Macrophytes as phytoindicators and potential phytoremediators in aquatic ecosystems

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Introduction

Macrophytes confirm very well to many of the criteria listed for an "ideal" biomonitor organism: they are sedentary, visible to the naked eye, easy to collect and to handle, easy to identify in the field, they concentrate metals and nutrients in their tissues and reflect the environmental contamination (ST-CYR et al., 1997). Monitoring of macrophyte species diversity, abundance and distribution of established populations, provides an indicative information of environmental impacts upon aquatic ecosystems. Macrophytes are especially good bioindicators in continuous, long period monitoring. They do not have strong mechanisms regulating the uptake of nutrients and heavy metals. Some species have expressive ability of bioconcentration, and therefore, increased accumulation, of nutrients and heavy metals, (STANKOVIC et al., 2000). High concentrations in plant tissues of some elements, may be the result of substantial availability of those elements in the surrounding environment. In this way, macrophytes can be used as bioindicators. Some of those species can also be used, to remove, degrade or transform harmful hazardous materials, present in the aquatic environment. This application of plants, as phytoremediators, highly depends on factors, which define absorption, accumulation and organic production of each taxa.

The aim of this research was to determine accumulating ability of some macrophyte species and to identify any potential pollution sources influencing the Jegricka river watercourse in Vojvodina province (Serbia).

Methods

Plant material was sampled in september 2004, at the finish of organic production, so that sample content of a specific element indicate seasonal availability of that element in a sorrounding environment. Samples were taken from four localities (1. Zmajevo, 2. Temerin, 3. Gospođinci and 4. Žabalj), positioned in each of the three different levelled basins of 65 km long Jegrička river. Jegrička River used to be a typical natural lowland watercourse (Vojvodina province, Serbia). During the 19^{th} and 20^{th} century, river was adapted and today its water regime is artificially synchronized as regulated part of Danube-Tisa-Danube Hydrosystem network. Surrounding area is under intensive agricultural influence, with no larger industrial polluters in direct contact with the watercourse.

Plant material was selected, classified, dried and prepared for analyses following Standard methods for the examination of water and wastewater APHA (1995). Dried and grinded samples were used to determine total N concentrations using standard micro Kjeldahl method (NELSON and SOMMERS, 1973). After dry ashing at 450ºC and treatment with 25% HCl, concentrations of heavy metals were measured by atomic apsorption spectrophotometry, K and Na by flame emision photometry. Total P concentration was assayed spectrophotometrically by ammonium-vanadate-molybdate method.

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Results

There is no clear locality dependent variation of macronutrients content in plant tissue (Table 1).

Table 1. Content of N, P, K and Na in macrophytes on Jegrička river in 2004
Values with the same letter, in vertical columns, do not differ significantly at the level p=0,05. Letter **a** represents the highest values, which decrease, following the alphabetical progression.

Locality (Jegrička river)	Species	%	mg %			
		Total ash	N	P	K	Na
1. Zmajevo	*Ceratophyllum demersum* L. 1753	59.59 a	1821 e	152 cd	875 e	356 d
	Salvinia natans (L.) All. 1785	24.57 d	2204 d	173 c	1347 c	562 c
	Phragmites australis (Cav.) Trin ex. Stendei 1841 – overground part	11.06 f	1214 g	85 f	403 fg	45 hi
	Phragmites australis (Cav.) Trin ex. Stendei 1841-rhizome	8.36 g	845 i	128 de	1097 d	86 h
2. Temerin	*Ceratophyllum demersum* L. 1753	35.04 b	2599 b	373 a	2139 a	299 e
	Hydrocharis morsus-ranae L. 1753	24.24 d	2462 c	244 b	1833 b	646 b
	Phragmites australis (Cav.) Trin ex. Stendei 1841- overground part	13.12 ef	1491 f	75 fg	347 f	25 i
	Phragmites australis (Cav.) Trin ex. Stendei 1841- rhizome	6.68 g	952 h	118 e	1181 d	88 h
3. Gospođinci	*Ceratophyllum demersum* L. 1753	31.86 c	2652 b	227 b	2139 a	230 f
	Nymphaea alba L. 1753	15.07 e	2773 a	148 d	1194 d	1150 a
	Phragmites australis (Cav.) Trin ex. Stendei 1841- overground part	6.57 g	908 hi	89 f	278 fg	50 hi
	Phragmites australis (Cav.) Trin ex. Stendei 1841- rhizome	13.59 e	1258 g	94 f	1084 d	138 g
4. Žabalj	*Phragmites australis* (Cav.) Trin ex. Stendei 1841- overground part	8.41 g	1535 f	80 f	208 g	133 g
	Phragmites australis (Cav.) Trin ex. Stendei 1841- rhizome	7.43 g	670 j	53 g	1208 d	141 g

The highest total ash content was recorded in *Ceratophyllum demersum*, which was the only submersed species analysed. The concentrations of necessary elements N, P, K and useful element Na, had very heterogenous values on each locality. There was no any locality, that can be distinguished with higher or lower values of concentrations, in each plant species. However, submersed species *Ceratophyllum demersum* and flotant species *Hydrocharis morsus-ranae*, *Nymphaea alba* and *Salvinia natans*, generaly had higher tissue content of these elements, comparing to emerged species *Phragmites australis.*

Content of heavy metals in 2004 (Table 2) also did not show any distinguished grouping of data, regarding any locality. Highest concentration was established for Fe content, followed by Mn. Iron concentrations were particularly low in *Phragmites australis,* especially in the above ground part. This species accumulated lower amounts, regarding most of analysed elements, except for Zn and Cu on localities 1 and 3. Submerged species *Ceratophyllum demersum* had the highest concentrations of heavy metals, with only few exceptions. Cd was not detected in any sample, while Co was found in small concentrations only in *Ceratophyllum demersum.*

Table 2. Content of heavy metals in macrophytes on Jegricka river in 2004
Values with the same letter do not differ significantly at p=0,05

Loc.	Species	µg/g							
		Fe	Mn	Zn	Cu	Ni	Pb	Cd	Co
1.	*Ceratophyllum demersum* L. 1753	4829 a	687 d	20.60 bc	5.83 a	7.73 a	1.90 d	<0.05	2.10
	Salvinia natans (L.) All. 1785	2527 d	552 e	23.90 b	5.40 a	2.34 de	2.80 c	<0.05	<0,02
	Phragmites australis (Cav.) Trin ex. Stendei 1841-oveground part	92 h	224 fg	31.53 a	2.13 e	3.01 cd	<0.01 f	<0.05	<0,02
	Phragmites australis (Cav.) Trin ex. Stendei 1841- rhizome	1022 f	58 h	19.73 c	4.43 b	1.83 def	1.53 e	<0.05	<0,02
2.	*Ceratophyllum demersum* L. 1753	3963 b	4745 a	16.13 d	6.00 a	5.18 b	2.07 d	<0.05	2.03
	Hydrocharis morsus-ranae L. 1753	1007 f	2717 c	23.70 b	3.83 bc	1.64 efg	3.73 b	<0.05	<0,02
	Phragmites australis (Cav.) Trin ex. Stendei 1841- overground part	83 h	135 fgh	12.73 de	3.27 cd	0.58 fg	1.83 de	<0.05	<0,02
	Phragmites australis (Cav.) Trin ex. Stendei 1841- rhizome	847 fg	253 f	9.23 ef	2.97 cde	1.56 efg	2.13 d	<0.05	<0,02
3.	*Ceratophyllum demersum* L. 1753	3376 c	3901 b	15.00 d	5.37 a	5.18 b	4.87 a	<0.05	2.13
	Nymphaea alba L. 1753	353 gh	225 fg	10.43 ef	2.67 de	0.40 g	1.93 d	<0.05	<0,02
	Phragmites australis (Cav.) Trin ex. Stendei 1841- overground part	122 h	99 gh	32.97 a	2.03 e	1.68 efg	<0.01 f	<0.05	<0,02
	Phragmites australis (Cav.) Trin ex. Stendei 1841- rhizome	2042de	82 gh	31.80 a	6.00 a	2.69 cde	2.07 d	<0.05	<0,02
4.	*Phragmites australi s*(Cav.) Trin ex. Stendei 1841- overground part	98 h	173 fgh	5.50 g	2.23 e	0.46 g	<0.01 f	<0.05	<0,02
	Phragmites australis (Cav.) Trin ex. Stendei 1841- rhizome	1885 e	73 h	8.33 fg	3.90 bc	3.63 c	1.57 e	<0.05	<0,02

Discussion

Results indicate significant variation of element concentrations in different macrophyte species. The concentration of a substance in an organism is the result of the difference between the amount and speed of the substance intake and that released into the environment, which is specific for each taxa (RAVERA, 2001). Since the ratio of accumulation is specific, it is possible that samples of different species, taken at the same time, from some influx moment of certain element into the environment, indicate to different level of load, or contamination, in a diagnosed environment. This is especially possible if the influx of some element into the environment has an uneven tempo, with higher or lower amplitudes of influx. These variations, however, have limits defined by quantity of element load in the ecosystem, so that common tendency of element concentrating on same locality, is often evident, especially if the content of an element is critically high. This bioindicative application of macrophytes, also depends from the varying of ecologycal conditions (ST-CYR et al., 1997), between different localities and during the seasonal period. Problems in bioindicative aplication of macrophytes can often be made, because the chemical availability of elements in the environment, can be significantly different. For example, a literature review covering 105 cases where metal concentrations had been determined both in aquatic plants and in the underlaying sediment, reveales that 65% of the cases showed no relationsheep between (CAMPBELL ET ALL., 1985). Total amount of elements is not always equal to bioavailable amounts of elements.

The obtained results of macronutrient concentrations, with only few exceptions, are similar with results on similar localities, in other typical lowland rivers in the Serbian north province of Vojvodina (STANKOVIĆ et al., 1994; PAJEVIĆ ET AL., 2002; 2004; NIKOLIĆ et al., 2003). GERLOFF & KROMBHOLZ (1966) experimentally established that minimal content of N and P necessary for maximum growth of *Ceratophyllum demersum* is 1,3% for N and 0,13% for P. Concentration of N where 1,8%-2,6% on Jegrička river, and for P, 0,15%-0,37%. Therefore, the available amount of these essential elements was not a limitation factor for growth. The values of analysed macronutrients indicate typical lowland eutrophic ecosystem, which is in accordance with the fact that this lowland river is under intense agricultural and some small municipal influence.

The high amounts of Fe were expected, considering the fact that this useful micronutrient, usually has the highest level in plants, regarding all microelements. It is important that concentrations of two potentially harmful elements (Pb and Cd), were undetected or very low, compared to other localities in Vojvodina province (STANKOVIĆ et al., 1994; PAJEVIĆ ET AL., 2002; 2004; NIKOLIĆ et al., 2003). Also, compared with same lowland river localities, concentration of other heavy metals, were mostly lower on Jegricka river, indicating that there is no any large source of pollution on this river. That is in accordance with actual condition on Jegrička river, where the last inustrial factory influencing the water course, ceased with work in 1980.

Ceratophyllum demersum showed the highest potential for accumulation of elements. This species had the highest measured amount of total ash. Submerged species always have larger amount of total ash, compared to emerged macrophytes, probably due to adsorption of clay and sand particles, and incrustation of $CaCO_3$ (STANKOVIĆ and PAJEVIĆ, 2001). Considering the fact that floating species have bigger or smaller parts under water, total ash amounts are usually between typical hydrophytes and helophytes. Therefore, it can be concluded, that *Ceratophyllum demersum,* is the best "accumulator", with high potential for phytoremediation in this ecosystem. However, it is known that helophytic species, like *Phragmites australis* have certain advantage as well, because of great biomass production, which makes it possible to regard them as suitable for heavy metal phytoremediation in anthropogenic influenced water basins (OSMOLOVSKAYA AND KURILENKO, 2005). Great organic production of plants like *P. australis* or *Typha angustifolia,* highly magnifies the amount of potentially harmful substances accumulated by macrophytes. Regarding this fact, the abundance and distribution of plants must be taken into consideration, on each researched locality. For example, on Jegricka river, *Ceratophyllum demersum* is the most dominant hydrophytic species with highest relative plant mass, and most even, homogenuos pattern of distribution, whereas, the most dominant coastal macrophyte on this locality, in the similar way is *Phragmites australis* (BORIŠEV et al., 2004). Thus, the potential harvesting and excavation of these macrophytes may be the right way to prevent any possible secondary contamination, conditioned with the fact, that any action must be scientifically founded through ecological principle of sustainable development and advancement.

Summary

The content of macronutrients (N, P, K, Na) and heavy metals (Fe, Mn, Zn, Cu, Ni, Pb, Cd, Co) in plant samples of dominant aquatic macrophytes from the river Jegricka (Serbia) is presented. Samples were taken from four localities, positioned on lowland Jegrička River, as part of Danube-Tisa-Danube Hydrosystem network. Macronutrients content in plant tissue indicate to substantial availability of those elements, pointing out to typical eutrophic environment. Chemical tissue composition varied in relation to plant species. Some species turned out to be more successful bioaccumulators for certain elements, therefore showing high potential in possible use as environment phytoremediators, depending from ecological nature of each species and the ecosystem itself.

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