperature and conductivity are connected. The higher the water temperature was, the higher was the conductivity. Wetzel and Likens (1991) found out that conductivity increases about 2 to 3% per 1 °C. The span of pH in continental waters was from 2 to 12 pH, but in Slovenia it is mostly between 6 and 8.5 pH (Rejic 1988). In all the three waterfalls the pH was about 7 to 8 pH. The amount of dissolved oxygen in water was above 10 mg/l in all the three waterfalls at the time of measuring and the percentage saturation was above 100%.

Biological Parameters

Altogether, 143 species and subspecies of algae were determined (Table 4). Most of them (101) belonged to Bacillariophyceae, 24 belonged to Cyanophyceae, 13 to Chlorophyceae, three to Zygnematophyceae, one to Chrysophyceae and one to Florideophyceae. For the list of algal species with the estimation of abundance by seasons in individual waterfalls see Krivograd Klemenčič (2001).

There were 52 species and subspecies of algae determined in the Savica Waterfall, 81 in the waterfalls of the

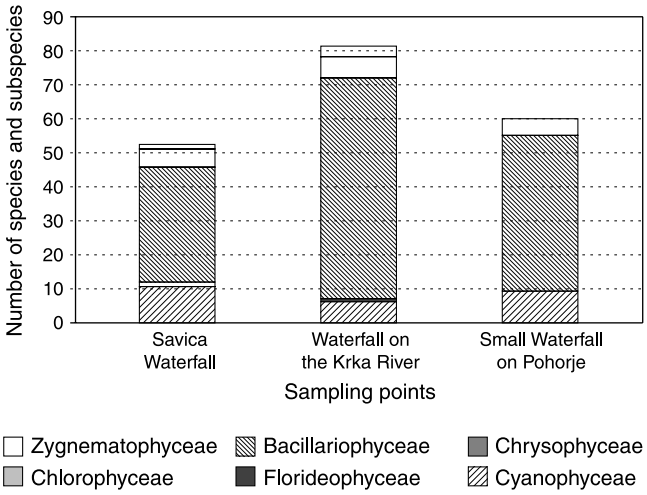
Krka River and 60 in the small waterfall on Pohorje (Table 4). The algal structure by classes in all the three waterfalls is shown in Text-fig. 1. The most frequent class of algae in all the three waterfalls was Bacillariophyceae. The Bacillariophyceae was the most frequent class of algae in various rivers in Slovenia, also according to the research of other authors (Vrhovšek et al. 1994; Smolar 1997; Krivograd 1997). In the Savica Waterfall and in the small waterfall on Pohorje they were followed by Cyanophyceae. In the waterfalls of the Krka River, Cyanophyceae and Chlorophyceae were equally frequent classes. In the Savica Waterfall *Hydrurus foetidus* from the class Chrysophyceae was present and in the waterfalls of the Krka River *Audouinella chalybea* from the class Florideophyceae was present. High species diversity was found in summer and autumn samples. The species diversity was higher in summer and autumn than in the other seasons of the year, this fact was proved also by other authors (Vrhovšek et al. 1994; Smolar 1997; Szarek 1994).

In all Savica samples the following species were determined: *Gloeocapsa sanguinea*, *Cocconeis placentula*, *Cymbella minuta* and *Diatoma mesodon*. *Gloeocapsa sanguinea* is a typical species of the drizzle zone in waterfalls (Starmach 1966). The most frequently found species were *Phormidium foveolarum* and *P. setchelianum*. *P. foveolarum* is typical for eutrophic environments rich in nutrients. *Hydrurus foetidus* was common in spring samples, which can be explained by low water temperature (Ward 1974).

In all samples from the waterfalls of the Krka River, the following species and subspecies were recorded: *Amphora pediculus*, *Cocconeis placentula*, C. *pediculus*, *Diatoma vulgaris*, *Gyrosigma attenuatum*, *Melosira varians*, *Navicula tripunctata*, *N. veneta*, *Nitzschia dissipata* var. *dissipata*, *N. fonticola* and *Rhoicosphenia abbreviata*, among which the most frequently found were *Amphora pediculus*, *Diatoma vulgaris* and *Navicula tripunctata*. *Audouinella chalybea* from the Florideophyceae class was also a very common species. The genus *Closterium* appeared only in the summer samples. Among diatoms, many species were typical for waters with high values of electrolytes and for waters rich in nutrients.

In all samples taken at the small waterfall on Pohorje, the following species and subspecies were determined: *Chamaesiphon incrustans*, *Achnanthes lanceolata* ssp. *lanceolata* var. *lanceolata*, *A. minutissima*, *Cymbella silesiaca*, *Diatoma mesodon*, *Eunotia minor*, *Fragilaria capucina*, *Frustulia rhomboides* and *Trentepohlia aurea*, among which the most frequently found were *Achnanthes minutissima*, *Chlorogloea microcystoides*, *Cymbella silesiaca*, *Diatoma mesodon*, *Eunotia minor*, *Gloeocapsa dermochroa* and *Ulothrix tenerrima*. Among diatoms, most species were typical for waters with low values of electrolytes and for waters poor in nutrients.

In all samples of the three waterfalls, *Achnanthes minutissima*, *Cocconeis placentula* and *Cymbella silesiaca* appeared.



Text-fig 1: Algal structure by classes in the Savica Waterfall, the waterfalls of the Krka River and the small waterfall on Pohorje in 1998, 1999 and 2000.

In the three waterfalls, 27 species and subspecies new to Slovenia were determined, of these fifteen in the waterfalls of the Krka River, ten in the small waterfall on Pohorje and two in the Savica Waterfall (Table 4). 24 of the new species and subspecies belonged to Bacillariophyceae and three to Cyanophyceae. The most frequent genera among the new species and subspecies were *Navicula* and *Nitzschia,* both with five species and subspecies.

Summary

Periphyton studies were carried out in the Savica Waterfall, the waterfalls of the Krka River and the small waterfall on Pohorje. The purpose of the investigation was to establish qualitative species structure and the abundance in 1998, 1999 and 2000. Five samples were taken in the Savica Waterfall and the waterfalls of the Krka River and four samples in the small waterfall on Pohorje. Algal species were determined with a light microscope. Abundance was estimated by the numbers 1, 3 and 5 (1-single, 3-customary, 5-dominant). In 1999 and 2000, some physical and chemical parameters were measured.

Altogether, 143 species and subspecies of algae (of six classes) were determined, of these 52 in Savica Waterfall, 81 in waterfalls of the Krka River and 60 in the small waterfall on Pohorje. Most of them belonged to Bacillariophyceae, followed by Cyanophyceae and Chlorophyceae.

In all the three waterfalls, 27 species and subspecies new to Slovenia were determined, of these 15 in the waterfalls of the Krka River, ten in the small waterfall on Pohorje and two in the Savica Waterfall. 24 of the new species and subspecies belonged to Bacillariophyceae and three to Cyanophyceae. The most frequent genera among the new species and subspecies were *Navicula* and *Nitzschia,* both with five species and subspecies.

Table 4. A list of algal species with estimation of abundance in the Savica Waterfall, the waterfalls of the Krka River and the small waterfall on Pohorje in 1998, 1999 and 2000, the species new to Slovenia are marked.

Taxon	Sampling point			Taxon	Sampling point		
	A	B	C		A	B	C
PROKARYOTA				**Epithemia turgida* var. *granulata* (Ehren.) Brun			1
CYANOPHYTA				*Eunotia bilunaris* (Ehren.) Mills			1
CYANOPHYCEAE				*Eunotia exigua* (Breb.) Raben.	1		
Chamaesiphon curvatus Nordstedt		1		**Eunotia microcephala* Krass.			1
Chamaesiphon incrustans Grun.			1	*Eunotia minor* (Kuetz.) Grun. et Van Heurch			3
Chlorogloea microcystoides Geitler			3	**Eunotia paludosa* Grun.			1
Gloeocapsa crepidinum Thuret		1		*Eunotia* sp.			1
Gloeocapsa dermochroa Naegeli			3	*Fragilaria capucina* Desm.	1	1	1
Gloeocapsa rupestris Kuetz.			1	*Fragilaria construens* (Ehren.) Grun.		1	
Gloeocapsa sanguinea (Ag.) Kuetz.	3			*Fragilaria tenera* (W. Smith) Lan.-Bert.			1
Gloeocapsa turgida (Kuetz.) Holler.	1			*Fragilaria ulna* var. *Ulna* (Nitzsch) Lan.-Bert.		1	1
Lyngbya sp.	1			*Fragilaria virescens* Ralfs			1
Oscillatoria amoena (Kuetz.) Gomont			1	*Frustulia rhomboides* (Ehren.) De Toni	1		1
Oscillatoria curviceps Agardh	1			**Gomphonema amoenum* Lan.-Bert.			1
Oscillatoria irrigua (Kuetz.) Gomont			1	*Gomphonema angustatum* (Kuetz.) Raben.	1		1
Oscillatoria sp.		1		*Gomphonema angustum* Agardh	3	1	1
Phormidium corium (Agardh) Gomont	1			*Gomphonema clavatum* Ehren.	1		1
Phormidium foveolarum (Mont.) Gomont	5			**Gomphonema clevei* Hust.		1	
Phormidium fragile (Menegh.) Gomont	1			*Gomphonema olivaceum* (Horn.) Breb.	1	3	
**Phormidium henningsii* Lemm.		1		*Gomphonema parvulum* Kuetz.	1	1	1
Phormidium retzii (Agardh) Gomont		1		*Gyrosigma acuminatum* (Kuetz.) Raben.	1		
**Phormidium setchelianum* Gomont	5			*Gyrosigma attenuatum* (Kuetz.) Raben.	1	1	
Phormidium sp.	1	1	1	**Gyrosigma nodiferum* (Grun.) Reimer		1	
**Phormidium valderiae* (Delp.) Geitler			1	*Gyrosigma scalproides* (Raben.) Cleve		1	
Pleurocapsa minor Hansg.	1			*Gyrosigma spencerii* (Quekett) Griffith et Henfrey		1	
Pseudanabaena constricta (Szafer) Lauterb.	1			*Melosira varians* Agardh	1	1	
Synechocystis pevaleckii Erceg.			1	*Meridion circulare* (Grev.) Agardh	1	1	
EUKARYOTA				*Navicula bacillum* Ehren.		1	
RHODOPHYTA				**Navicula bryophila* Peter.			1
FLORIDEOPHYCEAE				*Navicula capitatoradiata* Germain	1	1	
Audouinella chalybea (Lyngbe) Fries		3		*Navicula contenta* Grun.	1		
HETEROKONTOPHYTA				*Navicula cryptocephala* Kuetz.	1	1	1
CHRYSOPHYCEAE				*Navicula lanceolata* (Agardh) Ehren.		1	
Hydrurus foetidus Kirch.	3			*Navicula medioconvexa* Hustedt			1
BACILLARIOPHYCEAE				*Navicula menisculus* var. *menisculus* Schum.		1	
Achnanthes delicatula (Kuetz.) Grun.	3	1	1	*Navicula pupula* var. *pupula* Kuetz.			1
Achnanthes lanceolata ssp. *lanceolata* var. *lanceolata* (Breb.) Grun.	3	1	1	*Navicula reinhardtii* Grun.		1	
				Navicula rhynchocephala Kuetz.		1	
**Achnanthes lanceolata* ssp. *dubia* (Grun.) Lan.-Bert.		1		**Navicula salinarum* Grun.		1	
Achnanthes minutissima Kuetz.	3	1	3	**Navicula schroeterii* Meister		1	
**Achnanthes oblongella* Oestrup			1	*Navicula* sp.	1	1	1
Achnanthes sp.	3	1	1	**Navicula subhamulata* Grun. et Van Heurck		1	
Amphora libyca Ehren.		1		*Navicula tripunctata* (Muell.) Bory.		5	
Amphora montana Krass.		1		*Navicula veneta* Kuetz.	1	3	1
Amphora ovalis (Kuetz.) Kuetz.	1	1		**Navicula viridula* var. *linearis* Hustedt		1	
Amphora pediculus (Kuetz.) Grun.	1	5	1	*Navicula viridula* var. *viridula* (Kuetz.) Ehren.		1	
Caloneis silicula f. *silicula* (Ehren.) Cleve		1		**Neidium bisulcatum* (Lager.) Cleve			1
Cocconeis pediculus Ehren.		3		**Nitzschia constricta* (Kuetz.) Ralfs		1	
Cocconeis placentula Ehren.	1	3	1	*Nitzschia dissipata* (Kuetz.) Grun.	1		
Cyclotella sp.		1		*Nitzschia dissipata* var. *dissipata* (Kuetz.) Grun.		1	
Cymatopleura solea (Breb.) W.Smith		1		*Nitzschia fonticola* Grun.	1	1	
Cymbella affinis Kuetz.	1		1	*Nitzschia linearis* var. *linearis* (Agardh.) W. Smith		1	
**Cymbella caespitosa* (Kuetz.) Brun	1			**Nitzschia linearis* var. *subtilis* (Grun.) Hustedt		1	
Cymbella cistula (Ehren.) Kirch.			1	*Nitzschia palea* (Kuetz.) W.Smith	1	1	
**Cymbella descripta* (Hust.) Kramm. et Lan.-Bert.			1	*Nitzschia recta* var. *recta* Hant.		1	
Cymbella minuta Hilse	3			*Nitzschia sigmoidea* (Nitzsch) W. Smith		1	
Cymbella prostrata (Berk.) Cleve		1		**Nitzschia sinuata* var. *delognei* (Grun.) Lan.-Bert.		1	
Cymbella silesiaca Bleisch	1	1	3	*Nitzschia* sp.			1
Cymbella sinuata Greg.		1	1	**Nitzschia vermicularis* (Kuetz.) Hant.		1	
Denticula tenuis Kuetz.	1	1		**Nitzschia wuellerstorffii* Lan.-Bert.		1	
Diatoma mesodon (Ehren.) Kuetz.	1		3	*Pinnularia borealis* var. *borealis* Ehren.			1
**Diatoma moniliformis* Kuetz.		1		*Pinnularia microstauron* var. *microstauron* (Ehren.) Cleve			1
Diatoma vulgaris Bory	1	5	1	**Pinnularia rupestris* Hant.			1
Diploneis oblongella (Naegeli) Cleve-Euler		1		*Pinnularia subcapitata* Greg.			1
Ellerbeckia arenaria (Moore) Craw.		1		*Pinnularia viridis* (Nitzsch) Ehren.			1

Table 4. Continued

Taxon	Sampling point			Taxon	Sampling point		
	A	B	C		A	B	C
Rhoicosphenia abbreviata (Agardh) Lan.-Bert.		1		*Microspora pachyderma* (Wille) Lagerh.		1	
Stauroneis anceps Ehren.			1	*Microspora stagnorum* (Kuetz.) Lagerh.		1	
Stauroneis kriegerii Patrick			1	*Stigeoclonium* sp.		1	
Surirella angusta Kuetz.		1		*Stigeoclonium tenue* (Agardh) Kuetz.			1
**Surirella brebissonii* Kramm. & Lan.-Bert.		1		*Trentepohlia aurea* (L.) Martius	1		1
Surirella spiralis Kuetz.		1		*Ulothrix subtilissima* Raben.			1
Tabellaria flocculosa (Roth) Kuetz.			1	*Ulothrix tenerrima* Kuetz.			3
CHLOROPHYTA				*Ulothrix variabilis* Kuetz.	3		
CHLOROPHYCEAE				*Ulothrix zonata* (Web. et Mohr.) Kuetz.	1	1	
Cladophora glomerata (L.) Kuetz.		1		ZYGNEMATOPHYCEAE			
Dictyosphaerium pulchellum Wood.	1			*Closterium ehrenbergii* Menegh.		1	
Klebsormidium flaccidum (Kuetz) Silva, Mattox et Black.	1			*Closterium moniliferum* (Bory.) Ehren.		1	
Microspora amoena (Kuetz.) Rab.		1	1	*Mougeotia* sp.	1	1	

Legend: A – Savica Waterfall; B – Waterfalls of the Krka River; C – Small waterfall on Pohorje; * – species and subspecies new to Slovenia

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