Utricularia vulgaris L. AND *Salvinia natans* (L.) All. HEAVY METAL (Fe, Mn, Cu, Zn AND Pb) BIOACCUMULATION SPECIFICITY IN THE AREA OF BARDAČA FISHPOND

TANJA MAKSIMOVIĆ¹, SRĐAN RONČEVIĆ², BILJANA KUKAVICA^{3*}

¹Department of Biology, Faculty of Natural Sciences and Mathematics, University of Banja Luka, Mladena Stojanovića 2, 78000 Banja Luka, Republic of Srpska, Bosnia and Herzegovina; e-mail: tanja.maksimovic@pmf.unibl.org

²Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 2, 21000 Novi Sad, Serbia; e-mail: srdjan.roncevic@dh.uns.ac.rs

³Department of Biology, Faculty of Natural Sciences and Mathematics, University of Banja Luka, Mladena Stojanovića 2, 78000 Banja Luka, Republic of Srpska, Bosnia and Herzegovina; e-mail: biljana.kukavica@pmf.unibl.org

* Author for correspondence

Abstract

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Paper deals with seasonal changes in heavy metal bioaccumulation (Fe, Mn, Cu, Zn and Pb) in *Utricularia vulgaris* L. and *Salvinia natans* (L.) All. of two localities (Necik and Sinjak – active fishpond basins) in the area of Bardača fishpond. According to our results, the better accumulator of Fe (3035 mg/kg) and Zn was *S. natans* (163.55 mg/kg), whereas *Utricularia vulgaris* better accumulates Mn (620 mg/kg) and Cu (10.18 mg/kg). Amounts of Pb in both investigated macrophyte were below the detection level (<0.51 mg/kg). The values of the bioaccumulation factor (BAC) of the tested metals were >1 or ~1 for both species, and the BAC values decreased in the following order in both investigated species: Fe > Mn > Cu > Zn. The results obtained indicated that tested macrophyte show very good characteristics as bioaccumulators and, thanks to this fact, they could be used in phytoremediation technique successfully in water-polluted ecosystem.

Key words: heavy metals, bioaccumulation, *Utricularia vulgaris* L., *Salvinia natans* (L.).

Introduction

Heavy metals are natural components of Earth's crust, but in many ecosystems, concentration of certain heavy metals reached toxic levels because of consequences of anthropogenic activities. In the recent years, pollution of environment with heavy metals has become a great global problem of modern society with characteristic cumulative effect (Prasad, 2003; Ghosh, Singh, 2005; Prasad et al., 2006; Liu et al., 2007; Rai, 2009; Nouri, Haddioui, 2016). Exposure of plants to toxic levels of heavy metals starts a wide spectrum of physiological and metabolic changes (Prasad, 2003; Prasad et al., 2006), which include the following: decrease in plant's growth, changes in cell metabolism, damage of cell membranes, inhibition of mem-

brane proteins, changes mineral nutrition and inhibition of photosynthesis, which leads to senescence and, at the end, to plants death (Prasad, 2003; Prasad et al., 2006). Aquatic plants have a good ability to tolerate increased levels of heavy metals and accumulate them up to unusually high concentrations, causing accumulative effect without significant consequences to metabolic processes (Liu et al., 2007; Rai, 2009; Babović et al., 2010; Pant, Tripathi, 2014). Plants growing in polluted environment are very often under stress because of bioaccumulation through direct uptake by root, stem or sprouts (Prasad et al., 2006; Liu et al., 2007; Borišev et al., 2008; Rai, 2009; Babović et al., 2010).

Current technologies available for mitigation of pollution are very expensive, and in most of cases, they represent a cost for industry (Rai, 2009). Hence, lately, aquatic macrophytes are used as bioindicators of water quality and phytosanitors of water pools more often. There is a constant intention to incorporate waste water purification methods by these plants into directives. Different studies (Liu et al., 2007; Borišev et al., 2008; Rai, 2009; Babović et al., 2010) showed that aquatic macrophytes concentrate certain metals up to different degree and, hence, critical levels could vary among species.

Numerous studies of aquatic plants were performed in laboratory conditions, whereas small number of researches on potential of heavy metals bioaccumulation was made in the field environment. Owing to this, the aim of our study was to examine the ability of aquatic plants to accumulate heavy metals in their natural environment and the possibility of their use as bioindicators. Macrophytes can accumulate a considerable amount of heavy metals (10–10⁶ times higher than their concentration in aquatic environments) in their tissue without disturbing their normal metabolism (Prasad, 2006). Plants chosen for investigation were different in position of sprout in air or water environment, as well as in relation of connection to the ground or free floating (emerged, submerged-not-rooted and floating-not-rooted) and per system of heavy metals bioaccumulation. *Utricularia vulgaris* (submerged-not-rooted) because of a thin cuticle absorbs heavy metals through the entire surface of the leaf from the water (Prasad, 2006), whereas *Salvinia natans* (floating-not-rooted) absorbs pollutants from the water and also from the air (Prasad, 2006).

Material and methods

Study area

Swamp-marsh ecosystem complex Bardača is located at the far North-East of Lijevče polje (Lijevče field in English), bordering the Sava river at North, Brzaja and Vrbas rivers at East, Matura at West, whereas perimeter canal Osorna-Borna-Ljevčanica (O-B-LJ) is located in immediate vicinity at South (Fig. 1) (Šarić et al., 2004).

On 02 March 2007, Bardača was declared as Ramsar area (number 1658), which confirmed its international importance as the 'Important Bird Area'. However, after gaining Ramsar area status, under the strong anthropogenic influence, there was a significant devastation of this sensitive ecosystem. Consequently, constant monitoring and assessment of the heavy metal load in this endangered area is one of the measures of revitalisation. Previous research (Maksimović et al., 2007; Maksimović, Ilić, 2008; Maksimović et al., 2016) and our results related to the content of heavy metals in aquatic macrophytes will determine the reliability of their use for water quality monitoring as well as the role of macrophyte vegetation in the remediation of pollutants, especially during the period of intensive fish breeding.

Plants samples (1 kg) were collected in shallow parts of fishponds. From each site, the collection and analysis of whole plants of *S. natans* and *Utricularia vulgaris* during the vegetation season were carried out at all stages of their

Fig. 1. Map of Bardaća fishpond (a detail from topographic map 1:25,000), Nova Gradiška (Razboj-Ljevcanski) 4-4, Vojnogeografski institut, 1977 (Military Geographic Institute).

growth and development (May to September). At the same places, sediment samples were taken from a depth of 0–20 cm. Sediment was dried first at room temperature and then at 105 °C, milled to a powder and sieved through a fine sieve ($\leq 500 \mu\text{m}$). Sediment samples were prepared for further analyses by standard methods (APHA, 1995).

Sample analysis

In the laboratory, plant material was sorted, rinsed in tap and distilled water, dried in dryer at 105 °C and was prepared for further chemical analysis applied for water and water plants (APHA, 1995). Concentrations of micro-elements (heavy metals) were defined by atomic absorption spectrophotometry (AAS) directly from basic liquid. Samples were recorded on atomic absorption spectrometer Analyst 700, produced by Perkin Elmer, USA, using flame technique, standard method EPA 7000B.

Statistical analysis

The results were statistically processed using SPSS program (Statistical Package for the Social Sciences) 13.0 POZA 69. All the analyses were performed in three independent repetitions, and the analysed parameters were processed using variance method (ANOVA) factorial experiment. On the basis of the results obtained for the metal content in this article, water categorisation was made by the Decree on Water Classification and Categorization of Water-courses, Sl. glasnik Republike Srpske (2001) and classification of sediments according to the Netherlands (VROM, 2000) and Canadian recommendations (Canadian Council of Ministers of the Environment, 1999). Each analysis was repeated three times.

Data analysis

The values of BCF and BAC were used to evaluate potential plant species in phytoremediation techniques (Rahmani, 1999; Li et al., 2007). The ability of plants to accumulate heavy metals from water is estimated using the bioconcentration factor (BCF). Bioaccumulation coefficient (BAC) calculated as the ratio of heavy metal content in the above ground to the content of heavy metals in the sediment (Li et al., 2007).

$$BAC = \frac{[Metal]_{plant\ above-ground\ part}}{[Metal]_{sediment}} \ .$$

The BCF value is calculated as the ratio of the concentration of heavy metals in the tissue of plants relative to its content in water (Rahmani, Sternberg, 1999). High BCF values involve a higher ability of the plant to bioaccumulate a particular heavy metal.

$$BCF = \frac{[Metal]_{part\ of\ plant}}{[Metal]_{wather}} \ .$$

Results and discussion

Heavy metal concentration in water

The results of Maksimović and coworkers (Maksimović et al., 2007, 2016) showed increased concentrations of Pb and Zn in fishponds, Necik and Sinjak. On the basis of the concentrations of Pb and Zn and according to the Regulation on Classification of Water and Categorization of Watercourses (2001), investigated fishponds belonged to the class III/IV of water quality. On the other hand, according to the concentrations of Fe, Mn and Cu, the investigated fishponds belonged to class III/IV (Fig. 2). The authors emphasised that fishponds are waste water recipes: agricultural activities near the pool can cause pollution in an extent that is higher than the pools self-purification, which leads to an increase in the content of heavy metals.

Fig. 2. Average values of heavy metal content in water at research sites (mg/L) for locality Necik (left) and Sinjak (right) during the period from May to September.

Heavy metal concentration in sediments

We measured the content of heavy metals (Fe, Mn, Zn and Pb) in sediments of fishponds, Sinjak and Necik, as well as their content in tissues of *U. vulgaris* and *Salvinia natans*. Fe content in the sediments on both the investigated fishponds was significantly higher compared to other metals (Table 1).

Table 1. Heavy metal contents (Fe, Mn, Zn, Cu and Pb) in sediment on Necik and Sinjak locality (mg/kg). Values are expressed as mean ± SD (n = 3). The different letters in each row show a statistically significant difference (p < 0.05) for one heavy metal per month.

	Heavy metal	Period (month)				
		May	June	July	August	September
Necik	Fe	618.33 ^a	615.82 ^b	616.66 ^b	619.16 ^a	619.16 ^a
	Mn	206.66 ^d	257.50 ^b	226.66 ^c	189.99 ^c	224.99 ^c
	Zn	66.74 ^d	63.33 ^c	69.74 ^b	71.66 ^a	71.00 ^a
	Cu	6.08 ^d	7.16 ^c	17.72 ^a	10.50 ^b	6.91 ^d
Sinjak	Fe	620.00 ^a	618.33 ^b	617.49 ^c	618.33 ^b	618.33 ^b
	Mn	355.83 ^a	345.83 ^a	250.83 ^c	204.49 ^d	292.49 ^b
	Zn	67.25 ^a	60.00 ^b	55.16 ^c	51.66 ^d	60.08 ^b
	Cu	9.99 ^a	6.99 ^b	2.83 ^f	5.83 ^d	5.16 ^e

Concentration of Fe was in the range 616.66–620 mg/kg, and in the fishpond Sinjak, higher Fe content was measured in comparison with the pond Necik. The values that we measured for Fe in the sediment of Sinjak and Necik were lower compared to that of Srebrno jezero (9.060 mg/kg) (Yurkova, Kochev, 1996), Begečka jama (1.2374 mg/kg) and Koviljski rit (16.154 mg/kg) (Štrbac et al., 2014). Mn content in the sediment varied more during the season (Table 1) and was two to three times lower than Fe contents. However, the measured concentrations of Mn was five times higher in relation to the previously obtained results on the same localities (Maksimović, Ilić, 2008) and also higher in comparison with other studies of similar localities (Yurkova, Kochev, 1996; Stanković et al., 2000; Pajević et al., 2002) where authors stated that Mn concentration varied depending on the adoption ability of aquatic macrophytes and chemical conditions of sediment. Zinc content in sediment of Necik during the research period was in the range 63–71 mg/kg, and that in Sinjak was 51–67 mg/kg, wherein the highest Zn concentration was measured in July in Necik sediment. Compared to localities Obedska Bara, Ludoš, Carska Bara (Prica et al., 2005), Tisa River (Štrbac et al., 2014) and Velenjsko jezero (Slovenia) (Grudnik, 2010), the detected values for Zn on the research localities were significantly lower. As was shown in previous research, the higher zinc concentrations in river sediments is in soluble form, associated with Fe and Mn oxide, carbonate and organic matter, whereas 30% of Zn is not dissolved (Tyler, Olsson, 2001), which probably resulted in lower content of Zn in the sediment compared to that of Fe and Mn. It is known that in acidic environment and in oxidising conditions, contents of soluble form of zinc are increased (Tyler, Olsson, 2001), so it could be assumed that changes in pH and oxygen contents during season affected the availability of Zn in sediment of researched basins.

Copper contents in the sediment of Sinjak and Necik (Table 1) were significantly lower comparing to those in other researched elements. So, Cu contents in Necik locality during the research period was in the range 6.08–17.72 mg/kg, and that in Sinjak locality was in the range 2.83–9.99 mg/kg, whereas in Necik locality, 34% higher contents of Cu was measured. Compared to localities Obedska Bara, Ludoš, Carska Bara (Prica et al., 2005), Paličko jezero (Raičević et al., 2011), Tisa River (Štrbac et al., 2014) and Velenjsko jezero (Grudnik, 2010), where Cu values exceeded the allowed limits, significantly lower values were detected in the basins of Bardača fishpond. Our data indicate that the level of Cu in the area of the fishpond Bardača not reached a critical level and that should not have a negative impact on the plant growth and development. Considering the fact that it is a mildly alkali soil, and because availability of copper decreases when pH values are more than 7 (Šarić et al., 2004), this could explain lower values of Cu in this area. Concentrations of available Pb in sediment are most often very low, because of its strong connection to organic substance, Fe–Mn oxides, clay and deposition in the form of carbonates, hydroxides and phosphates (Prasad et al., 2006; Tyler, Olsson, 2001). Lead values in the sediment of Sinjak and Necik were under the detected limit (<0.51 mg/kg) in contrast to previous studies in this area when the lead concentrations were in the range 27.62–32.26 mg/kg (Maksimović et al., 2007). If we compare concentrations of heavy metals (Table 1) in the sediment of the researched fishponds with *Netherlands* (VROM; 2000) and *Canadian* recommendations (1999), it can be concluded that the ponds were unpolluted by the investigated metals.

Heavy metal concentrations in plant organs

Depending on species, seasonal cycle of aquatic macrophytes is characterised by slower or faster growth in spring, peak of growth at the end of summer and smaller or bigger fall in autumn, so it is considered that macrophytes could affect seasonal storage and metal circulation in aquatic environment (Prasad et al., 2006). Degree of heavy metal accumulation in tissues of investigated macrophyte was not consistent with their contents in sediment. Therefore, the content of Fe and Mn in the tissue of *S. natans* and *Utricularia vulgaris* was significantly higher than that in the sediment.

In contrast, immersed, floating and submerged species accumulate metals in leaves and thus significantly contribute to the extraction of heavy metals from water basins (Prasad et al., 2006). The correction is fine. The content of Zn in the tissue of the investigated macrophytes did not significantly differ from the content in the sediment. In contrary, the measured copper concentrations were lower in the tissue compared to those of Fe, Mn and Zn and did not correlate with the concentrations in sediments, indicating a lower translocation of Cu in plant tissues.

Accumulation of iron

The results obtained indicate different Fe concentrations in the tissue of examined plant species (Table 2).

Fe is one of the essential elements; however, high concentrations of Fe may be very harmful for the plants. Fe is a redox active metal that, through the Fenton reac-

T a b l e 2. Fe contents (mg/kg) in tissues of *Salvinia natans* and *Utricularia vulgaris* on two researched localities. The different letters in each row show a statistically significant difference ($p < 0.05$) for one heavy metal per month.

Plant species		Period (month)				
		May	June	July	August	September
Necik	<i>Salvinia natans</i>	3035 ^a	1539 ^b	1190 ^c	866 ^d	454 ^e
	<i>Utricularia vulgaris</i>	1184 ^a	938 ^b	874 ^d	893 ^c	741 ^e
Sinjak	<i>Salvinia natans</i>	-	1646 ^a	720 ^d	875 ^b	758.26 ^c
	<i>Utricularia vulgaris</i>	731 ^e	747 ^d	877 ^a	865 ^b	861 ^c

tion, leads to the formation of hydroxyl radicals, which is highly reactive and can cause damage and death of plant cells (Dhir, Srivastava, 2013).

In the tissue of *Salvinia natans*, Fe contents varied from 453.74 to 3035.20 mg/kg. During season, higher values were measured in the beginning of vegetation period (May) and significantly lower (80%) by the end of research period (September). Fe content in the tissue of *S. natans* was in accordance with the research of other authors for Ribnjak Ečka (198–5979 mg/kg; Babović et al., 2010) and Jegrička River (2.527 mg/kg; Borišev et al., 2008). Fe concentrations in tissue of *S. natans* were twofold higher at Necik locality compared to Sinjak. Grisey et al. (2012) showed in their studies that seasonal changes in heavy metals contents depend on dynamics in plant growth and ability of metal translocation from roots to leaves, which could also be connected to the results obtained in this study.

The highest Fe value in the tissue of *Utricularia vulgaris* (1.184 mg/kg) was measured in May on Necik locality, whereas by the end of research period, the values were up to 60% lower. Stanković et al. (2000) showed that increase in Fe values in tissue of submerged species *Myriophyllum spicatum* and *Ceratophyllum demersum* (1.157–2.075 mg/kg) in Vrbas–Beždan and Banatska Palanka–Novi Bečej canals results from surrounding agricultural surfaces as well as emission of metals from sediments, which most probably is one of the reasons for increased Fe concentration in this area. Submerged aquatic macrophytes (*Utricularia vulgaris*) accumulate significantly higher heavy metal concentrations, which was also supported by other researches (Borišev et al., 2008; Babović et al., 2010). During season, different distribution of Fe accumulation was detected; higher concentration was recorded at the beginning of vegetation period at Necik locality, whereas the opposite observation was observed at Sinjak locality. Also, during the season(May- September), Fe contents varied in tissue of *Salvinia natans* and *Utricularia vulgaris*: the highest level was measured in growing period (May–June), followed by a significant reduction at the end of vegetation period. Similar results have been demonstrated by Grudnik and co-workers (Grudnik, 2010) in their research of some submerged and floating plants.

Accumulation of manganese

Different adoption of Mn (Table 3) amongst submerged and floating species was also pointed out by other researchers (Yurkova, Kochev, 1996; Pajević et al., 2002; Borišev et al., 2008; Branković et al., 2009; Babović et al., 2010).

T a b l e 3. Mn contents (mg/kg) in tissues of *Salvinia natans* and *Utricularia vulgaris* at researched localities. The different letters in each row show a statistically significant difference ($p < 0.05$) for one heavy metal per month.

Plant species		Period (month)				
		May	June	July	August	September
Necik	<i>Salvinia natans</i>	350 ^d	399 ^c	579 ^a	481 ^b	266 ^e
	<i>Utricularia vulgaris</i>	620 ^a	440 ^e	495 ^b	497 ^c	453 ^d
Sinjak	<i>Salvinia natans</i>	-	374 ^c	446 ^b	479 ^a	325 ^d
	<i>Utricularia vulgaris</i>	382 ^e	410 ^d	520 ^a	424 ^c	472 ^b

T a b l e 4. Zn contents (mg/kg) in tissues of *Salvinia natans* and *Utricularia vulgaris* at researched localities. The different letters in each row show a statistically significant difference ($p < 0.05$) for one heavy metal per month.

Plant species		Period (month)				
		May	June	July	August	September
Necik	<i>Salvinia natans</i>	163 ^a	60 ^e	81 ^b	44 ^d	39 ^d
	<i>Utricularia vulgaris</i>	55 ^a	54 ^a	45 ^d	48 ^b	47 ^c
Sinjak	<i>Salvinia natans</i>	-	54 ^a	42 ^c	43 ^b	32 ^d
	<i>Utricularia vulgaris</i>	39 ^e	52 ^a	47 ^b	45 ^d	46 ^c

Data on the ability of plants to adopt different types of metal could be very important in the selection of species in phytoremediation technique. In the tissue of *Salvinia natans*, the highest Mn concentrations were measured in July and August (vegetation peak), whereas in September, a significant decrease in the Mn content was observed. Research by Branković et al. (2009) showed that submerged plants had smaller Mn accumulation capacity compared to floating plants, which is not in accordance with our findings. The value of Mn was measured in the tissue of *Utricularia vulgaris* (620 mg/kg) was highest in May in Necik locality, whereas the Mn content in the tissue of *U. vulgaris* varied more during the (May–September) season compared to *Salvinia natans*.

Accumulation of zinc

The results presented in Table 4 show that, on an average, the Zn contents for investigated species was highest at the beginning of vegetation period (May–June) and decreased in autumn, which was in line with the previous results (Maksimović et al., 2014).

Such a seasonal distribution could be a result of antagonism with other elements, Mn and Fe, first of all, but it could also be connected to other environmental factors (pH, temperature, oxygen contents). Significant differences in Zn contents (accumulation capacity) were recorded between studied species: the highest accumulation capacity was expressed by floating *S. natans* in comparison with submerged *Utricularia vulgaris* species. Zn contents during the season (May–September) in *Salvinia natans* tissue vary from 32 to 163 mg/kg, where measured values were higher compared to the results for Ečka fishpond (Babović et

al., 2010) and Jegrička River (Borišev et al., 2008). Highest Zn content was measured in *S. natans* tissue in May (163 mg/kg), whereas Zn content decreased for 80% by the end of vegetation period. It is well known that all fertilisers and pesticides contain Zn (Prasad et al., 2006), so that their increased usage at the beginning of season consequently increases Zn accumulation in plants. Afterwards, Zn content in *S. natans* tissue decreases as its deposition in sediments increases. In the tissue of *Utricularia vulgaris*, 35% lower contents of Zn was measured compared to *Salvinia natans* at Necik locality, and 9% higher was measured at Sinjak locality (Table 4). The results obtained in this study show that Zn contents was higher in submerged leaves in comparison to floating leaves, which had been in accordance with the results of Stanković et al. (Stanković et al., 2000). Different studies (Liu et al., 2007; Tyler, Olson, 2001; Maksimović et al., 2014) show that Zn adsorption is much better in alkali soil. As the investigated localities belong to the slightly alkali soil, it could be supposed that changes in Zn contents in our research could be because of mobility of Zn from sediment during the season (May– September) (Tables 1 and 4). As the investigated localities belong to the slightly alkali soil, it could be supposed that changes in Zn contents could be connected to mobility of Zn from sediment during the season (May–September).

Accumulation of copper

Contents of copper in *S. natans* tissue were at the detection limits during May, June and October at both the localities and increased contents (7.94 mg/kg) were detected in August and September (Table 5).

T a b l e 5. Cu contents (mg/kg) in tissues of *Salvinia natans* and *Utricularia vulgaris* at researched localities. The different letters in each row show a statistically significant difference ($p < 0.05$) for one heavy metal per month.

Plant species		Period (month)				
		May	June	July	August	September
Necik	<i>Salvinia natans</i>	<0.043	<0.043	3.00 ^b	7.33 ^a	7.94 ^a
	<i>Utricularia vulgaris</i>	8.00 ^a	6.03 ^c	4.75 ^c	5.87 ^d	6.56 ^b
Sinjak	<i>Salvinia natans</i>	-	<0.043	6.30 ^a	6.25 ^a	1.87 ^b
	<i>Utricularia vulgaris</i>	10.18 ^a	1.70 ^d	3.87 ^c	4.37 ^b	4.37 ^b

As a consequence of Cu antagonism with Fe, on the one hand, absorption of Cu from sediment is decreased, and, on the other hand, Cu toxic concentrations can be mitigated by adding Fe (Prasad, 2003; Rai, 2009). Owing to it antagonistic relations with Fe and as a consequence of increased Fe concentration at researched localities, both availability and intake of Cu by aquatic plants drastically decreased. Cu contents in the tissue of *Utricularia vulgaris* varied from 1.7 to 10.18 mg/kg, whereas higher contents were measured at Necik locality compared to Sinjak locality. Other authors also showed that Cu accumulated better in tissue of submerged plants compared to floating and emerged plants (Stanković et al., 2000; Pajević et al., 2002; Babović et al., 2010).

Accumulation of lead

Lead contents in the tissue of *Salvinia natans* and *Utricularia vulgaris* during the research period was under the detection limit (<0.51 mg/kg), which was significantly lower compared to the previous researches (Branković et al., 2009; Khellaf, 2009; Štrbac et al., 2014). In all plant species, contents of Fe, Mn, Cu and Zn were higher at Necik locality compared to Sinjak locality, which are most probably consequence of different physical–chemical environmental conditions, better availability of researched element and the presence of metals in soluble form, that is, its faster release from sediment.

Depending on the species, the seasonal cycle of aquatic macrophytes can mainly be characterised by faster growth in spring, maximum of growth at the end of the summer and more or less rapid growth decline in autumn, so macrophytes are thought to affect seasonal storage and circulation of elements in the aquatic environment (Prasad et al., 2006). The degree of accumulation of heavy metals depends on the plant species, locality and the sampling period. From the results obtained shown in the Tables 2–5, it can be seen that accumulation of Mn in *U. vulgaris* was increased during the period of flowering, whereas the content of Fe, Zn and Cu was lower compared to the beginning of the season (May–September). In *Salvinia natans*, the higher content of Fe and Zn was recorded at the beginning of the season (May–September) and Mn was recorded during the period from July to August, whereas Cu content increased more with the plant aging.

Phytoremediation potential of *Salvinia natans* and *Utricularia vulgaris*

The level of bioaccumulation is the result of the difference between the amount of metals that the plant adopts and its amounts in water and sediment and is specific to each plant species (Ghosh, Singh, 2005; Prasad et al., 2006). Also, the bioaccumulation coefficient depends on many factors of the environment in which the plant is located (pH, temperature and oxygen concentration).

The BAC is used as an indication of the potential of heavy metal accumulation for those plant species that have a well-developed cellular mechanism for detoxification and tolerance of heavy metals (Ghosh, Singh, 2005; Maksimović et al., 2008). The BAC values varied in relation to the type, metal, and sampling period (Table 6).

The BAC values for Fe in *Salvinia natans* leaves ranged from 1.40 to 2.29, 1.89–2.30 for Mn; 0.73–1.15 for Zn and 1.21–1.23 for Cu. The BAC values obtained for Fe and Zn in *Utricularia vulgaris* were twice lower, whereas Mn was higher in relation to *Salvinia natans*. For Cu, BAC values similar in both the species. The average BAC values were higher at the Necik locality compared to Sinjak for all heavy metals. Therefore, the investigated species have mostly BAC >1 or, for Zn, BAC ~ 1 , indicating that *S. natans* and *Utricularia vulgaris* have pronounced accumulation properties and can be successfully applied in phytoremediation techniques. It is very important to note that the results obtained depend not only on the total concentration of metals in the sediment but also on the physical and chemical characteristics of water, in particular the pH, as well as the ability to change the ions between the sediment of water and plant species (Yoon et al., 2006).

T a b l e 6. Average values of the BAC coefficient in relation to the content of heavy metals in sediment for Fe, Mn, Zn and Cu at the investigated localities in the area of Bardača fishponds during the period from May to September.

	Fe	Mn	Zn	Cu
Locality	<i>Salvinia natans</i>			
Necik	2.29	1.90	1.14	0.66
Sinjak	1.61	1.26	0.60	1.22
	<i>Utricularia vulgaris</i>			
Necik	1.40	2.30	0.73	0.79
Sinjak	1.32	1.60	0.79	0.84

T a b l e 7. Average values of the BCF coefficient in relation to the content of heavy metals in water for Fe, Mn, Zn and Cu at the investigated localities in the area of Bardača fishponds during the period from May to September.

	Fe	Mn	Zn	Cu
Locality	<i>Salvinia natans</i>			
Necik	16.902	7.918	2.901	215
Sinjak	5.769	3.358	1.515	271
	<i>Utricularia vulgaris</i>			
Necik	8.494	9.686	1.884	223
Sinjak	4.854	4.939	1.579	276

The plant accumulates heavy metals independently of their concentration in water and sediment, which is obvious from the results obtained (Fig. 2, Table 1). Differences between plants in bioaccumulation can be a consequence in the translocation of heavy metals through the plant because the bioaccumulation capacity of plants' tissue for certain metals is different. According to Zayed et al. (1998), plant is considered as good bioaccumulator if the BCF exceeds 1.000. BCF in relation to the water in the leaves of *Salvinia natans* and *Utricularia vulgaris*, shown in Table 7, indicates that the accumulation of heavy metals decreases in the following order: Fe > Mn > Zn > Cu at both the localities. *Salvinia natans* have a higher BCF for Fe and Zn, whereas *Utricularia vulgaris* showed a higher bioaccumulation capacity to Mn and Cu.

Conclusion

On the basis of the measured heavy metals concentrations (Fe, Mn, Cu, Zn and Pb) in sediment, we can conclude that investigated localities are not overloaded by these pollutants, which are dangerous for ecosystem. Taking into account all the results obtained, we can conclude that *U. vulgaris* and *Salvinia natans* accumulate Fe, Mn and Zn in a high degree. Both species proved to be insufficient bioindicators for Cu and Pb. The results acquired in this study at the area of Bardača fishpond imply that bioaccumulation of heavy metals and their availability to the plants had not reached critical level. Hence, it is important to set a constant

monitoring to include monitoring of seasonal and spatial variations in the accumulation of heavy metals with the aim of estimating the capacity of researched species in phytoremediation techniques.

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