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ALGAE AND MACROPHYTES OF MINE PIT LAKES IN THE WIDER AREA OF TUZLA, BOSNIA AND HERZEGOVINA

JASMINA KAMBEROVIĆ[1] & SENKA BARUDANOVIĆ[2]

[1]University in Tuzla, Faculty of Science, Univerzitetska 4, 75 000 Tuzla (E-mail: jasmina.kamberovic@untz.ba)

[2]University in Sarajevo, Faculty of Science, Ulica Zmaja od Bosne, 33-35, 71000 Sarajevo (E-mail: sebarudanovic@gmail.com)

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The algal and macrophytic occurrence in the pit lakes of the wider area of Tuzla (Bosnia and Herzegovina) was investigated in 2008. The purpose of this investigation was to establish the qualitative composition and the relative abundance of the phytobenthos and epiphyton communities and the structure of the aquatic vegetation in the littoral area of the seven pit lakes. The basic physical and chemical parameters were measured and in total 73 algal taxa and 8 macrophytic species were determined. Most of the algal species belonged to *Bacillariophyceae*. The macrophytic vegetation was differentiated into two types of habitat. Using the statistical method of the numeric classification, a grouping of samples of phytobenthos and epiphyton compared to the habitat type in which samples were taken was established.

Key words: phytobenthos, epiphyton, macrophytes, water quality, pit lakes

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Struktura zajednica algi i makrofita je istraživana tijekom 2008. godine na umjetnim jezerima koja su nastala na mjestima okončane površinske eksploatacije ugljena u široj okolici Tuzle (Bosna i Hercegovina). Cilj istraživanja bio je utvrđivanje kvalitativnog sastava i relativne brojnosti algi i makrofita u litoralnom području sedam umjetnih jezera. Mjereni su osnovni fizikalno-kemijski pokazatelji, a u uzorcima algi su utvrđena 73 taksona algi, od kojih su najzastupljenije bile dijatomeje. Makrofitska vegetacija s determiniranih 8 vrsta diferencirana je u dva tipa staništa. Koristeći se statističkom metodom numeričke klasifikacije, utvrđeno je grupiranje uzoraka fitobentosa i epifitona u odnosu na tip staništa na kome su uzorkovani.

Ključne riječi: fitobentos, epifiton, makrofiti, kvaliteta vode, umjetna jezera

INTRODUCTION

As a consequence of the exploitation of coal in the wider area of Tuzla, many deep pit lakes were created in the mining voids left through inflow of ground and surface water in the wider area of Tuzla (Bosnia and Herzegovina). Some mine voids are filled with mine waste behind dams, where surface water accumulates and creates shallow lakes held back by dams (KAMBEROVIĆ, 2010).

A special problem of many mining pit lakes is severe acidification due to pyrite oxidation in the overburden dumps (NIXDORF *et al.*, 2005) and other water quality problems, such as high metal concentrations, high suspended and dissolved solids (LEVY *et al.*, 1995; In: KALIN *et al.*, 2001).

There is only sparse information on the water regime, the physical/chemical properties and potential uses of these coal pit lakes of Tuzla area. PAŠIĆ-ŠKRIPIĆ *et al.* (2008) describe the hydro-geological characteristics of the pit lake Turija, within the Banovići basin. VELAGIĆ-HABUL *et al.* (2005) studied the influences of tailings on the quality of water in the streams and one pit lake in Đurdevik coal basin. They showed that neutralisation and acidification are producing a circumneutral water quality.

Only one hydrobiological study has been carried out on the pit lakes from the area of Tuzla, Lake Šićki Brod (ORUČ & ARNAUTALIĆ, 1996). Organisms which dominated indicated β-mesosaprobic and oligosaprobic water quality. The nutrient concentrations (low nitrogen and phosphate but high calcium and sulphates at neutral pH) determined the status of the water (ORUČ & ARNAUTALIĆ, 1996).

Freshwater algae as bioindicators have been extensively summarized by BELLINGER & SIGEE (2010). These species can be very useful in monitoring in space and time, predicting potential change in water quality, very important in pit lakes.

Studies of the structure and the dynamics of algae communities in pit lakes in the world have beenconducted over the years by several authors (BENNET, 1969; LEDIN & PEDERSON, 1996; NIXDORF *et al.*, 1998a, 1998b; AXLER *et al.*, 1998; KALIN *et al.*, 2001;

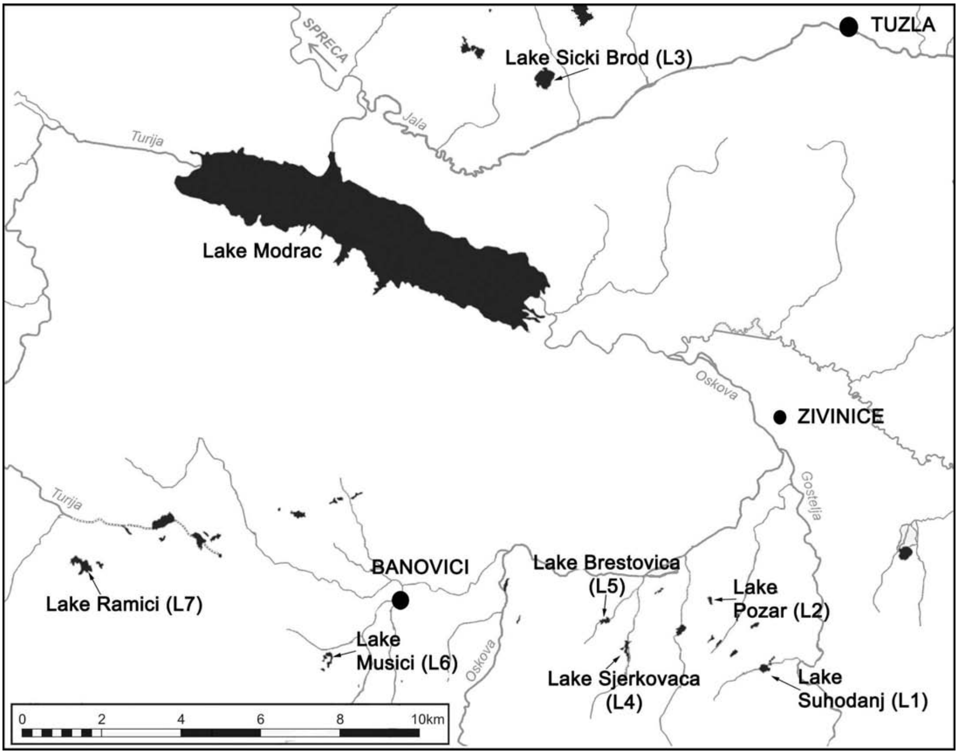

Fig. 1. Researched area map

Fig. 2. Lake Suhodanj

Fig. 3. Lake Šićki Brod

KALIN *et al.*, 2006). In some pit lakes stressful physico-chemical conditions lead to the development of communities comprising restricted taxa, with micro-organisms dominating. Phytoplankton communities initially consist of »weedy« taxa that are tolerant to a wide range of variation of environmental conditions, as demonstrated in studies of phytoplankton in the B-Zone pit-lake in Canada. With time comes increased diversity of taxa, as the result of more favorable physico-chemical properties of the water (KALIN *et al.*, 2001). As a large number of pit lakes in the world have acidic reaction, most biological studies research the structure of phytoplankton communities and remediation capabilities of these habitats (FYSON *et al*., 2006; KALIN & WHEELER, 2009). FYSON *et al.* (2006) found that in Lake Grünewalde, one of the 500 flooded lignite open cast pits in Germany, the most common phytoplankton taxa were: *Eunotia exigua*, *Chlamydomonas* sp., *Ochromonas* sp. and *Nanochlorum* sp.. Taxa *Ochromonas* sp. and *Chlamydomonas* sp. were also found to be the most common in Boomerang Lake in Canada, which is affected by acid mine drainage (KALIN *et al*., 2006).

Literature data on the macrophytes of pit lakes are even rarer than those on the microbiota. According to PIETSCH (1996), the development of macrophyte communities passes through five stages and depends on the morphometry and age of the lake, geographical location and water characteristics. During research in East Pit Lake in Alberta in Canada, SUMER *et al*. (1995) found that the distribution and abundance of water macrophytes are more conditioned by the morphometry of the lake than by the increase of the nutrient concentration in the water. KADLEC (1962) presents similar conclusions stating that the development of communities of aquatic plants depends on the width of the littoral zone of the lake. GAMMONS *et al.* (2009) state that the first macrophytes that colonise pit lakes will be pioneer plant species for a certain area, in most cases pondweed (*Potamogeton* spp.), cattails (*Typha* spp.), bulrushes (*Scirpus* spp.) and sedges (*Carex* spp.).

The first objective of the present work is to determinate the species composition of the phytobenthos, epiphyton and aquatic plant communities in the littoral zone of seven pit lakes in the coal basin of Tuzla. Secondly, we wanted to assess water quality in the investigated lakes. Our third aim was to evaluate the impact of macrophytes on algal communities.

Study area

The area of Tuzla belongs to the temperate – continental climate region with relatively mild winters and obvious transition of the seasons. The average temperature varies from 9°C to 10.6°C, and the annual total of rainfall is 830 L/m^2 do 1.150 L/m^2 (SMAJIĆ, 2007).

The lakes Suhodanj, Požar, Sjerkovača, Brestovica and Ramići were formed by damming water over the coal mine wastes, thus forming shallow pit lakes. This is in contrast to lakes Mušići and Šićki Brod where the pit lakes are formed in mining voids (Figs. 1, 2 and 3). Lakes were formed during the period from 1982–1987 and each has its own water regime. Lakes Suhodanj, Požar, Sjerkovača, Brestovica and Ramići receive water from surface runoff and lose it by evaporation and to the underground through porous barriers. Lakes Mušići and Šićki Brod are supplied with water from surface water and groundwater and the water levels are maintained by an outflow weir. All investigated lakes are small, ranging in size from 1–21 hectares, with maximum depths to 33 meters (Tab. 1).

The bottom of the littoral zone in almost all the lakes is partially covered with aquatic vegetation. The littoral zone of Suhodanj Lake is completely overgrown with macrophyte vegetation of *Chara* spp. due to its small inclination. The communities at the shores fragmentarily develop with *Typha* spp. and progradational stages of willow grove (with *Salix* spp.). The sampling of materials was performed in the littoral zone of the north side (Location 1). The littoral area of Požar Lake on the west side (Location 2) is also overgrown with the vegetation of the class *Charetea fragilis*. The submerged vegetation is attached to the vegetation, with *Typha* spp

Tab. 1. The basic characteristics of the researched lakes (Kamberović, 2010)

Lake's charact.	L.1	L.2	L.3	L.4	L.5	L.6	L.7
Lakes	Suhodanj	Požar	Šićki Brod	Sjerkovača	Brestovica	Mušići	Ramići
Year of origin	1985	1985	1987	1982	1982	1982	1983
Elevation (m)*	293	287	207	318	285	357	378
Geographic coordinates	44°23'37''N 18°38'41''E	44°24'33''N 18°37'40''E	44°31'42''N 18°34'44''E	44°23'56''N 18°36'07''E	44°24'14''N 18°35'38''E	44°23'45''N 18°30'24''E	44°25'06''N 18°25'29''E
Lakes area (ha)	2.5	1.38	20.8	–	–	5.53	6.2
Max. lake depth (m)	18	14	33	20.5	8	6	18
Geological basis	marl	marl	sandy	marl	serpentine	marl	marl and serpentine
Bottom vegetation	Cl. *Charetea fragilis*	Cl. *Charetea fragilis*	Cl. *Charetea fragilis*	not present	not present	Cl. *Potametea*	Cl. *Potametea*

*Elevation refers to the surface of lake water

dominating. The other sides of the lake consist of steep cliffs without vegetation. The littoral area of Šićki Brod Lake on the north side (Location 3) and on the east side is covered with submerged vegetation of the *Charetea fragilis* class, while other sides are steep and provide no conditions for the development of submerged plants. At this lake there are also progradational stages with *Salix* spp., while the south and west shores are covered with a spread belt of vegetation with *Phragmites australis* dominating. Macrophytic vegetation is absent at Sjerkovača Lake (Location 4) and Brestovica Lake (Location 5). The shore area of Sjerkovača Lake is covered with weed communities of the class *Bidentetea tripartiti*, while Brestovica Lake is surrounded by meadow communities and progradational stages of willow grove. The littoral zone of the Mušići Lake on the south side (Location 6) and on the west side is partially covered with the vegetation from the class *Potametea*, to which communities with *Typha* spp. and *Phragmites australis* are attached. Aquatic vegetation is not present at the other sides due to the vertical pit wall. The littoral zone of Ramići Lake on the north and east sides (Location 7) is overgrown with fragmentarily developed vegetation of the class *Potametea*. Submerged vegetation is absent on the west and south sides; however, the shore area is covered with emergent vegetation dominated by *Phragmites australis*.

MATERIALS AND METHODS

The research was conducted in August 2008 on seven pit lakes of the Tuzla area in north-eastern Bosnia and Herzegovina. In the field phase phytobenthos and epiphyton samples were collected, phytosociological observations of the macrophytic vegetation were made and samples for the physical and chemical water analyses were taken.

The samples of phythobenthos and epiphyton were collected by scrubbing from the natural surface and by filtrating macrophytic species in the littoral area of the seven investigated lakes at the depth of 0.3–0.5 meters. The chosen samples are from different physiographical characteristics: the presence and absence of macrophytic vegetation, the type of macrophytic vegetation and the geological surface. The algal samples were fixed on site with 4% formaldehyde.

The research into the physical/ chemical properties of the water was done in the field and in the laboratory. The water temperature and the pH of water were measured in the field, while other physical/chemical parameters (turbidity, total alkalinity, carbonate hardness, noncarbonated hardness, total hardness, dissolved oxygen, oxygen saturation, $KMnO_4$ consumption, total nitrogen, ammonium, nitrite, nitrate, calcium, magnesium, electrical conductivity) were determined in the laboratory of the Institute for Chemical Engineering in Tuzla, by the standard procedure of the American Health Organization (APHA, AWWA & WEF, 1995). Water samples for physical/chemical analysis were taken at a depth of 0.5 m below the water surface.

Shortly before algal samples were taken, phytosociological observations of the macrophytic vegetation were made by using the method of the Zürich – Montpellier school (BRAUN-BLANQUET, 1964). Detailed determination of the macrophytic plant species was made based on herbarium material and the use of following literature sources: DOMAC (1973), JAVORKA & CSAPODY (1979), TUTIN *et al.*, (1964–1993), KREMER (2005). Based on the phytosociological observations, the determination of the type of habitat on the researched localities was done using the instructions from Annex I of the Habitat Directive (EUROPEAN COMMUNITIES, 1992).

The determination of algae was made in the laboratory. Macroscopically visible representatives of different parts of algae were identified by a binocular magnifying glass and removed, and the remaining materials were reviewed under magnifying light microscope (magnification 400 x and 1000 x). Diatoms were identified from the permanent preparations, made after chemical treatment of the materials by the method of HUSTEDT (1930) and embedded in Canada balsam. The laboratory identification was carried out to species or genus level using keys for determination: HUSTEDT (1930), ZABELINA *et al.* (1950), LAZAR (1960), HINDAK *et al*. (1978), CVIJAN & BLAŽENČIĆ (1996). Relative abundance was estimated according to PANTLE & BUCK (1955) with numbers 1, 3 and 5 (1 – single, 3 – customary, 5 – dominant). The saprobic state of the pit lakes (Saprobic Index) was calculated on the basis of a list of indicator organisms (according to WEGL, 1983) using the Pantle-Buck Index (PANTLE & BUCK, 1955).

In the statistical analysis we used the method of numeric classification. The Bray – Curtis index (BRAY & CURTIS, 1957) was used as a distance measure, following by cluster analysis. The aim of numeric classification in the vegetation research is to group the set of samples into classes based on their floristic composition. The analysis was conducted with the use of the BioDiversity Pro version 2 software packages.

RESULTS AND DISCUSSION

Physical and chemical properties of water

The physical/chemical water analysis shows that the water of all seven researched lakes has a neutral or weak alkaline reaction, satisfactory oxygen regime and

Tab. 2. The physical and chemical parameters of water quality of the researched lakes

Indicators	Unit	L. 1	L. 2	L. 3	L. 4	L. 5	L. 6	L. 7
Water temperature	°C	26	26	25.5	26	26.5	24	26
Turbidity	NTU	1.5	2	1.3	3.4	12	2.5	3.5
pH value		8.1	8.3	8.2	8.3	8	7.8	8.3
Total alkalinity	mg $CaCO_3$/L	157	255	147	85	182	287	172
Carbonate hardness	°dH	8.8	14.3	8.3	4.8	10.2	16.1	9.7
Noncarbonated hardness	°dH	11.2	2.2	8.3	0	0	40.3	0.1
Total hardness	°dH	20.2	16.5	26.5	4.8	10.2	56.4	9.8
Dissolved oxygen	mg/L	10	10.2	8.7	9.6	8.7	10.2	8.5
Oxygen saturation	%	116	133	109	119	110	127	104
$KMnO_4$ consumption	mg/L	10.5	16.3	14.2	16.9	24	12.6	17.2
Total nitrogen	mg/L	0.18	0.32	0.02	0.15	0.27	1.46	0.18
Ammonium	mg/L	0.16	0.31	0.02	0.1	0.22	0.59	0.16
Nitrite	mg/L	0.018	0.013	0.004	0.016	0.007	0.424	0.004
Nitrate	mg/L	0	0	0	0.03	0.04	0.45	0.02
Calcium	mg/L	44.1	31.1	122	26	35.1	222.4	31.1
Magnesium	mg/L	60.2	52.9	40.7	4.9	23.1	110	23.7
Electrical conductivity	μS/cm	535	413	682	154	279	1562	280

generally low concentration of total nitrogen, except for Mušići Lake. This lake has the highest level of water hardness, high calcium and magnesium concentrations, high value of electrical conductivity and the highest value of total nitrogen. Sjerkovača Lake has the lowest values of total alkalinity, total water hardness and concentration of calcium and magnesium and electrical conductivity (Tab. 2).

Taking in consideration the results of cluster analysis based on the physical/chemical parameters, Mušići Lake shows the least similarity with other lakes. On the other hand, the lakes Brestovica and Ramići make a clearly differentiated group on the dendrogram (Fig. 4), and they have relatively similar physical and chemical parameter values. The cause is probably the similarity of the geology as serpentine rocks are present in both lakes (Tab. 1).

The dendrogram singled out the lakes Suhodanj, Šićki Brod and Požar, which are characterized by the lowest values of water turbidity, relatively higher values of total alkalinity and total water hardness and low concentration of nitrogen compounds.

NIXDORF *et al.* (2005) developed an approach to classify mining lakes according to their acidity, buffering systems and planktonic colonization. This authors classified pit lakes into five categories: neutral (pH>7), weakly acidic A1 (pH 4.5–7), mo-

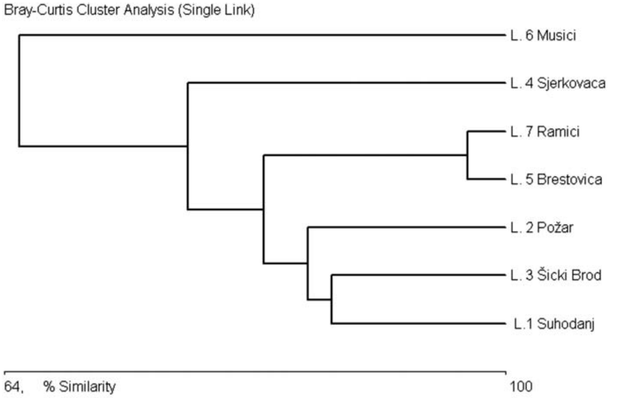

Fig. 4. Cluster analysis of the samples based on the physical and chemical water analysis

derately acidic A2 (pH 3.5–4.5), very acidic A3 (2.8–3.5) and extremely acidic A4 (<2.8). According to these authors, almost all investigated pit lakes in the Tuzla area can be classified as mesotrophic hard water lakes.

The submerged macrophytes in the pit lakes

Comparing the floristic composition of the macrophytic communities in the field with the floristic composition of swamp habitats stated in the Interpretation Manual of European Union Habitats (EUROPEAN COMMUNITIES, 2007), the aquatic vegetation was differentiated in two types of habitat. At the localities of the lakes Suhodanj, Požar and Šićki Brod the type of habitat determined was: hard oligo-

Tab. 3. Vegetation of the habitat type: Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp. The first number in the table for each taxon stands for cover, while second number refers to sociability of taxa, Braun-Blanquet approach (1964).

The habitat type	**Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.**		
Natura code		3140	
Localities	L. 1	L. 2	L. 3
Date	8.8.2008.	8.8.2008.	9.8.2008.
Floristic composition			
Chara vulgaris Vail.	4.5	4.4	2.3
Myriophyllum spicatum L.	1.1	3.2	1.1
Potamogeton natans L.	3.3	.	1.1
Potamogeton crispus L.	+.1	.	.
Batrachium trichophyllum /Chaix/Bosch	.	.	.
Chara globularis Thuillier	.	.	4.4
Potamogeton filiformis Pers.	.	.	3.4
Nitella sp.	.	.	2.2

-mesotrophic waters with benthic vegetation of *Chara* spp. (Natura code 3140). This habitat consisted of lakes and pools with waters fairly rich in dissolved bases (pH often 6–7) or with mostly blue to greenish, very clear, waters, poor (to moderate) in nutrients, base-rich (pH often >7.5). The bottom of these unpolluted water bodies is covered with charophyte, *Chara* and *Nitella*, algal carpets (EUROPEAN COMMUNITIES, 2007).

In the macrophyte communities of this type of habitat, taking in consideration all localities, eight species were identified. At Suhodanj Lake (locality 1) this type of habitat comprised: *Chara vulgaris* Vail., *Myriophyllum spicatum* L., *Potamogeton natans* L., *Potamogeton crispus* L. and *Batrachium trichophyllum* /Chaix/Bosch. At Požar Lake, the habitat Natura code 3140 is made up of only two species: *Chara vulgaris* Vail. and *Myriophyllum spicatum* L. At locality 3, Šićki Brod Lake the following species were found: *Chara globularis* Thuillier, *Potamogeton filiformis* Pers., *Chara vulgaris* Vail., *Nitella* sp., *Myriophyllum spicatum* L. and *Potamogeton natans* L. (Tab. 3).

At the localities of lakes Mušići and Ramići, the type of habitat identified was: natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* – type vegetation (Natura code 3150). This habitat consists of lakes and ponds with mostly dirty grey to blue-green, more or less turbid, waters, particularly rich in dissolved bases (pH usually >7), with free-floating surface communities of *Hydrocharition* or, in deep, open waters, with associations of large pondweeds (*Magnopotamion*) (EUROPEAN COMMUNITIES, 2007). At those localities only two macrophytic species were identified: *Myriophyllum spicatum* L. and *Potamogeton natans* L. (Tab. 4).

At the localities Sjerkovača and Brestovica (L.4 and L.5) no aquatic vegetation in the littoral zone of the lake was present.

Macrophytes growing on the shores of coal mine pit lakes in the Lusatian lignite mining district were studied by PIETSCH (1996), who distinguishes five main stages of vegetation succession in aquatic, semiaquatic and in terrestrial areas: the stage of primary colonization and spontaneous vegetation; the stage of monodominant species stands; the stage of the formation of vegetation mosaics; the stage of the formation of plant associations; the final stage of succession. In the Lusatian lignite mining district, *Juncus bulbosus* is the indicator species of aquatic colonization (PIETSCH, 1996). Following the successive stages described by Pietsch, the structure of vegeta-

Tab. 4. Vegetation of the habitat type: Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* – type vegetation. The first number in the table for each taxon stands for cover, while second number refers to sociability of taxa, Braun-Blanquet approach (1964).

The habitat type	**Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* – type vegetation**	
Natura code	3150	
Localities	L. 6	L. 7
Date	8.8.2008.	9.8.2008.
Floristic composition		
Potamogeton natans L.	3.2	2.1
Myriophyllum spicatum L.	1.1	2.2
Chara vulgaris Vail.	.	+.1

tion in all the investigated lakes, except for lakes Sjekovača and Brestovica, pertains to the third and fourth phase of the colonization of macrophytes in the littoral area. This indicates that lakes formed by degradation activities have an ability to remediate. However, it should be noted that aquatic vegetation in the studied lakes develops only in fragments, in the littoral coast of the lower slope. KAMBEROVIĆ (2010) observes the phenomenon of the water-level variations during a year at the Sjerkovača and Brestovica lakes in the range higher than one metre. This process may be one of the reasons for the absence of aquatic plants in the littoral zone of these lakes.

The presence of species of *Characeae* in the investigated pit lakes has a favourable effect on water quality, as according to many authors these species have the ability to remove metals and radio-nuclides from contaminated waters (KRAUSE, 1981; DUSAUSKENE-DUZ & POLIKARPOV, 1978; In: KALIN & SMITH, 2007). Bearing in mind that the presence of macrophytes is very important in the remediation of pit lakes, KALIN & SMITH (2007) conducted a survey on the relevant factors that influence germination of oospores of various *Characeae* species, from clean and mining-contaminated water bodies. They suggest that changes in the redox regime can be triggers to initiate germination of oospores. They also found that oospores taken from nickel--contaminated mine water bodies have a reduced viability. According to our observations, species of *Characeae* were observed in lakes with similar values of electrical conductivity (413–682 µS/cm), but for more concrete conclusions it is necessary to conduct much more detailed research.

The algal flora of the pits lakes

A total of 73 taxa of algae were identified in the investigated microhabitats. The most numerous are *Bacillariophyceae* with 48 taxa (65.8 %), followed by the *Cyanobacteria* with 11 taxa (15 %), *Zygnematophyceae* with 10 taxa (14%), *Chlorophyceae* with 3 taxa (4.1%) and *Dinophyceae* with one representative (1.4 %). The number of taxa varied from 17 at L.1 and L.4 to 23 at L.2 and L.6 (Fig. 5, Tab. 5).

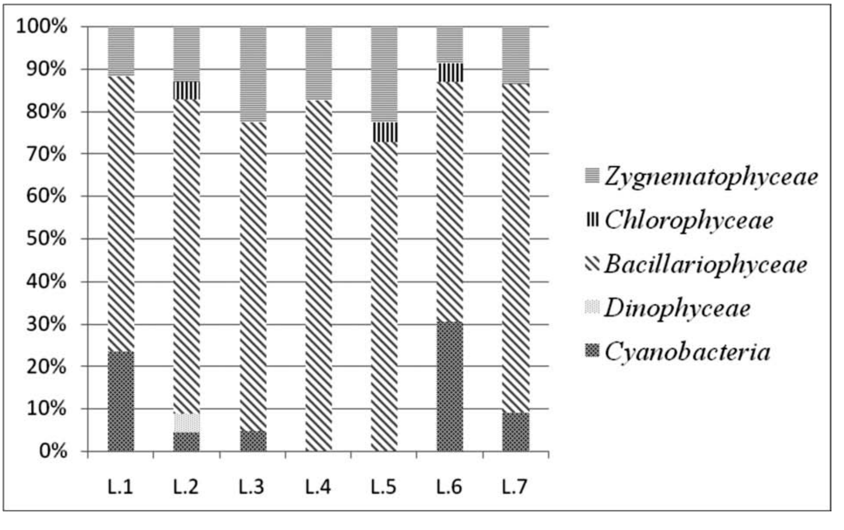

Fig. 5. The average proportion (%) of algal groups

Tab. 5. Qualitative and quantitative (relative abundance) composition of phytobenthos and epiphyton from investigated localities

Taxon /Locality	**L.1**	**L.2**	**L.3**	**L.4**	**L.5**	**L.6**	**L.7**
Cyanobacteria							
Gleocapsa sp.(Kutz.) Holerb.						1	
Merismopedia glauca (Ehr.) Nag.						1	
Merismopedia tenuissima Lemm.						3	1
Microcystis sp.(Kutz.) Elenk.	1						
Oscillatoria agardhii Gom	3						
Oscillatoria amoena (Kutz.) Gom.						1	
Oscillatoria deflexoides Elenk. et Kossinsk.			1				1
Oscillatoria grannulata Gom.	3					1	
Oscillatoria simplicissima Gom.	1						
Oscillatoria sp.		1				1	
Spirulina subtilissima Kutz.						1	
Dinophyceae							
Peridinium bipes Stein.		1					
Bacillariophyceae							
Achnanthes flexella (Kutz.) Brun	1	1					
Achnanthes minutisima Kutz.		1		3	3	1	1
Amphipleura pellucida (Kutz.) Kutz.			1				
Amphora ovalis (Kutz.) Kutz.	1		1		1	1	1
Cocconeis placentula Ehrenb.		3				1	1
Cyclotella compta (Ehrenb.) Kutz.	5	1					
Cyclotella meneghiniana Kutz.						1	1
Cyclotella sp. Kutz.			1	1			
Cymatopleura elliptica var. elliptica (Breb.) W. Smith					1		
Cymatopleura solea (Brébisson) W. Smith			1	3	3		
Cymbella affinis Kutz.	3	3	3	1	3		
Cymbella cistula (Hempr.) Kirchn.		1					
Cymbella helvetica Kutz.		3					
idctlpar*Cymbella lanceolata* (Ehrenb.) V. Heurck		1					
Cymbella prostrata (Berk.) Cl.				1	1		
Cymbella tumida (Breb.) V. Heurck						1	1
Diatoma tenue Ag.	1						
Diatoma vulgare Bory		1	1	3		1	1
Eunotia arcus Ehrenb.	1	1	1				
Fragillaria construens (Ehrenb.) Grun.		3					
Fragillaria crotonensis Kitt.					1		
Gomphonema acuminatum Ehrenb.				1			

Gomphonema olivaceum (Lyngb.) Desm.							3
Gyrosigma attenuatum (Kutz.) Rabenh.			1	3	3		
Hantzschia amphioxys (Ehrenb.) Grun							1
Meridion circulare (Grev.) Ag.		1		1			1
Navicula cryptocephala var. cryptocephala Kutz						3	
Navicula cuspidata (Kutz.) Kutz.			1	3	5	3	1
Navicula exigua Grun.	3					1	
Navicula gracilis Ehrenb.		1					3
Navicula pupula Kutz.				1	1	1	1
Navicula radiosa Kutz.	3	3	3	5			
Navicula rhynchocephala var. elongata Mayer					3		
Nitzschia angustata (W. Smith) Grun.							1
Nitzschia linearis (Ag.) W. Smith		1		1	1		
Nitzschia sigmoidea (Ehrenb.) W. Smith						5	
Nitzschia sinuata (W. Smith) Grun.			1				
Pinnularia microstauron (Ehrenb.) Cl.							1
Pinnularia sp.Ehrenb.					3		1
Pinnularia viridis (Nitzsch) Ehrenb.			1				
Rhopalodia gibba (Ehrenb.) O. Mull.	1	1	3				1
Stauroneis anceps Ehrenb.			1				
Surirella capronii Breb.					1		
Surirella elegans Ehrenb.					1		
Surirella splendida (Ehrenb.) Kutz.			1				
Synedra acus Kutz.	1						
Synedra fasciculata (Ag.) Kutz.						1	
Synedra ulna (Nitzsch) Ehrenb.	1	1	1	1	1	1	1
Chlorophyceae							
Hormidium nitens Menegh em. Klebs.		1					
Hormidium sp. Klebs.					1		
Scenedesmus abundans (Kirchn.) Chod.						1	
Zygnematophyceae							
Closterium sp.Nitzsch			1	1	1		
Cosmarium sp. Corda	1		1			1	
Cosmarium subtumidum Nordst.					1		
Mougeotia sp. Ag.	1	5	5		3	3	5
Pleurotaenium trabecula (Ehrenb.) Nag.				1	1		
Spirogyra sp. Link							1
Spirogyra tenuissima (Hass.)Kutz.				1	1		
Spirogyra varians (Hass) Kutz.		1					
Staurastrum brevispinum Breb.			1				
Zygnema insigne (Hass.) Kutz.		1	1				3

The genera with the greatest number of algae present were *Navicula*, *Cymbella*, *Nitzschia* and *Oscillatoria*. A certain number of species were present in almost all samples: *Synedra ulna* (Nitzsch) Ehrenb., *Mougeotia* sp. Ag. and *Cymbella affinis* Kutz. The highest degree of stability of species (present in over 50% of the samples) was for these algae: *Cymbella affinis, Navicula cuspidata, Synedra ulna, Rhopalodia giba, Navicula radiosa, Cocconeis placentula* and *Mougeotia* sp.

In the sample from Suhodanj Lake the species *Cyclotella compta* and *Cymbella affinis* were dominant and according to HINDAK *et al.* (1978) they inhabit the alkaline bottom of still and flowing waters having oligo-/β-mesosaprobic degree of saprobity. *Cymbella affinis* is cosmopolitan species in the Nordic and temperate area, alkaliphilic, preferring waters with an average electrolyte content (300–400 μS/cm) and a hardness of more than 15 °dH (KRAMMER, 2002).

At Lake Požar, *Cocconeis placentula* and *Mougeotia* sp., which are widespread in alkaline still and flowing waters, frequently as epiphytes (HINDAK *et al.*, 1978), had a dominating role in the composition of phytobenthos and epiphyton.

In the algal sample on Šićki Brod Lake the dominant taxa were *Cymbella affinis, Rhopalodia gibba, Navicula radiosa* and *Mougeotia* sp. which indicate oligosaprobic and β-mesosaprobic water quality (WEGL, 1983). *Rhopalodia* is most common in alkaline water, occupying microhabitats that are relatively poor in quantities of fixed nitrogen (nitrate and ammonium) (FAIRCHILD *et al.*, 1985; In: WEHR & SHEATH, 2003). A total of 22 taxa were determined in phytobenthos and epiphyton of this lake. The analysis of qualitative composition of phytoplankton, conducted in 1994 (ORUČ & ARNAUTALIĆ, 1996) indicated relative poorness in terms of number of species. In summer samples, they found a total of five taxa (*Pinnularia* sp., *Ceratium hirundinella*, *Gymnodinium* sp., *Ulothrix* sp. and *Zygnema* sp.), and altogether 13 taxa during the whole year. Although they sampled a different community of algae, we can assume that higher species diversity was observed in our investigation (after 14 years). This trend would indicate an improved water status.

On Sjerkovača Lake, taking in consideration the absence of aquatic vegetation in the water, there is a change in the composition of phytobenthos, so this lake is dominated by *Cymatopleura solea*, which according to HINDAK *et al.* (1978) inhabits the benthos of eutrophic β-mesosaprobic to α-mesosaprobic still waters.

At the locality Brestovica, a great abundance of *Navicula cuspidata* was determined and this species, according to HINDAK *et al.* (1978), inhabits the alkaline bottom of still and flowing waters of β-mesosaprobic-/α-mesosaprobic water.

In the algal sample from Ramići Lake a significant share was taken by *Mougeotia* sp. and *Navicula gracilis*, indicators of β-mesosaprobic water status (WEGL, 1983).

At Mušići Lake, *Nitzschia sigmoidea* and *Merismopedia tenuissima* are dominant. *M. tenuissima* is very common in planktonic communities and it is more frequent in eutrophic freshwaters, but occasionally it can be also found in brackish waters (SANT'ANNA *et al.*, 2004). *N. sigmoidea* is common and widespread benthic species in meso- to eutrophic waters (BELLINGER & SIGEE, 2010). WEHR & SHEATH (2003) describe many varieties of the *Nitzschia* genus as indications of organic pollutions in water. In their book, they present Cholnoky's observations (1968) that this taxon is »pollution dependent« due to its ability to capitalise on organic nitrogen molecules in the water. High concentrations of total nitrogen in the water of Mušići Lake dominated by the species *N. sigmoidea* confirm these assumptions. This lake differs

Tab. 6. The number of algal taxa and Saprobic Index values

Locality	Lake	Number of algal taxa	Saprobic Index	Saprobity Degree*
L.1	Suhodanj	17	1.60	o-β
L.2	Požar	23	1.61	o-β
L.3	Šićki Brod	22	1.71	o-β
L.4	Sjerkovača	17	1.91	β
L.5	Brestovica	22	1.91	β
L.6	Mušići	23	2.11	β
L.7	Ramići	22	1.82	β

* o-β – oligo/beta-mesosaprobic zone, β – beta-mesosaprobic zone

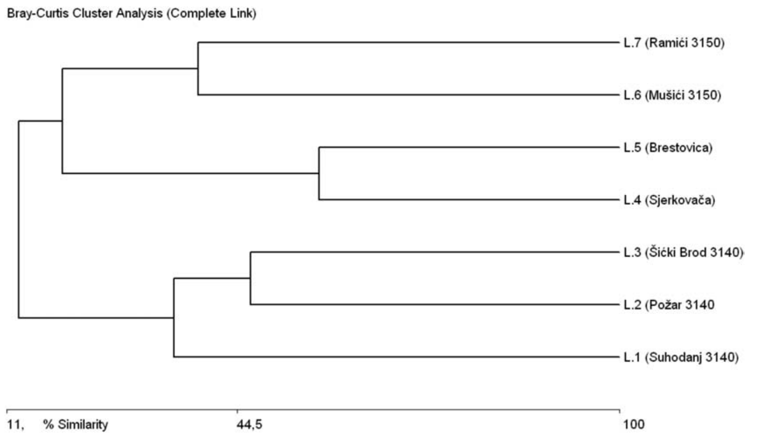

Fig. 6. Cluster analysis of the algal samples (numbers in brackets refers to the Natura codes of habitats)

from the other lakes by eight (8) taxa that not present and also has the highest percentage of *Cyanobacteria* (Tab. 5) found in the study. The observed properties might be due to the physical and chemical properties of the water of Mušići Lake (Tab. 2, Fig. 4).

Since the available literature data refer only on the phytoplankton communities of pit lakes, we cannot validly compare our results with results of similar studies. However, in a study of phytoplankton communities of B-zone pit-lake (Canada) a total of 35 genera, plus 8 unidentified taxa were recorded during 1992–1998. Six genera were dominant or abundant at least during certain times of the sampling period: *Dictyosphaerium*, *Cryptomonas*, *Oscillatoria*, *Nitzschia*, *Chlamydomonas* and *Dinobryon* (KALIN *et al.*, 2001). Compared with our results, only 7 genera were common amongst these two studies: *Achnanthes*, *Cosmarium*, *Cymbella*, *Nitzschia*, *Oscillatoria*, *Peridinium* and *Pinnularia.*

Studies on phytoplankton of 32 acidic lignite pit lakes of Lusatia (northeastern Germany) have shown that *Ochromonas* and *Chlamydomonas* are the most abundant genera where pH is less than 3 (NIXDORF *et al.*, 1998; LESSMAN *et al.*, 2000; in: KALIN *et al.*, 2006). A study of Bumerang Lake shows changes in the composition of phytoplankton throughout 17 years, after the lake was affected by acid mine drainage. As the pH of water decreased in this period from 5 to 3 and the concentration of metals in the water increased, some algae populations proliferated, such as *Lepocinclis*, while others declined, such as *Peridinium*, *Pinnularia* and *Euglena* (KALIN *et al.*, 2006). A comparison of our results with the results of the mentioned studies indicates large differences in the composition of algal communities. Taxa *Ochromonas* and *Chlamydomonas*, which are listed as most common in the majority of acidic pit lakes, were not found in pit lakes in the area of Tuzla. Considering the neutral and weakly alkaline water of these lakes, the differences in algal community structure are to be expected.

Statistical data analysis

The values of Saprobic Index of water quality for all localities are in the range from 1.60 to 2.11. The lakes Suhodanj, Požar and Šićki Brod were, as identified on the basis of phytobenthic and epiphytic algal community structure, characterized by oligo-/β-mesosaprobic status of water, while lakes Sjerkovača, Brestovica, Mušići and Ramići had β-mesosaprobic water status.

Cluster analysis of phytobenthos and epiphyton samples of the studied lakes, bearing in mind the presence of macrophytes and type of habitat, showed separation of samples into two groups (Fig. 6). The first group consists of algal samples L.1, L.2 and L.3, sampled at localities with vegetation of *Chara* spp., habitat type Natura code 3140. The biggest similarity in this group is among samples L. 2 and L.3 (% similarity = 46.4). Lakes Suhodanj, Šićki Brod and Požar also show similarity in the grouping of physical/chemical parameters. These results support the hypothesis that the algal community structure reflects the physical and chemical structure of water.

The second groups of the algal samples on the dendrogram are samples L.4, L.5, L.6 and L.7. Within this group there is a distinctly clustered subgroup of samples L.4 and L.5, which were taken from the lakes in which the macrophytes were absent (% similarity = 56.3). Another subgroup consists of samples L.6 and L.7 with vegetation of *Magnopotamion*, habitat type Natura code 3150 (% similarity = 38.8).

Cluster analysis of the phytobenthos and epiphyton samples confirmed grouping based on the type of habitat in which samples are taken. Specific taxa of algae for samples L.1, L.2 and L.3 (localities with vegetation of *Chara* spp.) were: *Cymbella affinis* Kutz., *Eunotia arcus* Ehrenb., *Navicula radiosa* Kutz., *Rhopalodia gibba* (Ehrenb.) O. Mull., *Synedra ulna* (Nitzsch) Ehrenb. and *Mougeotia* sp. Ag. In the samples of localities L. 6 and L.7 (localities with vegetation of the alliance *Magnopotamion*), specific species were: *Merismopedia tenuissima* Lemm, *Cyclotella meneghiniana* Kutz. and *Cymbella tumida* (Breb.) V. Heurck. The characteristic algal species of samples L. 4 and L. 5 were *Cymbella prostrata* (Berk.) Cl., *Gyrosigma attenuatum* (Kutz.) Rabenh., *Pleurotaenium trabecula* (Ehrenb.) Nag. and *Spirogyra tenuissima* (Hass.) Kutz.

Bearing in mind that this work presented preliminary results based on a sampling in the summer season, one can get only a restricted insight into the structure of communities of algae and macrophytes in pit lakes of the Tuzla area. There is a need for future investigations with monthly dynamics of sampling in order to get more a comprehensive view of the macrophyte and algal communities in investigated lakes.

CONCLUSION

The artificial lakes created by degradation activities during surface mining of coal in the wider area of Tuzla, unlike the majority of such lakes in the world, are characterized by a neutral or weak alkaline reaction of water, which gives them great potential for eventually becoming a wildlife habitat. In most cases, they have a good potential for colonization by macrophyte and microphyte taxa. Communities of algae were primarily influenced by water properties, but were also dependent on the presence and structure of macrophyte vegetation.

Our results suggest that further work addressing the ecological interactions in the pit lakes would lead to an understanding of the process of the colonization of the water bodies and thereby to a definition of useful and appropriate measures for restoration of the water quality and the preservation of the aquatic ecosystem.

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SAŽETAK

Alge i makrofiti kopovskih jezera šireg područja Tuzle, Bosna i Hercegovina

J. Kamberović & S. Barudanović

Na degradiranim površinama područja Tuzle i okolice, na površinskim kopovima ugljena, došlo je do formiranja brojnih vodenih tijela, tzv. kopovskih jezera. Jezera su formirana osamdesetih godina prošlog stoljeća i imaju vlastiti vodni režim. Osnovni cilj rada bio je ustanoviti strukturu zajednica fitobentosa, epifitona i makrofita u litoralnom području umjetnih jezera na površinskim kopovima ugljena u okolini Tuzle. Kao ciljevi su također postavljeni procjena kvaliteta vode istraživanih jezera i procjena utjecaja makrofita na zajednice algi.

Istraživanje je provedeno tijekom 2008. godine na sedam kopovskih jezera šireg područja Tuzle: Suhodanj, Požar, Sjerkovača, Brestovica, Mušići, Ramići i Šićki Brod. Na terenu su prikupljeni uzorci algi, uzorci za fizičko-kemijsku analizu vode i napravljeni su snimci makrofitske vegetacije.

U statističkoj analizi podataka korištene su metode indirektne ordinacije podataka. U okviru istraživanja sastava fitobentosa, determinirane su 73 svojte algi. Najprisutnije su bile *Bacillariophyceae* sa 48 taksona (65.8 %), potom *Cyanobacteria* sa 11 taksona (15 %), *Zygnematophyceae* sa 10 taksona (14%), *Chlorophyceae* sa 3 svojte (4.1%) i *Dinophyceae* sa samo jednom vrstom (1.4 %). U makrofitskoj vegetaciji svih istraživanih jezera pojavljuje se osam vrsta. Usporedbom rezultata klaster analize podataka, utvrđena je velika podudarnost u grupiranju uzoraka na osnovu fizičko-kemijske analize vode i uzoraka algi prikupljenih na tim jezerima. Takođe, klaster analiza zajednica algi potvrđuje grupiranje uzoraka i po kriteriju tipa staništa i sastava makrofitske vegetacije na lokalitetima uzorkovanja algi. U većini slučajeva, umjetna jezera nastala usljed degradacijskih aktivnosti površinske ekspoatacije uglja na širem području Tuzle, imaju dobar potencijal za kolonizaciju makrofitskih i mikrofitskih vrsta.