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Changes in physico-chemical characteristics and the succession of phytoplankton in the lake Velenjsko jezero following its restoration

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Abstract: The species composition of phytoplankton in the artificial lake Velenjsko jezero has been monitored since 1994 while physico-chemical characteristics of the lake water since 1998. Before the year of lake remediation, 1994, the pH of lake water was around 12. In 1994, only filamentous cyanobacteria *Oscillatoria* ssp. were present in high abundance, with the rare appearance of *Synedra* sp. and *Ceratium* sp.. In 1995, the pH in the upper water layers decreased to 9, as a consequence of the construction of a fly ash system with a closed loop water cycle in October 1994. The number of algae taxons increased to 7 (*Coelosphaeria* sp., *Gomphosphaeria* sp., *Scenedesmus* sp., *Pediastrum* sp., *Asterionella* sp., *Synedra* sp. and *Ceratium* sp.). In 1996, when the pH fell to 8, it increased to 13. The lake provided good conditions for algal development since it was rich in nutrients. Since 1996 the level of nutrients in the upper layers of the water column has remained more or less the same, but in the deeper layers the reduced form of nitrogen (NH_4^+) has increased and the oxygen curve has become clinograd. Velenjsko jezero can be classified according to OECD, as hypereutrophic on the basis of the level of total phosphorus (120 µg L^{-1}) and total nitrogen (1500 µg L^{-1}), the average transparency of 5.38 m corresponds to mesoeutrophic status, and the average concentration of chlorophyll *a* at 1.03 µg L^{-1} to oligotrophic status. Despite the high availability of nutrients the primary production was not as high as in a similar natural lake ecosystem, which could be ascribed to the high concentration of ions Ca^{2+}, K^+, Mg^{2+}, Na^+, Cl^- and particularly, SO_4^{2-}. The predominant algae in the lake in 2007 were cyanobacteria *Pseudanabaena* cf. catenata, *Planktothrix rubescens*, from which the first bloom occured in June and the second from November to January, and dynophyta *Ceratium hirundinella* and *Peridinium cinctum*.

Keywords: pH, lake water, nutrients, phytoplankton

Izvleček: Vrstna sestava in abundanca fitoplanktona se v Velenjskem jezeru določa že od leta 1994. Vrednost pH jezerske vode je bila 12 vse do leta 1994, ko so v Termoelektrarni Šoštanj uvedli zaprti krog transportne vode (oktober 1994). Ob visokem pH, so bile v jezeru v velikem številu prisotne le filamentozne cianobakterije *Oscillatoria* ssp., z redko prisotnostjo taksonov *Synedra* sp. in *Ceratium* sp.. V letu 1995, ko je pH zgornjih plasti jezera narastel do 9, je število taksonov zraslo na število 7 (*Coelosphaeria* sp., *Gomphosphaeria* sp., *Scenedesmus* sp., *Pediastrum* sp., *Asterionella* sp., *Synedra* sp. in *Ceratium* sp.) in v letu 1996, ko je pH padel na 8, smo lahko v jezeru določili že 13 taksonov. Jezero nudi zelo ugodne razmere za razvoj alg, saj je bogato s hranili. Od leta 1996 sicer ostajajo koncentracije hranil v epilimniju bolj ali manj enake, v spodnjih plasteh pa se z leti povečujejo koncentracije amonija (NH_4^+) in kisikova krivulja je postala klinogradna. Medtem ko je bilo jezero v letu 1996 še prezračeno do dna (45 m), je že v letu 2000 kisik skoraj popolnoma izginil pod globino 20 metrov. Velenjsko jezero lahko glede na OECD klasifikacijo uvrstimo glede na količino celotnega fosforja (120 µg L^{-1}) in celotnega dušika (1500 µg L^{-1}) med hiperevtrofna jezera, na osnovi povprečne prosojnosti (5.38 m) med mezoevtrofna jezera, in na osnovu povprečne koncentracije klorofila a (1,03 µg L^{-1}) med oligotrofna jezera. Kljub veliki koncentraciji hranilnih snovi v jezeru, pa primarna produkcija ni tako velika kot je v drugih podobnih jezerskih ekosistemih. Vzrok za to lahko iščemo v drugačnem kemizmu, saj se zaradi bližine industrije jezero polni z ioni Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, Cl^{-}, še posebej pa z SO_4^{2-}. Prevladajoči algi v letu 2007 sta bili cyanobacteria *Pseudanabaena* cf. catenata in *Planktothrix rubescens*. Cvet prve vrste se je pojavil v juniju, druga vrsta pa je cvetela od novembra do januarja. Pogosti vrsti v letu 2007 sta bili tudi dynophyta *Ceratium hirundinella* in *Peridinium cinctum*.

Ključne besede: pH, jezero, hranila, fitoplankton

Introduction

The lake Velenjsko jezero can be used as a model of colonization of an empty habitat, since the high pH prevented the existence of most organisms before 1994. Colonization of macrophytes has been already described (Mazej & Epšek 2005, Mazej & Germ 2008). The massive development of submersed macrophytes indicated that Velenjsko jezero is very rich in nutrients.

Coexistence of a number of phytoplankton species is a conspicuous feature of fresh waters. Although a few species commonly dominate a phytoplankton assemblage, a number of rarer algae coexist with the dominant species. Many differences in algal physiological characteristics, requirements, and tolerances, together with seasonal and spatial variations in environmental parameters, permit an apparently multispecific equilibrium to exist for short periods. Algae have defined temperature optima and tolerance ranges that interact with other parameters to cause seasonal succession. For example, many diatoms can photosynthesize successfully at cooler water temperatures, whereas the temperature optima of many green algae and cyanobacteria are higher (Wetzel 2001).

Attributes considered to be symptoms of negative impacts of nutrient enrichment in many ecosystems include blooms of toxic algae, increased growth of epiphytic algae, the growth of macroalgae, the loss of submerged vegetation due to shading, the development of hypoxic (and anoxic) conditions due to the decomposition of accumulated biomass, and the changes in the community structure of benthic animals due to oxygen deficiency or the presence of toxic phytoplankton species (Revilla & al. 2009). The phytoplankton, because of its relationship with the eutrophication processes, is one of the biological elements considered within the Water Framework Directive (WFD). Phytoplankton biomass, composition and abundance, together with frequency and intensity of blooms, are the metrics to be assessed according to the WFD. Among the advantages of using phytoplankton to assess water quality are the rapid response of this group of organisms to the changes in the environment, their primary role in the food web and their influence on other organisms (Willén 2001).

In this paper we evaluated the trophic status of Velenjsko jezero between 1996 and 2007, considering some physico-chemical and biological parameters and analysed the succession of algae species composition and abundance following completion of the restoration measures in 1995.

Materials and Methods

Study area

Velenjsko jezero is located in central Slovenia, in the Šalek Valley, at an altitude of 366 m, It has a surface area of 135,000 m^2 and a maximal depth of 54 m. It is an artificial lake resulting from mining activity. Whole settlements, meadows and fields were submerged and flooded as a result of subsidence. Until 1983, fly ash slurry from the Šoštanj Thermal Power Plant was transported by pipeline and emptied into Velenjsko jezero. This brought ash and calcium hydroxide to the lake, raising the pH of the water to 12. Since 1983 the ash has been used to build embankments, but effluent with a pH around 12 remained the predominant polluter of the lake until 1994. After construction of a fly ash system with a closed loop water cycle in October 1994, biota appeared in the lake. It was colonized by phyto- and zooplankton, fish, macrophytes (Mazej & Epšek 2005) and other organisms. The pH of the lake is now around 8 and the lake is dimictic.

Physical and chemical parameters

The water samples from the different depths at deepest part of Velenjsko jezero were taken and analysed four times a year (spring, summer, autumn, winter) in the years 1996, 1998, 2000, 2002, 2004 and 2007. Transparency was measured by Secchi disk. Temperature, pH and oxygen profiles were obtained using a portable oxygen meter WTW multiline P4. Water samples for laboratory analysis were obtained from different depths using a depth (Van-Dorn) sampler. Before 2000, parameters were determined by following standard methods: total phosphorus (SIST ISO 6878:1996), ammonium nitrogen (SIST ISO 5664: 1996), nitrate nitrogen and sulphate (SIST ISO 10304-2: 1996), SEP (DIN 38404), magnesium and calcium (SIST EN ISO 7980). From 2000 onwards, parameters were determined by the following standard methods: total phosphorus (SIST ISO 6878: 1996), ammonium nitrogen (SIST ISO 5664: 1996), nitrate nitrogen, chloride and sulphate (SIST ISO 10304: 1998), SEP (SIST EN 27888:1998), magnesium and calcium (SIST EN ISO 7980).

Biological parameters

Samples for Chl-a were obtained using a Van-Dorn sampler. After filtration through glass microfibre Watman GF/C filter they were analyzed by the standard method ISO 10260.

The plankton samples were taken and analysed four times a year (spring, summer, autumn, winter) in the years 1994, 1995, 1996, 2000, 2002, 2004 and 2007. Qualitative 20 µm mesh plankton net samples were taken as a vertical profile, preserved in 3% formaldehyde and analysed for phytoplankton species community composition. The species were identified using a light microscope according to Hindak (1978), Ettl & Gärtner (1988), Ettl & al. (1999), Krammer & Lange-Bertalot (1991, 1997, 2000a, 2000b, 2004), Komarek & al. (2005), Starmach (1985), Popovski & Pfiester (1990), Streble & Krauter (2002), Vrhovšek & al. (2006). Their abundance was rated into three categories: present (1), subdominant (3) and dominant (5). Unicellular Cyanobacteria were counted like trichomes.

Results and Discussion

After construction of a fly ash system with a closed loop water cycle in October 1994, pH of water started to decrease (Ramšak & Rejic 1995, Ramšak 1996). Only filamentous cyanobacteria (*Oscillatoria* sp.) were present in higher abundance, and rare appearance of *Synedra* sp., and *Ceratium* sp. was observed in 1994, when the pH was still above 11. In 1995, when water quality improved, the pH in the upper water layers decreased to 9, the number of algae taxons increased to 7 (*Coelosphaeria* sp., *Gomphosphaeria* sp., *Scenedesmus* sp., *Pediastrum* sp., *Asterionella* sp., *Synedra* sp. and *Ceratium* sp.) and to 13 in 1996, when the pH fell to 8. The lake was rich in nutrients, providing good conditions for algae development (Table 1, Table 2). Velenjsko jezero is relatively deep lake, but accelerated eutrophication, due to non-point sources of nutrients from drainage areas, nevertheless occurred between

Table 1: OECD recommendations for classification of lakes into trophic categories (OECD 1982) based on total phosphorus, total nitrogen and chlorophyll contents and transparency of the water. The values for Velenjsko jezero in 2007 are shaded.

Tabela 1: Priporočila OECD (1992) za uvrstitev jezer v trofične kategorije na podlagi povprečnih letnih koncentracij celotnega dušika in fosforja, koncentracij klorofila a ter prosojnosti vode. Kategorije, v katere lahko uvrstimo Velenjsko jezero so osenčene.

OECD value	Total phosphorus (µg L^{-1})	Total nitrogen (µg L^{-1})	Transparency (m)	Chlorophyll (µg L^{-1})
Ultraoligotrophic	<4	<200	>12	<1
Oligotrophic	<10	200–400	>6	<2.5
Mesoeutrophic	10–35	300–650	6–3	2.5–8
Eutrophic	35–100	500–1500	3–1,5	8–25
Hyper eutrophic	>100	<1500	<1.5	>25

Table 2: Mean physico-chemical characteristics of water of 30 cm depth in Velenjsko jezero in the years of sampling; n=4, average value ± SD
Tabela 2: Povprečni rezultati fizikalnih meritev in kemijskih analiz vode iz globine 30 cm v Velenjskem jezeru v letih vzorčevanja; n=4, povprečna vrednost ± SD

	1996	1998	2000	2002	2004	2007
Transparency (m)	7.75±1.77	4.83±1.08	4.35±0.92	4.50±1.74	6.78±2.81	5.38±1.73
pH	8.75±0.25	8.75±0.26	8.40±0.20	7.80±0.10	8.20±0.20	8.80±0.40
SEP (μs cm^{-1})	–	661±126	905±71.9	924±68.2	1085±81.0	1398±29.9
NH_4^+ (mg L^{-1})	–	0.05±0.005	0.33±0.14	0.36±0.07	0.30±0.08	0.26±0.26
NO_3^- (mg L^{-1})	–	4.36±0.51	2.90±0.42	3.38±0.52	4.70±0.63	3.74±0.75
P – total (mg L^{-1})	–	0.05±0.011	0.05±0.03	0.08±0.05	0.09±0.06	0.06±0.03
Chlorophyll a (μg L^{-1})	–	–	1.40±0.51	2.10±0.98	1.70±0.10	1.03±0.38
SO_4^{2-} (mg L^{-1})	–	159±65.5	369±38.7	403±43.1	595±32.5	623±31.2
Ca^{2+} (mg L^{-1})	–	70.8±8.10	81.3±22.1	119±14.2	175±15.3	192±18.6
K^+ (mg L^{-1})	–	42.4±4.24	44.1±9.5	40.0±6.01	48.0±3.52	43.1±2.25
Mg^{2+} (mg L^{-1})	–	11.8±0.87	13.1±1.27	14.6±2.20	14.2±1.06	16.2±0.49
Na^+ (mg L^{-1})	–	41.6±0.85	46.2±5.40	48.2±3.42	46.7±2.70	63.7±8.60
Cl^{-+} (mg L^{-1})	–	–	–	–	21.1±0.22	34.2±4.57

1996 and 2007. The transparency of the lake and the nutrient concentration, and the concentration of chlorophyll *a* in the epilimnium remained at the same levels from 1996 to 2007, while the concentrations of ions were increasing regularly, especially sulphate and calcium, and consequently the specific electrical conductivity (SEP). While in 1996 the lake water was fully aerated to the bottom (45 m), oxygen was almost completely exhausted below a depth of 20 m in August and in November 2000 and November 2007. As a consequence the concentration of NH_4^+ started to arise, and the concentration of NO_3^- decreased below 10 metres.

Average values measured at different depths and the volume of each stratum was used to calculate average annual concentrations of parameters. On the basis of the levels of total phosphorus (120 μg L^{-1}) and total nitrogen (1500 μg L^{-1}) determined in 2007, Velenjsko jezero was classified as hyper eutrophic, while the average transparency of 5.38 m corresponded to meso eutrophic status and the average concentration of chlorophyll *a* 1.82 μg L^{-1} to oligotrophic status (OECD 1982). It was expected that primary production would be higher due to the relatively high concentration of nutrients, but it appeared that other factors limited development of phytoplankton. Concentration of chlorophyll *a* in Velenjsko jezero is smaller in comparison with the lakes with the same trophic status (Remec Rekar 2008). The concentration of chlorophyll *a* is directly connected with the presence of phytoplankton and cyanobacteria, which are holders of primary production in lake water. Chlorophyceae, Cryptophyceae and cyanobacteria have a high impact on the concentration of chlorophyll a, while Bacillariophyceae, Dinophyceae and Chrysophyceae are of lesser importance (Kasprzak & al. 2008).

A small but general increase of all taxons was observed in the period from 1996 to 2007, but the increase of taxons of Bacillariophyceae, especially Chlorophyta was notable. Of the 66 species recognized, only a few contributed at least once during the year to the major percentage of total density (Cyanophyceae: *Pseudanabaena cf. catenata*, *Planktothrix rubescens* and *Phormidium* sp., Dynophyta: *Ceratium hirundinella* and *Peridinium cinctum* and Bacillariophyceae: *Cyclotella meneghiniana* and Stephanodiscus sp.) (Table 3). The phytoplankton assemblage, in which a number of rarer species were found among the dominant ones, shows the eutrophic status of the Lake. From 1996 onwards, a very significant part of the phytoplankton biomass consisted of dinoflagellates from genus *Ceratium* and *Peridinium*. They had been prevailing in the biomass till 2004, when the predominance of filamentous

Table 3: Relative abundance (1 – present, 3 – subdominant and 5 – dominant) of phytoplankton taxons in Velenjsko jezero was assessed throughout the years 1996, 2002, 2004 and 2007.

Tabela 3: Relativna abundanca (1 – redko prisotna vrsta, 3 – zmerno prisotna ali pogosta vrsta; 5 – prevladujoča ali množična vrsta) fitoplanktonskih taksonov v Velenjskem jezeru v letih 1996, 2002, 2004 in 2007.

Taxa	Spring					Summer					Autumn					Winter				
	May 1996	20. 04. 2000	06. 05. 2002	11. 05. 2004	17. 04. 2007	Avg. 1996	17. 08. 2000	18. 07. 2002	27. 07. 2004	08. 08. 2007	Sept. 1996	09. 11. 2000	23. 10. 2002	25. 10. 2004	08. 11. 2007	Dec. 1996	19. 12. 2000	16. 12. 2002	07. 12. 2004	20. 12. 2007
ph: Cyanobacteria (Modrozelene alge)																				
Anabaena constricta										1										
Pseudanabaena cf. catenata.				3	3		3		1	1			1							
Aphanizomenon flos- aquae					1		1	1		1					1					
Aphanizomenon gracile					1							1								
Aphanizomenon sp.							1													
Dactylococcopsis sp. (D. fascicularis)										1										
Coelosphaeria sp.						1														
Gomphosphaeria sp.							1													
Oscillatoria agardhii					1															
Oscillatoria brevis			1					1		1										
Oscillatoria formosa							1	1							1					
Oscillatoria limosa									1											
Oscillatoria limnetica								1												
Oscillatoria sp.	1			1		1		1		1	1	1	1			1		1		1
Oscillatoria tenuis					1										1					
Oscillatoria rubescens (Planktothrix rubescens)					5		5		5	5				5	5				5	5
Merismopedia sp.											1									
Phormidium sp.							1	1	1				3				1	5		
Phormidium retzii					1															
Spirulina sp.							1													
ph: Pyrrhophyceae (Dinoflagellatae – ognjene alge) cl: Gymnodinales																				
Ceratium hirundinella	1		3		1	2	5	3	5	3	3	1	5	5	3	1			1	3
Gymnodinium paradoxum										1										
Gymnodinium sp.					1															
Peridinium sp.										1										
Peridinium cinctum (Peridinopsis penardii)					1		1	1	3	1			1	5	1				1	1
Peridinium tabullatum					1															
Peridinium umbonatum																				

Taxa	Spring					Summer					Autumn					Winter				
	May 1996	20. 04. 2000	06. 05. 2002	11. 05. 2004	17. 04. 2007	Aug. 1996	17. 08. 2000	18. 07. 2002	27. 07. 2004	08. 08. 2007	Sept. 1996	09. 11. 2000	23. 10. 2002	25. 10. 2004	08. 11. 2007	Dec. 1996	19. 12. 2000	16. 12. 2002	07. 12. 2004	20. 12. 2007
ph: Chlorophyta																				
Ankistrodesmus acicularis (Monoraphidium griffithii)		1	1								1									1
Ankistrodesmus falcatus (Monoraphidium contortum)															1					
Chlorococcum infusionum			1				1	1		1		1								
Coelastrum microporum										1		1	1							
Coelastrum reticulatum				1	1				1	1					1					1
Coelastrum sphaericum															1					
Cosmarium bloculatum							1													
Monoraphidium convulatum																				
Microspora sp.															1					
Pandorina morum							1	1											1	
Pediastrum clathratum					1			1					1					1		1
Pediastrum boryanum		1			1		1	1	1											
Pediastrum gracillinum							1													
Pediastrum simplex								1												
Pediastrum sp.	3					2					1									
Planktosphaeria gelatinosa																				1
Scenedesmus obliquus												1					1			
Scenedesmus platydiscus															1					
Scenedesmus sp.										1	1		1		1					1
Sphaerocystis sp.								1												
Staurastrum gracile											1		1							
Staurastrum paradoxum													1							
Volvox sp.																			1	
ph: Euglenophyta Euglena sp.			1					1												
ph: Heterokontophyta cl: Chrysophyceae																				
Dinobryon divergens															1					
Dinobryon sp.				1						1										
cl: Bacillariophyceae (Diatomeae)																				
Achnantes minutissima					1															
Amphora veneta			1					1												
Amphora ovalis												1								
Amphora sp.		1	1					1												
Asterionella formosa	1	1	1			1		1			1	1				1				1
Caloneis amphisbaena								1							1			1		
Cocconeis sp.										1										

Taxa	Spring					Summer					Autumn					Winter				
	May 1996	20. 04. 2000	06. 05. 2002	11. 05. 2004	17. 04. 2007	Aug. 1996	17. 08. 2000	18. 07. 2002	27. 07. 2004	08. 08. 2007	Sept. 1996	09. 11. 2000	23. 10. 2002	25. 10. 2004	08. 11. 2007	Dec. 1996	19. 12. 2000	16. 12. 2002	07. 12. 2004	20. 12. 2007
Cyclotella meneghiniana (C. kuetzingiana, C.melosiroides)		1					1			1					3					1
Cyclotella sp.				1	1			1	1											
Cymatopleura solea (C. librilis)					1															
Cymbella lanceolata										1										
Diatoma elongatum (D. tenue)					1															1
Diatoma vulgare (D. vulgaris)					1															
Fragilaria crotonensis		1						1												1
Hantzschia amphioxys																	1			
Gyrosigma attenuatum (G. acuminatum)															1					
Melosira varians																			1	
Navicula cryptocephala			1																	
Navicula cuspidata																				
Navicula radiosa																	1			
Navicula sp.			1							1	2				1	1				
Nitzschia sigmoidea															1					
Nitzschia sp.	2																			
Stephanodiscus sp. (S.hantzschii)												3					5			
Surirella sp.					1													1		
Synedra acus	3		1			3	1			1	3		1		1	2				1

Cyanobacteria was observed. Nutrient enrichment of lakes is usually accompanied by characteristic shifts within the phytoplankton community. During eutrophication, small flagellated taxa are replaced by increasing proportions of green algae, with cyanobacteria finally predominating (McQueen & al. 1986). The distribution of dinoflagellates as a function of major chemical and physical factors shows that most dinoflagellate species have restricted ranges with respect to calcium, pH, dissolved organic matter, and temperature (Taylor & Pollingher 1987). Some are however highly tolerant and widespread, especially species of *Ceratium* and *Peridinium*, which were present in high abundance in Velenjsko jezero. Many other (micro) algae species, especially greens (22 species), occurred infrequently during warmer periods of the year.

Populations of filamentous cyanobacteria is increased in hypereutrophic lakes (Wetzel 2001). Although the number of cyanobacteria taxons was only 9 in 2007, their biomass was greater than that of other taxons almost all the year (Remec Rekar 2008). Only in April 2007 the diatoms prevailed, in June the density of cyanobacteria *Pseudanabaena* sp. was very high especially in the metalimnium (>$24.42*10^6$ cells/L) While in August Chlorophyta and Dinophyta constitutes 50% and Cyanobacteria 50% of the phytoplankton biovolume, in November a bloom of *Planktothrix rubescens* occurred prevailing over other taxons (Remec Rekar 2008). It is generally recognized that cyanobacterial blooms are the direct consequence of eutrophication (Reynolds & Petersen 2000). In Velenjsko jezero massive, long-lasting blooms of *Planktothrix rubescens* were observed (from November 2007 to February 2008). *Planktothrix*

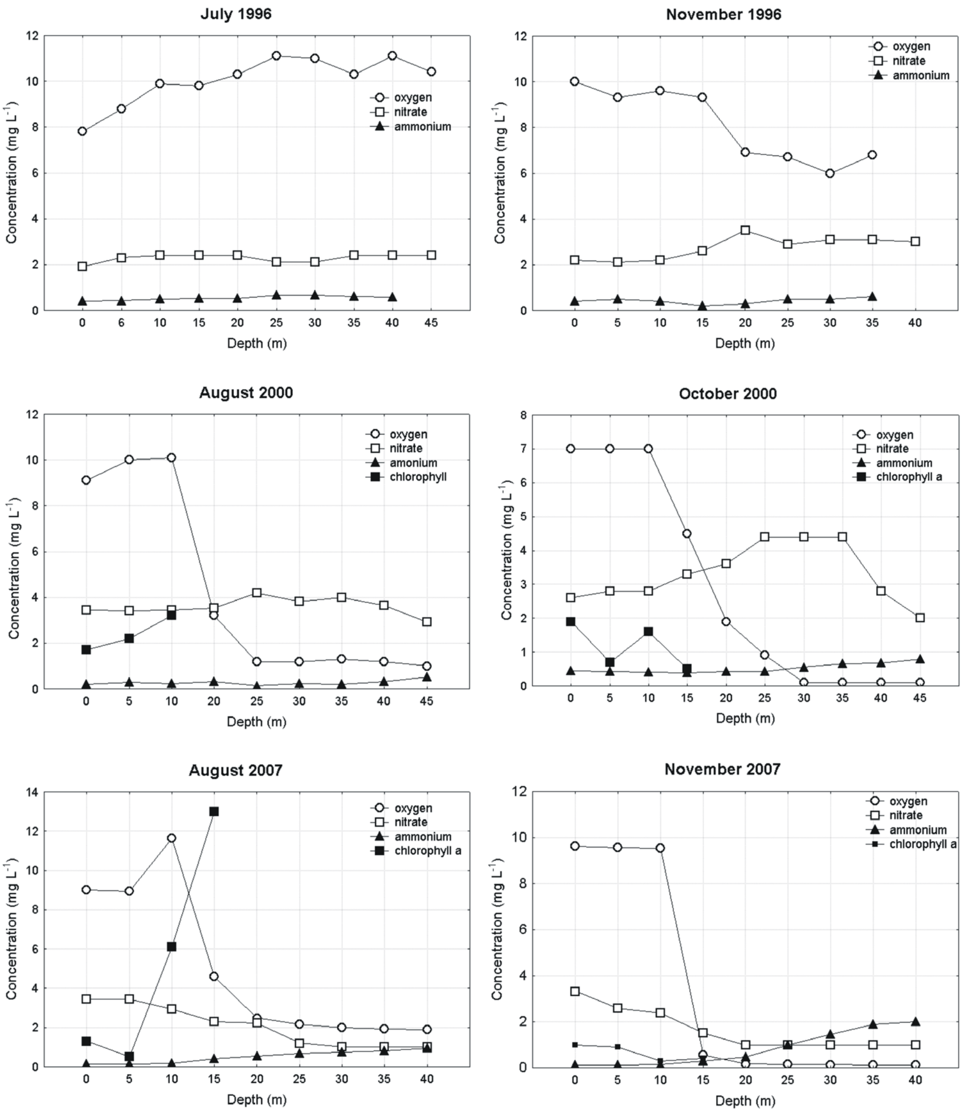

Fig. 1: Vertical distribution of oxygen, nitrate, ammonium and chlorophyll a concentrations in Velenjsko jezero in summer and autumn of 1996, 2000 and 2007.

Slika 1: Vertikalna razporeditev koncentracij kisika, nitrata, amonija in klorofila a poleti in jeseni v letih 1996, 2000 in 2007.

rubescens is a cold-water stenotherm species distributed mainly in middle European (Reynolds 1984) and Southern sub-alpine lakes. During the summer stratification it is usually located within the metalimnium (Chorus & Bartram 1999, Sedmak & Kosi 1997), where it is photosynthetically active (Micheletti & al. 1998). It usually grows at a depth where the penetrating PAR is around 1–5% of the surface values (Chorus & Bartram 1999). In favourable meteorological and climatic conditions, it migrates to the surface forming a surface bloom frequently covering almost the entire lake surface. Such blooms can persist on the surface even in January and can grow under ice cover (Sedmak & Kosi 2001). In such cases microcystin-YR can normally be detected in bloom samples (Sedmak & Kosi 2001). Not all cyanobacteria blooms are toxic, and even blooms caused by known toxin producers may not actually produce toxins, or may only do so at undetectable levels. The triggers of toxin production are not known well. This type of toxin has been shown to persist in water for a week or more after the bloom has disappeared. No human deaths have been directly associated with these cyanotoxins, however they may cause skin irritations or nausea (Carmichael 1997). The presence of microcystins can also influence the growth of other phytoplanktonts in the bloom. High densities of *Planktothrix* can inhibit the growth of other phytoplankton species and thus reduce the number of alternative food particles for zooplankton. The diversity in the blooms is thus low. It has been suggested that there this is due to the combined effect of light limitation and microcystin influence on susceptible phytoplankton species (Sedmak & Kosi 2002).

Compared with other lakes (Remec Rekar 2008), very high average annual concentrations of sulphate (>590 mg L^{-1}), chloride (>40.0 mg L^{-1}), sodium (>60 mg/L^{-1}) and potassium (>50 mg L^{-1}) were detected in Velenjsko jezero (Table 2). Washing out of the ash disposal site is the most probable ion's source. The concentration of sulphate was almost four times higher than the maximum level in rivers provided for by Slovenian legislation (OGRS No. 11/2002). The usual concentration in lakes is in the range about of 5 to 30 mg L^{-1}, with an average value of about 11 mg SO_4^{2-} L^{-1}. SO_4^{2-} has no influence on the trophic status of the water. Velenjsko jezero contains very high concentrations of divalent cations, especially Ca^{2+}, providing good conditions for the development of green algae, which have high requirements for Ca^{2+}. Sodium can influence the development of large populations of cyanobacteria and maximal growth of several cyanobacteria species has been found at 40 mg L^{-1} (Wetzel 2001), but values in Velenjsko jezero were even higher (63.7 mg/L^{-1}) in 2007. Diatoms were also the dominant species in the lake in early spring, since they dominate in very hard water lakes, like Velenjsko jezero, with ratios: monovalent cations:divalent cations much less than 1.5 (Round 1981). Distribution of most species of desmids of the Conjugales is limited to water with low concentrations of calcium and magnesium.

Conclusions:

1. The transparency of the lake and the nutrient concentration, and the concentration of chlorophyll *a* in the epilimnium remained at the same levels from 1996 to 2007, while the concentrations of ions were increasing regularly, especially sulphate and calcium, and consequently the specific electrical conductivity (SEP). Changes were detected in the phytoplankton community structure, blooms of toxic algae and the development of hypoxic (and anoxic) conditions in the hypolimnium occurred in the last years.
2. Concentration of chlorophyll *a* in Velenjsko jezero was smaller in comparison with the lakes with the same trophic status. Very high concentrations of sulphate, chloride, sodium and potassium can be one of the reasons for that phenomenon.
3. Filamentous cyanobacteria *Oscillatoria* sp., diatom *Synedra* sp., and dynophyta *Ceratium* sp. grew in lake even at pH 11. In recent years, following the first year after the normalisation of pH, Cyanobacteria have replaced Dinophyta as the predominant species. The predominant algae in the lake ten years later were cyanobacteria *Pseudanabaena cf. catenata* and *Planktothrix rubescens* as well as dynophyta *Ceratium hirundinella* and *Peridinium cinctum*. The first bloom of the former usually occurs in June and the second from November to January.

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