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Research Article

THE ABILITY OF LEAVES AND RHIZOMES OF AQUATIC PLANTS TO ACCUMULATE MACRO- AND MICRONUTRIENTS

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ABSTRACT

The samples of macrophytes and bottom sediments originated from the littoral zone of the Słupia River were collected in summer 2013. The aim of this study was to compare the properties of the accumulation of leaves and rhizomes of *Glyceria maxima, Phragmites australis, Typha latifolia* and *Phalaris arundinacea* for macro- and micronutrients. The largest quantities of macroelements were found in the leaves of the examined species, and microelements dominated the rhizomes of most examined macrophytes except for Mn in *P.australis* and *T.latifolia*. The obtained results show that N and K dominated in the leaves of *P.arundinacea*, P and Mg in the leaves of *P.australis*, and Ca in the leaves of *G.maxima*. The largest quantities of N, P and K were cumulated in the rhizomes of *P.arundinacea*, while Mg and Ca in the rhizome of *T.latifolia.* The leaves of aquatic plants accumulated from 1354.9 $\text{mmol}_c \cdot \text{kg}^{-1}$ (*T.latifolia*) to 1844.0 $\text{mmol}_c \cdot \text{kg}^{-1}$ (*P.arundinacea*), and rhizomes from 985.8 $\text{mmol}_c \cdot \text{kg}^{-1}$ (*G.maxima*) to 1335.2 $\text{mmol}_c \cdot \text{kg}^{-1}$ (*P.arundinacea*) of all the analyzed components. In these species of macrophytes lower accumulated value of the sum of macro- and microelements were found in the rhizomes. The share of nitrogen was 42.4–59.8% of this amount, phosphorus 4.3–8.6%, potassium 22.8–35.1%, calcium from 2,6% to 12.4%, magnesium 3.0–7.5%, and heavy metals were from 0.6% (*G.maxima*) to 1.2% (*T.latifolia*) in leaves and from 2.2% (*T.latifolia*) to 8.7% (*G.maxima*) in rhizomes.

Keywords: bottom sediments, *Glyceria maxima, Phragmites australis, Phalaris arundinacea, Typha latifolia,* accumulation of nutrients.

INTRODUCTION

Dynamic development of civilization and progressive urbanization lead to comprehensive pollution of the natural environment. Waters as well as plants and bottom sediments of many rivers were encumbered with various toxic compounds [Garbisu and Alkorta 2003]. Their sources originate as the consequences of industrial and agricultural activity along with natural processes. At present, the intensity of exploitation of catchments and the inflow of sewage connected therewith have substantial impact on the chemical composition of bottom sediments [Salati, Moore 2009]. Most pollutants introduced to rivers are connected with transported suspended matter whose deposition leads to origination of bottom sediments [Caldwell et al. 2002], and at the same time to increase of the content of macro and microelements of bottom sediments which constitute an important element of the water environment. Most components accumulated in the bottom sediments are available for littoral plants which accumulate them it in their sprouts. The research studies done hitherto confirm that the water plants reflect very well the status of pollution of water reservoirs both with biogenic compounds and heavy metals [Cardwell et al.

2002, Klumpp et al. 2002, Kohler and Schneider 2003, Baldantoni et al. 2004, Demirezen and Askoy 2004, Schneider and Melzer 2004, Aksoy et al. 2005, Letachowicz et al. 2006, Sasmaz et al. 2008, Baldantoni et al. 2009, Bonanno and Lo Giudice 2010, Bonanno 2011, Klink et al. 2013]. In this respect, an increase in certain nutrients and the presence of pollutants are known to have an effect on the distribution of aquatic macrophytes [Bernez et al. 2001, Samecka-Cymerman and Kempers 2002]. Intake and bioaccumulation of necessary constituents is an element of the natural cycle [Kabata-Pendias and Szteke 2005, Dummee et al. 2012]. Aquatic macrophytes can obtain nutrients from the sediment as well as directly from the water itself [Schulz et al. 2003, Thiébaut and Muller 2003]. Differences in the quantity of accumulated elements can be observed not only among the species but also depending on the part of the plant, vegetation season and availability of the components [Alberts and Camardese 1993, Zhang et al. 2009]. The lower of the organization of the plants, the weaker their physiological barriers are developed, and accumulation of metals is passive. Some plant species form certain physiological barriers limiting transfer of the tonic compounds from rhizomes to leaves [Hozhina et al. 2001, Parzych et al. 2015]. Heavy metals content in aquatic plants can exceed many times their content in the biotopes surrounding water due to their fibrous root system of large contact surface area [Alberts and Camardese 1993, Burke et al. 2000, Aksoy et al. 2005, Bragato et al. 2009], and the wide scope of variability is caused by biological and ecological character of particular species.

Plants also play an essential role in the proper functioning of aquatic ecosystems. Produce oxygen dissolved in water, are involved in the circulation of nutrients, is a place of refuge for many aquatic organisms are involved in the process of self-purification of water and stabilize bottom sediments. Controlling the chemical composition of coastal vegetation and bottom sediment allows primarily the identification of existing and potential risks arising from the toxic effects of pollution on the aquatic environment and human health.

The aim of this study was to compare the properties of the accumulation of leaves and rhizomes of *Glyceria maxima* (Hartm.) Holmb., *Phragmites australis* (Cav.) Trin. ex Steud., *Typha latifolia* L. and *Phalaris arundinacea* L. for macro- and micronutrients. The contents of elements in aquatic plants were analyzed considering each component separately and in an integrated way – by comparing the demand for nutrients. The study takes into account the effect of the bottom sediments to the tested macrophytes.

MATERIAL AND METHODS

Sampling site locations

The research was carried out in summer 2013 year within the area of 10 stations situated with the limits of the city of Słupsk (54^{o}28’N, 17^{o}02’E) along the Słupia River. The Słupia River is situated in the central part of Pomerania (northern Poland), (Figure 1). It is a lowland watercourse of the length of 138.6 km and of the area of the catchment of 1620 km^2. The Słupia River headwater is at the

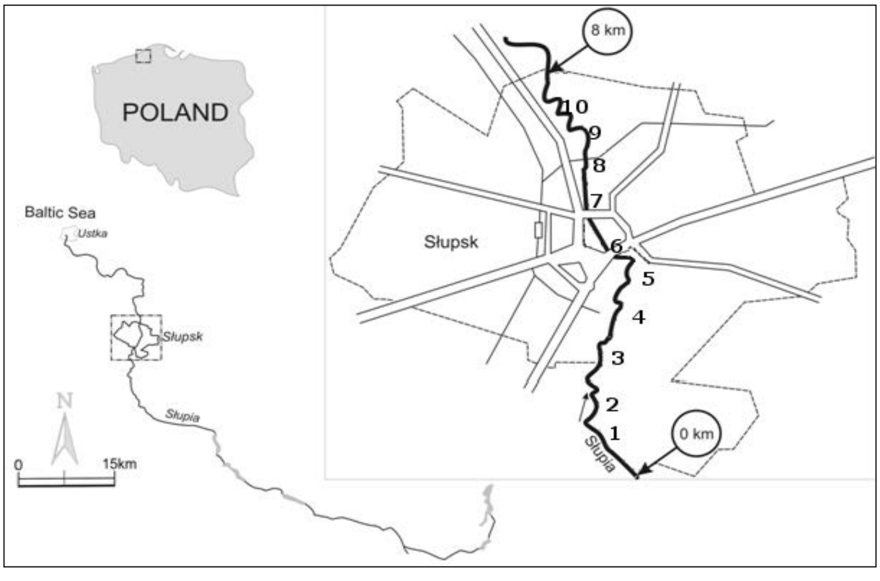

Figure 1. Distribution of the sampling points on the river Słupia

Kashubian Lake District close to Sierakowska Huta at the height of 178 m a.s.l. The width of the water bed varies from 7 m in the upper part of the river to 40 m at its mouth, where the average flow is 15.5 $m^3 \cdot s^{-1}$. The area of the City of Słupsk covers a 8 km stretch of the Słupia River, whose shores are covered with numerous macrophytes.

Sample preparation and analytical methods

The samples of bottom sediments and of leaves and rhizomes *of Glyceria maxima*, *Phragmites australis, Typha latifolia* and *Phalaris arundinacea,* originated from the littoral zone of the Słupia River (Figure 1). The bottom sediments were collected with the use of the *Eckman* sampler from the depth of 0–15 cm. The samples were dried at the temperature 65 °C (Drying Over), they were sieved through a sieve of 1 mm and grinded in a mortar. In bottom sediments acidity (pH, H_2O) and organic matter content were indicated – by the method of heat loss in a muffle furnace at the temperature 550 °C for 4 h. The samples of macrophytes within the area of each station were taken for the tests from several plants by preparation of mixed samples separately made of leaves and separately of rhizomes. The plant material was cleaned of mineral parts of the soil, flushed in the distilled water, dried to constant mass at the temperature of 65 °C for 48 h. Then, it was homogenized in a laboratory grinder (IKA A 11 basic, Germany). The total contents of nitrogen in bottom sediments and in plants was determined by Kiejdahl method (Büchi K-350, Destilation Unit, Switzerland), and the phosphorus by the molybdate method (spectrophotometer UV-VIS, Hitachi U-5100, Japan), after digested in the mixture of 98% H_2SO_4 and 30% H_2O_2. In order to determine the metallic elements, the bottom sediments and plant samples were digested wet in a closed system, in the mixture of 65% HNO_3 and 30% H_2O_2. The extracts were diluted to final volumes of 50 ml with deionized water. The concentration of Mg, K, Ca, Zn, Fe, Mn, Ni and Cu in plants determined by atomic absorption spectrometry (AAS), (Aanalyst 300, Perkin Elmer, USA). The analyses were performed in the oxy-acetylene flame. The tests were carried out following the original standards (Merck KGaA, 1 g/1000 mL).

Elaboration of results

The distribution of the content of the analyzed elements was tested by the Shapiro-Wilk test. Due to the lack of normal distribution of data, non-parametric test was used. The significance of the differences in the macro- and microelements in the leaves and rhizomes of aquatic plants was verified by Mann Whitney U test. Moreover, the ratio was calculated rhizomes/leaves concentration (mean) ratios of research elements in *G.maxima, P.australis, T.latifolia* and *P.arundinacea.* Aquatic plant's demand for nutrients was described by the ANE (Accumulation Nutrient Elements) method according to Ostrowska [1987]. The sum of the components (Y) $mmol_c \cdot kg^{-1}$ was calculated from the formula:

$$Y = \sum_{i=1}^{i} (Z : z),$$

where: Z – content of the element in $mg \cdot kg^{-1}$,
z – atomic weight/ion valency.

After the calculation of Y, the percentage (X) of each element in the sum of:

$$X = \frac{(Z : z) \cdot 100}{Y}$$

was calculated. The study contained the effect of the sediments on the tested macrophytes (Table 1).

RESULTS AND DISCUSSION

The content of macroelements in sprouts of the plants reflects the level of their supply with nutrients. The largest quantities of N, P, K, Mg and Ca were found in the leaves of the examined species of (Table 2, Table 3), which according to Sharma et al. [2006], is fully substantiated due to the process of photosynthesis which takes place therein. An exception was found only in the case of Mg (*P.australis*) and P (*T.latifolia*)*,* whose quantity was little larger in the rhizomes than in the leaves (Table 3). The obtained results show that N and K dominated in the leaves of *P.arundinacea* (N = 15320 $mg \cdot kg^{-1}$, K = 19774 $mg \cdot kg^{-1}$), P and Mg in the leaves of *P.australis* (P = 3131 $mg \cdot kg^{-1}$, Mg = 2508 $mg \cdot kg^{-1}$), while Ca dominate in the leaves of *G.maxima* (Ca = 6864 $mg \cdot kg^{-1}$). The largest quantities of N, P and K were cumulated in the rhizomes of *P.arundinacea* (N = 9840 $mg \cdot kg^{-1}$, P = 2638 $mg \cdot kg^{-1}$, K = 16443 $mg \cdot kg^{-1}$), and Mg and Ca in the rhizomes of *T.latifolia* (Mg = 1990 $mg \cdot kg^{-1}$, Ca = 4258 $mg \cdot kg^{-1}$) (Table 2). The highest values of N/P were found in the leaves of *P.arundinacea* (6.3), the lowest in the leaves of *P.australis* (3.7). The low levels of N/P ratio re-

Table 1. Physical and chemical properties of bottom sediments

Specification		Average ± SD	Median	Range	CV, %
pH (H_2O)		7.84 ± 0.36	7.95	7.00 – 8.19	4.6
Organic matter, %		2.14 ± 2.51	0.91	0.56 – 7.94	117.0
N	mg·kg^{-1}	969.5 ± 558.1	665.0	560.0 – 2030.0	57.5
P		609.9 ± 241.2	514.8	396.2 – 1197.7	39.5
K		506.7 ± 191.7	448.1	296.3 – 852.7	37.8
Ca		2268.8 ± 1471.5	1677.7	848.3 - 5836.7	64.9
Mg		842.9 ± 309.7	767.5	316.3 – 1328.7	36.7
Zn		34.1 ± 28.0	22.8	12.4 – 104.7	82.2
Mn		152.1 ± 111.5	119.0	58.1 – 376.7	73.3
Fe		9293.5 ± 4203.6	7935.0	4008.0 – 15503.3	45.2
Cu		8.4 ± 4.4	7.5	2.6 – 15.1	52.8
Ni		11.9 ± 2.8	11.7	8.5 – 16.8	23.5

SD – standard deviation, CV – coefficient of variation.

sult from a small nitrogen content in the leaves of the examined aquatic plants as the effect of intensive growth in the summer season. According to Zhiguo et al. [2007] the most effective growth of plants takes place at the N/P = 9.5, and according to Güsewell [2004] for most species the N/P ratio takes the levels 10–20. The differences in the number of accumulated nutrients results from a physiological need and difference in species. Similar relations in the content of microelements in the leaves and rhizomes of aquatic plants were also presented in the studies of Vardanyan and Ingole [2006], Baldontini et al. [2009], as well as Klink et al. [2013].

The largest mean quantities of Zn and Ni were found in the leaves of *P.australis* (Zn = 50.1 mg·kg^{-1}, Ni = 22.9 mg·kg^{-1}), Mn in *T.latifolia* (Mn = 721.0 mg·kg^{-1}), Fe in *P.arundinacea* (Fe = 261.3 mg·kg^{-1}), and Cu in w *G. maxima* (Cu = 10.2 mg·kg^{-1}) (Table 2). The largest quantity of Zn, Mn and Ni was found in the rhizomes of *P.arundinacea* (Zn = 92.2 mg·kg^{-1}, Mn = 1564.5 mg·kg^{-1}, Ni = 36.9 mg·kg^{-1}), and Fe as well as Cu in the rhizomes of *G. maxima* (Fe = 4259.9 mg·kg^{-1}, Cu = 21.1 mg·kg^{-1}). The heavy metal content in the leaves of the examined aquatic plants was within the limits of permissible levels (Zn = 70 mg·kg^{-1}, Cu = 30 mg·kg^{-1}) or exceeded them depending on a species and element (Mn >500 mg·kg^{-1}, Fe >250 mg·kg^{-1}, Ni >5 mg·kg^{-1}), [Kabata-Pednias and Pendias 1999]. The increased content of Mn in sprouts of *T.latifolia* and *P.arundinacea,* in relation to physiological demand, may be species characteristic and may indicate a positive impact of these macrophytes on purification of waters and bottom sediments of manganese compounds. The research studies done by Teuchies et al. [2013], Klink et al. [2013], Letachowicz et al. [2006] and Demerizen and Aksoy [2004] confirm strong cumulative properties of leaves of *T.latifolia* in relation to manganese. The reaction of bottom sediments had a positive impact on bioavailability of Mn (Table 1). Manganese is characterized by an increased solubility not only in the acid biotope (pH=6), but also in alkaline one (pH~8), [Alloway 1995]. A little higher Fe content (>250 mg·kg^{-1}) was found only in the case of the leaves of *P.arundinacea,* Table 2, which can be an effect of increased demand for that element in the summer time. The bottom sediments of the Słupia River, in which substantially increased Ni content was found (Table 1), [Parzych, et al. 2015]. Strong cumulative properties of some macrophytes in relation to Ni were confirmed by the studies of Salt and Kramer [2000] as well as Mays and Edwards [2001]. Nickel is easily accumulated by the plants and transported to their aboveground parts, and when in excess, it is accumulated in the roots [Kabata-Pendias and Pendias 1999].

Microelements dominated the rhizomes of most examined macrophytes except for Mn in *P.australis* and *T.latifolia* (Table 3). The level of rhizomes/leaves ratio (Fe) for *G.maxima* is worth mentioning. It confirms the retention of large quantities of iron in rhizomes in relation to leaves, which indicates the existence of a protective barrier limiting transfer of Fe to leaves [Hozhina et al. 2001, Parzych et al. 2015]. In

Table 2. Average and (±) standard deviation of elements content in aquatic plants

Element mg·kg^{-1}	*Glyceria maxima*, n=30	*Phragmites australis*, n=24	*Typha latifolia*, n=15	*Phalaris arundinacea*, n=21
	Leaves			
N	10770 ± 2739	11424 ± 2644	8253 ± 1041	15320 ± 3001
P	2576 ± 433	3131 ± 1137	2200 ± 609	2419 ± 531
K	12723 ± 6015	15293 ± 3860	17634 ± 1829	19774 ± 4848
Ca	6864 ± 3501	2789 ± 669	6642 ± 1420	2414 ± 706
Mg	1981 ± 149	2508 ±803	1448 ± 481	2091 ± 404
Zn	29.3 ± 12.7	50.1 ± 24.1	21.0 ± 6	29.1 ± 6.4
Mn	261.7 ± 179.1	196.0 ± 99	721.0 ± 453	632.3 ± 150.3
Fe	154.9 ± 106.2	150.2 ± 32	116.0 ± 19	261.3 ± 98.2
Cu	10.2 ± 2.3	8.0 ± 1.5	7.2 ± 0.3	6.6 ± 1.9
Ni	17.4 ± 4.5	22.9 ± 10.8	13.8 ± 4.2	17.1 ± 12.1
	Rhizomes			
N	6510 ± 2227	5391 ± 2072	6580 ± 2381	9840 ± 3346
P	2399.0 ± 678	1657 ± 262	1856 ± 433	2638 ±1027
K	9329 ± 5146	8292 ± 3856	15151 ± 6468	16443 ± 5016
Ca	2952 ± 2135	1051 ± 248	4258 ± 2354	1338.4 ± 556
Mg	1067 ± 570	570 ± 78	1990 ± 752	930.7 ± 190
Zn	59.3 ± 33.2	68.0 ± 66.6	54.8 ± 14.2	92.2 ± 28.5
Mn	441.2 ± 383.1	145.7 ± 109	320.1 ± 209.1	1564.5 ± 1096
Fe	4259.9 ± 5912.0	719.8 ± 716	1018.6 ± 1147.3	1706.6 ± 639
Cu	21.1 ± 11.7	13.0 ± 14.8	14.0 ±4.9	11.1 ± 3.7
Ni	24.9 ± 4.6	23.8 ± 4.9	27.3 ± 7.5	36.9 ± 26.9

Table 3. Rhizomes/leaves concentration (mean) ratios of research elements in *G.maxima, P.australis, T.latifolia* and *P.arundinacea*

Element	Rhizomes / Leaves			
	Glyceria maxima	*Phragmites australis*	*Typha latifolia*	*Phalaris arundinacea*
N	0.60	0.47	0.79	0.64
P	0.93	0.53	0.84	1.10
K	0.73	0.54	0.86	0.83
Ca	0.43	0.38	0.64	0.55
Mg	0.54	0.23	1.37	0.44
Zn	2.02	1.36	2.45	3.17
Mn	1.68	0.74	0.44	2.47
Fe	21.50	4.79	8.77	6.53
Cu	2.06	1.68	1.01	1.68
Ni	1.43	1.04	1.96	2.16

fact, the heavy metals may be mobilized in the bottom sediment of aquatic plants and to be taken up by plants or lost by leaching. In general, the concentration of heavy metals were relatively lower in leaves than in rhizomes [Baldontini et al. 2009, Klink et al. 2013]. However, the bioavailability and accumulation of heavy metals by plants depends on various factors such as: heavy metals content in bottom sediments, their bioavailability for plants, plant species, climatic factors and others. Translocation of trace metals from sediment to aboveground plant tissues differs greatly between species [Deng et al. 2004; Fitzgerald et al. 2003].

Macro- and microelements accumulation in leaves and rhizomes of selected species of aquatic plants showed a trends of:

- *Glyceria maxima*:
K>N>Ca>P>Mg>Mn>Fe>Zn>Ni>Cu in leaves
K>N>Fe>Ca>P>Mg>Mn>Zn>Ni>Cu in rhizomes
- *Phragmites australis*:
K>N>P>Ca>Mg>Mn>Fe>Zn>Ni>Cu in leaves
K>N>P>Ca>Fe>Mg>Mn>Zn>Ni>Cu in rhizomes
- *Typha latifolia*:
K>N>Ca>P>Mg>Mn>Fe>Zn>Ni>Cu in leaves
K>N>Ca>Mg>P>Fe>Mn>Zn>Ni>Cu in rhizomes
- *Phalaris arundinacea*:
K>N>P>Ca>Mg>Mn>Fe>Zn>Ni>Cu in leaves
K>N>P>Fe>Mn>Ca>Mg>Zn>Ni>Cu in rhizomes

Some of them are supported by the literature [Bonanno and Lo Giudice 2010]. The sum of the components reflects the whole so-called nutritional factor. The leaves of aquatic plants accumulated from 1354.9 $\text{mmol}_c\cdot\text{kg}^{-1}$ (*T.latifolia*) to 1844.0 $\text{mmol}_c\cdot\text{kg}^{-1}$ (*P.arundinacea*), and rhizomes from 985.8 $\text{mmol}_c\cdot\text{kg}^{-1}$ w (*G.maxima*) to 1335.2 $\text{mmol}_c\cdot\text{kg}^{-1}$ (*P.arundinacea*) of all the analyzed components. In these species of macrophytes lower accumulated value of the sum of macro- and microelements were found in the rhizomes (Table 4). Macroelements from 54.7% (*T.latifolia*) to 67.9% (*P.australis*) were collected in leaves, and from 32.1% (*P.australis*) to 45.3% (*T.latifolia*) in rhizomes. Microelements characterized by a different distribution, from 8.9% (*G.maxima*) to 38.4% (*T.latifolia*) were accumulated in leaves, and from 61.6% (*T.latifolia*) to 91.1% (G.*maxima*) in rhizomes. The share of nitrogen was 42.4–59.8% of this amount, phosphorus 4.3–8.6%, potassium 22.8–35.1%, calcium 2,6% do 12.4%, magnesium 3.0–7.5%, and trace elements were from 0.6% (*G.maxima*) to 1.2% (*T.latifolia*) in leaves and from 2.2% (*T.latifolia*) to 8.7% (*G.maxima*) in rhizomes. The similar relations between the measured amount of ingredients in various plant species were shown by Parzych and Sobisz [2012]. A large share of manganese and iron in all components measured in leaves and rhizomes iron evidence of their excessive withdrawal from the bottom sediments, and encouraged neutral and alkaline bottom sediments (Table 1).

The U Manna Whitney test indicated a series of statistically vital differences in cumulative properties of the examined aquatic plant species in relation to macro- and micronutrients (Table 5). The most frequent diversification related to Mg, Mn and N. The differences in accumulation of P in the leaves of *Typha latifolia* and *Phragmites australis* as well as K in rhizomes of *Glyceria maxima* and *Phalaris arundinacea*. Only in the case of Ni, no statistically vital differences in accumulation were found in the leaves and in rhizomes of examined macrophytes.

Table 4. Average of elements accumulation* in aquatic plants

Element	Leaves				Rhizomes			
	Glyceria maxima	*Phragmites australis*	*Typha latifolia*	*Phalaris arundinacea*	*Glyceria maxima*	*Phragmites australis*	*Typha latifolia*	*Phalaris arundinacea*
Σ macro [mmol_c/kg]:	1433	1483	1339	1827	900	701	1108	1274
% N in Σ	53.7	55.0	44.0	59.8	51.7	55.0	42.4	55.2
% P in Σ	5.8	6.8	5.3	4.3	8.6	7.6	5.4	6.7
% K in Σ	22.8	26.4	33.8	27.8	26.6	30.3	35.1	32.5
% Ca in Σ	11.9	4.7	12.4	3.3	8.2	3.7	9.6	2.6
% Mg in Σ	5.8	7.1	4.5	4.8	4.9	3.4	7.5	3.0
Σ micro [mmol_c/kg]:	8.4	7.6	15.9	17.0	85.8	17.0	25.5	61.2
% Zn in Σ	5.3	10.3	2.0	2.4	1.1	5.9	3.2	2.4
% Cu in Σ	1. 9	1.6	0.8	0.6	0.4	1.2	0.9	0.3
% Ni in Σ	3.5	5.2	1.5	1.8	05	2.3	1.8	0.9
% Mn in Σ	56.5	47.4	82.4	67.6	9.4	15.3	22.7	46.6
% Fe in Σ	32.8	35.5	13.3	27.6	88.6	75.3	71.4	49.8
Σ macro + Σ micro	1441.4	1490.6	1354.9	1844.0	985.8	718.0	1133.5	1335.2

* Expressed as a form of the amount of these components and their participation in the total.

Table 5. Statistical significance of differences (U Manna-Whitney's test)

in relation:		N	P	K	Ca	Mg	Zn	Mn	Fe	Cu	Ni
G. maxima – P. australis	leaves	*	ns	ns	***	ns	*	ns	ns	*	ns
	rhizomes	ns	ns	ns	**	**	ns	ns	ns	**	ns
G. maxima – T. latifolia	leaves	ns	ns	ns	ns	ns	ns	*	ns	**	ns
	rhizomes	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
G. maxima – P. arundinacea	leaves	**	ns	ns	***	ns	ns	**	*	**	ns
	rhizomes	ns	ns	*	*	ns	ns	*	ns	*	ns
P. australis – T. latifolia	leaves	*	*	ns	*	*	**	**	ns	ns	ns
	rhizomes	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P. australis – P. arundinacea	leaves	ns	ns	ns	**	ns	*	***	*	ns	ns
	rhizomes	**	ns	ns	ns	**	ns	**	ns	ns	ns
T. latifolia – P. arundinacea	leaves	*	ns	ns	*	ns	**	**	ns	ns	ns
	rhizomes	*	ns	ns	*	ns	ns	ns	ns	ns	ns

ns - no significance, * significance level of $p<0.05$, ** significance level of $p<0.01$,
*** significance level of $p<0.001$.

CONCLUSIONS

The largest quantities of macroelements were found in the leaves of the examined species, and microelements dominated the rhizomes of most examined macrophytes except for Mn in *P.australis* and *T.latifolia*. The content of macro- and microelements in aquatic plants was varied, depending on the species, and part of the shoot. The largest amounts of macronutrients in the leaves, and the smallest in rhizomes of macrophytes with the exception of manganese in *P. australis* and *T. latifolia*. The largest average amount of zinc and nickel were found in the leaves of *P. australis*, manganese in *T. Latifolia*, iron in *P. arundinacea*, and copper in *G. maxima*. Most of Zn, Mn and Ni demonstrated in rhizomes of *P. arundinacea*, and Fe and Cu in rhizomes of *G. maxima.* Increased Mn content in shoots of *T. latifolia* and *P. arundinacea* in relation this physiological needs refers to the beneficial effects of these species in the water treatment and sludge from the bottom sediment of manganese compounds. In the case of *G. maxima* the existence of protective barriers restricting movement of Fe from rhizomes to the leaves were found.

The leaves of aquatic plants accumulated from 1354.9 $\text{mmol}_c\cdot\text{kg}^{-1}$ to 1844.0 $\text{mmol}_c\cdot\text{kg}^{-1}$, and rhizomes from 985.8 $\text{mmol}_c\cdot\text{kg}^{-1}$ w to 1335.2 $\text{mmol}_c\cdot\text{kg}^{-1}$ of all the analyzed components. Macroelements from 54.7% to 67.9% were collected in leaves, and from 32.1% to 45.3% in rhizomes studied of aquatic plants. Microelements characterized by a different distribution, from 8.9% to 38.4% were accumulated in leaves, and from 61.6% to 91.1% in rhizomes.

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