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Bioaccumulation of Heavy Metals by Selected Plant Species from Uranium Mining Dumps in the Sudety Mts., Poland

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Abstract

Concentrations of the heavy metals Cd, Pb, Cu, Ni, Mn, Zn and Fe in soils of uranium-bearing dumps (Sudety Mts. SW Poland, the dumps containing a high proportion of polymetallic minerals), as well as in two tree species (*Salix caprea* L., *Betula pendula* Roth.) and a shrub (*Rubus idaeus* L.), which frequently occur in this area, in spite of being disturbed by mining activities in the past. The accumulation ratio values of heavy metals were calculated. It was revealed that all the species examined, especially the tree species, accumulated high concentrations of heavy metals, above the average values given for plants in literature. *R. idaeus* generally exhibited the lowest concentrations of heavy metals except Mn, while *S. caprea* accumulated the highest levels of Cd exhibiting the greatest accumulation capability for this metal within all the examined dumps. There is a potential of using the examined plants in the monitoring of heavy metals in the environment on the basis of a significant correlation between heavy metal content of foliage and soil.

Keywords: *Salix caprea*, *Betula pendula*, *Rubus idaeus*, accumulation ratio, monitoring, phytoremediation

Introduction

Within the Polish region of the Karkonosze-Izera Block (the Sudety Mts., SW Poland) extensive uranium exploration and mining activities were carried out in the 1950's. The entire zone of the eastern Karkonosze granite metamorphic mantle exhibits a high degree of mineralization. Previously mined uranium ores were polymetallic and contained a vast abundance of minerals, e.g. pitchblende, autunite, metatorbenite, gummite and uraninite [1]. Both exploration and mining operations left several dumps with spoils and soils with an elevated uranium and heavy metal content. The contamination has gradually dispersed, causing hazardous localized pollution [2].

The dumps, as relics of past explorative works are colonized by an abundance of spontaneous vegetation in the natural process of succession. Plants contribute to the circulation of heavy metals in the food chain through their active and passive absorption, accumulation in tissues as well as subsequent grazing by animals or consumption by humans. Species growing within polymetallic mineralization zones tend to exhibit elevated levels of heavy metals in their tissues, which are not necessarily reflected by a simple correlation with metal concentrations in the dump

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material [3]. In addition, levels of heavy metals in various species of wild plants growing in the same habitats may vary considerably [4]. Detailed ecological studies enable the distinction of species with particular accumulative capacities with respect to one or several heavy metals, thereby serving as bioindicators of contaminated areas [5]. *Salix caprea* L., *Betula pendula* Roth. and *Rubus idaeus* L. investigated in this study were dominant species of trees and shrubs of the Sudety uranium spoil heaps.

The objective of this study was to determine the chemical properties as well as the heavy metal content of soils from certain uranium mining dumps in the Sudety Mts. providing a substrate for plants. Also to ascertain whether any relationship exists between the heavy metal contents of soils and the two tree species *S. caprea* and *B. pendula* and the shrub *R. idaeus*, which frequently occur in this area. The heavy metals content as well as the accumulation capacities of these species were investigated.

Species which bioaccumulate pollutants have been frequently used for monitoring purposes as well as heavy metal prospecting in areas of polymetallic anomalies. Tree and shrub foliage is regarded as a reliable bioindicator of environmental pollution. Nutrient content as well as non-essential elements are therefore used in the assessment of soil pollution. *B. pendula* and *S. caprea* have proved to be good bioindicators of heavy metals in contaminated environments of both natural and anthropogenic origin [6, 7]. So the aim of this paper was to study the bioindicative value of all examined species.

Materials and Methods

Study Area

The investigation was carried out within the area of four uranium mine dumps located in Kowary [N 50°48' E 15°49'] (I), Radoniów, [N 51°01' E 22°15'] (II), Kromnów [N 50°55' E 15°29'] (III) and Kopaniec [N 50°53' E 15°33'] (IV). The area of examined dumps range from 1500 to 25000 m^2 and all the dumps are wooded and covered by an abundance of spontaneous vegetation.

Samples of soils from the superficial mineral layer (5-20 cm) and leaves of *Salix caprea, Betula pendula* and *Rubus idaeus* colonizing the dumps, were collected in triplicate in September 2001 from areas with the greatest vegetation cover. A total of 21 sampling sites, each measuring 10mx10m were selected. The number of sampling sites within a given dump was determined by its size as well as area diversity and amounted to 8, 6, 4 and 3 in Kowary, Radoniów, Kopaniec and Kromnów, respectively.

Soil and Plant Analyses

Prior to analysis soil samples were air-dried at 20°C and ground in a mortar to pass a 2 mm sieve. Leaves of the examined plants were washed thoroughly in deionized water to remove particulates, dried at 70°C and pulverized. Soil and plant materials (200 mg) were digested with concentrated nitric acid and hydrogen peroxide (30%) at 95°C until the evolution of nitrous oxide gas stopped and the digest became clear. The digest was diluted with distilled water to 10 mL and the total concentration of K, Ca, Mg, Fe, Mn, Zn, Pb, Cu, Cd, and Ni were determined by Inductively Coupled Plasma Emission Spectrophotometry (ICP Spectroflame SIMSEQ). Dried and homogenized plant and soil samples were used to determine the total contents of nitrogen and soil organic carbon (flash combustion and thermal conductivity detection with Carlo Erba NA-1500 CNS analyzer).

The plant-available fraction of phosphate was extracted from soil with 0.3 M sodium citrate and 1 M sodium bicarbonate [8] and the plant-available fractions of Ca, Mg, K, and Na were extracted with a 1 M ammonium acetate solution [9] and determined by atomic absorption spectrophotometry. The exchangeable acidity was determined in 1 M KCl by titration with 0.1 M NaOH to pH 7.6. The pH of the substrate in water and in 1M KCl were measured potentiometrically (1:2.5 ratio).

All analyses were carried out in triplicate and all elements were measured against standards (BDH Chemicals Ltd., reagent grade), blanks were prepared in 0.5 M nitric acid. Replicate samples were analyzed separately and the results for soil and plants were calculated on a dry weight basis. The reproducibility of these procedures was compared to the results of an interlaboratory study by digesting and analyzing the reference material RTH 907 Anthropogenic Soil (LCG Prochem GmbH) and poplar leaves GBW 07604 (Institute of Geophysical and Geochemical Exploration, Lanfang, China). Values were found to be within 97±4%.

Statistical Analysis

The normality of the analyzed data was checked by Shapiro-Wilk's W test, and the homogeneity of variances was checked by Bartlett's test [10, 11]. Differences between study sites with respect to mean concentrations of elements in soil and plants were evaluated by analysis of variance with the F Snedecor test and the least significant difference was calculated [12]. Pearson regressions and correlation coefficients were calculated to examine the relationships between the concentrations of elements in soil and plants [12].

The accumulation ratios (i.e. the ratio between the concentrations of an element in plant and in the underlying substrate) for the examined metals were calculated.

All calculations were carried out using the STATISTICA software [13].

Results and Discussion

The analysis of variance indicated that soils and plants for all study sites differed significantly with respect to the contents of the examined elements ($p < 0.05$). Ranges of mean concentrations of elements in soil and plants are presented in Tables 1, 2 and 3.

The pH_{H2O} of soil samples ranged between 2.3 and 6.9. Most samples (86%) displayed pH values between 4.0-4.5. The pH_{KCl} ranged from 2.1 to 5.3 indicating that the soil from dumps was acidic. The average pH as well as median value were similar in all dumps, revealing similar acidic conditions for plants growing on these dumps.

The carbon contents in the dump soils were relatively high, the highest content being found in dump III.

Total N concentration in all soils was much lower than the ranges of the average values given by Markert [14] for natural soils of the world. This indicates that the examined soils were poor in N. According to Alvarez et al. [15], N deficiency is one of the factors responsible for limiting the establishment of vegetation in mine soils. In addition, the calculated C/N ratio was relatively high, reaching values ranging from 41 to 64 in dumps I and III respectively, however in dump IV the calculated value was lower and amounted approximately to 30. Following Gliński [16] elevated C/N ratios (>33) indicate a reduction in the speed of organic matter decomposition. Moreover, the N available for plants is taken up by microorganisms and therefore temporarily immobilized. Furthermore, the high acidity of dump soils makes the nutritional potential of the soils poor.

As regards the exchangeable cations, the Ca, Mg, K, and Na content was found to be within the average values reported by Gliński [16]. Ca was the most abundant among alkali and alkaline-earth metals. The analysis of soil samples revealed high levels of Na, even higher than those of K and Mg. Comparisons of the chemical characteristics of the soils examined with those given by Borkowski et al. [17] for soils in the same region of the Sudety showed that considerably higher amounts of some elements were present. The soils from the uranium dumps contained 30 times as much Na, 10 times as much Ca and Mg as well as several times higher concentrations of K. The differences between elemental concentrations within this region may have been as a result of the specific geochemistry of the uranium dumps, and the presence of various ore minerals in the underlying bedrock such as pyrochlore, autunite or sklodowskite, containing Na, Ca, Mg as well as U [18].

The concentrations of Na in the soils studied were also 30 times higher compared to the mine dump soils from Galicia [15]. Although the sequence of alkali and alkaline-earth metals found in the Sudety (Ca, Na, Mg, K) and Galicia (Ca, Mg, Na, K) seems to be similar, Na levels were very high in the examined dumps.

The CEC (cation exchange capacity) of the soils was relatively high, ranging between 9.3 and 15.9 cmol(+) kg^{-1}. Base saturation of the soil sorption complex was moderately high (between 51–90%), mainly due to the elevated exchangeable Na, Mg and Ca fraction.

The concentration of available P for plants ranged within the average values reported by Markert [14], even though some authors reported lower levels of available P in mine soils [15, 19].

The content of macroelements in plants leaves ranged within the average values [14]. In spite of low N levels, the species studied accumulated and maintained

Table 1. General chemical characteristics of soil from the mine dumps in the Sudety Mountains (Poland). EA (exchangeable acidity); BC=Ca^{2+}+Mg^{2+}+K^{+}+Na^{+} (exchangeable base cations); eCEC=EA+BC (cation exchange capacity); BS=100·BC/eCEC (base saturation); SD (standard deviation).

Dump	Parameter	pH H_2O	pH KCl	Organic C%	Total N%	EA	Ca	Mg	K	Na	BC	eCEC	BS %	Available P mg kg^{-1}
						cmol(+) kg^{-1}								
I	Min	2.3	2.1	1.67	0.071	1.02	3.51	1.25	0.16	1.20	6.7	9.3	57	77
	Max	6.9	4.3	9.24	0.145	6.35	4.67	2.12	0.31	4.57	10.2	15.9	89	131
	Average	4.4	3.5	3.57	0.087	4.47	4.02	1.72	0.23	2.35	8.3	12.8	66	102
	SD	1.4	0.9	2.72	0.025	1.87	0.43	0.35	0.05	1.23	1.3	2.2	12	17
	Median	4.5	3.8	2.57	0.076	5.05	3.86	1.67	0.21	2.10	8.2	12.5	60	105
II	Min	3.3	2.8	1.95	0.065	1.23	3.22	0.89	0.19	2.84	8.1	11.9	58	80
	Max	6.1	5.3	4.90	0.081	5.79	5.41	1.91	0.33	4.42	10.9	14.7	90	106
	Average	4.6	3.8	3.11	0.071	4.18	4.37	1.38	0.25	3.37	9.4	13.6	70	92
	SD	0.9	0.8	1.00	0.005	1.69	1.07	0.37	0.05	0.59	1.2	1.0	12	9
	Median	4.5	3.7	2.82	0.071	4.94	4.40	1.40	0.25	3.21	9.2	13.8	65	92
III	Min	2.3	2.1	2.75	0.071	1.90	2.41	1.29	0.11	1.35	5.3	10.5	51	92
	Max	5.1	4.6	7.54	0.080	6.02	3.79	2.37	0.22	4.57	9.8	13.9	84	112
	Average	4.1	3.5	4.86	0.076	4.54	3.34	1.63	0.19	2.77	7.9	12.5	64	101
	SD	1.2	1.0	2.28	0.005	1.81	0.64	0.50	0.05	1.65	1.9	1.7	14	10
	Median	4.5	3.7	4.57	0.076	5.12	3.57	1.43	0.21	2.58	8.3	12.7	60	100
IV	Min	4.4	3.7	1.30	0.073	4.43	2.41	1.26	0.11	1.35	5.3	10.5	51	54
	Max	4.8	3.9	3.50	0.075	5.87	3.95	1.55	0.26	2.83	8.6	13.0	66	130
	Average	4.6	3.8	2.25	0.074	5.15	3.20	1.42	0.20	1.87	6.7	11.9	56	94
	SD	0.2	0.1	1.13	0.001	0.72	0.77	0.15	0.08	0.84	1.8	1.3	8	38
	Median	4.6	3.7	1.95	0.073	5.16	3.26	1.45	0.23	1.43	6.2	12.1	51	97

a sufficient level of this macronutrient in their tissues. All plants accumulated high amounts of Na (from 3203 up to 8490 mg kg^{-1}), proportionally with the elevated concentrations of this element in the soil. A significant positive correlation between Na concentration in plant leaves and the corresponding soil samples were found for trees: *B. pendula* (r= 0.29, p=0.04) and *S. caprea* (r= 0.30, p=0.03).

The tree species studied in this paper accumulated more N, Ca and especially Na than *S. caprea* and *B. pendula* growing on black coal mine dumps in the same area of Poland, which were poorer in nutrients [19].

The concentrations of Fe and Mn in the dump soils were within the ranges of the average values given for all types of soils [14]. However, the content of other heavy metals exceeded considerably the upper limits according

Table 2. Total concentration of heavy metals in soil from the mine dumps in the Sudety Mountains (Poland) [mg kg^{-1}] ($F_{tabular}$=2.70).

Dump	Parameter	Fe	Mn	Zn	Pb	Cu	Ni	Cd
I	Min	15900	252	49	32	15	12	0.05
	Max	175000	883	1876	249	1380	2210	3.80
	Average	49620	449	274	87	178	222	0.74
	SD	40744	192	473	66	354	557	1.36
	Median	38000	384	104	57	28	28	0.05
II	Min	16000	147	49	22	16	9	0.05
	Max	74500	545	370	2750	42	45	4.60
	Average	35684	306	136	380	30	29	0.72
	SD	17119	162	98	958	8	14	1.59
	Median	32250	274	103	37	31	37	0.05
III	Min	26300	62	65	14	6	25	0.05
	Max	113000	835	260	1450	56	63	5.30
	Average	52837	393	132	228	33	42	1.28
	SD	27690	234	63	496	18	14	1.77
	Median	43800	382	122	36	37	43	0.85
IV	Min	18100	71	39	13	4	4	0.05
	Max	129000	720	2850	341	120	68	2.98
	Average	64657	314	500	76	32	42	0.80
	SD	37133	225	1037	118	42	20	1.03
	Median	60000	270	112	34	19	45	0.70
Fest.		7.44	3.62	4.03	12.4	15.7	7.44	2.61
LSD		11345	222	17.4	4.08	2.20	16.6	-

Table 3. Concentration of macroelements and heavy metals in plant leaves from the mine dumps in the Sudety Mountains (Poland) [mg kg^{-1}] ($F_{tabular}$=3.15).

Species	Parameter	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Pb	Cu	Ni	Cd
Betula pendula	Min	16993	1398	7246	222	1596	3203	191	284	114	22.9	0.20	0.10	0.46
	Max	34333	3326	39253	17437	12921	8347	2902	1790	430	41.3	6.93	8.63	1.18
	Average	28564	2341	19389	8904	3570	4743	589	893	248	28.5	2.67	2.69	0.76
	SD	4812	474	9996	4652	2556	1317	862	523	98	5.2	2.53	3.05	0.21
	Median	29780	2255	16699	9835	2788	4508	278	603	208	27.4	1.26	1.53	0.76
Salix caprea	Min	16170	1360	1390	3673	1923	4223	35	27	77	13.6	4.53	0.10	0.83
	Max	40473	5455	2483	14216	8175	8490	67	286	330	92.3	12.17	24.70	12.13
	Average	23845	2605	2022	10138	4183	5619	46	102	234	24.2	7.59	6.57	4.11
	SD	6589	926	297	3517	1940	1039	7	95	62	17.6	2.15	8.48	3.01
	Median	22853	2545	1973	11350	3396	5315	46	57	232	19.7	7.38	2.43	3.25
Rubus idaeus	Min	14133	1778	4895	5626	2510	3916	8	182	27	17.6	1.20	0.10	0.40
	Max	29290	4815	17944	20783	8996	5903	57	949	88	27.9	10.50	4.26	1.60
	Average	24411	2974	11634	11146	5628	4978	26	449	57	21.4	5.27	1.65	0.76
	SD	4487	952	4583	4567	2147	563	17	214	20	2.9	2.87	1.41	0.36
	Median	25343	2831	12359	9797	5997	5004	19	501	51	20.6	5.16	1.46	0.70
Fest.		3.60	2.11	7.19	0.98	2.88	4.80	5.87	23.7	27.2	1.36	17.4	3.23	17.0
LSD		3407	-	4258	-	-	730	325	210	44.6	-	1.53	3.51	1.18

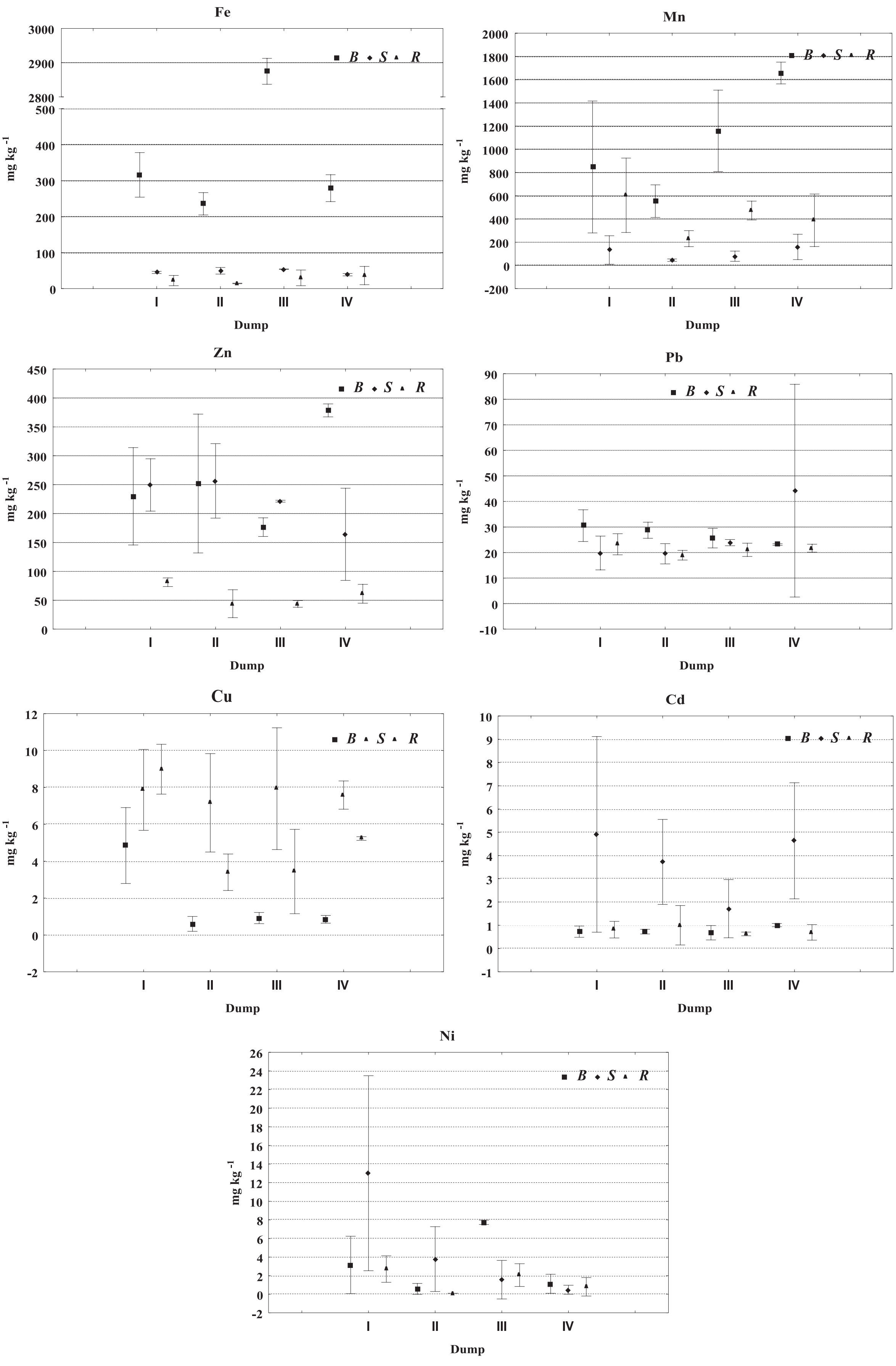

Fig. 1. Comparison of the heavy metal content of *B. pendula* (B), *S. caprea* (S) and *R. idaeus* (R) from the Sudety uranium dumps. Point (mean), whiskers (standard deviation).

to the threshold of pollution established by Kabata-Pendias [20], as 50 (Pb), 70 (Zn), 25 (Ni), Cd (0.5) and 25 (Cu) mg kg^{-1} d.w. The concentrations of Pb in dumps I and II exceeded the value cited above by a factor of almost 30 and 55, respectively, and were likely associated with the presence of secondary radiogenic lead, which is characteristic of spoils containing uranium [21].

In general the toxic concentrations of heavy metals found in the uranium dumps seem to correspond to the mineral assemblage of the bedrock which, amongst others, are composed of several uranium minerals (torbenite, zeunerite, samarskite) [18]. Interestingly, the excessive heavy metal burden of the soil within the dumps was comparable or even higher (in respect of Zn, Ni and Pb) than those found in soils from the polymetallic anomalies of the Rudawy Janowickie Mts. (Western Sudety) [4]. Remarkably high concentrations of Zn, Pb, Cu and especially Ni were noted in Kowary (dump I) where polymetallic mineral ores rich in chalcopyrite were reprocessed.

The observed elevated levels of heavy metals in the soils are reflected by the high content of Fe, Zn, Pb and Cd in the leaves of *B. pendula,* Zn, Pb, Cd and Ni in *S. caprea* and Pb and Cd in *R. idaeus* within all the dumps (Fig. 1). The observed concentrations exceeded the average values for plants of nonpolluted areas given by Markert [14] and by Kabata-Pendias and Pendias [22]. The high metal accumulation patterns characteristic of *S. caprea* [23] has been confirmed in this study. Borgegärd and Rydin [24] reported increased Zn and Pb concentrations in *B. pendula* leaves growing within a contaminated area as compared to those from uncontaminated regions. High concentrations of these metals found in birch leaves from uranium dumps corroborate these findings. The relatively high uptake of heavy metals by the species examined may also be attributed to the low pH of the soils.

Although elevated concentrations of heavy metals were determined in the plants, no significant positive correlations were found between the heavy metal content in leaves and corresponding soils, with the exception of *S. caprea* where a significant correlation was observed between Pb in leaves and soil ($r=0.32$, $p=0.02$). This correlation gives an indication of the potential usefulness of this tree species in monitoring lead contamination of the examined dumps.

The average levels of Cd in the plants examined exceeded the mean range of values (0.05–0.2 mg kg^{-1}) reported by Kabata–Pendias and Pendias [22] for plants growing in unpolluted areas. *S. caprea* is considered by many authors [25, 26, 27, 28] to be a species having a particular ability to accumulate Cd. The high concentration of Cd in *S. caprea* within all the dumps in this study was also very pronounced (Fig. 1). By contrast, *B. pendula* from the uranium dumps extracted Cd at a lower rate than *S. caprea*. This kind of Cd accumulation pattern in *S. caprea* and *B. pendula* has also been reported by several authors [29, 30, 31]. Higher accumulation ratios (54.1) for Cd are also characteristic of *S. caprea* as compared to *B. pendula* and *R. idaeus*, for which the following values were obtained: 11.8 and 8.1 (Table 4), respectively. These results are in agreement with Samecka-Cymerman and Kempers [19], who demonstrated the Cd accumulation ratios for *S. caprea* to be significantly higher than those calculated for *B. pendula*. However, comparing the Cd accumulation ratio values, it could be concluded that in general the tree species (*S. caprea* and *B. pendula*) exhibit a higher ratio than that of *R. idaeus*. This confirms the findings of Reimann et al. [32] who reported that trees show a much higher concentration of Cd in leaves compared to shrub species.

Looking at the data obtained in this study, the higher bioaccumulation potential of trees compared to shrubs is even more obvious for Zn. It is evident from Fig. 1 that leaves of *R. idaeus* contained a considerably lower concentration of Zn than leaves of *B. pendula* and *S. caprea* within all the dumps studied. Furthermore, a lower accumulation ratio (see below) for this metal was exhibited by *R. idaeus* as compared to the examined tree species. However, in contrast to Cd, no significant differences were noted between concentrations of Zn in *B. pendula* (114 to 386 mg kg^{-1} d.w.) and *S. caprea* (97 to 315 mg kg^{-1} d.w.).

In addition, relatively high concentrations of Mn were noted in *B. pendula* (284 to 1724 mg kg^{-1} d.w.) from the dumps. Within the majority of sampling sites, the Mn level in the plant leaves exceeded those considered by Kabata-Pendias and Pendias [22] as toxic (500 mg kg^{-1}). The sensitivity to excessive Mn levels is diverse, even within the same genus or plant species [22]. According to Kitao et al. [33, 34] *Betula platyphylla* var. *japonica* was relatively tolerant to high levels of Mn. Also the early successional

Table 4. Accumulation ratios for heavy metals in plant leaves from mine dumps in the Sudety Mountains ($F_{tabular}=3.15$).

Species	Fe	Mn	Zn	Pb	Cu	Cd	Ni
Betula pendula	0.020	3.7	2.4	0.96	0.14	11.8	0.08
Salix caprea	0.010	0.5	2.2	0.8	0.3	54.1	0.20
Rubus idaeus	0.001	1.8	0.6	0.7	0.3	8.1	0.05
Fest.	5.16	18.9	10.8	1.56	6.25	10.9	1.57
LSD	0.009	0.97	0.55	-	0.11	19.1	-

species such as *Betula ermanii* have a greater tolerance for excess levels of Mn in leaves than late successional species [35]. The present study showed that *B. pendula* also showed a high Mn accumulation capacity but no toxic effects were observed. The accumulation ratios of Mn in the leaves of *B. pendula* (1.04–9.56) from the investigated areas were higher than the mean value (0.1) for various species of plants reported by Kabata-Pendias and Pendias [22]. Furthermore, relatively high concentrations of Mn (182 to 949 mg kg^{-1} d.w.) and accumulation ratios (1.24 to 3.62) were noted in the leaves of *R. idaeus*. However, the leaves of *S. caprea* contained a low level of this metal (26.7 to 286 mg kg^{-1} d.w.). Alvarez et al. [15] and Vandecasteele et al. [36] observed that *Salix atrocinerea* and *Salix cinerea* were capable of accumulating Mn at contaminated sites.

According to Kabata-Pendias and Pendias [22] the ratio of Fe/Mn in vegetal tissue should be between 1.5 and 2.5 since both elements are involved in metabolic processes hence, they must be present in suitable proportions for adequate plant growth. In the present study the ratio of Fe/Mn was lower, amounting 0.73 in *B. pendula*, 0.12 in *R. idaeus* and 0.88 in *S. caprea*.

The accumulation ratio is an important factor in understanding the relative availability of trace elements to plants [37, 38]. Sequences of accumulation ratios (Table 4), established for plants growing on the uranium dumps, indicated the following heavy metal absorption capability of *B. pendula*: Cd > Mn > Zn > Pb > Cu > Ni > Fe, *S. caprea*: Cd > Zn > Pb > Mn > Cu > Ni > Fe and *R. idaeus*: Cd > Mn >Pb > Zn > Cu > Ni > Fe. These accumulation sequences were similar for each of the examined species and corresponded to the general sequence proposed by Kabata-Pendias and Pendias [22] for plants. Different accumulation rates for Mn were evident (high in *B. pendula* and *R. idaeus* and low in *S. caprea*). The high accumulation ratio values for Pb and especially Cd were characteristic for all the investigated species and indicate a high accumulation ability.

Conclusions

The investigated plants from the uranium dumps in the Sudety Mts. grew on acidic soils with an unfavourable C/N ratio. However, the nutrient status as well as relatively high CEC and organic matter of the studied soil allowed the growth of spontaneous vegetation. Contamination by heavy metals (Pb, Zn, Cu, Cd and Ni), being associated with the mineral assemblage of the spoil material, was found to be significant within all dumps. All plants examined (*S. caprea*, *B. pendula* and *R. idaeus*) accumulated high amounts of heavy metals, but in general *R. idaeus* showed lower concentrations of all heavy metals (except Mn) in its leaves. However, Pb was accumulated to a similar degree in both the trees and *R. idaeus*. Among all the heavy metals analyzed in the three species, Cd exhibited the greatest accumulation rate and the Cd accumulation ratio was several times higher for *S. caprea,* in comparison to the other two species. *B. pendula* and *R. idaeus* exhibited higher accumulation rates for Mn than *S. caprea*. However, the potential use of *R. idaeus* in monitoring metal concentration in the environment requires further investigation. The significant positive correlation between Pb in soil and leaves of the same tree suggest that *S. caprea* should be employed for monitoring Pb in the environment.

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