Original Research

Macro- and Trace-Elements Accumulation in *Typha angustifolia* L. and *Typha latifolia* L. Organs and their Use in Bioindication

Agnieszka Klink[1]*, Magdalena Wisłocka[2], Maciej Musiał[1], Józef Krawczyk[1]

[1]Department of Ecology, Biogeochemistry and Environmental Protection, Institute of Plant Biology, University of Wrocław, Kanonia 6/8, 50-328 Wrocław, Poland
[2]School of Biotechnology, Dublin City University, Glasnevin, Dublin 9, Ireland

Received: 2 January 2012
Accepted: 18 September 2012

Abstract

The content of nutrients and heavy metals was indicated in different parts of *Typha angustifolia* and *Typha latifolia*, collected in lakes in western Poland. Three groups of metals were indicated, depending on the place of their accumulation. The cattail species studied differed significantly with their Cu, Pb, and Cd content, but were characterized by the same accumulation pattern in the leaves: Mn > Fe > Zn > Cu > Pb > Ni > Cd, and in the rhizomes: Fe > Mn > Zn > Pb > Cu > Ni > Cd. The statistical results of this research suggest the possibility of using *Typha latifolia* in the biological analysis of contamination by Mn.

Keywords: cattail, macroelements, trace elements, accumulation, bioindication

Introduction

Higher aquatic plants, as living components of aquatic ecosystems, play a vital role in keeping their ecological balance and in the biogeochemical cycle of elements in the environment, mainly because of their exceptional ability to absorb heavy metals [1] and nutrients [2]. Macrohydrophytes, while oxygenating bottom sediments, cause the metals to become more easily available and enable them to be absorbed through the roots and transported to the aerial plant parts. As a result of plant decomposition, the collected metals are released to the environment or become available for detritivores [3].

The distribution and behavior of many aquatic plants are often correlated with water quality [4]. Therefore plants are used in water quality studies to monitor heavy metals and other pollutants present in both water and sediments. Macrohydrophytes can accumulate pollutants at a high level irrespective of their content in the environment [5]. Moreover, in aquatic systems, where pollutant inputs are discontinuous and they are quickly diluted, analyses of plant tissues provides time-integrated information about system quality [6].

The aim of this research was to determine the macroelements and trace elements content in different organs of *Typha angustifolia* and *Typha latifolia*, and the assessment of the diversity of the content of nutrients and metals examined, depending on the plant species. It was also investigated whether the content of the metals in the macrohydrophytes examined mirrored their content in bottom sediments and the investigation was used as a basis for the assessment of the utility of these plants as bioindicators.

Material and Methods

Sample Collection and Preparation

Twelve study sites were randomly chosen within four lakes near Slawa (51º52′37″N, 16º4′17″E) in western Poland (Slawskie Lakeland): Gluchowskie (study sites 1, 2,

*e-mail: klink@biol.uni.wroc.pl

3), Kuznickie (Blotne) (study sites 4, 5, 6), Slawskie (study sites 7, 8, 9), and Pluszne (Brzezie) (study sites 10, 11, 12) (Fig. 1). The surface and volume of the examined lakes ranged from 9.5 to 817.3 ha and from 219.8 to 42,500,000 m^3, respectively. However the average depth of these reservoirs ranged from 1.5 to 5.2 m, and maximum depth from 2.3 to 12.3 m [7]. The Slawskie Lakeland is a tourist region, without intensive agriculture and industry. The examined lakes were surrounded by pine forest with some resorts. While the flora of the lakes was generally limited, the margins of their littoral zones were surrounded by a broad belt of emergent vegetation dominated by *Typha latifolia* and *Typha angustifolia* chosen for analysis herein. *Typha angustifolia* were analyzed at study sites 1 to 6, and *Typha latifolia* at sites 7 to 12 (Fig. 1).

In July 2011 samples of bottom sediments from the superficial layer (5-20 cm), together with plants, were collected in triplicate from each of the study sites. Prior to analysis bottom sediment samples were air-dried and ground in an agate mortar to pass a 2 mm sieve, and were then homogenized. Samples of *Typha latifolia* and *Typha angustifolia*, collected from each of the study sites, were cut up in the following parts: the tip of the leaf (20 cm long) and the lower part of the leaf (20 cm long), as well as the rhizome, and analyzed separately. Prior to analyses, plant material was washed thoroughly in distilled water, then dried at 60ºC and homogenized in an IKA Labortechnik M20 laboratory mill.

Sample Analysis

Sediment and plant material (0.5 g) were digested in an open system with concentrated nitric acid and hydrogen peroxide (30%), during which temperatures were raised to about 95ºC until evolution of nitrous gas stopped and the digest became clear. The concentrations of Fe, Mn, Zn, Pb, and Cu in plants and sediments were determined by atomic absorption spectrometry with flame atomization, whereas Cd and Ni were analyzed with electrothermal atomization (AVANTA PM by GBC Scientific Equipment).

Nitrogen concentrations in plant and sediment samples were analyzed with the Kjeldahl method. Cd, Mg, and K in plant materials were determined using a JENWAY Ltd. PFP7 flame photometer, as well as phosphorous by FIA

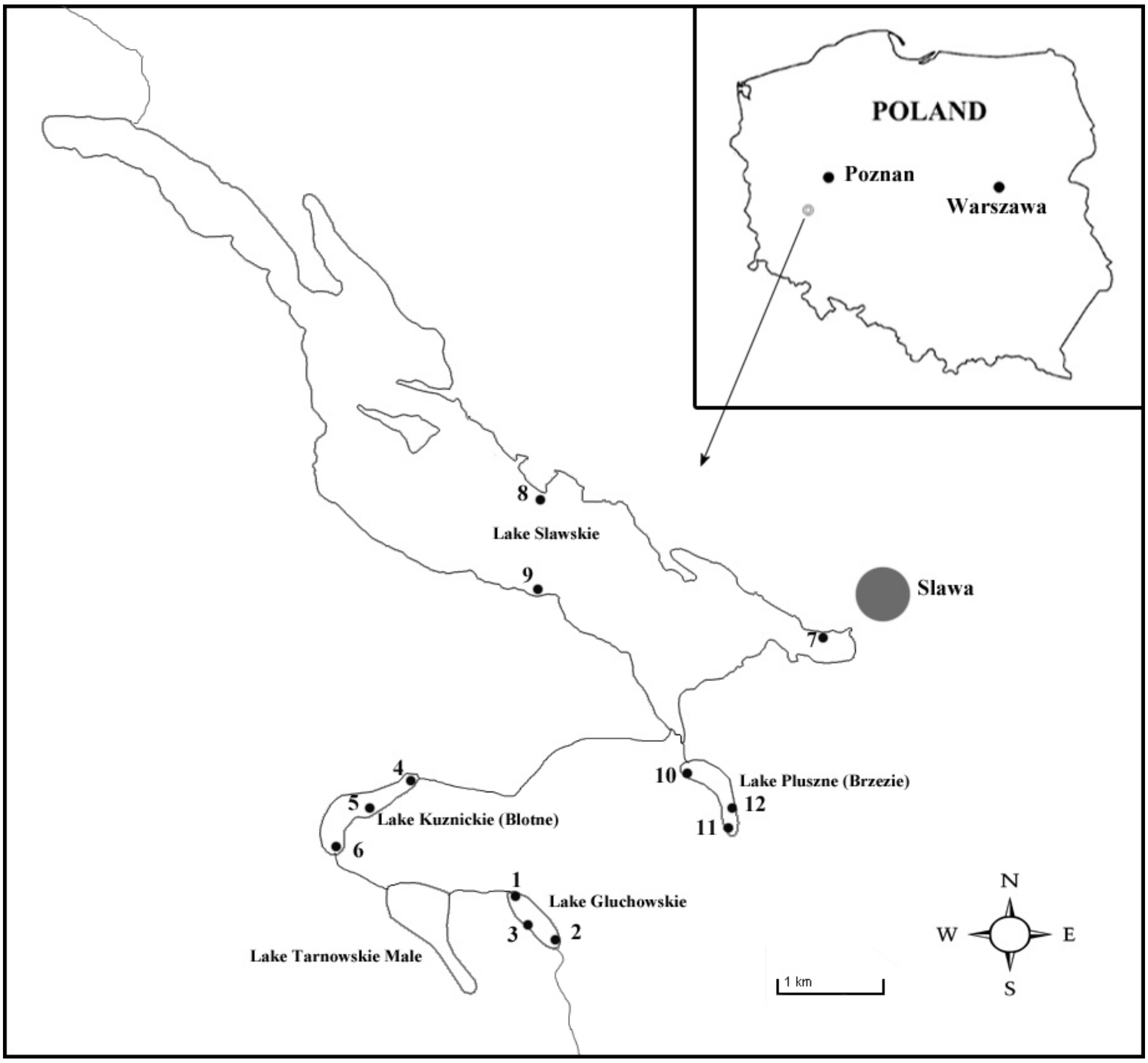

Fig. 1. Location of the lakes: Gluchowskie, Blotne, Slawskie, and Pluszne (Brzezie) of Slawskie Lakeland. Sampling sites are indicated by dots and numbers.

Table 1. Minimum/maximum (mg·kg^{-1}), mean, and SD of concentrations of elements in bottom sediments of *Typha latifolia* and *Typha angustifolia* sites from lakes in Slawskie Lakeland (t_{tab}=2.07; p<0.05).

Element	Minimum	Maximum	Mean	SD	Element	Minimum	Maximum	Mean	SD	test
Typha latifolia					*Typha angustifolia*					
N	2002	9044	5391	2465	N	420	4080	1521	1387	4.74
P	39.4	71.6	49.3	11.5	P	37.7	71.6	56.1	12.3	1.39
K	203	226	213	7.71	K	206	220	214	4.40	0.43
Ca	3020	37268	14106	12267	Ca	1242	3343	2091	726	3.39
Mg	1018	3083	1664	749	Mg	1032	1519	1225	150	1.99
Fe	1621	10749	6467	3217	Fe	3614	9618	6373	2045	0.09
Zn	42.5	108	69.8	24.2	Zn	21.5	36.7	28.6	5.42	5.75
Mn	98.3	426	216	128	Mn	145	223	182	25.3	0.090
Cu	22.4	96.1	41.7	25.9	Cu	24.7	60.9	36.5	12.7	0.62
Ni	2.65	6.78	5.31	1.56	Ni	2.53	8.62	4.27	2.26	1.30
Pb	9.79	33.5	20.9	9.58	Pb	11.1	31.8	21.0	9.11	0.04
Cd	0.16	1.04	0.54	0.33	Cd	0.02	0.76	0.33	0.28	1.69

compact from MLE GmbH. However, sediments were extracted for determinations of PO_4^{3-} with a solution of 0.3 M sodium citrate and 1 M sodium bicarbonate [8] and K, Ca, and Mg with 1 M ammonium acetate solution [9]. All elements were measured against SIGMA standards.

The precision of the measurements was determined by comparing the results of nutrient and heavy metal content in the solutions made from three separate weighted portions of each sample, having been analyzed using identical methods. The reproducibility of the methods used was compared to the results of an inter-laboratory study through digesting, and also by analyzing reference material GBW 07604 Poplar Leaves (Institute of Geophysical and Geochemical Exploration, Lanfang, China). Values were found to be 98±3 (percent±standard deviation).

Statistical Analysis

Differences between particular organs of *Typha latifolia* and *Typha angustifolia* with respect to mean concentrations of elements were evaluated by ANOVA on log-transformed data to obtain a normal distribution of features [10]. Normality of analyzed features was checked by Shapiro-Wilk's Test and the homogeneity of variances by Bartlett's Test [11]. Differences between study sites of broadleaf cattail and narrowleaf cattail with respect to mean concentrations of macro and trace elements in soil and plants were evaluated by the Student T-test [10]. Pearson regressions and correlation coefficients (n=18 and p<0.05) were calculated to examine the relationships between the concentrations of elements in bottom sediments and plant organs [12]. A plant's ability to take up elements from the environment was evaluated by the Index Bioaccumulation and expressed by the following ratio: metal concentration in root/metal concentration in sediment.

All statistical calculations were carried out using the CSS-Statistica Statsoft© [13].

Results and Discussion

The ranges of concentrations of elements in bottom sediments from lakes from Sławskie Lakeland, as well as different organs of *Typha latifolia* and *Typha angustifolia,* are displayed in Tables 1, 2, and 3. The mean concentrations in sediments and plants differed significantly (ANOVA, p=0.05).

The content of most of the elements studied in bottom sediments (Table 1) was relatively low and didn't exceed the value of the biogeochemical background given by Grosbois et al. [14], Woitke et al. [15], and Markert [16]. The exception was Cu content, which exceeded the specific values for unpolluted water bodies and the ones noted by Klink [17] in the bottom sediments of lakes in Slawskie Lakeland. Also, content of N in *Typha latifolia* sites was higher than that given by Markert [16]. In the studies carried out, the content of trace metals in the base was decreasing respectively: Fe > Mn > Zn > Cu > Pb > Ni > Cd.

The macroelement contents in the belowground and aboveground organs of both cattail species (Tables 2 and 3) did not exceed the natural ranges given by Markert [16]. Also, the heavy metals in the tissues of helophytes examined did not exceed the ranges given as physiological [17, 19] as well as the values specific for plants growing in unpolluted water basins [20], with the exception of Mn in the upper part of a leaf and Pb and Fe in the rhizomes.

Table 2. Concentrations of elements [mg·kg^{-1} DM] in leaves and rhizomes of *Typha latifolia* L. and results of Snedecor Test ($F_{tab.}$=3.28, p<0.05).

Element	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	F_{est}
	Rhizomes				Lower leaf part				Top leaf part				
N	12180	31360	21691	6768	3080	8400	5857	1831	13900	29260	21249	5751	21.1
P	2576	9356	5457	2807	829	4263	2368	1487	2302	7099	4825	1895	8.04
K	5976	11144	8523	1628	2578	26873	12272	9387	5956	31147	16630	8828	0.750
Ca	2450	7589	4424	1652	7328	10619	8994	1315	6776	8268	7540	494	41.7
Mg	1632	2710	2284	361	1655	2750	2310	394	1260	2457	1860	437	3.16
Fe	336	6166	1683	2136	52.3	92.8	67.3	12.5	66.6	124	95.9	18.5	5.78
Zn	28.4	67.8	41.4	13.9	16.0	37.5	24.06	7.59	16.2	26.9	21.2	2.96	9.60
Mn	33.1	242	128	73.3	61.4	284	190	81.1	367	928	539	203	13.2
Cu	3.44	12.4	7.43	2.86	3.97	7.74	5.57	1.19	2.25	6.61	4.03	1.35	24.9
Ni	0.90	1.76	1.29	0.32	0.21	1.64	0.65	0.44	0.53	1.89	1.23	0.42	1.33
Pb	8.32	10.9	9.61	0.72	3.36	5.96	4.61	0.84	1.07	2.94	1.64	0.59	41.9
Cd	0.05	0.30	0.17	0.08	0.014	0.035	0.020	0.007	0.005	0.039	0.015	0.011	11.8

$F_{est.}$ – F estimated

Table 3. Concentrations of elements [mg·kg^{-1} DM] in leaves and rhizomes of *Typha angustifolia* L. and results of Snedecor Test ($F_{tab.}$=3.28, p<0.05)

Element	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	F_{est}
	Rhizomes				Lower leaf part				Top leaf part				
N	8320	19460	14922	3884	3360	5600	4620	865	15260	23940	19775	3331	80.1
P	3130	8752	5833	1805	727	1720	1201	370	2129	4208	3239	695	44.6
K	10795	22977	15522	4483	2098	6305	3738	1604	2297	11956	7847	3711	26.1
Ca	3308	6778	5248	1365	6776	9821	7803	794	5169	6776	5951	490	22.9
Mg	1958	3461	2673	442	1089	1661	1340	173	1005	1955	1447	381	53.1
Fe	103	1643	476	549	68.8	248	104	62.9	55.7	124	81.3	21.4	5.78
Zn	18.7	61.9	29.3	14.9	5.70	23.8	12.7	5.81	12.4	26.9	16.7	4.71	9.60
Mn	53.9	248	146	64.1	83.9	324	205	94.6	162	841	477	269	13.2
Cu	3.58	4.98	4.22	0.43	2.96	4.22	3.69	0.40	2.31	3.62	3.01	0.43	24.9
Ni	0.62	2.79	1.32	0.72	0.56	1.87	0.98	0.37	0.68	1.90	1.16	0.34	1.33
Pb	5.14	9.96	7.60	1.47	3.36	6.30	4.83	0.89	1.27	5.14	2.88	1.37	41.9
Cd	0.018	0.093	0.040	0.022	0.008	0.027	0.016	0.0006	0.008	0.030	0.015	0.007	11.8

$F_{est.}$ – F estimated

To evaluate metal transfer from bottom sediment to plants, a transfer factor was calculated by dividing the rhizome metal concentration of *Typha latifolia* and *Typha angustifolia* in each site by the total metal concentration in the sediment. This factor of *Typha angustifolia* and *Typha latifolia* (between parentheses, respectively) was higher for the macroelements P (108, 113), K (72.4, 40), N (17.7, 4.6), and Mg (2.18, 1.55), and lower for Zn (1.01, 0.64), Mn (0.89, 0.61), Pb (0.44, 0.57), Cd (0.47, 0.42), Ni (0.39, 0.27), Fe (0.04, 0.24), and Cu (0.13, 0.23). According to Samecka-Cymerman et al. [20], transfer of potentially toxic heavy metals from soils into shoots of plants is typically low compared to those of macronutrients. Higher content of heavy metals in sediment (much lower in the roots and the lowest in top leaf parts) suggests that some kind of protective barrier exists to protect the tops of the plants from penetration by the toxicants from the roots [21].

The highest content of N was registered in the top leaf parts in both examined species (Fig. 2), whereas the highest contents of P, Mg, and K in *Typha angustifolia* and P and Mg in *Typha latifolia* were found in the rhizomes (Fig. 2). These findings corresponded with results cited by Baldatoni et al. [22], and Vardanyan and Ingole [23]. However, content of K and Ca in broadleaf cattail and Ca in narrowleaf cattail was higher in aboveground organs than in rhizomes (Fig. 2). According to Sharma et al. [24], photosynthetic tissue requires more nutrients than non-photosynthetic tissues, which may explain the relatively high content of macronutrients in the aboveground organs. This confirms also the data given by Baldantoni et al. [25], that concentration of macroelements in aboveground organs is higher than in roots. Also, the large values of macronutrients in the rhizomes suggest that these organs are a perfect reservoir of elements necessary for growth.

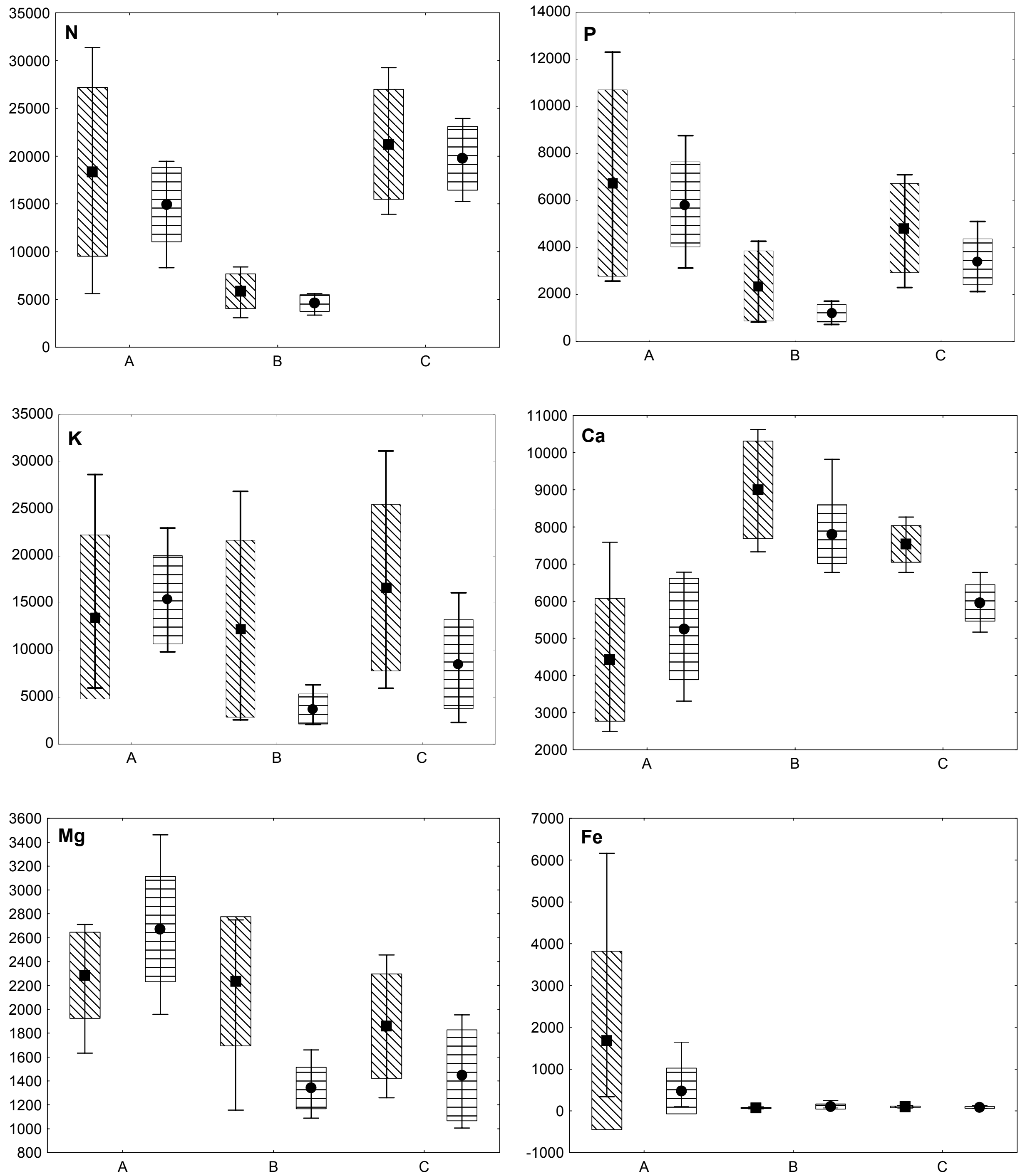

Fig. 2. Variability of nutrient element contents in leaves and rhizomes of *Typha latifolia* and *Typha angustifolia* from lakes in Slawskie Lakeland (– *Typha latifolia*, – *Typha angustifolia*; A – rhizomes, B – lower leaf part, C – top leaf part; mean, box: mean± standard deviation, whisker: minimum-maximum).

The highest content of Mn was registered in the top leaf parts of the broadleaf cattail and narrowleaf cattail (Fig. 3), where they repeatedly exceeded the physiological levels given by Kabata-Pendias and Pendias [18] (25 mg·kg⁻¹), and in some sites also exceeded the toxic level (500 mg·kg⁻¹). Substantially lower content of this metal, although also exceeding the physiological level [18], was noticed in the lower part of the leaf as well as rhizomes of both of the examined species. This confirms the data given by Kabata-Pendias and Pendias [18], that Mn is an element easily transported in a plant and that its greatest amounts gather in the aboveground, green parts of the plants. Letachowicz et al. [26] described a similar arrangement of Mn for *Typha latifolia* from around Nysa City and Demerizen and Aksoy [27] for a few aquatic plants species. Despite the high content in the leaves and rhizomes, no symptoms of toxic man-

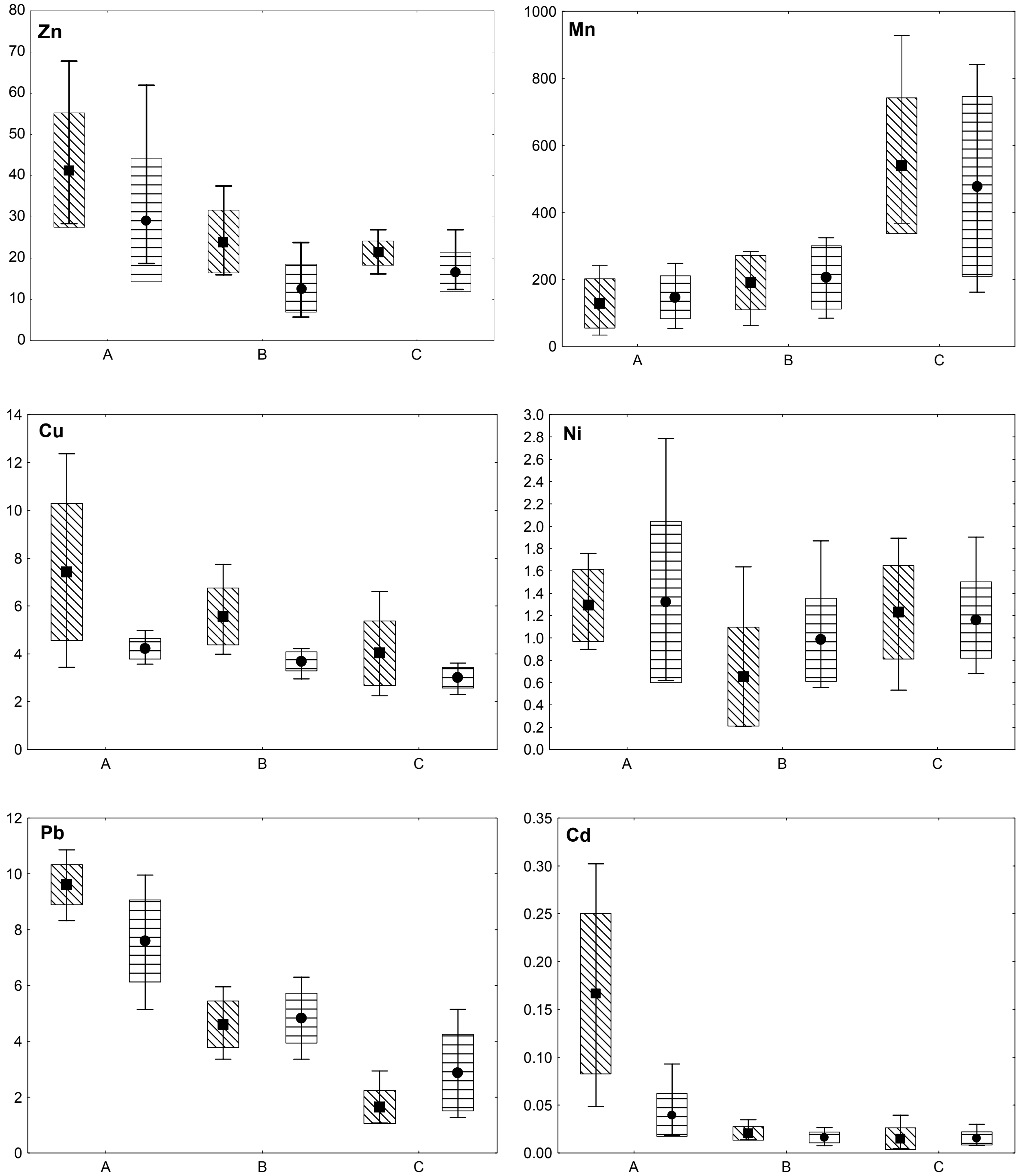

Fig. 3. Variability of trace metal contents in leaves and rhizomes of *Typha latifolia* and *Typha angustifolia* from lakes in Slawskie Lakeland (– *Typha latifolia*, – *Typha angustifolia*; A – rhizomes, B – lower leaf part, C – top leaf part; mean, box: mean± standard deviation, whisker: minimum-maximum).

ganese activity were noted on the organs of both species, which verifies the high ability of *Typha angustifolia* and *Typha latifolia* to accumulate this metal. Mn concentrations in leaves were much higher than that in roots and sediments, meaning that the leaves of *Typha latifolia* as well as *Typha angustifolia* can be considered as bioindicator organs for Mn [28]. Statistically significant, positive correlations were recorded between the content of Mn in bottom sediments and its content in the rhizomes (r = 0.58), and in the lower part of the *Typha latifolia* leaves (r = 0.55), which implies that these organs also are good bioindicators of environmental pollution with this metal [29].

The highest content of Pb and Cu was noted in the rhizomes of both examined species of cattail (Fig. 3). These findings are consistent with the data of Aksoy et al. [5, 30], stating that these metals have a relatively low mobility and were accumulated especially in the roots of macrohydrophytes. The limited mobility of Pb and Cu restricts their transportation in the aboveground organs of plants [18], which has been confirmed herein by the lowest content of these elements in the top leaf parts of cattail and the percentage of their content in the lower and upper parts of the leaf in relation to its content in the rhizomes. In the case of *Typha latifolia,* less than half of the amount of Pb (48.2±9.30), registered in the rhizomes, was transported to the leaves, and only 17.1±6.12 to its upper parts. Based on Student's Test, it was agreed that Pb accumulated in rhizomes of *Typha angustifolia* was transported to the leaves to a greater extent ($t_{tab.}$=2.07, $t_{est.}$=4.26) compared to that transported in *Typha latifolia*, which is confirmed by the higher values of the relations presented (65.9±17.5 and 41.7±28.2, respectively). In the case of Cu, no significant statistical differences between the species were noted, and the presented indicators gained higher values than those for Pb and equaled 87.9±10.5 and 71.5±8.76 for *Typha angustifolia,* and 86.4±43.1 and 63.0±30.9 for *Typha latifolia*.

According to Kabata-Pendias and Pendias [18], Cd, although it is easily absorbed and transported by plants, is an element mostly accumulated in roots. Confirming this are the studies herein, which showed that the greatest content of Cd and Zn existed in the rhizomes of *Typha angustifolia* and *Typha latifolia* than in the lower and upper parts of their leaves (Fig. 3). Aksoy et al. [30] explain that the narrowleaf cattail is a root accumulator for Zn and Cd, and Demirezen and Aksoy [31], that the content of Zn in the underground organs of this plant is twice as high in its upper parts.

The highest content of Fe was registered in the rhizomes, lower in the top leaf parts and the poorest in the lower part of the leaf in both species of cattail examined (Fig. 3). According to Kabata-Pendias and Pendias [18], Fe belongs to the low mobility elements in a plant and is mostly gathered in its underground parts. Furthermore, Aksoy et al. [5] and Demirezen and Aksoy [27] registered the highest contents of Fe in the underground parts of *Phragmites australis* and *Typha angustifolia.* Similar to the gathering process described in the helophytes examined was recorded in the case of Ni. Its content in the rhizomes of the broadleaf and narrowleaf cattail was 3.05 and 1.39 times higher than in the lower parts of the leaf, respectively. Following Kabata-Pendias and Pendias [18], this element is characterized by its high mobility in plants and can be easily moved to their upper parts. Mikryakova [32] and Vardanyan and Ingole [23], moreover, state that the Ni content in the underground parts of the rooted plants is higher than in their upper parts.

There was no differentiation in the contents of K, P, and Mg in the sediments between study sites of broadleaf and narrowleaf cattail, but the species were statistically significantly differed with examined nutrient contents. *Typha angustifolia* was characterized by a higher content of Mg (t_{tab} = 2.07; t_{est} = 2.36) and K (t_{tab} = 2.07; t_{est} = 5.08) in rhizomes, but *Typha latifolia* by a higher concentration of Mg (t_{tab} = 2.07; F_{est} = 7.80), P (t_{tab} = 2.07; t_{est} = 2.64), and K (t_{tab} = 2.07; t_{est} = 3.10) in the lower part of the leaf, and Mg (t_{tab} = 2.07; t_{est} = 2.46), P (t_{tab} = 2.07; t_{est} = 2.72), and K (t_{tab} = 2.07; t_{est} = 3.18) in the top part of the leaf.

The species of studied cattail differed statistically significantly with their contents of Cu, Pb and Cd, despite the lack of differentiation of content of those metals in the bottom sediments between the study sites (Table 1). Broadleaf cattail was distinguished by a higher content of Cu ($t_{tab.}$=2.07; $t_{est.}$=3.84), Pb ($t_{tab.}$=2.07; $t_{est.}$=4.26), and Cd ($t_{tab.}$=2.07; $t_{est.}$=5.06) in its rhizomes, and Cu in the lower ($t_{tab.}$=2.07; $t_{est.}$=5.19) and top parts of the leaf ($t_{tab.}$=2.07; $t_{est.}$=2.51). While the content of the metals was diverse, species of the cattail examined were characterized by the same accumulation pattern in the leaves: Mn > Fe > Zn > Cu > Pb > Ni > Cd, and in the rhizomes: Fe > Mn > Zn > Pb > Cu > Ni > Cd. Metal concentrations (except Mn) in aboveground organs were much lower than belowground organs, which may indicate the higher metal exclusion efficiency in both examined species.

Conclusions

This study showed that *Typha latifolia* and *Typha angustifolia* are prevalently belowground organ bioaccumulator species. Only a small fraction of the metals taken up by plants is allocated to the stems and leaves. The mobility of elements analyzed within the plants were different for particular elements and varied in different parts of the cattail.

Plants can be used as tools of ecological control when they show a direct response of the state of the environment. The strong positive correlations between the contents of Mn in bottom sediments and the levels of this element in the rhizomes and leaves of *Typha latifolia*, found in this research, indicate that the organs of broadleaf cattail reflect the cumulative effect of environmental pollution with Mn. As a result, rhizomes and leaves of *Typha latifolia* are potentially useful in biomonitoring environmental contamination with Mn.

References

1. KURILENKO V.V., OSMOLOVSKAYA N.G. Ecological-Biogeochemical Role of Macrophytes in Aquatic Ecosystems of Urbanized Territories (An Example of Small Bodies of St. Petersburg). Russ. J. Ecol+ **37**, (3), 147, **2006**.
2. NOGUEIRA F., DE ASSIS ESTEVES F., PRAST A.E. Nitrogen and phosphorous concentration of different structures of the aquatic macrophytes *Eichhornia azurea* Kunth and *Scirpus cubensis* Poepp&Kunth in relation to water level variation in Lagoa Infernao (Sao Paulo, Brazil). Hydrobiologia **328**, 199, **1996**.
3. WEIS J.S., WEIS P. Metal uptake, transport and release by wetland plants: implications for phytoremediation and restoration. Environ. Int. **30**, 685, **2004**.
4. ROMERO M., ONAINDIA M. Fullgrown aquatic macrophytes as indicator of river water quality in the northwest Iberian Peninsula. Ann. Bot. Fenn. **32**, 91, **1995**.
5. AKSOY A., DEMIREZEN D., DUMAN F. Bioaccumulation, Detection and Analyses of Heavy Metal Pollution in Sultan Marsh and its Environment. Water Air Soil Poll. **164**, 241, **2005**.
6. BALDANTONI D., MAISTO G., BARTOLI G., ALFAMI A. Analyses of three native aquatic plant species to assess spatial gradients of lake trace element contamination. Aquat. Bot. **83**, 48, **2005**.
7. CHOIŃSKI A. Catalogue of Polish lakes, third part: Wielkopolsko-Kujawskie Lakeland, Wydawnictwo Naukowe UAM: Poznań, **1995** [In Polish].
8. OLSEN S., SOMMERS L.E. Phosphorous. In: Page A.L. (Ed.) Methods of soil analysis, Part 2; American Society of Agronomy; Medison. WI, pp. 414-416, **1982**.
9. KNUDSEN D., PETERSON G.A. Lithium, sodium and potassium. In: Page A.L. (Ed.) Methods of soil analysis, Part 2. American Society of Agronomy; Medison WI, pp. 414-416, **1982**.
10. ZAR H. Biostatistical Analysis. Prentice Hall, Upper Saddle River, **1999**.
11. SOKAL R.R., ROHFL F.J. Biometry: The Principles and Practice of Statistics in Biological Research, W.H. Freeman: New York, **1995**.
12. PARKER R.E. Introductory Statistics for Biology, Edward Arnold Publishers Ltd.: London, **1983**.
13. StatSoft Inc., STATISTICA for Windows (data analysis software system), version 9, www.statsoft.com, **2008**.
14. GROSBOIS C.A., HOROWITZ A.J., SMITH J.J., ELRICK K.A. The effect of mining and related activities on the sediment-trace element geochemistry of Lake Coeur d'Alene, Idaho, USA. Part III. Downstream effects: the Spokane River Basin. Hydrol. Process. **15**, 855, **2001**.
15. WOITKE P., WELLMITZ J., HELM D., KUBE P., LEPOM P., LITHERATY P. Analysis and assessment of heavy metal pollution in suspended soils and sediments of the River Dunabe. Chemosphere **51**, 633, **2003**.
16. MARKERT B. Presence and significance of naturally occurring chemical elements of the periodic system in the plant organism and consequences for future investigations on inorganic environmental chemistry in ecosystems. Vegetatio **103**, 1, **1992**.
17. KLINK A. Content of selected chemicals in two protected macrophytes: *Nymphaea alba* L. and *Nuphar lutea* (L.) Sibith. & Sm. in reletion to site chemistry. Polish Journal of Ecology **52**, (2), 229, **2004**.
18. KABATA-PENDIAS A., PENDIAS H. Biogeochemistry of Trace Elements. Wydawn. Nauk. PWN: Warszawa, **1993** [In Polish].
19. DENG H., YE Z.H., WONG M.H. Accumulation of lead, zinc, copper and cadmium by 12 wetland plant species thriving in metal-contaminated sites in China. Environ. Pollut. **132**, 29, **2004**.
20. SAMECKA-CYMERMAN A., KOLON K., STANKIEWICZ A., KASZEWSKA J., MRÓZ L., KEMPERS A.J. Rhizomes and fronds of *Athyrium filix-femina* as possible bioindicators of chemical elements from soils over different parent materials in southwest Poland. Ecol. Indic. **11**, 1105, **2011**.
21. HOZHINA E.I., KHRAMOV A.A., GERASIMOV P.A., KUMARKOV A.A. Uptake of heavy metals, arsenic, and antimony by aquatic plants in the vicinity of ore mining and processing industries. J. Geochem. Explor. **74**, 153, **2001**.
22. BALDANTONI D., LIGRONE R., ALFANI A. Macro- and trace-element concentrations in leaves and roots of *Phragmites australis* in volcanic lake in Southern Italy. J. Geochem. Explor. **101**, 166, **2009**.
23. VARDANYAN L.G., INGOLE B.S. Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems. Environ. Int. **32**, 208, **2006**.
24. SHARMA P., ASAEDA T., MANATUNGE J., FUJINO T. Nutrient cycling in a natural stand of *Typha angustifolia*. J. Freshwater Ecol. **21**, 431, **2006**.
25. BALDANTONI D., ALFAMI A., TOMMASI P.D., BARTOLI G., VIRZO DE SANTO A. Assessment of macro and microelement accumulation capability of two aquatic plants, Environ. Pollut. **130**, 149, **2004**.
26. LETACHOWICZ B., KRAWCZYK J., KLINK A. Accumulation of Heavy Metals in Organs of *Typha latifolia* L. Pol. J. Environ. Stud. **15**, (2A), 407, **2006**.
27. DEMIREZEN D., AKSOY A. Common hydrophytes as bioindicators of iron and manganese pollutions. Ecol. Indic. **6**, 388, **2006**.
28. SASMAZ A., OBEK E., HASAR H. The accumulation of heavy metals in *Typha latifolia* L. grown in a stream carrying secondary effluent. Ecol. Eng. **33**, (3-4), 78, **2008**.
29. JONES K.C. Gold, silver and other elements in aquatic bryophytes from mineralized area of North Wales UK, J. Geochem. Explor., **24**, 237, **1985**.
30. AKSOY A., DUMAN F., SEZEN G. Heavy Metal Accumulation and Distribution in Narrow-Leaved Cattail (*Typha angustifolia*) and Common Reed (*Phragmites australis*). J. Freshwater Ecol. **20**, (4), 783, **2005**.
31. DEMIREZEN D., AKSOY A. Accumulation of heavy metals in *Typha angustifolia* (L.) and *Potamogeton pectinatus* (L.) living in Sultan Marsh (Kayseri, Turkey). Chemosphere **56**, 685, **2004**.
32. MIKRYAKOVA T.F. Seasonal Distribution of Chemical Elements in *Alisma plantago-aquatica* L. and *Sagittaria sagittifolia* L. Russ. J. Ecol+ **32**, (4), 284, **2001**.