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Element transfer at the soil-plant interface and accumulation strategies of vegetation overgrowing mining waste dumps in the Upper Silesia area (Poland)

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We describe new data constraining patterns of interaction of soils and vegetation in post-coal-mining and post-smelting waste heaps of Upper Silesia. Mosses show the highest levels of many elements. We use 3 standard bioconcentration indices to show directions of transfer of both trace and major elements (53 in soils, 37 in plants) in particular plant organs. *Solanum nigrum* around organic- and S-rich fumaroles of the "Ruda" heap (Zabrze) shows 36 indices with values 2 (31-element basis) suggesting the largest hyperaccumulation potential (HP), especially of Cd, Mo, Sr, Zn, Mn and Au; also Hg, U, Al, Ti, Fe, Cu, Au and few others. *Verbascum* (4 specimens) shows HP for Tl, Sb, Cd and Sr. It is the major scavenger of V, Cr, Co, Ni, Ga, As, Hg, P and Bi, and occasionally of B, Hg, Au and Te. *Crepis mollis* shows evident affinity for W and Au, and *Solidago gigantea* for Ag. Anomalies of W are also present in mosses (2 specimens) and a grass, and of Au in one moss, *Tussilago farfara* and *Eupatorium cannabinum*. Most elements are transferred to leaves, with the partial exception of Cd and Tl. Variable behaviour is found for Cd, Tl, Cu, Se, Sr, Mo; Cu, Zn, B and W.

Key words: soil-to-plant element transfer, waste heaps, bioaccumulation factor, bioconcentration indices, translocation factor, *Verbascum.*

INTRODUCTION

POST-COAL-MINING AND POST-SMELTING HEAPS OF UPPER SILESIA

Both coal mining and smelter transformation of Pb-Zn-Ag-Cd-Tl-bearing ores within the Upper Silesian Coal Basin (USCB), south Poland (Fig. 1) resulted in numerous waste heaps (coal-mining waste heaps, CWHs, and post-smelting waste heaps, SWHs). Of these, there are ~220 CWHs (Gawor, 2014), of which a small proportion has spontaneously burnt or is still burning. As of 2023, after 19 years of monitoring by one of us, less than 10 heaps are still on fire. The CWHs collect vast amounts of post-mining waste rocks (coal, coaly shales, and other mostly sedimentary rocks), with a total mass of >760 million tonnes (Gawor, 2014) and growing. They can have large areas, often >100 ha (e.g., at Czerwionka-Dębieńsko) and heights [e.g., 138 m above ground level (a.g.l.) in the case of the "Szarlota" heap in Rydułtowy; PZPWŚ, 2004]. Some heaps undergo deconstruction (e.g., at Zabrze-Mikulczyce), others recultivation (e.g., heaps in Łaziska and the Bańgów – Dąbrówka Wielka area), reconstruction (e.g. Radlin and Rydułtowy), or sudden fire outbreaks as in the Brynów district of Katowice (Przybytek, 2015). The formation and long-time existence of these heaps leads to severe environmental disturbance. Remediation of burning CWHs (BCWHs) is very costly. Spontaneous coal oxidation followed by combustion triggers numerous physico-chemical transformations, of main three types: high-temperature (~330–1200°C) pyrometamorphic, exhalative, and low-temperature supergene (e.g., Kruszewski et al., 2018, 2021, and references therein). Information on the causes of spontaneous gob fires are found in the papers cited. Coal-fire gas – the major agent of chemical and heat transfer within the burning heaps – has a complex and extremely spatiotemporally variable chemistry, though dominated by H_2O and CO_2, followed by CO, CH_4, thiophene, AsH_3, PH_3, organohalogens, and numerous other organic compounds and radicals. Hydroxides, carbonyls, nitrosyls, hydrides, and organo(semi)metallics represent the major gas-phase forms of (semi)metal and in part nonmetal transfer within the CWHs (e.g., Kruszewski et al., 2018, 2019, 2021). Fumarolic activity and newly formed condensate minerals (mainly hydrated and anhydrous sulfates and chlorides) introduce ammonium (the most characteristic cation of burning

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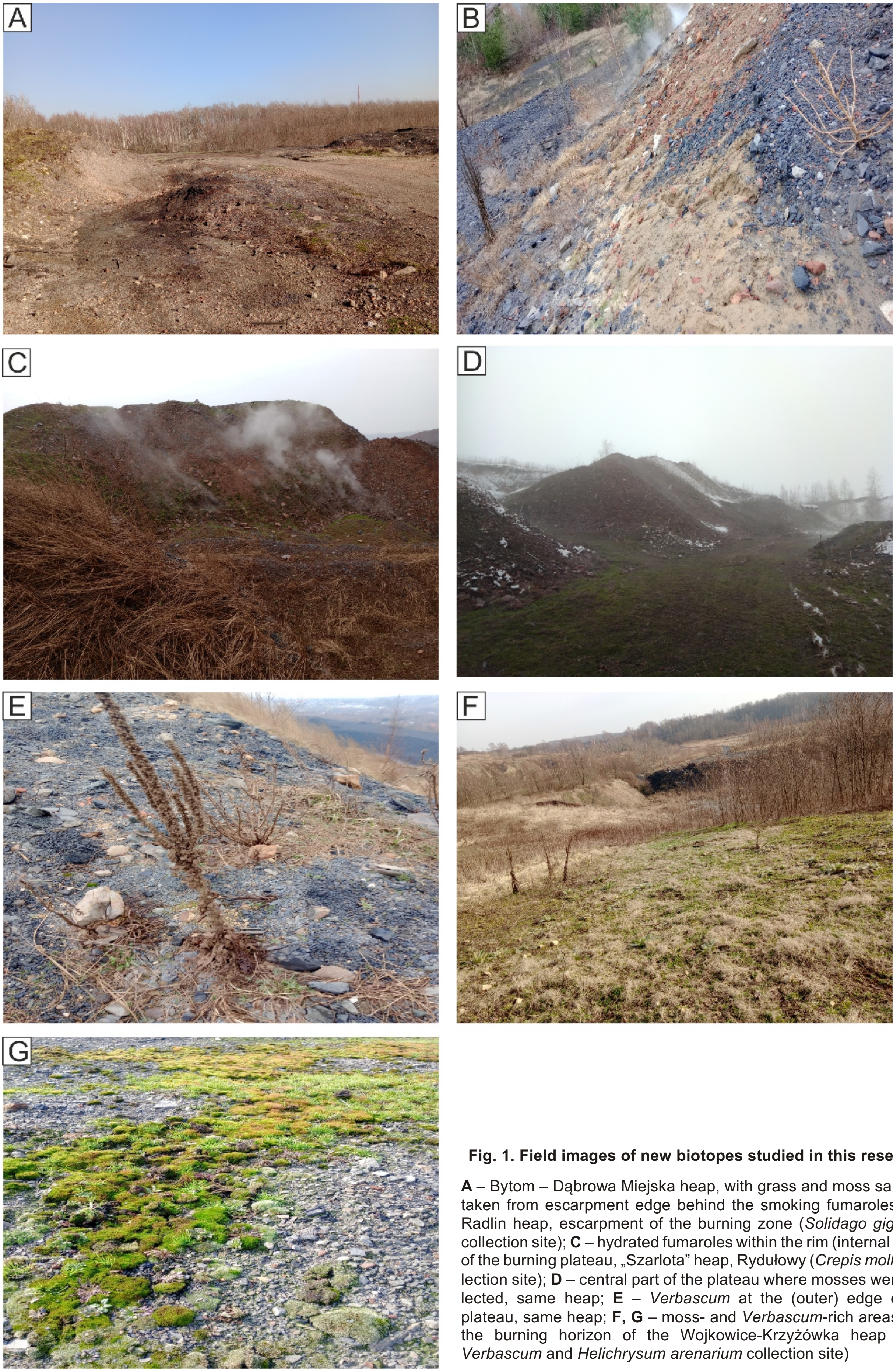

Fig. 1. Field images of new biotopes studied in this research

A – Bytom – Dąbrowa Miejska heap, with grass and moss samples taken from escarpment edge behind the smoking fumaroles; **B** – Radlin heap, escarpment of the burning zone (*Solidago gigantea* collection site); **C** – hydrated fumaroles within the rim (internal edge) of the burning plateau, „Szarlota" heap, Rydułowy (*Crepis mollis* collection site); **D** – central part of the plateau where mosses were collected, same heap; **E** – *Verbascum* at the (outer) edge of the plateau, same heap; **F, G** – moss- and *Verbascum*-rich areas over the burning horizon of the Wojkowice-Krzyżówka heap (G – *Verbascum* and *Helichrysum arenarium* collection site)

CWHs), B, F (e.g., as $[SiF_4]^{2-}$, $[Al(F,OH)_6]^{3-}$, and F^-), Cl^-, SO_4^{2-}, K, Na, Ca, Mg, Al, Ti, Cr, V, Mn, Fe, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Sr, rare earth elements (REE), Mo, Ag, Cd, In, Sn, Sb, Te, I, Ba, Re, Au, Hg, Tl, Pb, Bi, Th and U to the local environment (e.g., Kruszewski, 2018; Kruszewski et al., 2018). Thus, localized multi-element anomalies occur widely across the USCB from burning CWHs.

Mainly due to the fixation of many elements by the organic matter of coal, such elements may constitute anomalies within the fuel (Ketris and Yudovich, 2009) and, due to fire-driven transformations, they may be mobilized in the CWHs. The most common anomalies in different materials from the USCB CHWs concern Zn, Pb, Hg, Co and Ga, followed by Sb, Ni, Cu, Bi, As, Se, Tl and other elements (Kruszewski, 2018). This, in turn, suggests potential industrial utilization of heap-grown vegetation, by phytomining (e.g., Siwek, 2008a, b; Vural, 2017).

In the northern part of the USCB, CWHs are often mixed with post-smelting waste related to former Pb-Zn(Ag) mining in this area. Pure SWHs are also present in this region. This waste is a large source of not only Pb and Zn, but also Cd, Tl, Ag, and, to some extent, Ge and other elements (e.g., Wierzbicka et al., 2004).

SOILS AND VEGETATION IN THE HEAPS

Kruszewski et al. (2021) studied soils developing on burning and burnt CWHs of the USCB area, including organic- and sulfur-rich soil from the "Ruda" heap in Zabrze-Biskupice, further analyzed in the current study. Goethite was found in most soils as a marker of both pedogenesis and, likely, salinity. Some trace elements (TE; As, Sb, Pb, Ba, Cu) in these soils showed positive correlation with the finest silt fraction. Sb and Ba, alongside Zn, Ni, and Cr positively correlated with 0.5–0.25 mm sand, Th, Zr, La, Al with the coarse sand fraction, and Sb and Zn with gravel. Higher TE levels were positively correlated with temperature of crystallization of the inherited minerals. Comparing with data for the presumably fire-free heap habitats studied by Rahmonov et al. (2020), we found a higher degree of pH variability than their 4.1–5.9 range, though our pH data usually plotted around 7, in part due to enrichment in organonitrogen species.

Wojewódka-Przybył et al. (2022) found a high variation (CV>100%) in elemental content between the samples. The most common anomalies in the CWHs studied concern Zn, Pb and Hg – depending on waste type – followed by Bi, U and Tl. The local vegetation was able to colonize the heap habitats even though its Zn, Hg, and Tl levels are (much) higher than levels considered to be toxic ones. The highest phytostabilization and phytoremediation potential was attributed to *E. cannabinum* and *S. canadensis* which showed maximum contents of some elements in their roots. The former has shown higher than toxic levels of As, Ag, Cd and Pb. We have also suggested it as a potential B hyperaccumulator. In that paper just 9 plant specimens were studied and we noted that some dependencies initially identified, such as the TiLa and TiFe association, needed additional study. In this paper we continue research into soils (following Kruszewski et al., 2021) and vegetation (following Wojewódka-Przybył et al., 2022) on various types of heaps of the USCB area.

Species composition on the Polish heaps has had some study (e.g., Zając and Zarzycki, 2013; Hanczaruk and Kompała-Bąba, 2019; Rahmonov et al., 2020; Sitko et al., 2022). Due to the extreme conditions such as strong insolation, low substrate humidity, and lowered availability of nutrients, many heaps represent habitats with either a small number of plant species or with distinctive (e.g., endemic) fauna and flora. The plant successions include local metalophytes: hyperaccumulating species also known from distant environments, such as *Armeria maritima* (e.g., Siwek et al., 2008a, b). On heaps of coal fly ash (CFA), polycyclic aromatic hydrocarbons (PAHs) represent an important source of toxic elements (e.g., Atanassova et al., 2018). Substrate-derived elements are accumulated in various parts of the plants, depending on species. Heap-grown plants must develop strategies to survive ionic stresses. These include selective uptake (known, e.g., in water plants such as *Ludwigia palustris*, but also trees such as *Populus nigra*); avoidance mechanisms including arbuscular mycorrhiza (e.g., in *Trifolium pretense*, *Glomus moseae* and others); tolerance via neutralization related to synthesis of metal-binding compounds such as metallothioneins and protective proteins; delay of the vegetative season, or advantage of vegetative over selective reproduction. Although as much as 70-98% of the elements taken up may be kept in roots, some plants (e.g., *Salix atrocinerea*, *Lepidium sativum*) show root-to-shoot translocation. Shoot sequestration is known, e.g., in *Leptoplax emarginata*, *Nicotiana tabacum*, *Helianthus annuus* and *Brassica juncea*. In the case of hyperaccumulators – plants absorbing extreme levels of elements – processes including mechanical absorption, translocation, detoxification, compartmentation or via inducing of rhizosphere pH lowering take place. Hyperacumulator species are sometimes used in phytomining. Some are bioindicators of pollution, e.g., Zn pollution (*Cardaminopsis halleri*), Cu and Ni pollution (*Betula pubescens*) Elevation of pH may lower availability of B, P, Mn, Cu and Zn (Siwek, 2008a, b; Hanczaruk and Kompała-Bąba, 2019). Siwek (2008a, b) reported important arbuscular-mycorriza species overgrowing old Zn-rich heaps to be *Cardaminopsis arenosa*, *C. halleri*, *Biscutella laevigata*, *Thlaspi calaminare* and *Minuartia verna*. Many species arise in late stages of succession, including *Armeria maritima* and *Viola calaminaria*.

STUDY AREA AND METHODOLOGY

VEGETATION AND SOIL SAMPLES

For the current study, geochemical data on 11 vegetation samples characterized by Wojewódka-Przybył et al. (2022) were used. They come from a burning mixed (coal-smelter) waste heap in the Dąbrowa Miejska district of Bytom (*Rumex crispus* L., *Arctium tomentosum* Mill., *Verbascum* – river bank; *Solidago canadensis* L. and *Verbascum* – heap top; *Tussilago farfara* L. – post-smelter slag zone; *Betula pendula* Roth and *Populus* L. – burning escarpment), the "Ruda" heap in Zabrze- Biskupice (*Solanum nigrum* L. – organic- and S-rich fumaroles), and the "Ajska" post-smelter heap in Świętochłowice-Chropaczów (*Eupatorium cannabinum* L.). To elevate the statistical quality, 11 new samples (plant organs) from 6 new specimens were studied. The specimens collected within the current study are: a moss and a grass growing immediately above fumaroles of the burning escarpment at Bytom (BDM samples); *Solidago gigantea* Aiton from the Radlin CWH top, growing immediately above a long-term intense-fire zone; *Crepis mollis* Asch. being part of a rich vegetation assemblage overgrowing a hill within the outer part of a heap plateau (RDT-b) covering a long-term strong pile fire at the "Szarlota" CWH in Rydułtowy; *Verbascum* and a moss (most likely *Silene acaulis*) growing at the edge and centre of this plateau (RDT-plt); and *Verbascum* and *Helichrysum arenarium* collected from a zone immediately above an expiring fire zone at the CWH in the Krzyżówka district of Wojkowice (Fig. 1 and 2). Details on the old samples and their habitats are in the paper cited, while those regarding the new samples are given

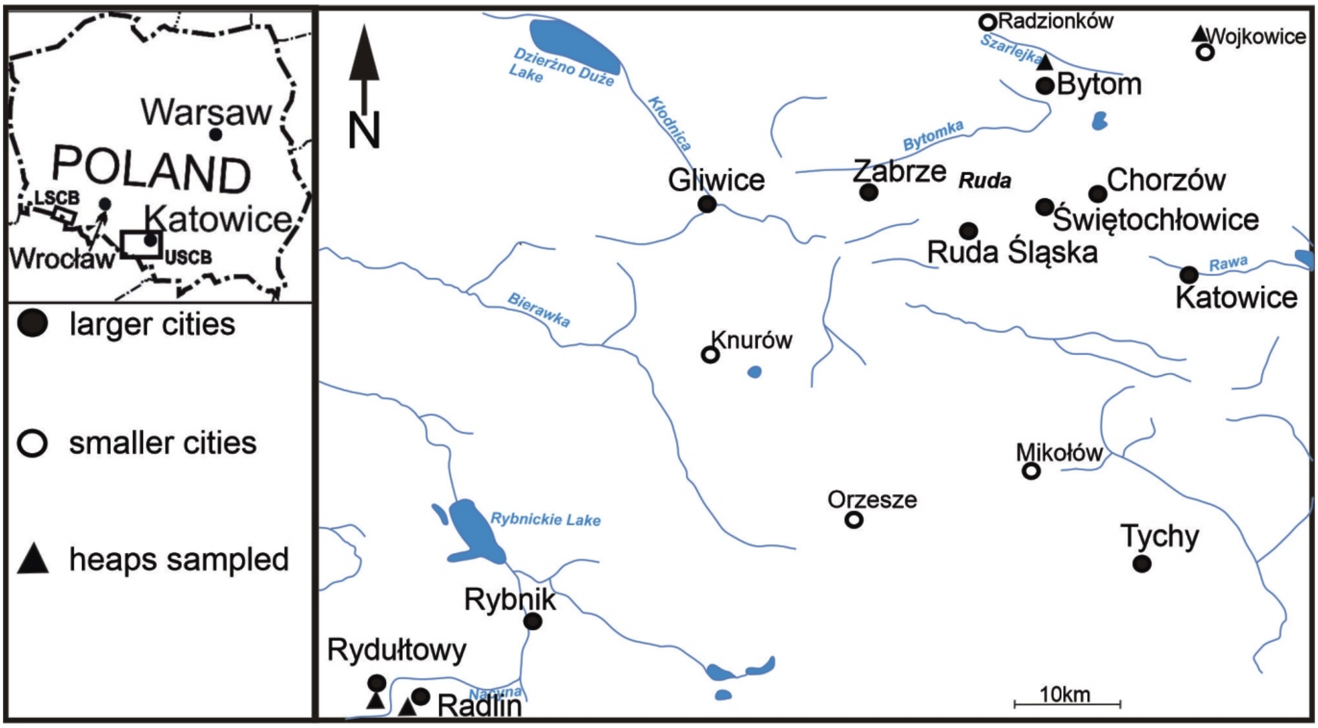

Fig. 2. Geographical location of the heaps studied

in Appendix Table 1 herein. At the RDT-b site, highly hydrated very-low-temperature fumaroles have been active for at least last 2 years. Additional plant species identified there include *Scandix pectin-veneris*, *Helminthotheca echinoides*, *Hypericum perforatum*, *Verbascum* (probably *V. thapsus*), *Sonchus oleraceus*, *Evolvus glomeratus*, *Bellis annua*, *Fragaria* L., and provisionally identified *Cirsium brevistylum* (abundant), *Poaceae* (most likely *Juncus effusus*; abundant), *Bryophyta* (possibly *Callitriche palustris;* abundant), *Hypochaeris glabra* (abundant), *Packera glabella* (quite abundant), *Sericocarpus asteroides*, *Hieracium gronovii* (and/or *H. scouleri*), *Lactuca serriola*, *Eruca vesicaria*, *Heteropogon centaurus*, *Glechoma hederacea* L., *Arnoseris minima*, *Picris hieracioides*, *Arabidopsis thaliana* and *Lapsana*. The "plt" habitat, by contrast, was species-poor, with *B. annua* as the only species identified in addition to those previously noted. No other species were identified at the BDM site. At the Radlin site, *S. gigantea* was likely associated with minor *H. echinoides* and a grass. The total number of specimens there was low. A few metres below the burning zone, on a terrace, rich planted vegetation represented mainly by *Elaeagnus angustifolia* and *Hippophae rhamnoides* occurs. The "Ajska" habitat in Świętochłowice was also poor in vegetation, with *E. cannabinum* mostly associated with *Poaceae*. The site in Wojkowice was rich in species and, in general, similar to the "b" habitat of Rydułtowy. Additional species seen on the Wojkowice heap were *Erigeron annuus* L. (rich), *Matricaria discoidea* (rich), *Echium vulgare*, *Lepidium densiflorum*, *S. gigantea*, *Centaurea* L. (probably *C. paniculata*), a moss, and tentatively identified *Rorippa sylvestris, Lamium amplexicaule, Plantago alfa* and *Plantago maritima*.

Soil samples were derived from the rhizosphere of these plant specimens and its immediate surroundings. We could not use the soil samples described in Kruszewski et al. (2021) because some of them came from already non-existent (collapsed) areas. The second, biogeochemical reason is explained below. Thus, for the purpose of the current study, 12 new soil samples were studied, along with a re-studied sample from Zabrze (see details below). In total, 13 soil samples were analyzed for 52 element contents.

SAMPLE PREPARATION AND LABORATORY ANALYSIS

Treatment and analysis details of the vegetation samples are essentially identical as in Wojewódka-Przybył et al. (2022), as the samples were studied using the vegetation-dedicated ICP MS at Bureau Veritas. The same holds for the soil samples, although in this case the dissolution was by the modified aqua regia (AR) method. This was done to gain data for additional elements (as compared to the formerly used multi-acid, i.e., MA digestion approach), namely Li, B, Ga, Ge, Se, Rb, Pd, In, Te, Cs, Ce, Hf, Ta, Re, Pt, Au, Hg and Tl. Geochemical analysis of the soil samples analyzed prior to this study was carried out by using a much more aggressive digestion treatment. In that case a multi-acid digestion was used. Although this gave total or nearly-total elemental composition data, it did not reflect elements availability for vegetation. In particular, the MA results show much higher contents of Al, K, Ti, Be, Sc, V, Cr, Sr, Y, Zr, Nb, Ba, La, Th and – in particular – Fe and Bi, due to their concentration in refractory and low- to very-low solubility mineral phases such as cordierite/indialite, oxyspinels, anorthite, rutile, zircon, monazite-(Ce) and glass. These phases strongly immobilize most of these elements. The results obtained are shown as received, and the typical average uncertainty is ~8%.

STATISTICAL ANALYSIS

Different statistical tools were used to ascertain the geochemical relations of the elements studied. The data was analysed using *PAST* software (Hammer et al., 2001). Correlation of logratioed data was studied by Kendall statistics, and principal component analysis (PCA) was also used. To obtain as many associations as possible, the soil and vegetation systems were both studied as merged and separated systems. Both the logratio and PCA approaches were chosen based on advice in papers devoted to statistics usage in geology, e.g., Pingitore and Engle (2022).

RESULTS

The ICP analysis results for both trace (and minor) and main elements in soil samples are shown in Table 1. The corresponding data for new vegetation samples is given in Table 2. Relations of the contents found to local coal, shale, and normal soil and vegetation levels are juxtaposed in Appendix Table 2, in the form of enrichment factors (EFs, i.e., levels measured divided by levels in the materials listed).

SOIL GEOCHEMISTRY

The soils studied show persistent high enrichment in Zn (geometric mean, i.e., GM, of 426, and maximum >10,000 mg/kg) Pb (170 and >10,000 mg/kg, respectively), Cu (59 and 961 mg/kg), As (16 and 2340 mg/kg, respectively), Cd (2.9 and 102), Sb (1.6 and 23), and Ag (0.47 and 7.7). Also Se (0.93 and 3.8), Te (0.07 and 0.19), Bi (0.68 and 2.1), Hg (0.10 and 4.1), and Tl (0.20 and 0.62 mg/kg) show elevated levels. Elements strongly undersaturated with respect to the multi-acid-soluble fraction (of the formerly studied soils) are Nb, Zr, Hf; W, Na, Ti; Al, Rb, Li, Cr, Be, Sr, Y, Mo, Ag, Mg, Th, Bi, Se, In, Sn, Sb, Ba, Ce and Tl. Average levels of Ni, Cu, Pb, Ca, Fe, V, and Mn are similar, and those of Cd, As, P, S, Co and Zn are higher (Table 1). The mean-and-whisker plot for the "new" soil samples (Fig. 3) shows Al, Fe and Ca (main elements), Zn and Pb (trace elements) having the largest spread. They are followed by K, Mg, S; As, Ba and Cu. The spread of other elements is negligible, although of the main elements P is the one with the lowest range. In general, much more variation is seen for the main elements. The Kendall statistics matrix for the soils is shown in Appendix Table 3.

PLANT GEOCHEMISTRY

The plants are particularly enriched in Zn (GM of 117 and maximum of 529 mg/kg), Pb (11 and 151, respectively) and Al (0.14 and 1.48), with lesser anomalies of U (0.37 and 6.0), Cd (1.0 and 4.7), As (1.1 and 6.7), Bi (0.18 and 1.9), Sb (1.2 and 2.5), Ag (0.13 and 0.50) and Se (0.32 and 1.1 mg/kg). The mean-and-whisker plot for the "new" soil samples (Fig. 3) shows K, Ca, and S showing a large spread, with Fe, Al and Mg having moderate spread (main elements); of the trace elements, Zn has the largest spread, although the logarithmic version suggests this characteristic may also be ascribed to As, Pb, La, Cd, Th and U. As in the case of the soil samples, the main elements have larger variations. The Kendall statistics matrix for the soils is given in Appendix Table 4. Element contents in the vegetation are compared with the published data in Figures 4–6; the corresponding concentration/translocation data is in Figures 7–11.

Leaves of *A. tomentosum* from Bytom are especially rich (>100 mg/kg) in Tl (EF of 28, i.e., 28 x normal vegetation levels), Cd and V (23x), Zn and Ba (12x), Cr (9x), Sc (8x), and Pb and U (5x), with higher (?2x) than typical levels of B, V, Ni, Cu, Se, Mo, Sb, Hg, Bi and Th; of the major elements, >4 wt.% K is notable. There has been little such published data on *A. tomentosum*, and we provide data for 30 elements seemingly previously unstudied for this species. Our specimen shows relative enrichment in Zn, with high values also for Ba, Pb and Sr, with moderately elevated B, Cu, Ni, Cr, V, As, K; Mo, Cd, La; Ca, Tl and Co. The BAF factor record belongs to K, followed by Na, Ba, Tl, S, P, Th, Mo, Sr, Au, B, Ca and Mg.

Leaves of *R. crispus* from Bytom are especially rich in Tl (43x), Mo (9x), Cd (7x), Pb (5x), Sc (4x), and Cr (~3), and this is the species richest in K (~6 wt.%), P, Na, and Mg. Its B enrichment level is very similar to that in the associated *A. tomentosum*. Relative to published values, there is enrichment of K, P, S, Na, and to some extent of Ti, Fe and Mg. Enriched elements are Zn, Ba, B, Pb, Cu, Sr, Ni, Mo, Cr, V, Tl and As. As in the case of the associated *A. tomentosum*, no comparative BAF (biological acumulation factor, i.e., leaf content/soil content) data was found. Elevated BAFs concern especially K, Na, P, S, Mo, Tl, Mg, B, Se and Au.

Of the *Solidago* species, *S. canadensis* is most extreme in its TE levels, with the highest, fifteen-fold enrichment against the norm. Other anomalies include Cd (49x), V (23x), Sb (20x), Se (13x), Sc (12x), Cr (10x), Zn and Hg (8x), Th (7x), Tl (5x), Cu (4x), U (~3), with the norm doubled in the case of Ni, Co, Pb and Bi. *S. gigantea* is relatively saturated in Sb (19x) and Hg (13x), with much smaller outliers for B, Cd, Cr, Cu, Zn, Sc, Ni, Bi and U.

E. cannabinum (various organs) shows, in relation to published data, outstanding levels of Cd (327x), Zn and As (~75x), Pb (34x), Sb (18x), V (17x), Ag (16x), Tl and Sc (10x), Cr (9x) and B (7x), with elevated Hg, Co, Ni, Cu, Ca, Fe and S. Numerous elements show different organ preferences than as previously reported: Mn (leaf); Cu, Fe, Pb, and to some extent Cr, Ni, Ba and U (root). Cd shows leaf preference. Other root-concentrated elements are Ga, Sb, Ag, Tl and Th. There are equal root-leaf levels of Al, Ti, Mn, V, Cr, Sc, Se, Te and Bi. There are high BCF (biological concentration factor, i.e., root level / soil level) levels of Zn and Pb, and elevated BCF, BAF and TF (translocation factor, i.e., leaf level / root level) of K, B, and P. Also, seemingly higher-than-published BCF and TF characterize As and Cd (plus Sr and Na), and Ca (TF and BAF). The only element seeming preferentially kept in the stem is Al.

Many elements have been determined in *T. farfara* (leaves mainly) and it is the most Zn-rich species (90x the norm). It is also extremely anomalous in terms of Tl (400x) and Cd (182x), also being rich in Sb and Pb (19x), Ni (17x), Sc (16x), As (12x), Se (7x), Cr (6x), Ag, Co and Bi (~4x), and B, Cu and V (~3x). Cr, Co, and Ni are also moderately elevated. Levels higher than those reported by other authors are Ca, Tl, Zn, Co, Ti, Mn, V, Hg and Fe; Na levels are comparable. The highest anomalies are observed for Zn and Pb, and then for Sr, B, Ba, As, Cu, Tl, Ca, K, S, V, Cr and Ni. Potentially strong leaf preference may be shown especially by V, Sc, Fe, Ni, Ga and U, with stem preference over leaves clearly in the case of Sb, K and Te. There are similar stem- and leaf-contents of B, Pb and Tl. The highest stem/leaf EF values are for Th, Al and Bi, followed by Hg, Au, La, Ga, Fe, Mn, Ti, Sc, As, Co, Ni, Zn, Ag and U.

The results obtained for the four *Verbascum* species seem to suggest that this genus is relatively non-selective as regards elements sorbed. The most enriched elements (i.e., log(value)>0.1), in general, are Zn, Cu, B, Ba, Pb, Sr, with smaller or single anomalies for Cr, V, Ni, Co, Cd; La, Ga, Sc, Sb, Tl, U; and Th, Ca and K. Norm-related enrichment is variable, but outstanding for Sc (4-620x), V (10-63x), Tl (6-60x), Sb (16-28x), Cd (3-49x), Zn (4-21x), Cr (5-16x), Cu (4-10x), Ni (2-9x) and B (2-4x). There are single anomalies of Co, Bi, Th, and U. Elements with levels higher than published ones are Ti, Fe, Sc, V, Pb, Hg and Tl. Most elements studied follow the same organ preference as in published data, with the exception of Pb, Mo, Cd, As, and in part Bi and Mn. Also, most elements show leaf preference (being the most persistent for Al, V, La, Se, S; W and Au), with variable behaviour noticed for Sr, Ag

Table 1

Results of bulk ICP analyses of soil samples collected on selected waste heaps of Upper Silesia

sample:	BDM-BP	BDM-VM	BDM-RIV	BDM-TOP	BDM-VP	BDM-PbZn	RDH	RDT-B	RDT-pM	RDT-pV	SWCA	WOJ	ZBB[1]	GM (new)[2]	GM (old)[3]	typical soil levels[4]
trace elements, mg/kg																
Li	27	15	3.6	11	8.1	11	14	31	**52**[5]	12	11	29	2.0	13	n.a.	25
B	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20		n.a.	31
Be	1.9	1.3	0.40	1.2	1.1	1.4	0.90	**2.8**	2.4	0.90	2.4	1.6	0.30	1.2	5.1	1.4
Sc	**5.6**	3.3	0.70	3.5	2.0	4.2	3.3	4.8	5.4	2.3	3.7	4.4	1.0	2.9	15	7.7
V	42	31	11	33	**93**	31	23	36	42	15	37	33	5.0	27	113	66
Cr	32	26	18	39	**61**	25	19	30	35	12	25	**59**	5.7	26	80	48
Co	13	11	4.0	8.9	11	8.9	6.5	11	11	7.7	**25**	14	1.5	8.7	15	8.0
Ni	31	25	13	24	36	23	17	30	29	12	**89**	40	5.0	23	48	18
Cu	44	75	44	**961**	87	60	24	46	49	22	245	49	9.3	59	68	23
Zn	882	1740	994	1210	6110	665	57	82	148	38	**>10000**	242	32	426	129	60
Ga	6.1	3.3	1.2	2.9	3.1	2.9	3.4	6.1	7.6	3.2	**9.2**	5.5	0.70	3.5	n.a.	18
Ge	<0.10	<0.10	<0.10	<0.10	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	**2.6**	<0.10	<0.10		n.a.	1.3
As	12	23	20	16	83	18	5.2	11	9.9	2.8	**2340**	10	1.2	16	13	6.1
Se	1.2	0.90	0.50	1.2	1.1	1.0	0.60	1.5	1.0	0.30	**3.8**	1.1	0.50	0.93	n.a.	0.19
Rb	**26**	16	5.5	15	8.1	16	16	20	**27**	17	7.0	17	4.9	13	n.a.	68
Sr	99	74	34	31	125	32	31	61	82	22	**133**	28	9.7	46	209	154
Y	7.0	8.1	3.4	7.8	7.4	8.8	7.0	**13**	**12**	6.0	11	7.8	2.6	7.2	27	26
Zr	10	1.4	0.20	5.7	5.8	5.5	4.2	4.0	4.4	5.2	**13**	1.9	1.6	3.4	82	251
Nb	0.10	0.32	0.24	0.38	0.22	0.42	0.37	**1.2**	0.69	0.41	0.25	0.39	0.14	0.33	12	13
Mo	0.44	1.0	1.1	1.1	2.1	0.60	0.48	0.75	1.3	0.25	**5.5**	0.97	0.13	0.80	2.1	1.4
Pd	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	**0.05**	und[6]	<0.01	<0.01		n.a.	0.003
Ag	0.40	0.95	0.88	0.82	2.6	0.64	0.09	0.20	0.25	0.11	**7.7**	0.60	0.06	0.47	0.50	0.18
Cd	7.8	11	5.2	8.2	44	3.2	0.97	0.35	0.89	0.11	**102**	1.6	0.39	2.9	0.52	0.42
In	0.05	0.06	0.02	0.04	0.09	0.04	0.03	0.05	0.11	0.03	**0.17**	0.04	<0.02	0.05	n.a.	0.10
Sn	2.4	5.8	4.9	5.5	7.9	2.4	1.9	4.9	7.0	3.1	**27**	2.3	0.60	3.9	11	1.5
Sb	2.3	1.9	1.7	3.8	2.5	2.4	0.44	2.0	1.5	0.43	**23**	0.75	0.39	1.6	7.3	0.65
Te	0.04	0.11	0.06	0.06	0.11	0.07	0.07	0.08	**0.19**	0.09	0.09	0.08	<0.02	0.07	n.a.	0.04

Tabl. 1 cont.

sample:	BDM-BP	BDM-VM	BDM-RIV	BDM-TOP	BDM-VP	BDM-PbZn	RDH	RDT-B	RDT-pM	RDT-pV	SWCA	WOJ	ZBB[1]	GM (new)[2]	GM (old)[3]	typical soil levels[4]
trace elements, mg/kg																
Li	27	15	3.6	11	8.1	11	14	31	**52**[5]	12	11	29	2.0	13	n.a.	25
B	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20		n.a.	31
Be	1.9	1.3	0.40	1.2	1.1	1.4	0.90	**2.8**	2.4	0.90	2.4	1.6	0.30	1.2	5.1	1.4
Sc	**5.6**	3.3	0.70	3.5	2.0	4.2	3.3	4.8	5.4	2.3	3.7	4.4	1.0	2.9	15	7.7
V	42	31	11	33	**93**	31	23	36	42	15	37	33	5.0	27	113	66
Cr	32	26	18	39	**61**	25	19	30	35	12	25	**59**	5.7	26	80	48
Co	13	11	4.0	8.9	11	8.9	6.5	11	11	7.7	**25**	14	1.5	8.7	15	8.0
Ni	31	25	13	24	36	23	17	30	29	12	**89**	40	5.0	23	48	18
Cu	44	75	44	**961**	87	60	24	46	49	22	245	49	9.3	59	68	23
Zn	882	1740	994	1210	6110	665	57	82	148	38	**>10000**	242	32	426	129	60
Ga	6.1	3.3	1.2	2.9	3.1	2.9	3.4	6.1	7.6	3.2	**9.2**	5.5	0.70	3.5	n.a.	18
Ge	<0.10	<0.10	<0.10	<0.10	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	**2.6**	<0.10	<0.10		n.a.	1.3
As	12	23	20	16	83	18	5.2	11	9.9	2.8	**2340**	10	1.2	16	13	6.1
Se	1.2	0.90	0.50	1.2	1.1	1.0	0.60	1.5	1.0	0.30	**3.8**	1.1	0.50	0.93	n.a.	0.19
Rb	**26**	16	5.5	15	8.1	16	16	20	**27**	17	7.0	17	4.9	13	n.a.	68
Sr	99	74	34	31	125	32	31	61	82	22	**133**	28	9.7	46	209	154
Y	7.0	8.1	3.4	7.8	7.4	8.8	7.0	**13**	**12**	6.0	11	7.8	2.6	7.2	27	26
Zr	10	1.4	0.20	5.7	5.8	5.5	4.2	4.0	4.4	5.2	**13**	1.9	1.6	3.4	82	251
Nb	0.10	0.32	0.24	0.38	0.22	0.42	0.37	**1.2**	0.69	0.41	0.25	0.39	0.14	0.33	12	13
Mo	0.44	1.0	1.1	1.1	2.1	0.60	0.48	0.75	1.3	0.25	**5.5**	0.97	0.13	0.80	2.1	1.4
Pd	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	**0.05**	und[6]	<0.01	<0.01		n.a.	0.003
Ag	0.40	0.95	0.88	0.82	2.6	0.64	0.09	0.20	0.25	0.11	**7.7**	0.60	0.06	0.47	0.50	0.18
Cd	7.8	11	5.2	8.2	44	3.2	0.97	0.35	0.89	0.11	**102**	1.6	0.39	2.9	0.52	0.42
In	0.05	0.06	0.02	0.04	0.09	0.04	0.03	0.05	0.11	0.03	**0.17**	0.04	<0.02	0.05	n.a.	0.10
Sn	2.4	5.8	4.9	5.5	7.9	2.4	1.9	4.9	7.0	3.1	**27**	2.3	0.60	3.9	11	1.5
Sb	2.3	1.9	1.7	3.8	2.5	2.4	0.44	2.0	1.5	0.43	**23**	0.75	0.39	1.6	7.3	0.65
Te	0.04	0.11	0.06	0.06	0.11	0.07	0.07	0.08	**0.19**	0.09	0.09	0.08	<0.02	0.07	n.a.	0.04

[1] – sample from the study of Kruszewski et al. (2021), re-analyzed using the new method (see the main text for details); [2] – geometrical mean of the new samples; [3] – geometrical mean for old (Wojewódka-Przybył et al., 2022) samples shown for an intra-method comparison; data for Re is overpriced due to a large number of records below detection limits; [4] – geometrical means calculated based on references cited in Shacklette and Boerngen (1984), Tagami and Uchida (2008), Jaguś et al. (2012), Yang et al. (2014), Belzile and Chen (2015), Savignan et al. (2020), Grygoć and Jabłońska-Czapla (2021), Wojewódka-Przybył et al. (2022), He et al. (2022); [5] – the highest and outstanding levels within the "new" batch of samples; [6] – undeterminable

Table 2

Results of bulk ICP analyses of the "new" vegetation samples collected on selected waste heaps of Upper Silesia

sample	BDM-VG	BDM-VM	RD-VSg		RDT-b-VCm		RDT-plt-VV	RDT-plt-VM	WOJ-VV		WOJ-VHa	GM (new)[1]	GM (whole)[22]	typical levels[3]
plant	L	whole	L	R	L	R	L	whole	L	R	shots			
species	(grass)	(moss)	*Solidago gigantea*				*Verbascum*	(moss)	*Verbascum*		*Helichrysum arenarium*			
trace[4] elements, mg/kg														
B	5.0	11	**75**[5]	21	35	26	59	16	31	19	50	25	29	14
Sc	0.10	1.0	<0.10	0.10	0.30	0.20	1.8	**2.6**	0.10	<0.10	<0.10	0.25	0.27	0.05
V	<2.0	13	<2.0	<2.0	10	7.0	19	**40**	3	<2.0	<2.0	5.1	3.2	0.05
Cr	6.6	22	2.3	3.6	8.0	6.4	15	**23**	6.1	2.4	2.1	6.3	4.3	0.31
Co	1.2	4.8	0.48	0.84	3.4	2.4	4.7	**5.6**	2.1	3.8	3.5	2.4	0.96	0.12
Ni	4.7	16	1.7	3.3	8.5	7.0	13	**19**	6.5	3.6	10	6.8	4.3	1.4
Cu	16	**40**	9.8	19	33	36	**41**	**40**	15	29	16	25	20	7.7
Zn	211	**529**	75	52	101	96	131	52	128	117	126	117	256	35
Ga	0.20	1.4	<0.10	0.20	1.5	0.90	2.5	**4.8**	0.50	0.10	<0.10	0.50	0.32	1.9
As	0.40	4.7	<0.10	0.60	2.8	1.6	3.4	**6.7**	1.8	0.60	0.20	1.1	1.3	0.46
Se	0.50	**1.1**	0.20	0.10	**1.0**	0.60	0.40	0.80	0.20	<0.10	<0.10	0.32	0.59	0.24
Sr	17	64	52	43	**100**	71	**102**	82	19	26	29	46	40	69
Mo	0.67	1.2	0.32	0.35	**1.5**	**1.6**	0.88	**1.5**	0.26	0.21	0.11	0.56	0.64	0.64
Ag	0.23	**0.50**	0.03	0.02	0.20	0.10	0.09	0.12	0.17	0.09	0.10	0.13	0.21	0.25
Cd	2.6	**4.7**	0.48	0.93	0.51	0.41	0.53	0.40	1.1	2.4	1.9	1.0	3.0	0.17
Sb	1.4	1.8	0.62	1.5	1.1	1.4	1.6	**2.5**	1.5	0.61	0.54	1.2	1.0	0.08
Te	0.04	0.05	**0.15**	<0.02	0.08	0.04	0.09	0.07	0.03	<0.02	<0.02	0.04	0.03	0.16
Ba	36	**114**	22	26	72	65	90	**117**	13	7.2	9.4	35	26	53

[1] – culated based on references cited in Wojewódka-Przybył et al. (2022), and on data from Kabata-Pendias and Pendias (2001), Domínguez et al. (2008), Hiller et al. (2019), and references cited in the figure captions, based

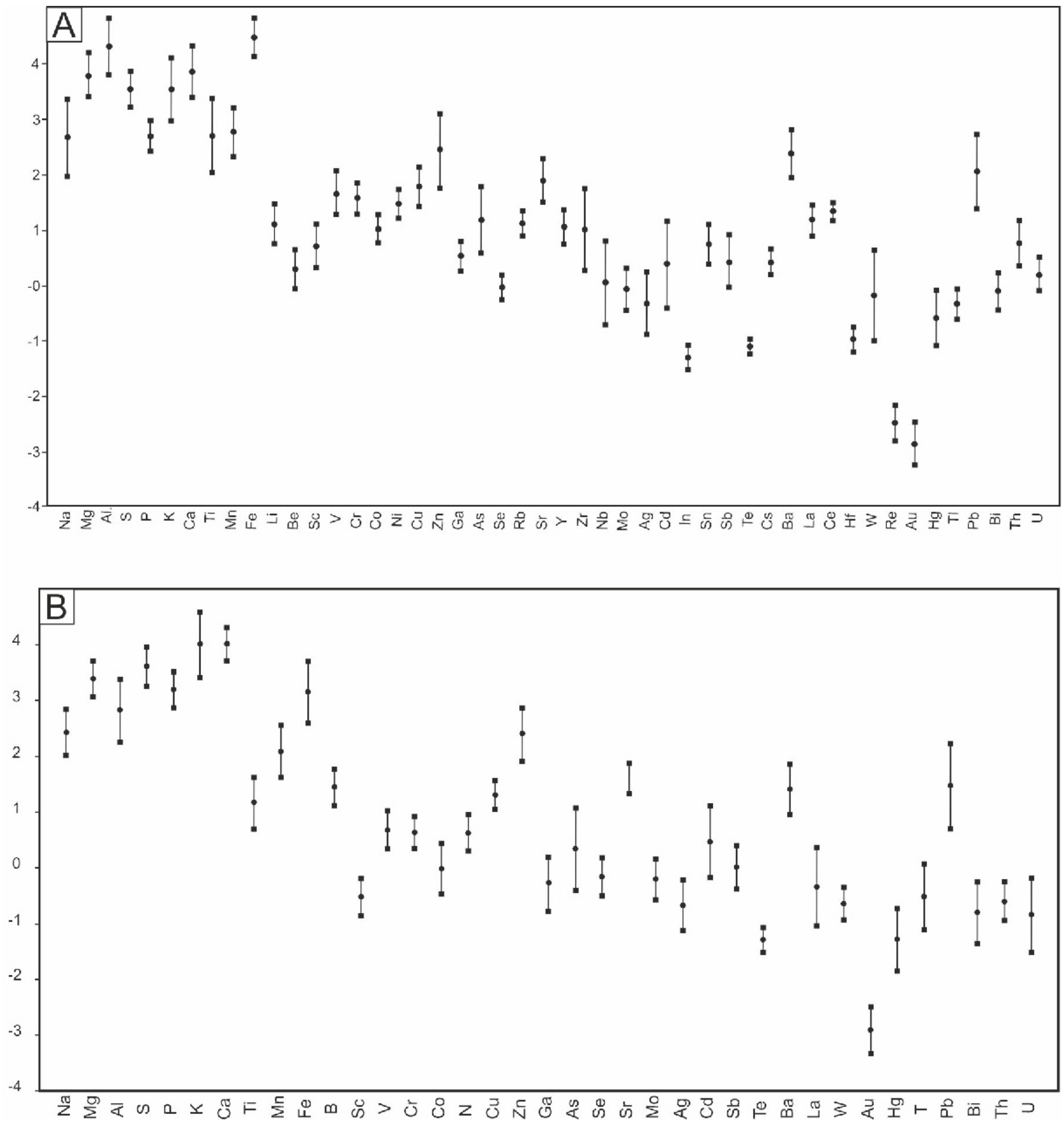

Fig. 3. Mean-and-whisker diagrams for the soil (a) and vegetation (b) samples

and Mg. Both Mn and Zn show comparatively elevated BCFs and TFs; the same is true for the BCFs of Ni, Cu and Cd, and TFs of Fe, B, Co, As, Mo, Pb and Bi. Mercury and gold show the strongest potential for the root ŕ shoot shift (TF>10), followed by Ga, Pb, Bi, Al, Fe, La and As. The highest BAFs are observed for Hg, Tl, Ca, Sr, Mo, Cd, W, Sb and Na; somewhat lower for K, P, Na, Zn, B, Cu, S, Mg, Se, Mn, Ti, V, Ba, As, Ni, Al and U.

The *S. nigrum* enrichment in relation to vegetation-typical levels is not that extreme, with 51 times the norm for Cd, elevated Sb (18x), Tl (12x), Zn and V (7x), Sc (6x), and to a lesser extent Ni, Th, Cr, Cu and B. Of the elements with values comparable to published ones, only Mn and Cd show different, i.e., leaf, affinity. BCF factors larger than published ones are of Cd, Tl and Zn. High values were also obtained for K, Na, P, Mo, Ca, Mg, Mn, Sr, Sb, Cu and Ag. Comparatively elevated TFs are of Cd, Au, Th and U, with still relatively high values for Hg, La, Mg, Al, P, S, Ca, Ti, Mn, Fe, Sc, B, Na, Cu, Zn, Ga, Ni, Se, Sr, Ba and Mo. There is relative root undersaturation of Sb, Tl, and K.

The Rydułtowy *C. mollis* shows high V (33x the norm), Bi (32x), Sb and U (18x), Tl (12x), Hg (8x), Ni (~7x), Sc (6x), Cu (5x), Cr, Co and Se (~4x), and is characterized by elevated Mo, W, Ba and La. Relatively to published data, Mn, Fe, Sc, Sr, Ag and Sb seem higher, and Na, S, P, Ca, Cr, Co, Ni, Cu, Zn, Mo and Cd are lower. Of these, Sr, Ni, and Cr behave differently in being preferentially enriched in different organs. Higher BCF, BAF and TF were found for Na and Mn; higher BCF and BAF for Cu, Sr and Ba; and higher BCF and TF for Pb and Cr. There are elevated BAF also for Cd and Al, and higher TF for S, K, and Zn.

The Wojkowice *Helichrysum arenarium* proved to be relatively TE-low, though still showing tenfold enrichment in Tl and elevated Ni, Sb, B, Co, Cr and Cu. By comparison with the norm, higher anomalies include Tl (10x), with much smaller ones of Ni, Sb, B, Co, Cr and Cu. Compared to the published data this species is enriched in Ag, K, Mn, B and Ni. Although the Ag enrichment might be expected based on the enrichment

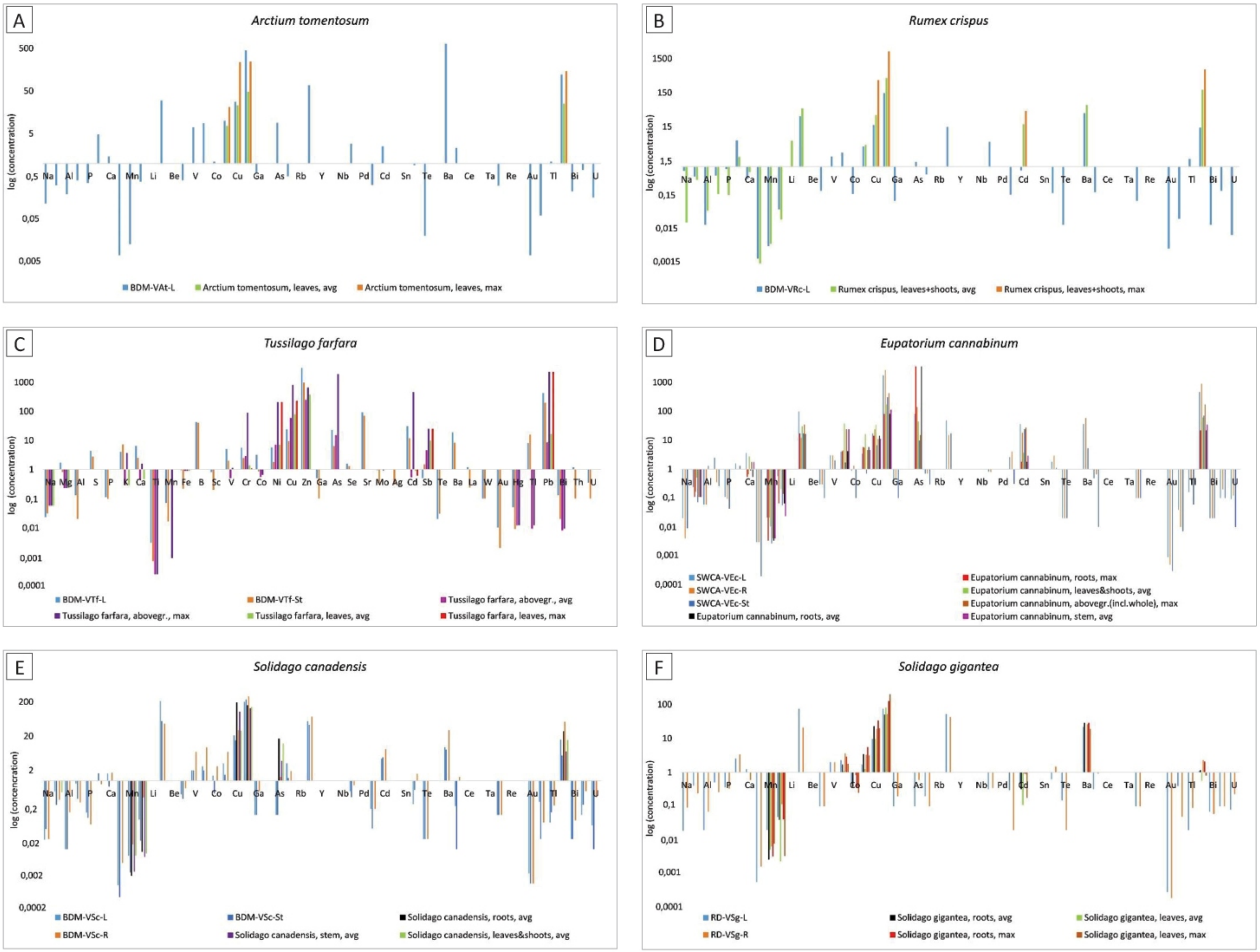

Fig. 4. Comparison of the studied and published elemental content of *A. tomentosum*, *R. crispus*, *T. farfara*, *E. cannabinum*, *S. canadensis* and *S. gigantea*

The Y scale may be made logarithmic for a better view. Literature: Hunter et al. (1987); Vanderhoven et al. (2005); Zhuang et al. (2007); Robinson et al. (2008); Kissoon et al. (2010); Kowalska et al. (2011); Antonijević et al. (2012); Faiku et al. (2012); Xue and Liu (2014); Al Harbawee et al. (2016); Dastan and Sarac (2018); Bielecka and Królak (2019); González et al. (2019); Jakovljević et al. (2019); Popova (2019); Wechtler et al. (2019); Branković et al. (2020); Królak et al. (2020); Przybysz et al. (2020); Siebielec et al. (2020); Foisner (2021); Sasmaz et al. (2021); Dambiec et al. (2022); Kenny et al. (2022); Kandić et al. (2023)

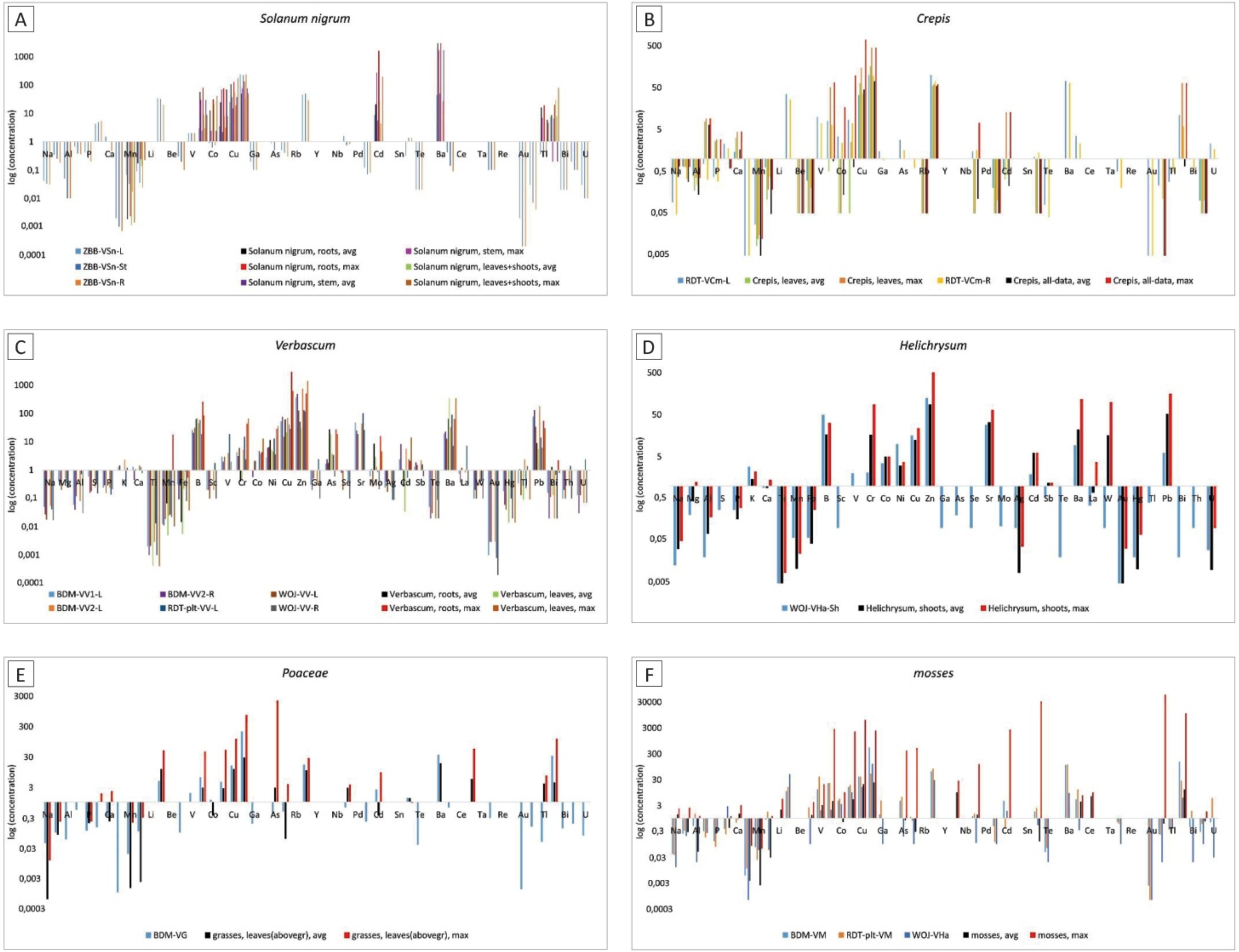

Fig. 5. Comparison of the studied and published elemental content of *S. nigrum*, *Crepis*, *Verbascum*, *Helichrysum*, *Poaceae* and mosses

The Y scale may be made logarithmic for better view. Literature: Adamo et al. (2003); Cesa et al. (2008, 2011); Robinson et al. (2008); Patorczyk-Pytlik (2009); Arslan et al. (2010); Malik et al. (2010); Morina et al. (2010); Yildiz et al. (2010); Antonijević et al. (2011); Kowalska et al. (2011); Bech et al. (2012); Díaz et al. (2012); Ugulu et al. (2012); Maheswari et al. (2013); Dogan et al. (2014); Erdemir et al. (2015); Güleyrüz et al. (2015); Wołejko et al. (2015); Wu et al. (2015); Ardan et al. (2016); Čudić et la. (2016); Chrzan (2016); Godlewska and Ciepiela (2016); Izquieta-Rojano et al. (2016); Salihaj et al. (2016); Cutillas-Barreiro et al. (2017); Hesami et al. (2017); Khan et al. (2017); Lazo et al. (2017); Radziemska (2017); Berthelot et al. (2018); Cowden (2018); Osmani et al. (2018); Yun et al. (2018); Busby et al. (2019); Kicińska (2019); Nworie et al. (2019); Popova (2019); Salinitro et al. (2019); Zhang et al. (2019); Boukaka and Mayache (2020); Gajić et al. (2020); Gawryluk et al. (2020); Maqbool et al. (2020); Przybysz et al. (2020); Siddiqui et al. (2020); Siebielec et al. (2020); Visconti et al. (2020); Yabalak et al. (2020); Foisner (2021); Glišić et al.(2021); Hajihashemi et al. (2021); Korzeniowska et al. (2021); Lommel (2021); Pedreiro et al. (2021); Xu et al. (2021); Kenny et al. (2022); Khan et al. (2022); Świsłowski et al. (2022)

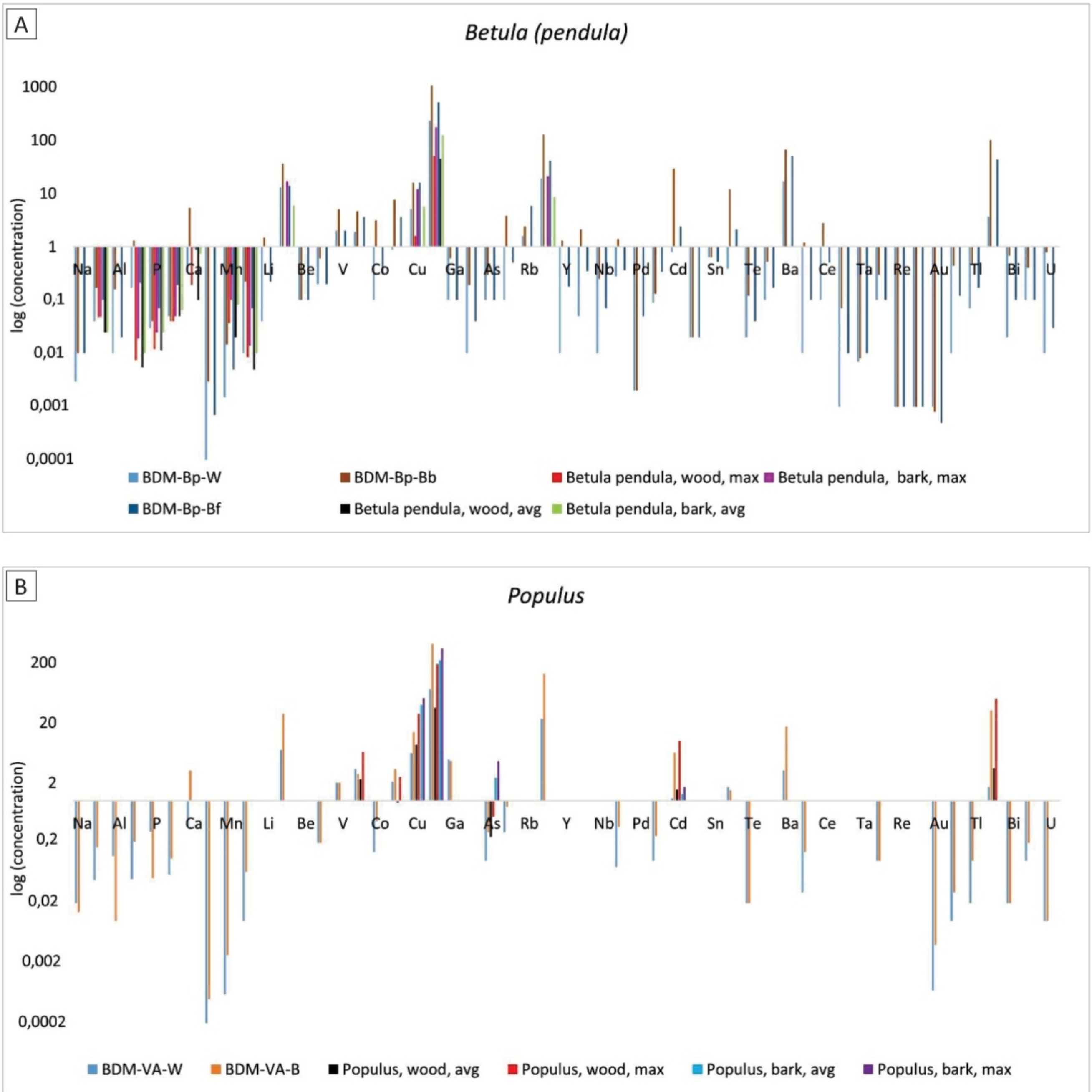

Fig. 6. Comparison of the studied and published elemental content of *B. pendula* and *Populus*

The Y scale may be made logarithmic for better view. Literature: Madejón et al. (2004); Robinson et al. (2008); Vangronsveld et al. (2009); Rafati et al. (2011); Rees et al. (2011); ; Antonijević et al. (2012); Evangelou et al. (2012); Marmiroli et al. (2013); Čudić et al. (2016); Mleczek et al. (2017); Pavlović et al. (2017); Szwalec et al. (2018); González et al. (2019); Kicińska (2019); Kataweteetham et al. (2020); Przybysz et al. (2020); Rahmonov et al. (2020); Gąsecka et al. (2021); Suo et al. (2021); Khan et al. (2022); Opeńa et al. (2022); Rustowska (2022); Sitko et al. (2022)

observed by Vural (Vural, 2017, 2018), this is not the case for Au. Even though most elements studied may be more enriched than in the Wojkowice sample, it shows much larger-than-known BAFs for U, Au, Ba, La, P and K, and elevated ones for Na, Mg, Ca, Ti, Mn, Sr and Cd.

B. pendula shows enrichment, compared with publsihed records (see Fig. 6), in Sr, S, Ca, B, Cu, Zn; and also Mg, P, K and Fe. All these elements are more enriched in the bark, consistent with previous observations. The BAF-like factors are higher than published ones in the case of Mo, Cd, P, S, Se, Sr, and to some extent B, K, Ni, Ag and Pb. The most enriched elements are Sb, S, Cd, Se, Mo, W, followed by Ca, B, P, Sr and Zn. We could not find any wood-to-bark translocation factors higher than published values. Enrichment in this case is largest for Au.

Populus elemental charge is smaller than published values, with only very minor enrichment in Zn. The most enriched elements, i.e., the ones with log(value) above 0, are B, Ca, Zn, Sr, Ba, Cu, Pb, Cd, Cr and Ni. All the elements but Ni, Cd and Pb show the same affinity for particular organs. The latter two elements in our case show higher concentration in the bark than in

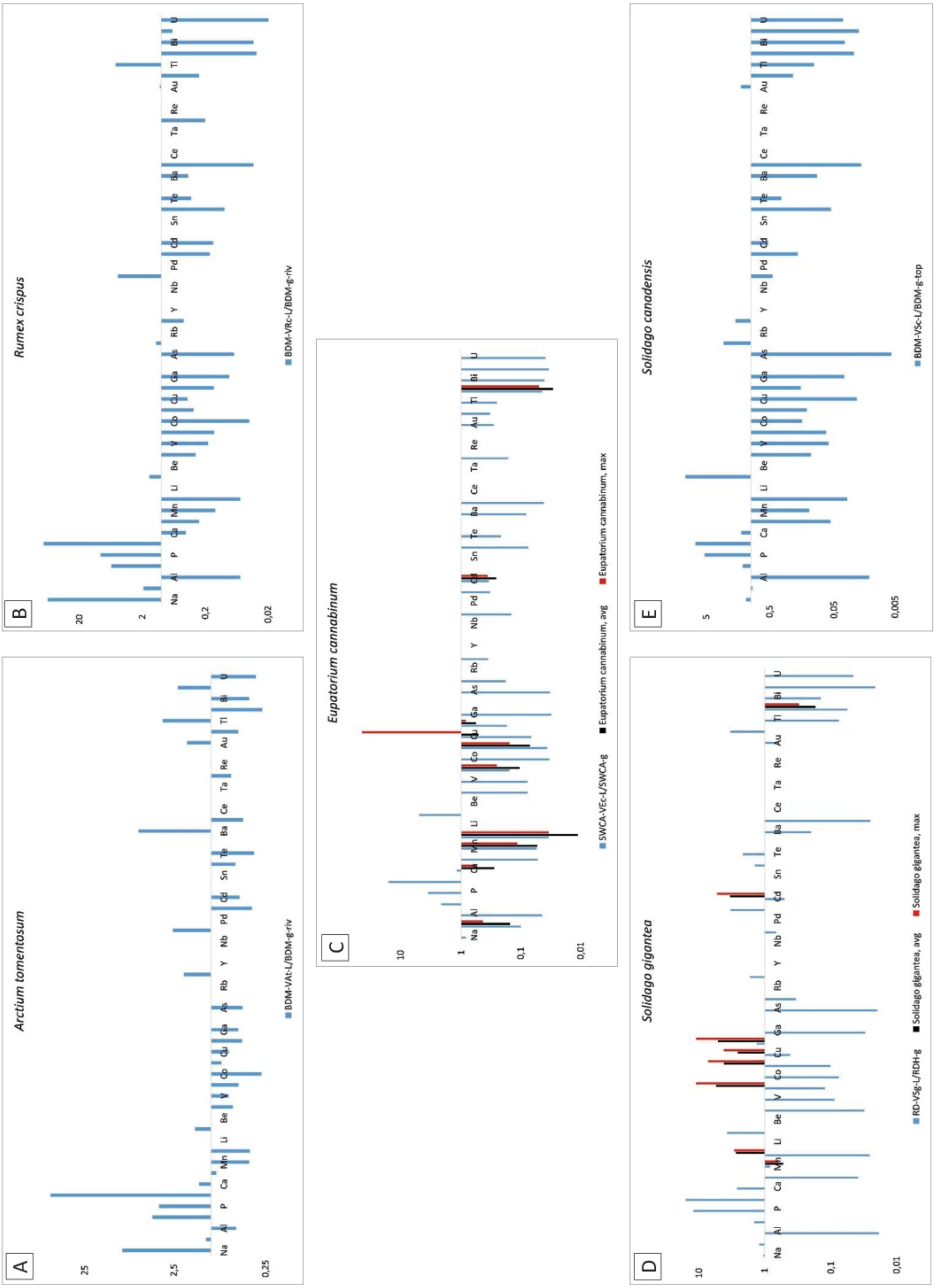

Fig. 7. **Comparison of the bioaccumulation factors (BAFs) calculated for *A. tomentosum*, *R. crispus*, *E. cannabinum*, *S. gigantea* and *S. canadensis* with published data (see caption to Fig. 3)**

The Y scale may be made logarithmic for better view

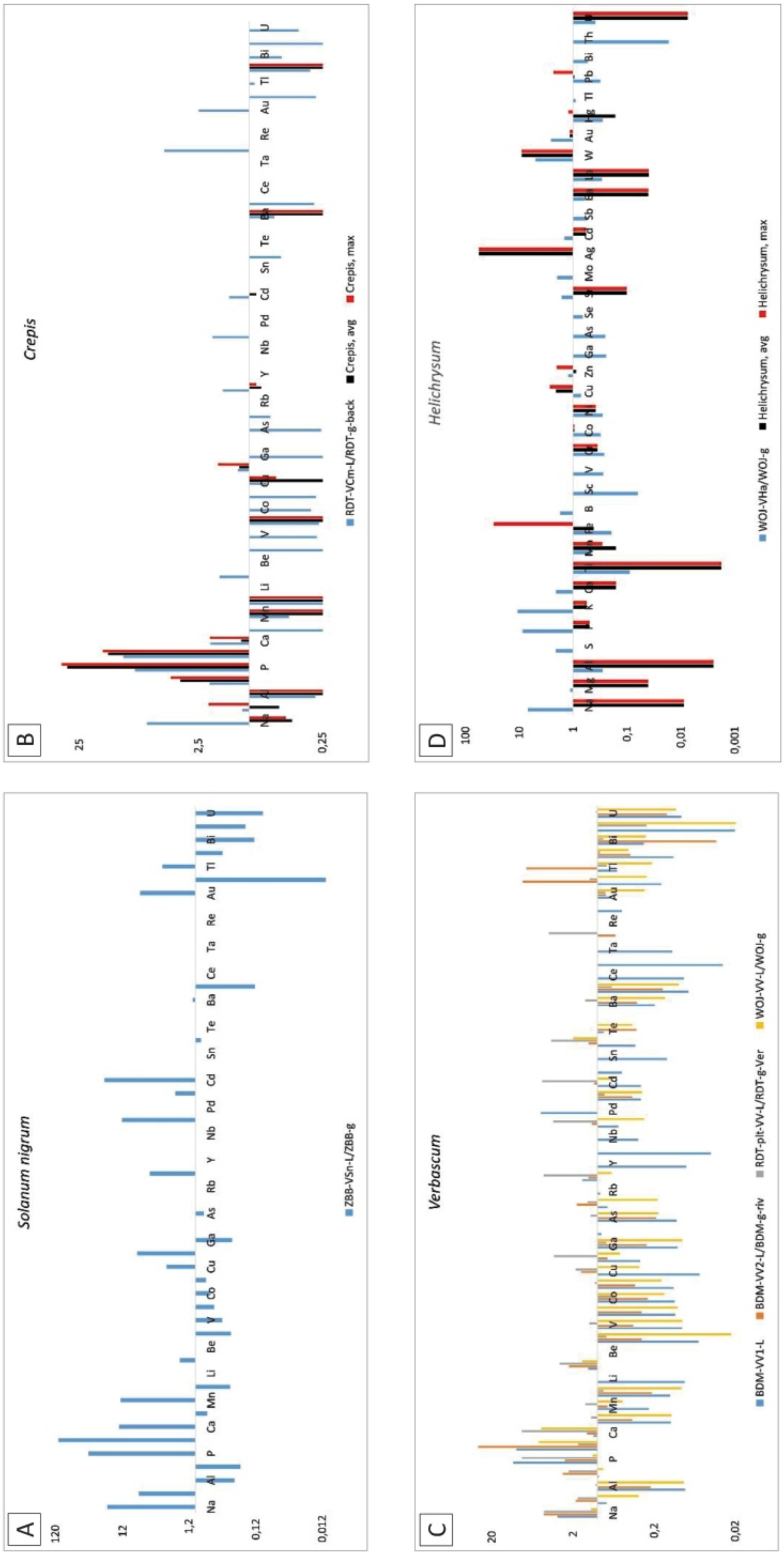

Fig. 8. Comparison of the bioaccumulation factors (BAFs) calculated for *S. nigrum*, *C. mollis*, *Verbascum* and *H. arenarium* with literature (see caption to Fig. 4)

The Y scale may be made logarithmic for better view

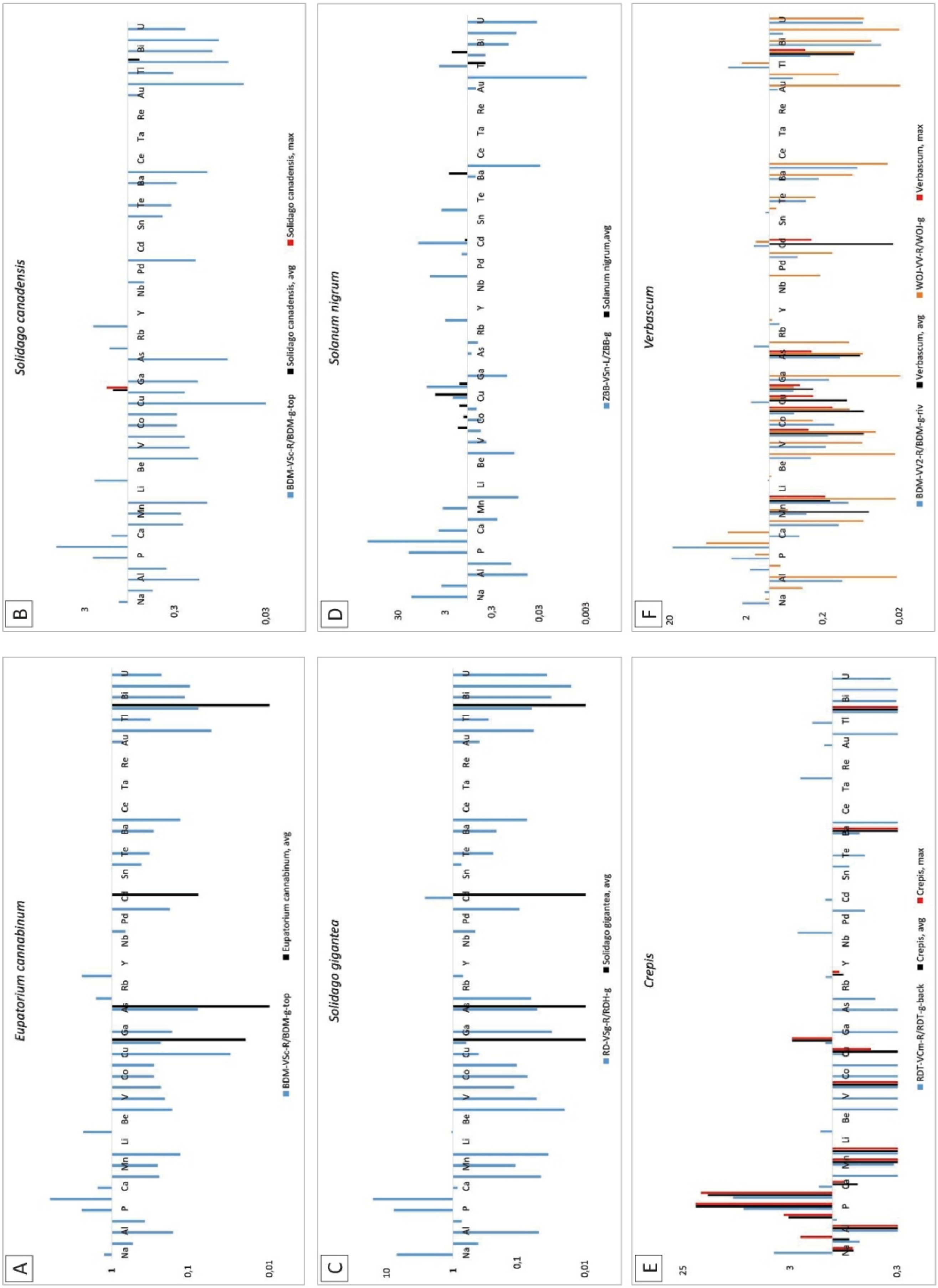

Fig. 9. Comparison of the bioaccumulation factors (BCFs) calculated for *E. cannabinum*, *S. canadensis*, *S. gigantea*, *S. nigrum*, *C. mollis* and *Verbascum* with published data (see caption to Figs. 3 and 4)

The Y scale may be made logarithmic for better view

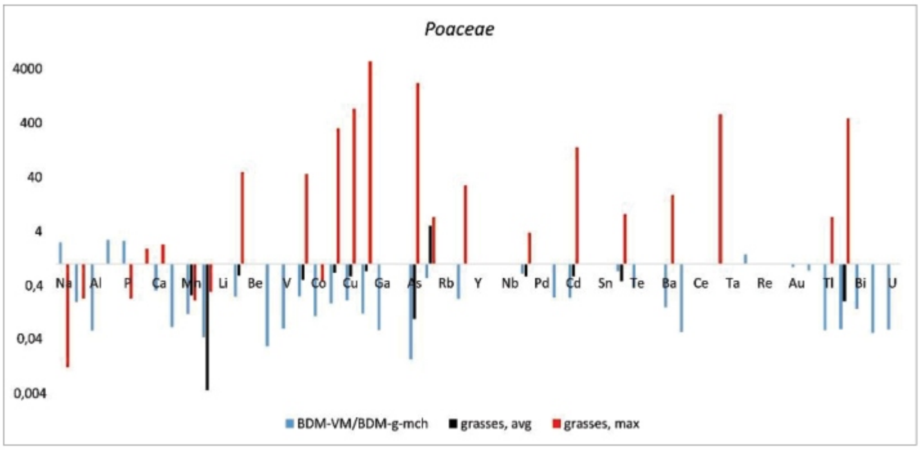

Fig. 10. Comparison of the bioconcentration factors (BCFs) calculated for Poaceae with published data (see caption to Fig. 5)

The Y scale made logarithmic for better view

the wood. Bark enrichment was also noted for Co, Zn, Se, Sr, Mo, Ag, Ba, Pb; and to lesser extent La, Mg, S, Mn, Fe, B, Ni, Cu, Au, Hg, Tl and Th. Slight wood preference is shown by Ca, Al, P, and to some extent by Na, Cr, Ga and Sb. We provide biogeochemical *Populus* data for ~30 usually unstudied elements. The BAF-like factors are higher in the Bytom *Populus* than in published examples in the case of Sb, Zn, and to some extent Pb. As for the former tree, we found no bark-to-wood translocation factors higher than values reported before.

The two moss samples show enrichment in W, Au, Ca, P, K, Ca, and to some extent Na, S, B and U. Compared with the norm, they show high enrichment in V (43-133x), Bi (15-63x), Sc (20-52x), U (5-46x), Cr (~23), Sb (~19), Ni (11-14x), Cr (6-23x), La (4-10x), Hg and Tl (~8), Th (4-9x), Cd (2-28x), Zn (2-15x), Cu and Co (~5), As (~3), and W and Mo (~2x). Compared with published data, we obtained higher values of K, V, Al, Mn, Fe and La. The only element showing a higher whole-plant-based BCF-like factor in the moss samples studied was Mo (Bytom and Rydułtowy samples). The Bytom grass is one of the least TE-loaded specimens studied, though is relatively high in Ba, Co, and Na, followed by Sb. In terms of the norm, the Sb enrichment factor is 15, Cd 15, Se 7, Zn 6, and that of Hg and Bi is 5. The whole-plant-based BCF-like factors are higher for Na, S, P and Al; also the corresponding value for W is relatively elevated.

BIOCONCENTRATION INDICES

To assess element transfer and fate at the soil/plant interface and within the plants themselves, we have calculated the most commonly used factors: (1) the bioaccumulation factor, or BAF (leaf content divided by soil content; Appendix Table 5), (2) the bioconcentration factor, or BCF (root content divided by soil content; Appendix Table 6), and (3) the translocation factor, or TF (shoot content divided by root content; Appendix Table 7). In addition, we provide similar data for the two previously analyzed tree specimens (Appendix Table 8).

Of the total 403 BAFs, 54 records (13%) are anomalous, i.e., with values   2. Elements showing the largest number of anomalous BAF are B (geometric mean, i.e., GM-BAF=2.2), Sr(GM-BAF=1.3), Mo (GM-BAF=1.3), and Tl (GM-BAF=0.71). The most extreme BAF,   10, was found for Cd (22, *S. nigrum*), Mo (12, *S. nigrum*), Mn (13, *S. nigrum*), and B (11, *S. canadensis*). Slightly lower single outliers concern Sr, Sb and W in the Rydułtowy *Verbascum* (5, 4 and 4, respectively), W in *C. mollis*, and Hg and Tl in the Bytom (VV2) *Verbascum* (8 in both cases). There is just a single average vegetation BAF >1 – for the Rydułtowy *Verbascum* (1.4) – although the corresponding value for *S. nigrum* is close to unity, too.

As for the BCFs, the number of evidently elevated ones is the least among the 3 factors calculated: of the 216 records just 21 (%) are anomalous. This especially concerns Cd (GM-BCF=1.6) and Tl (GM-TF=1.2). *S. nigrum* is clearly outstanding, while relatively high values were found for Cd (11), Zn, Mo, Sb and Tl. No average BCFs are higher than 0.6 (value for *S. nigrum* equals 0.56).

The most common aberrance is shown by the TFs, with 88 (41%) of the total 217 records showing values   2. Some elements show TF anomalies but no BCF or BAF anomalies: Sc, V, Cr, Co, Ni, Ga (5, *Verbascum*, Wojkowice), As; La (5, *S. nigrum*); Pb and Bi (5 and 6, respectively, *Verbascum*, Wojkowice); U, Al, Fe and Ti. Most outliers concern Hg (GM-TF=4.9), B (GM-TF=1.7), Au (GM-TF=3.0), and Se (GM-TF=1.6). The most extreme TF values (10) were found for Hg (17, *Verbascum*, Bytom, VV2), Au (15, *Verbascum*, Wojkowice; 10, *S. nigrum*), and Ag (15, *S. gigantea*), with still high though single anomalies of B (8, *E. cannabinum*) and Te (8, *S. gigantea*). The average TF with >1 value was found for the Wojkowice *Verbascum*, *S. nigrum,* Bytom *Verbascum* (VV2), *C. mollis* and *E. cannabinum*.

STATISTICS – CORRELATION (SOILS AND VEGETATION)

Element correlation pairs found for both the separated and merged systems (Appendix Tables 3, 4 and 9; with correlation strength varying depending on the system) are: NaMg, NaK, MgMn, AlV, AlNi, TiV, TiFe, TiNi, TiBa, MnFe, FeCr, NiFe, FeCu, FeSr, ScTh, VCr, VCo, VSr, VLa, VBa, CrBa, CrSb, CoNi, ZnPb, AsAg, AsPb, AsMo, GaLa, GaU, CdPb, TeFe, LaBi, LaU, BiU, BiCr, BiV, ThV, ThGa, and UTh (positive correlations). Among the negative ones are elements negatively correlated with Hg, Au, Ag, and Te (Na, Mg, Al, K, Ca, S, Sr); Hg, Ag, and Te (Fe); Au, Hg, and Te (Ca, Ba); Hg and Te (Zn); Te, Au, and Ag (Mn); Hg alone (Ti, Fe, V, Cu, Ni); Tl alone (K, S); Bi

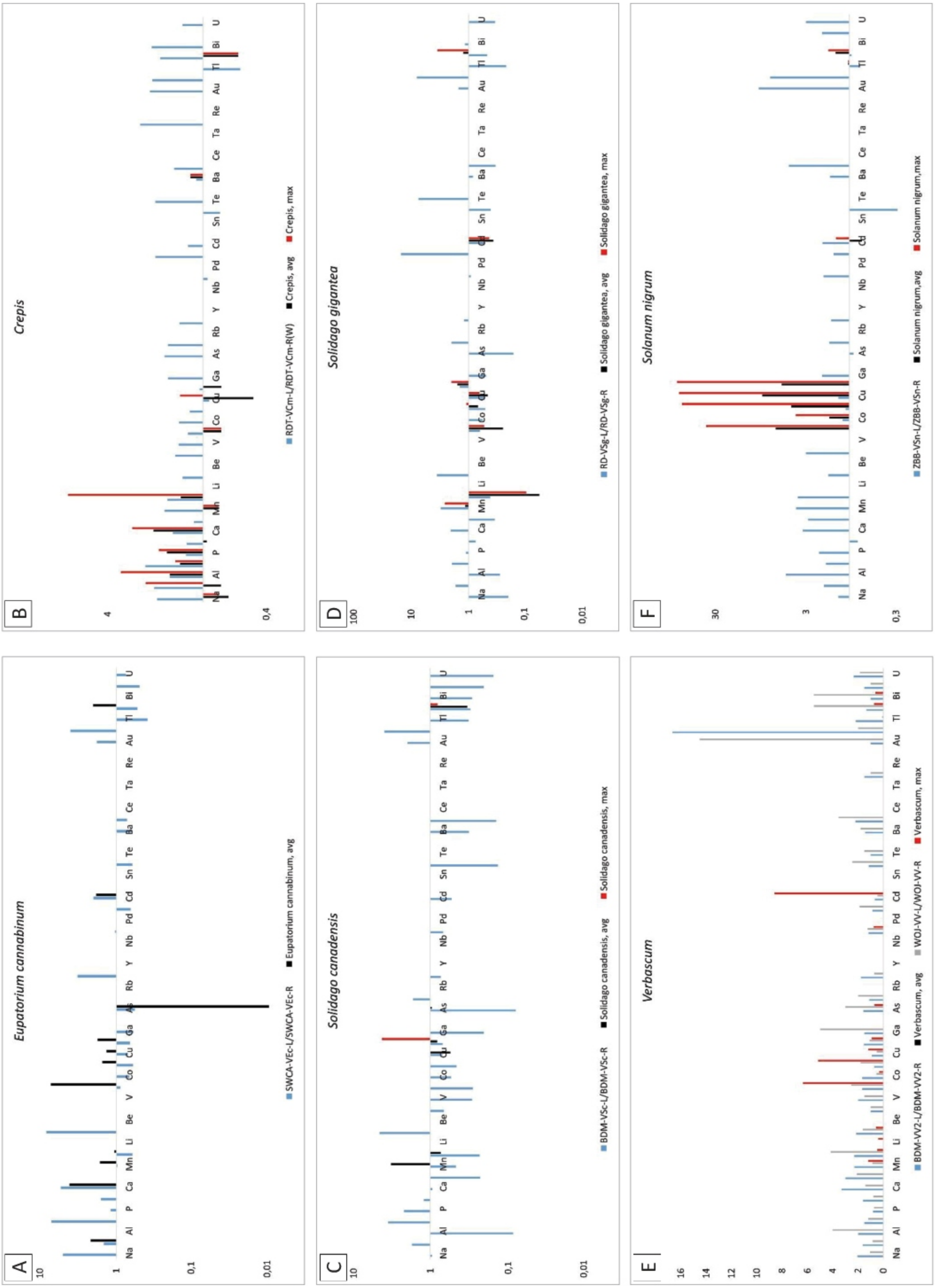

Fig. 11. Comparison of the translocation factors (TFs) calculated for the materials studied with published data (see caption to Figs. 3 and 4)

The Y scale may be made logarithmic for better view

(P, S, Zn); Th (Na, P, S, Mn, Cu, Zn, Ba, Pb); additional pairs are PSe, PAg, PAu, and KW. The soil-specific pairs include NaSr, NaAl, NaFe, KV, KTh, CaV, CaMn, CaAg, CaPb, MgTi, MgV, MgSr, AlSr, AlBa, PV, PNi, PBa, TiSr, TiSb, MnAg, FeV, CrSe, CrTh, NiSr, CuSe, CuAg, CuPb, ZnSe, AsSe, AsCd, AsLa, SrAg, SrBa, MoSe, MoAg, AgW, AgAu, AgTl, SbSe, SbAg, TeU, BaAg, WCd, WTl, AuTl, AuPb, TlSc, TlSe, TlPb, PbSe (positive correlations); SRe, SRb, SCe, PHg (also seen in the merged system), LiW, NiRe, SeRe, NbCd, TeHg, CsW, CeW, HgW, AuRe, AuHg, and PbRb (negative ones). The vegetation-specific pairs are MgP, MgCa, MgZn, AlFe, AlTi, AlCu, TiCu, CaSr, PK, SCa, TiPb, MnNi, MnCu, MnBa, VMn, FeZn, FeBa, ScGa, CrNi, CrTh, NiCu, CoLa, CuBa, GaBi, HgBi, MoW, MoU, As, and UFe (positive correlations); KGa and TeAu (negative ones).

STATISTICS – POLYCOMPONENT ANALYSIS

PCA (Fig. 12) was conducted separately for the new soil samples, collective vegetation samples, and collective new soil and new vegetation samples, to address element dependencies for different systems. The intra-soil PCA results can be summarized as:

- isolinear (or close – in parentheses) eigenvectors: CsRbNb, LiCe, USc, BiLaTe, AlZrLa(GaBeYSc), NaCrCoVTiCr(NiFeSrHf), MgFeBaTlHf(PInSrVCuNiCrSeU), MnSeSn, CaSb, AsAu(Ag), ZnW(PbCd);
- contra-directional eigenvectors: Hg vs. Hf(SrMgFeNi), Hg vs. MnPCuSeInTl, S vs. K(LiTh), S vs. NbTh, ZnPb vs. Re;
- the shortest vectors: Re, Te; S, Nb; Hf, P, In, Ce, K, Nb;
- the longest vectors: Cd, Pb, Zn, As; Ag, Mn; Ca, Mg, Sb; Fe, Mo, Cu, Sn, Hg; W, Sr, Na;

The intra-vegetation PCA results (“old” and “new” sample batch merged) consist of:

- (nearly) isolinear eigenvectors: AlHgU, TeV(WThU), FeMo, BaCoNiScSrCr, CaSe, CuTi, LaBi, MgSbAu, NaGa, AsTlPb, BCd(SAg);
- contra-directional eigenvectors: P vs. Cd, K vs. NaGa;
- the shortest vectors: P, Te, B; K, W;
- the longest vectors: La, Fe, Pb, Ti; U, As, Co, Al; Mn, Hg, Ba; Cd, Zn, Ag, Mo, Ba, Ni, Cr.

Finally, the PCA results for merged “new” soil and “new” vegetation samples are as follows:

- (nearly) isolinear eigenvectors: FeCu, AlCa, TiNiV, CaSb, SeW, NaMnZn, CdTeTh, AgHg;
- contra-directional eigenvectors: Mg vs. Au, Ca vs. Au, (NaMn)Zn vs. CdTeTh, S vs. Tl;
- the shortest vectors: Cd, Tl, W, Sb; Co, Se;
- the longest vectors: K; Ca, P; Al, Fe, S, Mg, Na, U, Bi, Au; Ti, Ba, Sr, Mn; La, As, Pb, Ga, Mo, Sr, Hg, Ag.

DISCUSSION

A number of the plants studied show evident, moderate to large enrichment in many elements. Analysis of the data makes it clear that there is a large gap in knowledge regarding levels of numerous elements in vegetation as a whole.

BEHAVIOUR OF ELEMENTS IN THE SOILS

Lead, arsenic, cadmium, zinc, and silver show the most extreme and persistent enrichment in the soils studied. The respective average enrichment factors are >8 (Pb), 3 (As), 7 (Cd), >7 (Zn), and 3 (Ag). The EF_{avg} of Se and Cu equals 3.These elements are followed by mercury (EF_{max}=46, EF_{avg}=1.1), caesium (EF_{max}=3, EF_{avg}=1.2), sulfur (EF_{max}=13, EF_{avg}=4), antimony (EF_{max}=35, EF_{avg}=2.5), thallium (EF_{max}=8, EF_{avg}=0.9), aluminum (EF_{max}=7, EF_{avg}=3), bismuth (EF_{max}=7, EF_{avg}=2.2), tellurium (EF_{max}=5, EF_{avg}=2), manganese (EF_{max}>20, EF_{avg}=1.2), tin (EF_{max}=18, EF_{avg}=3), calcium (EF_{max}=10, EF_{avg}=0.84), magnesium (EF_{max}=9, EF_{avg}=1.2), iron (EF_{max}=4, EF_{avg}=1.3), nickel (EF_{max}=5, EF_{avg}=1.3), phosphorus (EF_{max}=3, EF_{avg}=1); cobalt (EF_{max}=3), uranium (EF_{max}=2.4), and indium (EF_{max}=1.7).

Lithium is rarely found to be enriched in the soils, although 4 samples (Rydułtowy, ~2.5 times average; Bytom, escarpment) show levels higher than the soil average. Boron is undersaturated in all the soil samples. Beryllium soil levels are low, although 4 samples show slightly elevated contents. Vanadium and chromium are slightly enriched in the Bytom escarpment habitat, with the MA/AR being 4.2 and 3.1, respectively. Cobalt and nickel, by contrast, are enriched in many samples, with maxima for both on the Świętochłowice post-smelter heap (>3 and >4 times the average, respectively).

BEHAVIOUR OF ELEMENTS IN THE VEGETATION

Lead, arsenic, cadmium, zinc and silver show the most extreme and persistent levels. Most element records belong to the Rydułtowy (B, Sc, V, Cr, Co, Ni, Ga, As, Sb, Ba, La, Bi, U, Al, Ti, Fe; with still high Cu and Mo) and Bytom (Zn, Ag, Se, Cd, W, Pb, Mn; high Cu, Ba and Au) mosses. They are followed by the Rydułtowy *C. mollis* (Mo, Na, Mg, P, S, Ca; high Sr and Se) and Rydułtowy *Verbascum* (Cu, Sr, Th, Ti). The highest boron levels are recorded in *S. gigantea* (leaves; 75 mg/kg, i.e., ~3 times the new- and old-data average); compared to the “old” sample batch, this value is much higher than most former values, exception being organs of *S. canadensis* and leaves of *E. cannabinum*. Sc, V, Cr, Co, Ni, Ga, As, Sb, La, Bi, U, Al, Ti and Fe records of the Rydułtowy moss are much higher than the values obtained previously: ~10, 13, ~5, 6, 4, 15, 5, ~3, 31, 27, 67, 25, 8 and 13 times the whole-data average, respectively. Nickel records belong, equally, to the moss and to the formerly studied Rydułtowy *Verbascum* specimen collected in the same area. Copper levels in the two mosses and the Rydułtowy *Verbascum* cross are twice the average levels, but not larger than those found in Bytom’s VV2 *Verbascum*. The zinc extreme level of *T. farfara* (3150 mg/kg, leaves), the As record in *E. cannabinum* (140 mg/kg, roots), Se levels in *S. canadensis* and burnt bark of *B. pendula* (~3–4 mg/kg) were not suprpassed even by the moss samples. Gallium levels of ~5 mg/kg in *Populus* are similar to those of the Rydułtowy moss. Strontium levels (~100 mg/kg) of the Rydułtowy *C. mollis* and *Verbascum* are only slightly smaller than those found in tree-derived samples. Molybdenum is highest in *R. crispus*, with ~4 times less in *S. nigrum*, *C. mollis*, and the Rydułtowy moss. Levels of Ag, Cd, Sb, Ba, Au, Tl, Na, Mg, P, K, Ca. Concentrations of Pb are much smaller in the “new” batch, with the Bytom’s moss record of ~150 mg/kg being 6 times lower than that of the *E. cannabinum* roots. Levels of Te, Hg, Mn and Fe are similar or slightly lower/higher than in the “old” batch. La and W levels are notable. Few contents now measured are above or close to the former high of La in *A. tomentosum*, while some W values are higher in the seemingly strongly enriched (via direct contact with coal-fire gases) burnt bark of *B. pendula*. The titanium record is now set for the plants collected in the plateau habitat of the Rydułtowy heap. Finding the highest U and Th levels in the Rydułtowy vegetation is not surprising considering the known

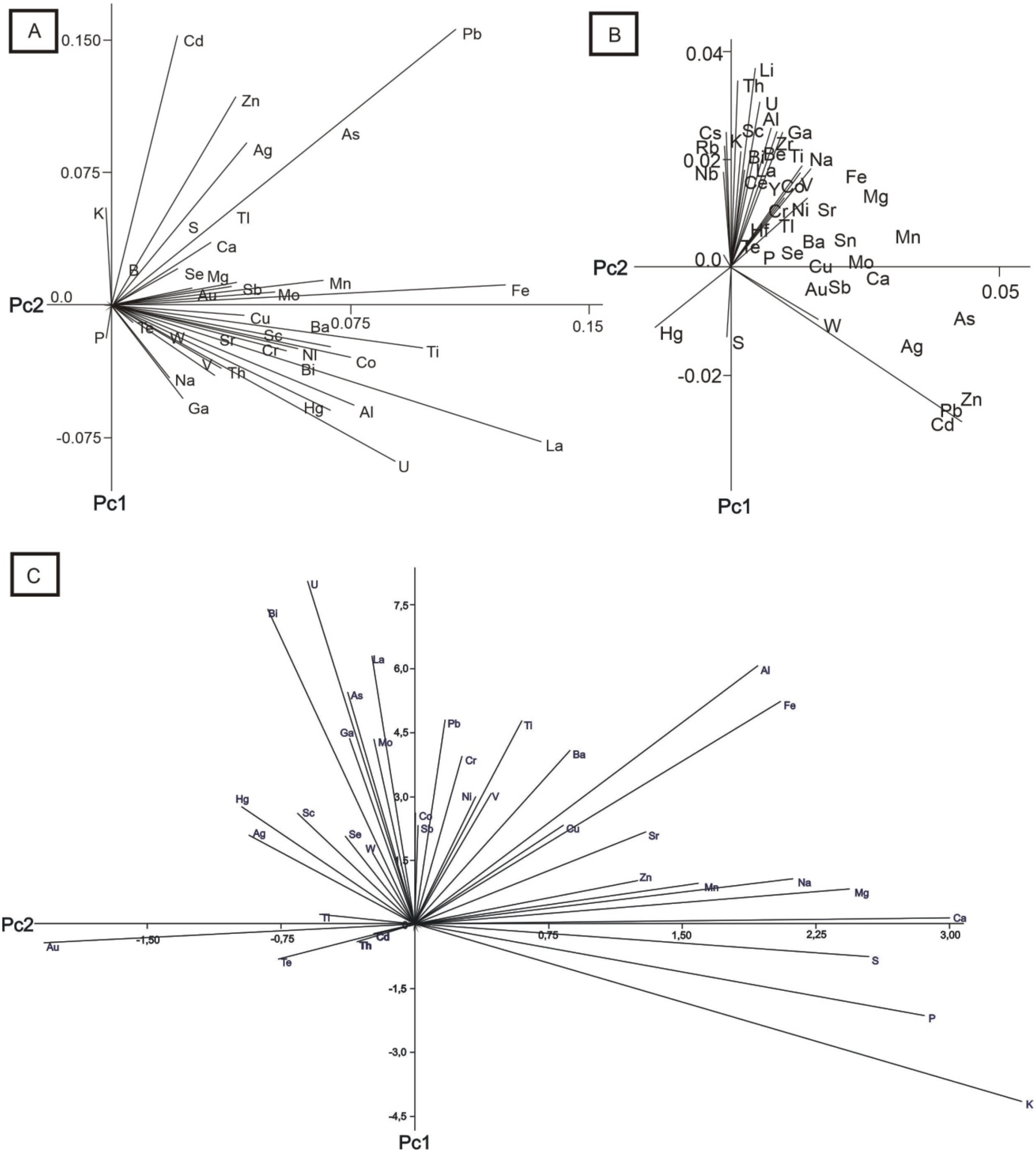

Fig. 12. Polycomponent analysis (PCA) diagrams for soil (A), vegetation (B) and merged (C) systems

enrichment of the local coals in these elements (average 1030 mg/kg, greater than at Jejkowice and Jankowice; Borzęcki, 2004). HFSE and siderophile elements tend to be transferred to plant leaves. Copper, by contrast, does not readily undergo this process despite elevated soil levels and the observation by Glišić et al. (2021) about its easy translocation in plants in general.

Boukaka and Mayache (2020) report *Solanum nigrum* as a species showing the highest TF of Zn, Cd, and Pb (with BCFs decreasing in this order), among plants studied in terms of soil phytoremediation. It may phytostabilize – but not necessarily hyperaccumulate – Cu and Pb, with Cu sequestered in roots, and followed by Cr, Zn, Ni, and Pb (Malik et al., 2010). Seasonal variation of metals including Zn was recorded by Siddiqui et al. (2020). Pb uptake, with both BAF and TF >1, in *S. nigrum* growing in the presence of mine-tailings may be mediated by some fungi (Sun et al., 2017). Phytoextraction of Cd may be enhanced by N fertilizing (Maqbool et al., 2020). Although Tl may limit its growth, *S. nigrum* is also a potent phytoremediator of this metal (Wu et al., 2015). Compared to published data, the Zabrze *S. nigrum* only shows different transfer behavior of Mn and Cd (leaf affinity). Its record-high TF values do not reflect the norm-related TE contents which, compared to other species studied, are rarely extreme.

Various *Verbascum* species are reported as either bioindicators (e.g., of elevated Cr, Zn, Cd and Pb pollution; Arslan et al., 2010) and phytoextractor-phytostabilizer hyperaccumulators (e.g., of Cd; Čudić et al., 2016). They are pioneer ruderal species common on heaps (Arslan et al., 2010). *V. phlomoides* is part of the plant population on European CFA deposits (Gajić et al., 2018). Antonijević et al. (2012) corroborates this, noting this species as the most suitable one for (root) phytostabilization of Mn, As and Pb in polluted soils around flotation tailing ponds. *V. cheiranthifolium* is a possible hyperaccumulator of many elements, including Zn, Cu, As, Mo, Ag and Pb, with enrichment factors as high as 3–4 (Kowalska et al., 2012). Their *Verbascum* species show average BAF in the 0.25–1.4 range, BCF<1, and TF>1. Čudić et al. (2016), in a few-years-long study of Zn-rich landfill sites, list elevated (>1) TF in *Verbascum* for Cd (0.44, rising to 8.6 in the middle part of the experiment), Cr (1–6.3), Ni (0.91–5.1), Zn (0.29–0.93), but not for Cu, As and Pb. The highest BCF is given for Zn (0.4, initial stage). In our case, elevated TF is shown for Cr, Pb and occasionally for Zn, while hyperaccumulation-level BCFs are seen for Tl, Cd and occasionally Cu and Cd. Endemic *V. bombyciferum* studied by them shows variable organ affinity for most elements studied, with maximum levels of Cr, Cu, Cd in shoots; Zn, Ni and Pb in roots; and Fe in flowers (Arslan et al., 2010). Leaf enrichment of Co, Ni, Pb, and Ba was reported by Kowalska et al. (2012), with BCF>1 only for Ba. The USCB *Verbascum* specimens readily uptake and translocate numerous TEs, with average TF close to 2 compared to a mean BAF of 0.67. A different affinity for TEs in our species is shown by Mo, Pb and Bi (leaf affinity) and Cd (root affinity), suggesting different stress-resolving strategies. The suggested Ba hyperaccumulation in *Verbascum* (Kowalska et al., 2012) is not confirmed; 3 of our 4 specimens are rather undersaturated in this element. In turn, the span of the elements potentially concentrated in *Verbascum* leaves is even larger than that of *S. nigrum* with Sr, Sb, W, Cr, Zn, Ni, As, Cd, Te, Pb and Bi as additional elements. Güleyrüz et al. (2015) corroborate that Cu stress is a mediator of elevated root accumulation of Li, B, Fe, Mn, Co, Ni, Mo, Zn, Pb and Bi in *V. olympicum*, with extreme levels up to 20000 mg/kg Cu sorbed in one experiment. Multi-element uptake in *V. thapsus*, with both root and shoot sinks of Pb, was also obserand Tl. In Wojewódka-Przybył et al. (2022) we suggested *Verbascum* to be a potentially useful phytoextractor of Zn, Pb, and other elements. This suggestion is now supported, based on finding 18 anomalous BAFs and 28 TFs for numerous elements.

T. farfara is one of major the plants readily colonizing both CFA heap sites and mine wastes (Gajić et al., 2018). Indeed, Jakovljević et al. (2019) report it to be a successive primary colonizer and stabilizer in technogenic substrates. It can actively uptake Zn, Cu, Cd, Mn and Sr. Root accumulation found by these researchers was especially clear in the case of Mg, Fe, Zn, Mn, Cu, Cd and Sr, with S, Ti, Ag and Pb translocated into shoots. Very high BCFs are reported: 4.7–8.3 for Ca, 12–4551 for Mn, 30–1167 for Fe, 7–70 for S, 1–15 for Cu, 13–32 for Sr, 1.5–15 for Zn, 0.7–8.8 for Cd. TF>1 is given for Pb (max. 38), As (max. 2.9), Sb (max. 1.4), Ag (max. 1.8), and Ti (max. 2.3). Kenny et al. (2022) note *T. farfara* as a hyperaccumulator of Cr, Fe, Co and Ni, with maximum content of the latter in flowers. Popova (2019) compares TE content data for *T. farfara* – a known hyperaccumulator – and a *Trifolium* grass growing near a municipal waste landfill and finds the former species to always accumulate maximum amounts of Cr (89 mg/kg), Zn (661 mg/kg), Ni (30 mg/kg) and Pb (162 mg/kg). She reports unvarying BAFs, with values slightly >1 for Cr, Zn and Ni. A similar comparison between *T. farfara*, *Equisetum arvense* grass and *Populus alba* of a military area was made by Robinson et al. (2008) who reported >1000 mg/kg Pb levels in both the first two species, but with maximum (of 2280 mg/kg) in the first one. BAFs reported for all three species are very low, suggesting strong root accumulation. Maximum levels of contamination with Cu and Cd in *T. farfara* compared to *E. arvense* were also found by Hunter et al. (1987), although the Cu is mostly concentrated in flowers. Compared to the above data, the Bytom *T. farfara* shows low BAF_{avg} (0.30).

E. cannabinum is a potential As phytostabilizer, with root preference, that tolerates As stress even at extreme pH. This is due to the production of thiols that are used in detoxification (González et al., 2019). Indeed, the species is an As excluder (Bertin et al., 2022). Branković et al. (2020) expand the phytoextraction potential list to metals including Cr, Zn, Cd, Ni, Cu and Pb. All these findings agree perfectly with our study. The same is true for B hyperaccumulation in shoots reported, e.g., by Sasmaz et al. (2021). The sample studied by Siebielec et al. (2020) is one of the least Zn-enriched species of a population from Polish SWHs (as opposed to our specimen from Świętochłowice), with lower contents only in *S. gigantea* (236 mg/kg) but much higher in *V. thapsus* and, especially, *Rumex acetosa* (5100 mg/kg). In the Bytom heap it is *T. farfara* which is Zn-richest, but this is not wholly comparable due to it growing directly in the post-smelter waste and not the mixed waste substrate. Of the latter, the descending row is *Verbascum* – *S. canadensis* – *R. crispus*.

Both *S. gigantea* and *S. canadensis* are reported as invasive species (Dambiec et al., 2022); the former is especially prone to inhabit polluted soils. These authors point to *S. gigantea* as a good biomonitor, report high BAF and low TF factors in *S. gigantea* of an urban area, show the species to be a metal-tolerant excluder. Interestingly, higher BAFs of Cr, Cu, Zn, Cd and Pb were obtained by them for specimens collected from low-metal soils, suggesting *S. gigantea* was able to reduce uptake. Kowalska et al. (2012) report BCF factors of Co, Ni, Pb and Ba in *S. gigantea* and *Tanacetum vulgare* being much lower than in the associated *Verbascum*. A slighly elevated factor of 0.21 was only given for Cu. Przybysz et al. (2020) report *S. gigantea* in an urban area to accumulate more particulate matter than its associated tree species, along with Cu, but note that *Populus canescens* has higher Cd and Zn and grasses higher Cr and Ni levels. Average BAFs and BCFs of both our *Solidago* representatives are low, while TFs are elevated, with TF_{avg} of *S. gigantea* equal to 1.

A. tomentosum is a known Zn and Pb hyperaccumulator and tolerates multi-metal pollution well (Al Harbawee et al., 2016). Their observation that Cu caused the most oxidative damage is coincident with low Cu levels in the Bytom sample. Both the local *A. tomentosum* and *R. crispus* clearly respond to river influence in having outstanding levels of Na and K related to brine input. Xue and Liu (2014) found *R. crispus* of a post-mining site to bear more Zn than other species, the element being slightly leaf-preferred. Cd levels are similar while Cu and Pb are lower in it, the two last elements showing root preference. This species is a high-biomass plant and is a candidate Zn and Cd phytoextractor.

The Rydułtowy *C. mollis* shows – as opposed to published results – leaf affinity for Sr, Cr and Ni, although levels of the last two are not much higher than in roots. Average BAF, BCF, and TF are 0.53, 0.36, and 1.4 and do not seem extreme. Indeed, Hesami et al. (2017), who studied TEs in numerous plants, did not point to *Crepis* sp. as a good phytoextractor. On the other hand, Glišić et al. (2021) report *C. setosa* (leaves) to readily phytoextract Ca, Mg, and Cu, being also a potent phytoremediator of Zn (BAF>1). A somewhat different Zn preference, with not just TF but also BCF>1 (the latter also true for Fe), was found in *C. pulchra* of a post-mining area in Iran by Hajihashemi et al. (2021). Neither Zn nor Cu are, however, dominant among TE anomalies in the *C. mollis* examined.

H. arenarium is a known and potentially extreme scavenger of Au and Ag, with BAF>1 and >50, respectively, for specimens collected from geologically variable areas in Turkey (Vural, 2017, 2018). Kharytonov et al. (2018) stated that the elemental composition of *H. arenarium* remains largely unstudied. Meanwhile, they show extremely high Cu and Mn contents, such as in a Ukrainian post-Mn-mining site. They report root preference of Pb, Cu, and Fe, and shoot shift of Mn, Hg, and Zn. Tomaszewska-Sowa et al. (2018) pointed to the (natural-habitat) species as always showing higher BCF_{Pb} and various Zn-related factors, and to a lesser extent TFs of Fe and Cu.

Many *Bryophyta* are good biomonitors, e.g., of Cr, Ni, Fe, Ti and Al pollution (Lazo et al., 2017; Świsłowski et al., 2022), and may be more efficient than lichen as their uptake is not necessarily influenced by relative humidity (Adamo et al., 2003). In a sorption experiment of Świsłowski et al. (2022), up to 95% of As, Cd, and Pb was sorbed in gametophytes of *Pleurozium schreberi*. Díaz et al. (2012) described intense uptake of As, Hg, and Sb, coincident with a drop in BCF, by aquatic *Fontinalis antipyretica*. Anomalous BCFs for the above elements (>10000) and Se (>6000) are given. The same is true for *Rhynchostegium riparioides* studied by Cesa al. (2008) especially for Al, Cu, Cr, Hg and Pb. They also noted strong CrPb and AsPb correlations also found by us (for BCF- and TF-expressed contents, respectively). The elements listed show above-norm levels in our samples, although not that large. Also, low enrichment in Cr versus high in Cd and Zn in *Pleurochaete squarrosa* of Izquieta-Rojano et al. (2016) is not fully corroborated by our study whereas moderate but not extreme Ni and Sb uptake is consistent. *Poaceae* of a Pakistani industrial site studied by Malik et al. (2010) show levels of Zn higher than in *S. nigrum*. In turn, similar maximum levels of As (1.7 vs 1.5 mg/kg), Tl (7.6 vs 6.0), and in part Cd (19 *versus* 32), in *Agrostis capillaries* grass and coexisting *B. pendula* of a polluted area were found by Kicińska (2019). Her results are, in general, correspond well to the Bytom fire-zone habitat, with As slightly elevated in the grass, and Tl and Cd somewhat higher in the local tree bark. Strong enrichment of Sb and Cd but not Zn and Pb in the Bytom grass only particularly reflects local TE availability and must be due to additional, most likely plant-related, factors.

Our choice of study of *B. pendula* and *Populus* from the Bytom sites was consciously made. Various species of *Populus* constitute successions in both European CFA and mine-waste heaps, with *B. pendula* also frequent in the latter environment (Gajić et al., 2018). Mleczek et al. (2017) point to B. pendula as the most efficient Zn translocator (TF>2, max content of ~3000 mg/kg) and a promising Tl and Pb phytoextractor compared to other trees growing on mining sludge. This birch has low nutrient demand (Evangelou et al., 2012). The dendroremediation usefulness of *Populus* reflects that it may hyperaccumulate Cu, Zn (with the largest BCFs), As, and Cd, as reported by Kataweteetham et al. (2020) who also note the BCF of bark and root being higher than for other organs. Observation of bark (compared to wood) enrichment of the Bytom *Populus* in Ni, Cd and Pb is contrary to at least some published data. During the few-year study of Čudić et al. (2016) their *Populus* has shown elevated, but <1 BCF for Cd; TF 1 were found for initial stages in the case of Ni and Cr (1), and late stages in the case of Cd (2.7), Zn (1.9) and As (0.96). Our *Populus* shows elevated soil-to-bark transfer of especially Ca, Au, Sr and Ga. The last element is also concentrated in the wood. In the case of *B. pendula* only Au is moderately concentrated, but only in the wood-to-bark path. A high level of phytostabilization of Zn in *Populus nigra* (roots) grown on post-flotation soils was expressed by a very high TF of 18 as reported by Antonijević et al. (2012). Interestingly, Rustowska (2022) indicates fire to be an important factor in nutrient management in *B. pendula*, triggering increased levels of Mn and Mg in the roots, and of K, P, and Zn in the biomass as a whole. This species tolerates B, Cu, Zn and Sr stress via increase in photosynthetic pigments, with leaves as the major sink, where compositional variation is much more dependent on soil chemistry than in the case of bark (Pavlović et al., 2017). This encourages further research into the USCB specimens.

BEHAVIOUR OF ELEMENTS AT THE SOIL-VEGETATION AND ROOT-SHOOT INTERFACE

Only some of the correlated element pairs – based on their concentrations alone – are also found in the correlation matrix of accumulation/translocation factors (Appendix Table 10). The BAF, BCF and TF values, along with the most enriched plants and plant bioaccumulation preference are juxtaposed in Appendix Table 11. A strong tendency of the waste-heap vegetation studied to collect most elements in their leaves was observed. Of the TE elements and micronutrients, Hg, Au, B and Se seem to show the highest soil-to-leaf affinity, alongside with La and Ga. Meanwhile, Cd and Tl show the highest root preference. Root-to-leaf movement is commonly observed and seems to be strongest in the case of Hg. About half of the TF records are anomalous (i.e., TF 2).

The elements studied may be arranged according to number of their anomalous calculated factors:

– BAF: B > Sr > Tl, Mo > Au > Cu, W > Zn, Se, Ag, Cd, Sb, Hg > Te, Ba, Th, Mn;
– BCF: Cd, Tl > Cu, Se, Sr, Mo > B, Zn, Sb, W, Mn;
– TF: Hg > B, Au > Se > Ga, Ag, La, Mn, Fe > As, Al, Ti, Te, Sr, U > Sc, V, Cr, Cd, Ba, W, Pb, Bi, Th > Co, Ni, Mo, Sb, Tl > Cu.

However, the element path related to BAF (soil leaf) is contained within the paths attributed to BCF (soil root) and TF (root leaf). Thus, at least some of the correlations listed may be artificial. A particular species may use uptake avoidance to a point – known as the critical point – when it changes its strategy. Thus, some correlations may result from variations in strategies and, simply, in soil contents of the particular elements.

The strongest correlations of factor-expressed element levels (Appendix Table 10) are:

– BAF, positive correlations: GaAl, GaFe, AlFe, LaU, BiU, LaAl, LaFe; CaMn, TiFe, MnZn, VBa, VGa, VNi, VTi, VFe, VCr, ScTi, CoCd, CoU, NiBa, NiGa, NiAl, NiTi, NiFe, CuNi, ZnCd, ZnAg, ZnCa, GaLa, GaTi, GaAs, GaU, AsAl, AsFe, AsLa, MoBa, MoMg, MoNa, AgZn, AgMn, CdCa, SbPb, BaNa, UAl; negative correlations are weak and include the STe and SCa systems;
– BCF, positive correlations: NaZn, MgMo, BaMo; ScSe, ScTh, VNi, VFe, CrAu, CrMo, CrPb, CrBa, CrMg, CoSr, CoMn, NiTh, CuTl, ZnSb, ZnCd, CdSb, GaSe, GaAu, GaAl, GaFe, AsMo, AsTe, AsP, MoTe, MoAu, SbTe,

SbNa, TeBa, TeW, TeHg, TeCa, BaAu, BaAl, WCa, AuMg, PbMg, PbTl;

- BCF, negative correlations: KU, CdU, HgCo, HgAs, BCu (and BTi), MnLa, WTh, KBi;
- TF, positive correlations: VCr, CoZn, AsPb, LaU, LaAl, LaFe, PbBi, UTi, UAl, UFe; ScMo, TiFe, VNi, VGa, VAs, VSb, VBi, VPb, GaNi, GaAs, GaBa, GaLa, GaPb, GaBi, GaAl, GaFe, AsSb, AsBi, AsFe, SrK, SrCa, AgTe, CdCa, SbPb, SbBi, BaLa, BaU, BaAl, PbFe and ThTi;
- TF, negative correlations: SeK, SeSr, GaS.

Additional associations are found when particular factors are treated separately:

- BCF: VMo, CrSe, CrSr, CuSb, NiSe, ZnMo, AsNa, AsSb, SeFe, SrTi, SrMo, SrTe, SrBa, MoTe, MoW, MoAu, MoPb, SbNa, SbMn, SbTe, TeNa, TeMg, TePb, BaW, WBi, AuPb and BiCa;
- TF: KCa, CoK, ZnK, SrK, SrNa, BS, ScMn, ScMo, AsSb, ZnTl, GaSb, SrCd, MoAl, MoP, MoMn, MoCd, MoTh, MoU, AgSe, SeTe, CdS, LaS, ThCa, ThZn, ThSr, ThBa, ThTl and WTl.

These relations may reflect some factor-specific reactions. Only some of all the above associations may be explained by the frequency of element transfer between particular environmental components; they are CaMn, STe, SCa, GaAl, GaFe, GaU, ZnCa, ZnMn, ZnCd, ZnAg, CdCa, and MoNa (BAF); CuSb, CuTl, ZnSb, CdNa, CdSb, TeBa, AsMo, AsTe, AsP, MoTe, MoAu, SbTe, SbNa, SrMo, SrTe, TeNa, TeW, TeHg, TeCa, and WCa (BCF); and TiFe, AlFe, BS, ScMn, VGa, VAs, GaAl, GaFe, GaS, GaAs, GaLa, AsFe, SeSr, SeAg, SeTe, SrCa, AgTe, CdS, BaAl, LaS, LaAl, LaFe, LaU, UAl, UTi (and possibly TiFe, VCr, VGa, VAs, VPb, AsPb, SeK, SrCd, MoCd, CdCa, LaTi, PbFe and PbBi, related to lower values) in the case of TF. Also, only a few correlation pairs are found for all three accumulation/translocation factors: GaAl, GaFe, VNi. The additional common pairs for the BAF-BCF system are MoMg, MoBa, VFe, ZnCd; those for the BCF-TF system are AlFe, TiFe, NiGa, AsFe, GaAs, CdCa, SbPb, LaAl, LaFe, LaU and UAl; and that for the BAF-TF system: BaAl.

Additional observations come from comparison of negative correlations for direct compositional data (Appendix Table 9) with the frequency of some elements within the particular soil-vegetation movement paths. This can be interpreted as an illustration of variable affinity to the particular plant organs and to strength of translocation. The most evident examples are:

- in the soil root path (BCF): KTl, CuSb;
- for the root leaf translocation path (TF): ZnHg, MgHg, MgAu, AlAu;
- in both the BCF- and TF-related paths: NaHg, BaAu;
- in different paths: PSe, PAg, KAg, KSe, KTe, STl, SHg, PHg, CaHg and CaAu.

These dependencies not only reflect preferential element movement but may also suggest exchange.

At least some of the listed positively correlated pairs of the root-related BCF and TF paths as well as the suggested factor-specific reactions may be related to deposition of low-solubility species, both in the rhizosphere and plant tissues. Indeed, Kabata-Pendias and Pendias (2001) mention some examples of such products, such as (hydroxyl)pyromorphite, $Pb_5(PO_4)_3(OH)$ and its Zn analogue, in some grass roots. Autunite, $Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12H_2O$, may precipitate in *Coprosma australis* roots. A similar phenomenon may explain some of the elemental associations found for the vegetation samples: Ag may be precipitated by very weakly soluble Ag_2Se (naumannite) and Ag_2Te (hessite). Similar observations may concern the soil deposition of Se with Mo, Pb, Sb, Cu and Tl. The same is true of the WCa and VPb pairs.

Al, Fe and Mn oxyhydroxides, and TiO_2, in soil are frequently reported as mineral forms capable of immobilizing numerous elements, such as Ag, Cd, Zn (with up to 38 and 63% Ba), via sorption. The same is true for clay minerals, with „illite" and kaolinite being most common in the coaly shales, and represent mainly Al and K enrichment. In the case of Zn, mobile forms in soil may comprise up to 20% of the total Zn content. Soils of the post-coal-mining waste heaps are rarely acidic, with their pH being usually close to or slightly above 7; their elevated salinity is due to deposit-derived juvenile brines saturating the pore space (Kruszewski et al., 2021). In such rather alkaline soils, deposition of Cd is expected. In such soils, where $Hg(OH)_2$ may be the major Hg form, at highly elevated Cl^- activity, lowered Mn-oxide- and organic-sorption of this element is expected. This would explain the Hg mobility. An important factor here is leaching of coal char deposited within fumaroles; these chars are known to concentrate large amounts of Hg. The SHg correlation, in turn, invokes the known deposition of HgS – often associated with gypsum (Ca) deposits – in the heaps. This, together with the general high Ca enrichment of the wastes (with carbonates and apatite-supergroup minerals being additional sources), would explain the known (Kabata-Pendias and Pendias, 2001) negative correlation of lime *versus* Hg_{root}. Plants are known to directly absorb Hg^0 vapours, the presence of which in the heaps was established in our earlier studies (Kruszewski et al., 2018). Although S shows negative rather then positive correlations with potentially toxic elements (Th, Hg, Tl), this correlation also invokes the previously observed correlation of S and the HFSE elements in the soils (Wojewódka-Przybył et al., 2020) and points to a need of further study of these very correlations in the context of leaching these elements out to the environment.

The soil salinity also favors B uptake. Elevated Al content in some of the plants studied may be explained by the known NH_4-Al cotolerance, with the NH_4 ion being one of the most common and characteristic components of burning CWHs. Elevated Al is known to suppress uptake of most macronutrients, including P. Phosphate-driven immobilization of Al, Sc and Fe is known in soils (Kabata-Pendias and Pendias, 2001) and expected for the (geo)chemically similar Ga and La.

The most easily uptaken B form is H_3BO_3; it is expected to be enriched in the CWH fumaroles, as exemplified by elevated B contents in fumarole-derived ash samples as well as local riverwater samples (Kruszewski et al., unpublished data). Gallium is expected to follow Al, and both the GaAl and GaFe strong correlations found follow known trends. Correlation of V with Ti, Cr, Ni, Co and Ga found by us is related to siderophile behaviour; indeed, these elements are commonly found in various Fe- (but also Ti) -rich oxide minerals of the pyrometamorphic component of the CWHs (Kruszewski, 2018) that is inherited by the soils studied. In Ca- and Mg-rich soils, forms of $CaSeO_4$ and $MgSeO_4$ (both relatively low-solubility) are suggested to govern Se mobility. On the other hand, goethite-absorbed selenite – somewhat mobile in pH-neutral soils – seems to be more significant in our case, both due to known goethite precipitation (Kruszewski et al., 2021) and rather counter-intuitive elevated Eh needed for Se^{4+} Se^{6+} oxidation. Although a CaSe association was found, this concerns the vegetation system alone. A reductive character of the soil-vegetation interface is possible not just due to known emissions from plants of compounds such as H_2Se and H_2Te, but also the generally low-Eh character of the coal-fire gases (at least below the rhizosphere and/or before their interaction with atmospheric components).

Soil treatment with S, P, and N is known to lower soil Se levels.This may be confirmed by the negative PSe correlation found. Se-Fe antagonism in plants is also known and corroborated in the study of our BCF data. Mercury leaching in the CWHs will be related to coal char leaching: the organic pyrolysates, found among fumaroles, bear clearly elevated levels of Hg, and also Pb and As. The UAl and UFe associations may be related to known precipitation of Al- and Fe phosphates in U-polluted soils treated with hydroxylapatite (Kabata-Pendias and Pendias, 2001). Element pairs reported by them as either synergistic (S), antagonistic (A) or being in variable and/or complex relationships coincide with some found in our study. Many of these pairs are found by us with the same type of dependence, though some observations are divergent. This is likely due to different plant strategies and element ratios.

In Wojewódka-Przybył et al. (2022) we have observed the association of some REEs (Sc, La, Th) with themselves and U, attributable to parallel uptake behaviour also following geochemical trends (i.e., common coexistence) known for these elements. We also suggested that the then-found TiLa, TiCr, TiNi, and TiFe pairs may indicate similar beneficial influence to plants, based on (1) known studies on both Ti and La, (2) the occurrence of Cr and Ni in cellular enzymes, and (2) known Ti support of uptake and utilization of Fe. We also suggested the existence of similarly correlated element pairs. Indeed, such pairs of (potentially) biologically active elements were found within this successor study and include NaZn, MgMo, CaMn, BTi, TiV, TiPb, MnNi, MnCu, FeZn, VMn, VFe, VCr, VNi, VPb, CrMg, CrNi, CrMo, CoMn, CoZn, CoLa, NiFe, NiCu, AsP, AsW, AsPb, WCa, LaFe, PbMg, and PbFe; the TiLa, TiNi, and TiFe correlation is also corroborated.

CONCLUSIONS

By studying 8 soil samples from various BCWRs, collected in both pyrometamorphic and non-pyrometamorphic niches, we conclude that:

– a gap in compositional and geochemical data for a dozen or so elements rarely or not discussed in the literature may be filled;
– Pb, Ag, Zn, Se, Cd, As and Cu show the highest and most persistent enrichment in the soils studied; they are followed by Hg, Cs, Sb, Sn, Bi, Te, U; S, Ca, Mg, Mn and Fe; other elements show fewer and lower concentration anomalies;
– in a row from the highest to lowest EFs, U, Al, Bi, Sb, Sn, Ni, Co and P are seemingly more concentrated in the refractory (and/or poorly soluble) soil fraction, with Fe, Mg, Tl, S and Ag only slightly enriched; Li, B, Be, Sc, Ga, Ge, Rb, Sr, Y, Zr, Nb, La, Ce, Hf, Ta, Pt, Th, Na, K, Ti; and to some extent also V, Cr, Mo, Pd, Ba, W and Au, follow; opposing trends are shown by Cd, Pb, Zn, Hg, Ca, Mn and As – these elements to be expected to be the most dangerous in the waste-heap soils due to their higher availability;
– the local vegetation tends to keep most elements in leaves, with B and Au showing the highest soil-to-leaf movement;
– *Solanum nigrum* is the most efficient species in biostabilization of numerous elements, followed by *Verbascum* that is relatively non-selective;
– Cd and Tl show the highest root preference (in terms of BCF values); other elements commonly associated with the soil root path are K, P, Na and Ca;
– B and Au seem to show the highest level soil-to-leaf movement, in terms of BAF values; other elements frequently associated with the soil leaf path are P, K, Ca, Sr, S, Na, W, Mo, Au and Sb, less frequently Tl, Mg, Zn, Se and Cd;
– The strength of the root-to-leaf transfer is also exemplified by translocation factors showing much more outlier values than the BAF and BCF; root-to-leaf movement is strongest in the case of Hg; other elements in this path are commonly B, Au, Se, Mg, Ag; also La, Mn, Sr, P, Ca, S, Fe and Al;
– The association of S, Se, and Te with elements such as Ag, Au, Mo, Pb, Cu, Sb, and Tl – typical of hydrothermal geoenvironments – suggests possible codeposition in the form of low-solubility sulfides (e.g., cinnabar), selenides (e.g., naumannite, clausthalite, etc.) and tellurides (e.g., hessite).

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APPENDIX TABLE 1

List and systematic position of the vegetation samples

Sample	Latitude	Longitude	City	Vegetation type	Habitat	heap waste	local waste
BDM-VM	50°22"43'	18°53"50'	Bytom	moss	edge of an outer escarpment, near an active fire zone	mixed	coal
BDM-VG	50°22"43'	18°53"50'		grass			
RD-VSg	50°02"23'	18°28"40'	Radlin	*Solidago gigantea*	heap top, near an active fire zone	coal	coal
RDT-plt-VV	50°03"43'	18°26"35'	Rydułtowy	*Verbascum*	plateau of a burning pile	coal	coal
RDT-plt-VM	50°03"45'	18°26"34'		moss			
RDT-b-VCm	50°03"46'	18°26"34'		*Crepis mollis*	outer rim of the plateau, low-temperature strongly hydrous fumaroles		
WOJ-VV	50°22"17'	19°01"33'	Wojkowice	*Verbascum*	heap top, directly above an expiring fire zone	coal	coal
WOJ-VHa	50°22"17'	19°01"33'		*Helichrysum arenarium*			

APPENDIX TABLE 2

Enrichment factor representation of elevated to extreme levels measured for the soil and vegetation samples

	number of records with					total elevated/extreme[1] records (TER)	% (TER) of the whole dataset
enrichment factor of:	4–9	10–19	20–99	100–199	>200		
soil[2] vs. local coals[3]	50 [21][4]	17 [7]	20 [~9]	8 [3]	5	95	40
soil vs. local shales	44 [18]	17 [7]	12 [5]	6	3	82	34
soil vs. typical soil levels	56 [28]	21 [10]	16 [8]	6 [1]	3	99	42
vegetation vs. local coals	35 [9]	13 [3]	7 [2]	-	-	57	15
vegetation vs. local shales	35 [31]	20 [5]	5 [~1]	-	-	60	16
vegetation vs. typical plant levels[3]	59 [16]	26 [7]	41 [11]	9 [~2]	4	135	36

[1] – records with enrichment factor <2 omitted; [2] – only samples analyzed within this study are counted; no. of records: soils: *n* = 238; vegetation: *n* = 378; records below or above the detection limit are omitted; [3] – data cited in Kruszewski et al. (2021) - soils; Wojewódka-Przybył et al. (2022; vegetation); [4] – % of the total records of the particular relation

APPENDIX TABLE 3

Kendall correlation statistics, soil samples

	Na	Mg	Al	S	P	K	Ca	Ti	Mn	Fe	Li	Be	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	As	Se	Rb	Sr	Y
Na		0.60	0.75	-0.03	0.52	0.61	0.25	0.70	0.43	0.61	0.26	0.68	0.60	0.78	0.68	0.52	0.62	0.38	0.01	0.47	0.20	0.33	0.20	0.75	0.62
Mg	0.60		0.57	0.15	0.43	0.40	0.51	0.58	0.64	0.87	0.26	0.55	0.50	0.65	0.57	0.67	0.74	0.52	0.22	0.55	0.37	0.62	0.21	0.62	0.52
Al	0.75	0.57		-0.13	0.46	0.84	0.09	0.77	0.26	0.58	0.70	0.83	0.85	0.78	0.67	0.56	0.62	0.26	-0.14	0.83	0.07	0.40	0.62	0.64	0.74
S	-0.03	0.15	-0.13		-0.22	-0.20	0.19	0.03	0.14	0.17	-0.26	-0.01	-0.08	0.00	-0.09	0.11	0.08	0.22	0.07	-0.05	0.10	0.36	-0.35	0.01	0.03
P	0.52	0.43	0.46	-0.22		0.34	0.17	0.47	0.31	0.48	0.24	0.46	0.41	0.55	0.56	0.49	0.52	0.26	0.13	0.21	0.28	0.12	0.08	0.54	0.47
K	0.61	0.40	0.84	-0.20	0.34		-0.06	0.65	0.12	0.42	0.87	0.72	0.79	0.65	0.60	0.41	0.48	0.14	-0.24	0.66	-0.06	0.23	0.88	0.49	0.62
Ca	0.25	0.51	0.09	0.19	0.17	-0.06		0.16	0.63	0.40	-0.07	0.10	0.06	0.24	0.18	0.35	0.33	0.43	0.51	0.22	0.58	0.42	-0.12	0.39	0.13
Ti	0.70	0.58	0.77	0.03	0.47	0.65	0.16		0.35	0.65	0.35	0.86	0.76	0.84	0.70	0.59	0.68	0.41	-0.03	0.64	0.23	0.66	0.26	0.72	0.81
Mn	0.43	0.64	0.26	0.14	0.31	0.12	0.63	0.35		0.64	0.18	0.31	0.22	0.44	0.33	0.57	0.52	0.57	0.43	0.46	0.59	0.52	0.11	0.49	0.32
Fe	0.61	0.87	0.58	0.17	0.48	0.42	0.40	0.65	0.64		0.39	0.62	0.50	0.67	0.61	0.78	0.82	0.60	0.22	0.62	0.41	0.62	0.21	0.61	0.57
Li	0.26	0.26	0.70	-0.26	0.24	0.87	-0.07	0.35	0.18	0.39		0.60	0.63	0.39	0.36	0.40	0.34	0.04	-0.14	0.68	-0.18	0.26	0.81	0.13	0.47
Be	0.68	0.55	0.83	-0.01	0.46	0.72	0.10	0.86	0.31	0.62	0.60		0.85	0.79	0.64	0.62	0.65	0.34	-0.12	0.68	0.14	0.64	0.52	0.66	0.88
Sc	0.60	0.50	0.85	-0.08	0.41	0.79	0.06	0.76	0.22	0.50	0.63	0.85		0.80	0.68	0.55	0.61	0.24	-0.15	0.58	0.09	0.49	0.65	0.63	0.79
V	0.78	0.65	0.78	0.00	0.55	0.65	0.24	0.84	0.44	0.67	0.39	0.79	0.80		0.83	0.65	0.76	0.42	0.03	0.55	0.25	0.62	0.37	0.77	0.74
Cr	0.68	0.57	0.67	-0.09	0.56	0.60	0.18	0.70	0.33	0.61	0.36	0.64	0.68	0.83		0.56	0.74	0.43	0.07	0.29	0.21	0.46	0.29	0.64	0.63
Co	0.52	0.67	0.56	0.11	0.49	0.41	0.35	0.59	0.57	0.78	0.40	0.62	0.55	0.65	0.56		0.85	0.51	0.24	0.64	0.42	0.62	0.33	0.59	0.54
Ni	0.62	0.74	0.62	0.08	0.52	0.48	0.33	0.68	0.52	0.82	0.34	0.65	0.61	0.76	0.74	0.85		0.54	0.22	0.58	0.40	0.68	0.21	0.70	0.59
Cu	0.38	0.52	0.26	0.22	0.26	0.14	0.43	0.41	0.57	0.60	0.04	0.34	0.24	0.42	0.43	0.51	0.54		0.47	0.17	0.61	0.48	-0.15	0.39	0.37
Zn	0.01	0.22	-0.14	0.07	0.13	-0.24	0.51	-0.03	0.43	0.22	-0.14	-0.12	-0.15	0.03	0.07	0.24	0.22	0.47		0.14	0.69	0.39	-0.23	0.12	-0.12
Ga	0.47	0.55	0.83	-0.05	0.21	0.66	0.22	0.64	0.46	0.62	0.68	0.68	0.58	0.55	0.29	0.64	0.58	0.17	0.14		0.11	0.47	0.57	0.42	0.47
As	0.20	0.37	0.07	0.10	0.28	-0.06	0.58	0.23	0.59	0.41	-0.18	0.14	0.09	0.25	0.21	0.42	0.40	0.61	0.69	0.11		0.36	-0.24	0.38	0.17
Se	0.33	0.62	0.40	0.36	0.12	0.23	0.42	0.66	0.52	0.62	0.26	0.64	0.49	0.62	0.46	0.62	0.68	0.48	0.39	0.47	0.36		0.15	0.46	0.51
Rb	0.20	0.21	0.62	-0.35	0.08	0.88	-0.12	0.26	0.11	0.21	0.81	0.52	0.65	0.37	0.29	0.33	0.21	-0.15	-0.23	0.57	-0.24	0.15		0.08	0.31
Sr	0.75	0.62	0.64	0.01	0.54	0.49	0.39	0.72	0.49	0.61	0.13	0.66	0.63	0.77	0.64	0.59	0.70	0.39	0.12	0.42	0.38	0.46	0.08		0.68
Y	0.62	0.52	0.74	0.03	0.47	0.62	0.13	0.81	0.32	0.57	0.47	0.88	0.79	0.74	0.63	0.54	0.59	0.37	-0.12	0.47	0.17	0.51	0.31	0.68	
Zr	0.62	0.46	0.62	0.05	0.28	0.51	0.15	0.71	0.20	0.47	-0.07	0.66	0.68	0.72	0.60	0.47	0.56	0.32	-0.05	0.28	0.18	0.46	0.05	0.66	0.60
Nb	0.44	0.30	0.64	-0.15	0.41	0.69	-0.12	0.68	0.06	0.37	0.45	0.71	0.72	0.58	0.56	0.37	0.43	0.23	-0.28	0.21	0.00	0.01	0.51	0.44	0.76
Mo	0.52	0.57	0.25	0.10	0.51	0.01	0.57	0.48	0.66	0.59	0.00	0.31	0.17	0.50	0.48	0.47	0.57	0.69	0.51	0.21	0.61	0.36	-0.21	0.61	0.45
Ag	0.32	0.40	0.03	0.01	0.30	-0.22	0.56	0.25	0.53	0.43	-0.20	0.05	-0.09	0.26	0.32	0.42	0.45	0.70	0.90	0.04	0.86	0.29	-0.28	0.55	0.18
Cd	0.22	0.39	-0.02	0.18	0.13	-0.22	0.66	0.11	0.53	0.36	-0.21	-0.02	-0.11	0.18	0.18	0.33	0.36	0.60	0.86	0.08	0.70	0.37	-0.29	0.38	0.00
In	0.51	0.60	0.43	0.32	0.19	0.13	0.39	0.68	0.78	0.75	0.21	0.58	0.35	0.68	0.35	0.65	0.64	0.46	0.43	0.55	0.38	0.48	0.10	0.67	0.52
Sn	0.65	0.57	0.53	0.07	0.34	0.41	0.28	0.60	0.48	0.60	0.04	0.57	0.43	0.58	0.47	0.50	0.60	0.54	0.17	0.30	0.37	0.35	-0.04	0.64	0.55

Sb	**0.53**	**0.56**	**0.45**	0.16	0.29	**0.38**	**0.42**	**0.66**	**0.44**	**0.57**	-0.05	**0.56**	**0.52**	**0.67**	**0.63**	**0.61**	**0.75**	**0.63**	0.27	0.18	**0.53**	**0.60**	-0.08	**0.65**	**0.57**
Te	0.25	0.19	0.16	-0.06	0.25	0.00	-0.11	0.26	0.29	**0.32**	0.19	0.18	-0.06	0.24	0.16	0.25	0.19	0.14	-0.02	0.29	0.03	-0.03	0.11	0.16	**0.31**
Cs	-0.03	0.11	**0.38**	-0.18	-0.03	**0.63**	-0.17	**0.36**	0.05	0.18	**0.67**	**0.54**	**0.66**	**0.31**	0.24	0.25	0.13	-0.01	-0.25	**0.37**	-0.21	0.20	**0.78**	0.03	**0.46**
Ba	**0.78**	**0.55**	**0.65**	-0.07	**0.52**	**0.53**	0.28	**0.73**	**0.45**	**0.56**	0.19	**0.65**	**0.60**	**0.77**	**0.67**	**0.55**	**0.71**	**0.42**	0.13	**0.48**	**0.34**	**0.42**	0.05	**0.82**	**0.63**
La	**0.68**	**0.45**	**0.86**	-0.17	**0.44**	**0.85**	0.04	**0.66**	0.17	**0.45**	**0.80**	**0.74**	**0.84**	**0.68**	**0.60**	**0.50**	**0.54**	0.17	-0.21	**0.66**	0.01	0.20	**0.74**	**0.62**	**0.69**
Ce	**0.32**	0.28	**0.71**	**-0.32**	0.17	**0.91**	-0.08	0.27	0.12	**0.30**	**0.87**	**0.51**	**0.66**	**0.34**	**0.33**	**0.39**	**0.30**	-0.03	-0.11	**0.63**	-0.17	0.16	**0.86**	0.15	**0.32**

Appendix Table 1 — continued

	Na	Mg	Al	S	P	K	Ca	Ti	Mn	Fe	Li	Be	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	As	Se	Rb	Sr	Y
Hf	0.14	0.18	0.13	0.14	-0.27	0.11	0.29	0.24	0.11	0.11	0.00	0.26	**0.34**	0.26	0.02	0.17	0.11	0.18	0.25	0.20	0.24	**0.34**	0.15	**0.30**	0.11
W	**0.55**	**0.44**	0.20	0.15	0.18	0.15	**0.78**	**0.49**	**0.49**	**0.38**	**-0.31**	0.29	0.15	**0.49**	**0.38**	**0.30**	**0.32**	**0.38**	0.18	0.00	**0.44**	0.22	-0.21	**0.61**	0.29
Re	**0.35**	-0.25	0.00	**-0.49**	-0.05	0.10	0.10	-0.26	0.20	-0.29	0.20	-0.15	-0.25	-0.05	-0.29	-0.26	**-0.39**	-0.25	-0.10	0.00	-0.05	**-0.55**	0.25	0.15	-0.05
Au	0.26	**0.37**	0.13	-0.22	**0.55**	-0.13	**0.38**	0.13	**0.42**	**0.42**	-0.08	0.09	-0.03	0.21	**0.37**	**0.44**	**0.47**	**0.44**	**0.61**	0.11	**0.53**	0.20	-0.18	**0.32**	0.07
Hg	-0.24	-0.18	0.01	**0.34**	**-0.36**	0.13	-0.12	-0.08	-0.13	-0.21	0.11	0.12	0.29	-0.04	0.05	-0.14	-0.13	0.01	-0.14	-0.11	-0.16	0.20	0.05	-0.18	0.12
Tl	**0.63**	**0.58**	**0.33**	-0.08	**0.39**	0.11	**0.54**	**0.40**	**0.76**	**0.58**	0.13	**0.33**	0.18	**0.62**	**0.55**	**0.52**	**0.55**	**0.57**	**0.61**	0.29	**0.50**	**0.31**	0.14	**0.53**	0.27
Pb	-0.02	0.22	-0.13	0.11	0.09	-0.23	**0.43**	0.01	**0.37**	0.18	-0.22	-0.12	-0.16	0.02	0.03	0.17	0.14	**0.49**	**0.89**	0.07	**0.62**	**0.42**	**-0.30**	0.04	-0.11
Bi	**0.34**	0.19	**0.40**	-0.21	0.17	**0.50**	0.07	**0.37**	0.27	0.28	**0.47**	**0.45**	**0.39**	**0.43**	**0.32**	0.28	0.21	0.17	-0.02	**0.34**	0.06	0.09	**0.53**	**0.43**	**0.41**
Th	**0.51**	**0.36**	**0.76**	-0.19	0.31	**0.83**	-0.05	**0.66**	0.10	**0.37**	**0.65**	**0.73**	**0.87**	**0.67**	**0.59**	**0.42**	**0.46**	0.17	-0.27	**0.44**	-0.03	0.21	**0.83**	**0.52**	**0.69**
U	0.29	0.21	**0.38**	0.03	-0.03	**0.31**	0.14	**0.53**	0.18	0.23	**0.34**	**0.38**	0.29	**0.33**	0.08	0.19	0.16	0.09	-0.06	**0.47**	0.03	0.24	**0.37**	0.26	**0.46**

	Zr	Nb	Mo	Ag	Cd	In	Sn	Sb	Te	Cs	Ba	La	Ce	Hf	W	Re	Au	Hg	Tl	Pb	Bi	Th	U
Na	**0.62**	**0.44**	**0.52**	**0.32**	0.22	**0.51**	**0.65**	**0.53**	0.25	-0.03	**0.78**	**0.68**	0.32	0.14	**0.55**	**0.35**	0.26	-0.24	**0.63**	-0.02	**0.34**	**0.51**	0.29
Mg	**0.46**	**0.30**	**0.57**	**0.40**	**0.39**	**0.60**	**0.57**	**0.56**	0.19	0.11	**0.55**	**0.45**	0.28	0.18	**0.44**	-0.25	**0.37**	-0.18	**0.58**	0.22	0.19	**0.36**	0.21
Al	**0.62**	**0.64**	0.25	0.03	-0.02	**0.43**	**0.53**	**0.45**	0.16	**0.38**	**0.65**	**0.86**	**0.71**	0.13	0.20	0.00	0.13	0.01	**0.33**	-0.13	**0.40**	**0.76**	**0.38**
S	0.05	-0.15	0.10	0.01	0.18	**0.32**	0.07	0.16	-0.06	-0.18	-0.07	-0.17	**-0.32**	0.14	0.15	**-0.49**	-0.22	**0.34**	-0.08	0.11	-0.21	-0.19	0.03
P	0.28	**0.41**	**0.51**	**0.30**	0.13	0.19	**0.34**	0.29	0.25	-0.03	**0.52**	**0.44**	0.17	-0.27	0.18	-0.05	**0.55**	**-0.36**	**0.39**	0.09	0.17	**0.31**	-0.03
K	**0.51**	**0.69**	0.01	-0.22	-0.22	0.13	**0.41**	**0.38**	0.00	**0.63**	**0.53**	**0.85**	**0.91**	0.11	0.15	0.10	-0.13	0.13	0.11	-0.23	**0.50**	**0.83**	**0.31**
Ca	0.15	-0.12	**0.57**	**0.56**	**0.66**	**0.39**	0.28	**0.42**	-0.11	-0.17	0.28	0.04	-0.08	0.29	**0.78**	0.10	**0.38**	-0.12	**0.54**	**0.43**	0.07	-0.05	0.14
Ti	**0.71**	**0.68**	**0.48**	0.25	0.11	**0.68**	**0.60**	**0.66**	0.26	**0.36**	**0.73**	**0.66**	0.27	0.24	**0.49**	-0.26	0.13	-0.08	**0.40**	0.01	**0.37**	**0.66**	**0.53**
Mn	0.20	0.06	**0.66**	**0.53**	**0.53**	**0.78**	**0.48**	**0.44**	0.29	0.05	**0.45**	0.17	0.12	0.11	**0.49**	0.20	**0.42**	-0.13	**0.76**	**0.37**	0.27	0.10	0.18
Fe	**0.47**	**0.37**	**0.59**	**0.43**	**0.36**	**0.75**	**0.60**	**0.57**	**0.32**	0.18	**0.56**	**0.45**	**0.30**	0.11	**0.38**	-0.29	**0.42**	-0.21	**0.58**	0.18	0.28	**0.37**	0.23
Li	-0.07	**0.45**	0.00	-0.20	-0.21	0.21	0.04	-0.05	0.19	**0.67**	0.19	**0.80**	**0.87**	0.00	**-0.31**	0.20	-0.08	0.11	0.13	-0.22	**0.47**	**0.65**	**0.34**
Be	**0.66**	**0.71**	**0.31**	0.05	-0.02	**0.58**	**0.57**	**0.56**	0.18	**0.54**	**0.65**	**0.74**	**0.51**	0.26	0.29	-0.15	0.09	0.12	0.33	-0.12	**0.45**	**0.73**	**0.38**
Sc	**0.68**	**0.72**	0.17	-0.09	-0.11	**0.35**	**0.43**	**0.52**	-0.06	**0.66**	**0.60**	**0.84**	**0.66**	**0.34**	0.15	-0.25	-0.03	0.29	0.18	-0.16	**0.39**	**0.87**	0.29
V	**0.72**	**0.58**	**0.50**	0.26	0.18	**0.68**	**0.58**	**0.67**	0.24	**0.31**	**0.77**	**0.68**	**0.34**	0.26	**0.49**	-0.05	0.21	-0.04	**0.62**	0.02	**0.43**	**0.67**	**0.33**
Cr	**0.60**	**0.56**	**0.48**	**0.32**	0.18	**0.35**	**0.47**	**0.63**	0.16	0.24	**0.67**	**0.60**	**0.33**	0.02	**0.38**	-0.29	**0.37**	0.05	**0.55**	0.03	**0.32**	**0.59**	0.08
Co	**0.47**	**0.37**	**0.47**	**0.42**	**0.33**	**0.65**	**0.50**	**0.61**	0.25	0.25	**0.55**	**0.50**	**0.39**	0.17	**0.30**	-0.26	**0.44**	-0.14	**0.52**	0.17	0.28	**0.42**	0.19
Ni	**0.56**	**0.43**	**0.57**	**0.45**	**0.36**	**0.64**	**0.60**	**0.75**	0.19	0.13	**0.71**	**0.54**	**0.30**	0.11	**0.32**	**-0.39**	**0.47**	-0.13	**0.55**	0.14	0.21	**0.46**	0.16
Cu	**0.32**	0.23	**0.69**	**0.70**	**0.60**	**0.46**	**0.54**	**0.63**	0.14	-0.01	**0.42**	0.17	-0.03	0.18	**0.38**	-0.25	**0.44**	0.01	**0.57**	**0.49**	0.17	0.17	0.09
Zn	-0.05	-0.28	**0.51**	**0.90**	**0.86**	**0.43**	0.17	0.27	-0.02	-0.25	0.13	-0.21	-0.11	0.25	0.18	-0.10	**0.61**	-0.14	**0.61**	**0.89**	-0.02	-0.27	-0.06

Ga	0.28	0.21	0.21	0.04	0.08	**0.55**	**0.30**	0.18	0.29	**0.37**	**0.48**	**0.66**	**0.63**	0.20	0.00	0.00	0.11	-0.11	0.29	0.07	**0.34**	**0.44**	**0.47**
As	0.18	0.00	**0.61**	**0.86**	**0.70**	**0.38**	**0.37**	**0.53**	0.03	-0.21	**0.34**	0.01	-0.17	0.24	**0.44**	-0.05	**0.53**	-0.16	**0.50**	**0.62**	0.06	-0.03	0.03
Se	**0.46**	0.01	**0.36**	0.29	**0.37**	**0.48**	**0.35**	**0.60**	-0.03	0.20	**0.42**	0.20	0.16	**0.34**	0.22	-0.55	0.20	0.20	**0.31**	**0.42**	0.09	0.21	0.24
Rb	0.05	**0.51**	-0.21	-0.28	-0.29	0.10	-0.04	-0.08	0.11	**0.78**	0.05	**0.74**	**0.86**	0.15	-0.21	0.25	-0.18	0.05	0.14	**-0.30**	**0.53**	**0.83**	**0.37**
Sr	**0.66**	**0.44**	**0.61**	**0.55**	**0.38**	**0.67**	**0.64**	**0.65**	0.16	0.03	**0.82**	**0.62**	0.15	**0.30**	**0.61**	0.15	**0.32**	-0.18	**0.53**	0.04	**0.43**	**0.52**	0.26
Y	**0.60**	**0.76**	**0.45**	0.18	0.00	**0.52**	**0.55**	**0.57**	**0.31**	**0.46**	**0.63**	**0.69**	**0.32**	0.11	0.29	-0.05	0.07	0.12	0.27	-0.11	**0.41**	**0.69**	**0.46**
Zr		0.51	0.23	0.25	0.14	**0.37**	**0.51**	**0.64**	-0.06	0.13	**0.67**	**0.59**	-0.04	**0.74**	**0.38**	-0.29	0.13	-0.11	0.29	-0.07	0.21	**0.66**	0.26
Nb	**0.51**		0.08	-0.25	**-0.40**	-0.06	**0.44**	**0.39**	0.23	**0.64**	**0.46**	**0.67**	**0.39**	-0.05	0.06	-0.05	-0.17	0.07	-0.16	-0.25	**0.39**	**0.81**	**0.50**
Mo	0.23	0.08		**0.66**	**0.49**	**0.48**	**0.76**	**0.54**	**0.30**	-0.13	**0.61**	0.06	-0.09	0.06	**0.57**	-0.10	**0.50**	-0.26	**0.55**	**0.53**	0.09	-0.04	0.13

Appendix Table 1 — continued

	Zr	Nb	Mo	Ag	Cd	In	Sn	Sb	Te	Cs	Ba	La	Ce	Hf	W	Re	Au	Hg	Tl	Pb	Bi	Th	U
Ag	0.25	-0.25	**0.66**		**0.76**	**0.33**	**0.62**	**0.66**	0.08	-0.25	**0.51**	-0.17	-0.21	0.22	**0.72**	-0.10	**0.67**	-0.25	**0.56**	**0.87**	0.01	-0.26	-0.06
Cd	0.14	**-0.40**	**0.49**	**0.76**		**0.41**	**0.35**	**0.52**	-0.13	**-0.32**	**0.34**	-0.13	-0.15	0.14	**0.72**	-0.20	**0.50**	-0.13	**0.55**	**0.82**	-0.03	-0.27	-0.14
In	**0.37**	-0.06	**0.48**	**0.33**	**0.41**		**0.59**	**0.37**	**0.46**	0.13	**0.71**	0.18	0.15	0.10	0.14	0.05	0.19	0.03	**0.60**	**0.36**	0.29	0.10	0.25
Sn	**0.51**	**0.44**	**0.76**	**0.62**	**0.35**	**0.59**		**0.64**	**0.40**	0.04	**0.65**	**0.41**	-0.05	0.21	**0.49**	0.00	**0.41**	-0.23	**0.57**	0.22	**0.40**	**0.41**	**0.30**
Sb	**0.64**	**0.39**	**0.54**	**0.66**	**0.52**	**0.37**	**0.64**		-0.10	0.00	**0.70**	**0.40**	-0.09	**0.43**	**0.61**	-0.20	**0.32**	0.11	**0.47**	0.24	0.17	**0.42**	0.21
Te	-0.06	0.23	**0.30**	0.08	-0.13	**0.46**	**0.40**	-0.10		0.10	0.21	0.07	0.08	-0.29	-0.07	0.45	0.03	-0.32	**0.32**	-0.02	0.24	-0.05	**0.35**
Cs	0.13	**0.64**	-0.13	-0.25	-0.32	0.13	0.04	0.00	0.10		-0.03	**0.49**	**0.63**	0.18	**-0.37**	0.10	-0.27	0.19	0.05	-0.25	**0.53**	**0.86**	**0.42**
Ba	**0.67**	**0.46**	**0.61**	**0.51**	**0.34**	**0.71**	**0.65**	**0.70**	0.21	-0.03		**0.61**	0.16	0.16	**0.59**	0.25	**0.31**	-0.24	**0.56**	0.06	**0.38**	**0.51**	0.29
La	**0.59**	**0.67**	0.06	-0.17	-0.13	0.18	**0.41**	**0.40**	0.07	**0.49**	**0.61**		**0.87**	0.15	0.18	0.25	-0.08	0.03	0.16	-0.23	**0.47**	**0.82**	**0.35**
Ce	-0.04	**0.39**	-0.09	-0.21	-0.15	0.15	-0.05	-0.09	0.08	**0.63**	0.16	**0.87**		0.00	**-0.31**	0.15	-0.09	0.07	0.15	-0.18	**0.44**	**0.71**	0.28
Hf	**0.74**	-0.05	0.06	0.22	0.14	0.10	0.21	**0.43**	-0.29	0.18	0.16	0.15	0.00		**0.33**	-0.25	0.10	-0.02	0.15	0.22	0.19	**0.36**	0.24
W	**0.38**	0.06	**0.57**	**0.72**	**0.72**	0.14	**0.49**	**0.61**	-0.07	**-0.37**	**0.59**	0.18	**-0.31**	**0.33**		0.11	0.21	**-0.69**	0.41	0.15	0.10	0.09	0.21
Re	-0.29	-0.05	-0.10	-0.10	-0.20	0.05	0.00	-0.20	**0.45**	0.10	0.25	0.25	0.15	-0.25	0.11		**-0.49**	0.15	0.35	-0.20	**0.68**	-0.05	0.29
Au	0.13	-0.17	**0.50**	**0.67**	**0.50**	0.19	**0.41**	**0.32**	0.03	-0.27	**0.31**	-0.08	-0.09	0.10	0.21	**-0.49**		**-0.32**	**0.51**	**0.54**	-0.13	-0.24	-0.26
Hg	-0.11	0.07	-0.26	-0.25	-0.13	0.03	-0.23	0.11	**-0.32**	0.19	-0.24	0.03	0.07	-0.02	**-0.69**	0.15	**-0.32**		-0.16	-0.12	-0.03	0.20	-0.16
Tl	0.29	-0.16	**0.55**	**0.56**	**0.55**	**0.60**	**0.57**	**0.47**	**0.32**	0.05	**0.56**	0.16	0.15	0.15	**0.41**	**0.35**	**0.51**	-0.16		**0.54**	0.29	0.03	0.08
Pb	-0.07	-0.25	**0.53**	**0.87**	**0.82**	**0.36**	0.22	0.24	-0.02	-0.25	0.06	-0.23	-0.18	0.22	0.15	-0.20	**0.54**	-0.12	**0.54**		-0.09	-0.26	-0.04
Bi	0.21	**0.39**	0.09	0.01	-0.03	0.29	**0.40**	0.17	0.24	**0.53**	**0.38**	**0.47**	**0.44**	0.19	0.10	**0.68**	-0.13	-0.03	0.29	-0.09		**0.58**	**0.39**
Th	**0.66**	**0.81**	-0.04	-0.26	-0.27	0.10	**0.41**	**0.42**	-0.05	**0.86**	**0.51**	**0.82**	**0.71**	**0.36**	0.09	-0.05	-0.24	0.20	0.03	-0.26	**0.58**		**0.43**
U	0.26	**0.50**	0.13	-0.06	-0.14	0.25	**0.30**	0.21	**0.35**	**0.42**	0.29	**0.35**	0.28	0.24	0.21	0.29	-0.26	-0.16	0.08	-0.04	**0.39**	**0.43**	

Statistically meaningful data in bold, τ values ~|0.75-0.90| marked by frame; p-values ≤ 0.05 underlined

APPENDIX TABLE 4

Kendall correlation statistics, vegetation samples

	Na	Mg	Al	S	P	K	Ca	Ti	Mn	Fe	B	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	As	Se	Sr	Mo	Ag	Cd
Na		**0.42**	0.14	0.12	**0.40**	**0.36**	-0.03	0.29	0.14	0.15	0.03	-0.08	0.16	0.19	0.08	0.14	0.28	-0.21	-0.07	0.03	0.00	0.13	**0.33**	-0.09	-0,28
Mg	**0.42**		0.02	**0.31**	**0.30**	**0.40**	**0.35**	0.28	**0.31**	0.23	**0.38**	0.19	0.19	0.10	0.27	0.13	**0.36**	-0.04	-0.04	0.22	0.26	**0.38**	0.24	0.04	-0,05
Al	0.14	0.02		-0.07	-0.06	-0.22	0.00	**0.60**	0.16	**0.57**	-0.17	**0.39**	**0.75**	**0.59**	**0.37**	**0.43**	**0.31**	-0.02	0.66	**0.35**	0.03	0.16	**0.30**	0.04	-0,05
S	0.12	**0.31**	-0.07		0.13	0.22	**0.38**	0.12	0.15	0.14	**0.31**	0.19	-0.07	0.05	0.11	-0.10	0.01	0.22	-0.04	0.15	0.19	0.23	0.18	0.07	0,25
P	**0.40**	**0.30**	-0.06	0.13		**0.40**	-0.14	0.07	0.10	-0.05	0.02	-0.14	-0.18	0.00	-0.02	0.03	0.19	-0.28	-0.13	-0.09	-0.26	-0.07	0.08	-0.11	-0,26
K	**0.36**	**0.40**	-0.22	0.22	**0.40**		0.07	-0.04	0.19	-0.08	0.23	-0.18	-0.20	-0.22	-0.10	-0.08	0.02	-0.04	**-0.37**	0.05	-0.05	0.01	0.17	0.00	0,02
Ca	-0.03	**0.35**	0.00	**0.38**	-0.14	0.07		0.21	0.25	0.26	**0.45**	**0.30**	0.09	0.12	0.25	0.08	0.11	**0.33**	0.03	0.16	0.28	**0.52**	0.15	0.20	**0,33**
Ti	0.29	0.28	**0.60**	0.12	0.07	-0.04	0.21		**0.41**	**0.74**	0.07	**0.49**	**0.75**	**0.71**	**0.55**	**0.62**	**0.57**	0.10	**0.50**	**0.38**	0.17	0.27	**0.45**	0.15	0,02
Mn	0.14	**0.31**	0.16	0.15	0.10	0.19	0.25	**0.41**		**0.42**	0.13	0.18	**0.41**	0.26	**0.54**	**0.34**	**0.34**	0.10	0.03	0.13	0.02	0.25	0.27	0.05	0,09
Fe	0.15	0.23	**0.57**	0.14	-0.05	-0.08	0.26	**0.74**	**0.42**		0.06	**0.43**	**0.65**	**0.65**	**0.54**	**0.53**	**0.48**	0.23	**0.42**	**0.48**	0.18	**0.30**	**0.36**	0.28	0,14
B	0.03	**0.38**	-0.17	**0.31**	0.02	0.23	**0.45**	0.07	0.13	0.06		0.27	-0.02	-0.07	0.10	0.03	-0.01	0.05	-0.08	0.08	0.25	0.27	0.01	0.02	0,10
Sc	-0.08	0.19	**0.39**	0.19	-0.14	-0.18	0.30	**0.49**	0.18	**0.43**	0.27		**0.48**	**0.38**	**0.44**	**0.35**	**0.31**	0.15	**0.43**	0.29	**0.40**	**0.37**	0.24	0.11	0,16
V	0.16	0.19	**0.75**	-0.07	-0.18	-0.20	0.09	**0.75**	**0.41**	**0.65**	-0.02	**0.48**		**0.84**	**0.67**	**0.59**	**0.38**	-0.02	**0.59**	0.14	0.03	**0.50**	**0.37**	-0.15	-0,16
Cr	0.19	0.10	**0.59**	0.05	0.00	-0.22	0.12	**0.71**	0.26	**0.65**	-0.07	0.38	**0.84**		**0.48**	**0.59**	**0.46**	0.10	**0.50**	0.28	0.07	0.24	**0.33**	0.16	0,00
Co	0.08	0.27	**0.37**	0.11	-0.02	-0.10	0.25	**0.55**	**0.54**	**0.54**	0.10	**0.44**	**0.67**	**0.48**		**0.55**	**0.47**	0.02	**0.32**	0.11	0.22	**0.38**	0.20	-0.07	0,01
Ni	0.14	0.13	**0.43**	-0.10	0.03	-0.08	0.08	**0.62**	**0.34**	**0.53**	0.03	**0.35**	**0.59**	**0.59**	**0.55**		**0.42**	0.01	**0.42**	0.08	0.17	0.17	**0.35**	0.11	-0,08
Cu	0.28	**0.36**	**0.31**	0.01	0.19	0.02	0.11	**0.57**	**0.34**	**0.48**	-0.01	**0.31**	**0.38**	**0.46**	**0.47**	**0.42**		0.12	0.12	0.23	0.17	0.21	**0.40**	0.05	0,01
Zn	-0.21	-0.04	-0.02	0.22	-0.28	-0.04	**0.33**	0.10	0.10	0.23	0.05	0.15	-0.02	0.10	0.02	0.01	0.12		-0.07	**0.31**	0.22	0.14	0.21	**0.42**	**0,69**
Ga	-0.07	-0.04	**0.66**	-0.04	-0.13	**-0.37**	0.03	**0.50**	0.03	**0.42**	-0.08	**0.43**	**0.59**	**0.50**	**0.32**	**0.42**	0.12	-0.07		0.11	0.04	**0.36**	0.22	-0.13	-0,13
As	0.03	0.22	**0.35**	0.15	-0.09	0.05	0.16	**0.38**	0.13	**0.48**	0.08	0.29	0.14	0.28	0.11	0.08	0.23	**0.31**	0.11		0.04	0.01	0.24	**0.44**	0,22
Se	0.00	0.26	0.03	0.19	-0.26	-0.05	0.28	0.17	0.02	0.18	0.25	**0.40**	0.03	0.07	0.22	0.17	0.17	0.22	0.04	0.04		0.25	0.06	0.15	0,18
Sr	0.13	0.38	0.16	0.23	-0.07	0.01	**0.52**	0.27	0.25	**0.30**	0.27	**0.37**	**0.50**	0.24	**0.38**	0.17	0.21	0.14	**0.36**	0.01	0.25		0.22	-0.07	0,10
Mo	**0.33**	0.24	**0.30**	0.18	0.08	0.17	0.15	**0.45**	0.27	**0.36**	0.01	0.24	**0.37**	**0.33**	0.20	**0.35**	**0.40**	0.21	0.22	0.24	0.06	0.22		0.12	0,15
Ag	-0.09	0.04	0.04	0.07	-0.11	0.00	0.20	0.15	0.05	0.28	0.02	0.11	-0.15	0.16	-0.07	0.11	0.05	**0.42**	-0.13	**0.44**	0.15	-0.07	0.12		0,25
Cd	-0.28	-0.05	-0.05	0.25	-0.26	0.02	**0.33**	0.02	0.09	0.14	0.10	0.16	-0.16	0.00	0.01	-0.08	0.01	**0.69**	-0.13	0.22	0.18	0.10	0.15	0.25	
Sb	-0.15	-0.15	0.19	-0.12	-0.23	-0.29	0.08	0.22	0.12	**0.30**	-0.12	0.05	0.20	**0.35**	0.16	0.22	0.18	**0.30**	0.22	0.15	-0.04	0.17	0.15	0.15	0,24
Te	0.13	0.28	0.17	0.24	0.01	-0.05	**0.35**	0.15	0.25	0.07	0.36	**0.32**	0.04	0.07	0.21	0.16	**0.34**	0.05	**0.39**	-0.10	0.07	**0.50**	**0.30**	-0.07	-0,03
Ba	0.24	0.11	0.27	0.08	0.07	-0.02	0.10	**0.53**	**0.36**	**0.39**	-0.07	0.22	**0.62**	**0.46**	**0.32**	**0.43**	**0.37**	0.15	**0.32**	0.13	-0.07	0.28	**0.55**	0.06	-0,03
La	0.24	0.25	**0.74**	0.00	0.06	-0.11	0.13	**0.77**	**0.39**	**0.71**	-0.02	**0.37**	**0.80**	**0.64**	**0.58**	**0.61**	**0.49**	-0.02	**0.53**	0.24	0.14	0.29	0.29	0.07	-0,12
W	0.16	0.10	**0.57**	0.03	-0.03	-0.15	0.03	**0.54**	**0.48**	**0.37**	0.01	**0.45**	**0.64**	**0.57**	**0.54**	**0.63**	0.27	-0.09	**0.49**	**0.32**	0.23	0.26	**0.49**	-0.08	-0,16
Au	0.24	0.27	0.01	-0.02	0.12	0.09	0.12	0.19	-0.06	0.15	0.01	0.08	-0.16	0.09	0.05	0.18	0.14	0.06	-0.08	0.06	0.29	0.01	0.07	0.27	-0,01
Hg	0.24	0.35	0.27	0.13	0.05	-0.16	0.21	**0.37**	0.15	**0.31**	0.13	**0.30**	**0.30**	**0.39**	**0.31**	**0.30**	**0.37**	-0.04	0.24	-0.02	**0.30**	**0.31**	0.20	0.14	-0,15
Tl	0.15	0.33	-0.03	0.12	0.22	**0.34**	0.14	0.18	**0.33**	0.13	0.01	0.00	0.13	0.06	0.18	0.17	0.28	0.21	-0.13	0.13	0.05	0.17	**0.30**	0.03	0,11
Pb	-0.06	0.05	0.13	0.17	-0.28	0.00	0.28	**0.32**	0.13	**0.43**	0.07	0.24	-0.08	0.29	0.11	0.28	0.19	**0.62**	-0.10	**0.47**	**0.30**	0.06	0.25	**0.65**	**0,46**

Bi	0.29	0.23	**0.68**	0.20	0.02	-0.13	0.08	**0.60**	0.19	**0.53**	-0.04	**0.42**	**0.44**	**0.56**	0.26	**0.46**	**0.36**	0.04	**0.51**	**0.40**	0.22	**0.30**	**0.60**	0.04	-0,12
Th	0.23	0.16	**0.58**	-0.19	0.03	-0.19	0.03	**0.63**	0.24	**0.48**	-0.13	**0.49**	**0.53**	**0.54**	**0.40**	**0.57**	**0.36**	-0.05	**0.51**	-0.01	0.09	**0.32**	0.26	-0.08	-0,20
U	0,18	0,14	**0,75**	0,07	-0,16	-0,21	0,10	**0,59**	0,12	**0,63**	-0,11	**0,39**	**0,71**	**0,57**	**0,48**	**0,42**	**0,30**	-0,03	**0,75**	0,24	0,12	**0,42**	**0,31**	-0,08	-0,11

	Sb	Te	Ba	La	W	Au	Hg	Tl	Pb	Bi	Th	U
Na	-0.15	0.13	0.24	0.24	0.16	0.24	0.24	0.15	-0.06	0.29	0.23	0.18

Appendix Table 2 — continued

	Sb	Te	Ba	La	W	Au	Hg	Tl	Pb	Bi	Th	U
Mg	-0.15	0.28	0.11	0.25	0.10	0.27	**0.35**	**0.33**	0.05	0.23	0.16	0.14
Al	0.19	0.17	0.27	**0.74**	**0.57**	0.01	0.27	-0.03	0.13	**0.68**	**0.58**	**0.75**
S	-0.12	0.24	0.08	0.00	0.03	-0.02	0.13	0.12	0.17	0.20	-0.19	0.07
P	-0.23	0.01	0.07	0.06	-0.03	0.12	0.05	0.22	-0.28	0.02	0.03	-0.16
K	-0.29	-0.05	-0.02	-0.11	-0.15	0.09	-0.16	**0.34**	0.00	-0.13	-0.19	-0.21
Ca	0.08	0.35	0.10	0.13	0.03	0.12	0.21	0.14	0.28	0.08	0.03	0.10
Ti	0.22	0.15	**0.53**	**0.77**	**0.54**	0.19	**0.37**	0.18	**0.32**	**0.60**	**0.63**	**0.59**
Mn	0.12	0.25	**0.36**	**0.39**	**0.48**	-0.06	0.15	**0.33**	0.13	0.19	0.24	0.12
Fe	**0.30**	0.07	**0.39**	**0.71**	**0.37**	0.15	**0.31**	0.13	**0.43**	**0.53**	**0.48**	**0.63**
B	-0.12	**0.36**	-0.07	-0.02	0.01	0.01	0.13	0.01	0.07	-0.04	-0.13	-0.11
Sc	0.05	**0.32**	0.22	**0.37**	**0.45**	0.08	**0.30**	0.00	0.24	**0.42**	**0.49**	**0.39**
V	0.20	0.04	**0.62**	**0.80**	**0.64**	-0.16	**0.30**	0.13	-0.08	**0.44**	**0.53**	**0.71**
Cr	**0.35**	0.07	**0.46**	**0.64**	**0.57**	0.09	**0.39**	0.06	0.29	**0.56**	**0.54**	**0.57**
Co	0.16	0.21	**0.32**	**0.58**	**0.54**	0.05	**0.31**	0.18	0.11	0.26	**0.40**	**0.48**
Ni	0.22	0.16	**0.43**	**0.61**	**0.63**	0.18	**0.30**	0.17	0.28	**0.46**	**0.57**	**0.42**
Cu	0.18	**0.34**	**0.37**	**0.49**	0.27	0.14	**0.37**	0.28	0.19	**0.36**	**0.36**	**0.30**
Zn	**0.30**	0.05	0.15	-0.02	-0.09	0.06	-0.04	0.21	**0.62**	0.04	-0.05	-0.03
Ga	0.22	**0.39**	**0.32**	**0.53**	**0.49**	-0.08	0.24	-0.13	-0.10	**0.51**	**0.51**	**0.75**
As	0.15	-0.10	0.13	0.24	**0.32**	0.06	-0.02	0.13	**0.47**	**0.40**	-0.01	0.24
Se	-0.04	0.07	-0.07	0.14	0.23	0.29	0.30	0.05	**0.30**	0.22	0.09	0.12
Sr	0.17	**0.50**	0.28	0.29	0.26	0.01	**0.31**	0.17	0.06	**0.30**	**0.32**	**0.42**
Mo	0.15	**0.30**	**0.55**	0.29	**0.49**	0.07	0.20	**0.30**	0.25	**0.60**	0.26	**0.31**
Ag	0.15	-0.07	0.06	0.07	-0.08	0.27	0.14	0.03	**0.65**	0.04	-0.08	-0.08
Cd	0.24	-0.03	-0.03	-0.12	-0.16	-0.01	-0.15	0.11	**0.46**	-0.12	-0.20	-0.11
Sb		0.11	0.29	0.17	0.19	-0.18	0.11	0.14	0.29	0.21	0.10	0.22
Te	0.11		**0.39**	0.20	0.20	**-0.65**	**0.67**	0.22	-0.10	0.23	**0.39**	0.25
Ba	0.29	**0.39**		**0.44**	**0.66**	-0.05	0.28	0.24	0.13	**0.52**	**0.39**	**0.31**
La	0.17	0.20	**0.44**		**0.54**	0.16	**0.43**	0.09	0.17	**0.60**	**0.68**	**0.74**
W	0.19	0.20	**0.66**	**0.54**		-0.15	**0.49**	0.09	0.00	**0.70**	-0.10	**0.42**
Au	-0.18	**-0.65**	-0.05	0.16	-0.15		0.15	0.13	0.22	-0.10	0.26	0.02
Hg	0.11	**0.67**	0.28	**0.43**	**0.49**	0.15		-0.06	0.11	**0.55**	**0.35**	0.29
Tl	0.14	0.22	0.24	0.09	0.09	0.13	-0.06		0.13	0.09	0.20	0.03
Pb	0.29	-0.10	0.13	0.17	0.00	0.22	0.11	0.13		0.25	0.02	0.09

Bi	0.21	0.23	**0.52**	**0.60**	**0.70**	-0.10	**0.55**	0.09	0.25		0.19	**0.65**
Th	0.10	0.39	**0.39**	**0.68**	-0.10	0.26	**0.35**	0.20	0.02	0.19		**0.57**
U	0.22	0.25	**0.31**	**0.74**	**0.42**	0.02	0.29	0.03	0.09	**0.65**	**0.57**	

Explanations as for Appendix Table 3

APPENDIX TABLE 5

Biological accumulation factors (BAFs) of the vegetation samples collected on selected waste heaps of Upper Silesia

sample	BDM-VRc	BDM-VAt	BDM-VV1	BDM-VV2	BDM-VSc	BDM-VTf	BDM-VG	RD-VSg	RDT-VCm	RDT-plt-VV	SWCA-VEc	WOJ-VV	WOJ-VHa	ZBB-VSn	%[2] of BAF ≥ 2
species	*Rumex crispus*	*Arctium tomentosum*	*Verbascum*	*Verbascum*	*Solidago canadensis*	*Tussilago farfara*	*Poaceae*	*Solidago gigantea*	*Crepis mollis*	*Verbascum*	*Eupatorium cannabinum*	*Verbascum*	*Helichrysum arenarium*	*Solanum nigrum*	
	trace elements[3]														
B	**2**	**2**	1	**2**	**11**	**2**	0.3	**4**	**2**	**3**	**5**	**2**	**3**	**2**	85
Sc	0.3	1	0.1	0.3	0.1	0.4	0.03	0.03	0.1	1	0.1	0.02	0.02	0.3	0
V	0.2	1	0.1	0.4	0.1	0.1	0.1	0.1	0.3	1	0.1	0.1	0.1	0.4	0
Cr	0.1	0.5	0.1	0.3	0.1	0.1	0.3	0.1	0.3	1	0.2	0.1	0.04	1	0
Co	0.04	0.3	0.1	0.2	0.2	0.3	0.1	0.1	0.3	1	0.04	0.2	0.3	1	0
Ni	0.3	1	0.1	0.3	0.1	0.2	0.2	0.1	0.3	1	0.04	0.2	0.3	1	0
Cu	0.4	1	0.1	**2**	0.02	0.3	0.2	0.4	1	**2**	0.1	0.3	0.3	**3**	23
Zn	0.1	0.5	0.3	1	0.2	1	0.1	1	1	**3**	0.2	1	1	**7**	15
Ga	0.1	1	0.1	0.3	0.03	0.2	0.1	0.03	0.3	1	0.03	0.1	0.02	0.3	0
As	0.1	0.5	0.1	0.2	0.01	0.3	0.02	0.02	0.3	1	0.03	0.2	0.02	1	0
Se	1	1	1	**2**	**3**	1	1	0.3	1	1	0.2	0.2	0.09	1	15
Sr	0.4	**2**	**2**	1	**2**	1	0.2	**2**	**2**	**5**	0.4	1	1	**5**	54
Mo	**5**	**3**	1	1	0.5	0.5	1	1	**2**	**4**	0.2	0.3	0.1	**12**	38
Ag	0.2	0.4	0.3	0.4	0.2	0.4	0.2	**3**	1	1	0.3	0.3	0.2	**2**	15
Cd	0.2	0.5	0.3	1	1	1	0.2	0.5	1	**5**	0.4	1	1	**22**	15
Sb	0.1	1	0.3	1	0.1	0.2	1	1	1	**4**	0.1	**2**	1	1	15
Te	0.3	0.3	1	0.3	0.3	0.2	0.4	**2**	1	1	0.2	0.4	0.3	1	8
Ba	0.4	**6**	0.2	0.3	0.1	0.1	0.2	0.2	1	1	0.1	0.2	0.1	1	8
La	0.03	0.4	0.1	0.2	0.02	0.2	0.1	0.02	0.3	1	0.04	0.1	0.03	0.1	0
W	0.2	1	1	1	1	0.01	**2**	1	**5**	**4**	0.2	1	1	1	23
Au	1	**2**	1	1	1	**4**	1	1	**3**	1	0.3	0.3	0.1	**7**	31
Hg	0.3	1	0.2	**8**	0.2	1	1	**3**	0.3	1	0.3	0.3	0.1	0.01	15
Tl	**5**	**3**	1	**8**	0.1	**5**	0.1	0.1	1	1	0.3	0.2	1	**3**	38
Pb	0.03	0.3	0.1	0.4	0.02	0.3	0.1	0.1	0.3	1	0.1	0.4	0.1	0.4	0
Bi	0.03	0.4	0.3	0.03	0.03	0.2	0.2	0.1	1	1	0.04	0.3	0.1	0.1	0
Th	1	**2**	0.02	1	0.02	0.5	0.1	0.02	0.02	0.3	0.04	0.02	0.02	0.2	8

	Table x. – continued														
sample	BDM-VRc	BDM-VAt	BDM-VV1	BDM-VV2	BDM-VSc	BDM-VTf	BDM-VG	RD-VSg	RDT-VCm	RDT-plt-VV	SWCA-VEc	WOJ-VV	WOJ-VHa	ZBB-VSn	% of BAF ≥ 2
species	*Rumex crispus*	*Arctium tomentosum*	*Verbascum*	*Verbascum*	*Solidago canadensis*	*Tussilago farfara*	*Poaceae*	*Solidago gigantea*	*Crepis mollis*	*Verbascum*	*Eupatorium cannabinum*	*Verbascum*	*Helichrysum arenarium*	*Solanum nigrum*	
U	0.02	0.3	0.1	0.1	0.04	0.2	0.1	0.04	0.4	1	0.04	0.1	0.003	0.1	
	main elements														
Na	64	10	3	5	1	0.4	3	1	7	5	1	1	1	21	
Mg	2	1	1	2	1	0.5	0.2	1	1	2	0.1	0.3	0.3	7	
Al	0.1	1	0.1	0.2	0.01	0.2	0.1	0.02	0.3	1	0.1	0.1	0.01	0.3	0
P	9	4	11	3	5	1	3	12	9	9	4	1	2	39	
S	6	4	1	3	1	10	3	1	2	2	2	1	1	0.2	
K	74	60	10	29	7	45	1	16	11	2	16	5	16	109	
Ca	0.4	1	1	1	1	1	0.3	3	2	9	1	5	4	14	
Ti	0.3	1	0.1	0.4	0.1	0.1	0.1	0.04	0.1	1	0.1	0.1	0.04	1	0
Mn	0.1	0.4	0.2	1	0.1	0.1	0.1	1	0.5	1	0.1	0.5	**2**	**13**	8
Fe	0.1	0.4	0.1	0.2	0.03	0.1	0.04	0.03	0.2	1	0.04	0.1	0.02	0.3	0
GM_{BAF}[4]	0.22	0.83	0.46	0.57	0.14	0.30	0.19	0.21	0.53	**1.4**	0.11	0.25	0.13	0.93	

[1] – BAF > 1 (marked in bold) suggest the particular plant to be a hyperaccumulator, while BAF < 1 points to plant excluders; [2] – trace elements plus Al, Ti, Mn, and Fe are considered; [3] – element division as that for the soil samples; [4] – geometrical-mean TF for trace elements (including Al, Ti, Mn, and Fe), with BAF>1 given in bold

APPENDIX TABLE 6

Biological concentration factors (BCFs) of the vegetation samples collected on selected waste heaps of Upper Silesia

sample	BDM-VV2	BDM-VSc	RD-VSg	RDT-VCm	SWCA-VEc	WOJ-VV	ZBB-VSn	%[2] of BCF ≥2
species	*Verbascum*	*Solidago canadensis*	*Solidago gigantea*	*Crepis mollis*	*Eupatorium cannabinum*	*Verbascum*	*Solanum nigrum*	
				trace elements				
B	1	**2**	1	1	1	1	1	14
Sc	0.3	0.2	0.02	0.04	0.1	0.02	0.1	0
V	0.2	0.2	0.1	0.2	0.2	0.1	0.4	0
Cr	0.2	0.2	0.1	0.2	0.1	0.04	1	0
Co	0.1	0.3	0.1	0.2	0.1	0.3	1	0
Ni	0.5	0.3	0.1	0.2	0.3	0.1	1	0
Cu	**2**	0.03	0.4	1	0.1	1	**2**	29
Zn	0.5	0.2	1	1	0.1	0.5	**7**	14
Ga	0.2	0.2	0.03	0.2	0.1	0.02	0.1	0
As	0.1	0.1	0.1	0.2	0.1	0.1	1	0
Se	**2**	**2**	0.1	0.4	0.2	0.1	1	29
Sr	1	**2**	1	1	0.1	1	**3**	29
Mo	1	1	0.5	**2**	0.1	0.2	**6**	29
Ag	0.4	0.2	0.1	1	1	0.2	1	0
Cd	**2**	1	**3**	1	0.2	**2**	**11**	57
Sb	1	0.4	1	1	0.1	1	**4**	14
Te	0.3	0.3	0.3	1	0.2	0.3	1	0
Ba	0.2	0.3	0.2	1	0.1	0.1	1	0
La	0.1	0.1	0.1	0.2	0.1	0.03	0.03	0
W		1	1	**2**	0.2	1	1	14
Au	1	1	0.4	1	0.2	0.02	1	0
Hg	1	0.1	0.1	0.1	0.1	0.1	0.001	0
Tl	**3**	0.3	0.3	**2**	1	**2**	**4**	57
Pb	0.3	0.1	0.1	0.2	0.1	0.1	0.4	0
Bi	0.03	0.1	0.03	0.3	0.04	0.1	0.1	0
Table x.— continued								
sample	BDM-VV2	BDM-VSc	RD-VSg	RDT-VCm	SWCA-VEc	WOJ-VV	ZBB-VSn	% of BCF ≥2
species	*Verbascum*	*Solidago canadensis*	*Solidago gigantea*	*Crepis mollis*	*Eupatorium cannabinum*	*Verbascum*	*Solanum nigrum*	
U	0.1	0.2	0.04	0.3	0.1	0.1	0.03	
Th	1	0.1	0.02	0.02	0.1	0.02	0.1	0
				main elements				
Na	2	1	7	4	0.2	1	16	
Mg	1	1	0.4	1	0.1	0.4	4	
Al	0.1	0.2	0.1	0.2	0.1	0.02	0.1	0
P	3	2	8	9	3	2	18	
S	2	0.4	1	2	0.3	1	0.1	
K	18	6	16	2	10	7	135	
Ca	0.4	2	1	9	0.2	4	4	
Ti	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0
Mn	0.3	0.3	0.1	0.3	0.1	1	**3**	14
Fe	0.1	0.1	0.04	0.1	0.1	0.02	0.1	0
GM_{BCF}[4]	0.40	0.28	0.15	0.36	0.14	0.15	0.56	

[1] – BCF > 1 (marked in bold) suggest potential for phytoextraction, i.e., hyperaccumulation; [2] – trace elements plus Al, Ti, Mn and Fe are considered; [3] – element division as that for the soil samples; [4] – geometrical-mean BCF for trace elements (including Al, Ti, Mn and Fe)

APPENDIX TABLE 7

Translocation factors (TFs) of the vegetation samples collected on selected waste heaps of Upper Silesia

sample	BDM-VV2	BDM-VSc	RD-VSg	RDT-VCm	SWCA-VEc	WOJ-VV	ZBB-VSn	% of TF ≥ 2
species	*Verbascum*	*Solidago canadensis*	*Solidago gigantea*	*Crepis mollis*	*Eupatorium cannabinum*	*Verbascum*	*Solanum nigrum*	
trace elements								
B	**2**	**5**	**4**	1	**8**	**2**	**2**	86
Sc	1	1	1	**2**	1	1	**3**	29
V	**2**	0.3	1	1	1	**2**	1	29
Cr	**2**	0.3	1	1	1	**3**	1	29
Co	**2**	1	1	1	1	1	1	14
Ni	1	0.5	1	1	1	**2**	1	14
Cu	1	1	1	1	1	1	1	0
Zn	**2**	1	1	1	1	1	1	14
Ga	**2**	0.2	1	**2**	1	**5**	**2**	57
As	**2**	0.1	0.2	**2**	1	**3**	1	43
Se	1	**2**	**2**	**2**	1	**2**	**2**	71
Sr	**2**	1	1	1	**3**	1	**2**	43
Mo	1	1	1	1	1	1	**2**	14
Ag	1	1	**15**	**2**	1	**2**	**2**	57
Cd	1	1	1	1	**2**	0.5	**2**	29
Sb	1	0.1	0.4	1	1	**2**	0.2	14
Te	1	1	**8**	**2**	1	**2**	1	43
Ba	1	0.3	1	1	1	**2**	**2**	29
La	**2**	0.1	0.3	**2**	1	**4**	**5**	57
W	**2**	1	1	**3**	1	1	1	29
Au	1	**2**	**2**	**2**	**2**	**15**	**10**	86
Hg	**17**	**4**	**8**	**2**	**4**	**2**	**8**	100
Tl	**2**	0.3	0.2	1	0.4	0.1	1	14
Pb	1	0.3	0.5	**2**	1	**5**	1	29
Bi	1	0.3	1	**2**	1	**6**	1	29
Th	**2**	0.2	1	1	1	1	**2**	29
Table x. — continued								
sample	BDM-VV2	BDM-VSc	RD-VSg	RDT-VCm	SWCA-VEc	WOJ-VV	ZBB-VSn	% of TF ≥ 2
species	*Verbascum*	*Solidago canadensis*	*Solidago gigantea*	*Crepis mollis*	*Eupatorium cannabinum*	*Verbascum*	*Solanum nigrum*	
U	**2**	0.2	0.4	1	1	**2**	**3**	43
main elements								
Na	2	1	0.2	2	5	1	1	
Mg	2	2	2	2	1	1	2	
Al	**2**	0.1	0.3	**2**	1	**4**	**5**	43
P	1	2	1	1	1	1	2	
S	2	4	2	2	7	1	2	
K	2	1	1	1	2	1	1	
Ca	3	1	2	2	5	1	3	
Ti	**3**	0.2	0.4	1	1	**2**	**3**	43
Mn	**2**	0.5	**3**	**2**	1	1	**4**	57
Fe	**2**	0.2	0.4	**2**	1	**4**	**4**	57
GM_{TF}[4]	**1.6**	0.53	1.0	**1.4**	**1.2**	**2.0**	**1.7**	

[1] – TF > 1 (marked in bold) suggest hyperaccumulation; [2] – trace elements plus Al, Ti, Mn and Fe are considered; [3] – element division as that for the soil samples; [4] – geometrical-mean TF for trace elements (including Al, Ti, Mn and Fe), with TF>1 given in bold

APPENDIX TABLE 8

Other translocation factors of the vegetation samples collected on selected waste heaps of Upper Silesia

sample	BDM-VM	BDM-VG	RDT-plt-VM	BDM-Bp			BDM-VP			%[2] of BCF ≥2
species	(moss)	(grass)	(moss)	*Betula pendula*			*Populus*			
factor	whole plant / soil	whole plant / soil	whole plant / soil	soil → wood	soil → bark	wood → bark	soil → wood	soil → bark	wood → bark	
trace elements[3]										
B	1	0.3	1	1	1	1	0.4	1	0.3	10
Sc	0.3	0.03	0.5	0.04	0.04	1	0.05	0.05	1	0
V	0.4	0.1	1	0.05	0.05	1	0.1	0.1	1	0
Cr	1	0.3	1	0.1	0.1	1	0.1	0.1	1	0
Co	0.4	0.1	1	0.01	0.03	0.3	0.02	0.1	0.3	0
Ni	1	0.2	1	0.03	0.1	0.3	0.1	0.1	1	0
Cu	1	0.2	1	0.1	0.4	0.3	0.1	0.2	0.4	0
Zn	0.3	0.1	0.4	0.3	1	0.5	0.1	1	0.2	0
Ga	0.4	0.1	1	0.02	0.02	1	**2**	**2**	1	20
As	0.2	0.02	1	0.01	0.01	1	0.01	0.02	0.3	0
Se	1	1	1	0.1	0.4	0.2	0.3	1	0.4	0
Sr	1	0.23	1	0.2	0.4	0.5	1	**4**	0.2	10
Mo	1	1	1	1	1	1	0.1	1	0.2	0
Ag	1	0.2	0.5	0.2	1	0.3	0.2	0.4	0.4	0
Cd	0.4	0.2	0.5	0.1	0.3	0.3	0.3	**2**	0.2	10
Sb	1	1	**2**	0.2	1	0.2	1	1	1	10
Te	0.5	0.4	0.4	1	1	1	0.3	0.3	1	0
Ba	1	0.2	1	0.08	0.2	0.3	0.04	0.2	0.2	0
La	0.4	0.1	1	0.001	0.01	0.1	0.003	0.01	0.2	0
W	**4**	**2**	**6**	1	1	1	1	1	1	20
Au	**2**	1	1	1	0.4	**2**	1	**4**	0.2	30
Hg	1	1	1	0.02	0.2	0.1	0.03	0.1	0.3	0
Tl	0.5	0.1	0.4	0.1	0.3	0.4	0.1	0.3	0.2	0
Table 8 ─ continued										
sample	BDM-VM	BDM-VG	RDT-plt-VM	BDM-Bp			BDM-VP			%[2] of F ≥2
species	(moss)	(grass)	(moss)	*Betula pendula*			*Populus*			
factor	whole plant / soil	whole plant / soil	whole plant / soil	soil → wood	soil → bark	wood → bark	soil → wood	soil → bark	wood → bark	
Pb	0.3	0.1	0.4	0.02	0.2	0.1	0.01	0.1	0.1	0
Bi	0.5	0.2	1	0.02	0.1	0.2	0.03	0.03	1	0
Th	0.1	0.1	0.1	0.01	0.01	1	0.02	0.04	1	0
U	1	0.1	1	0.01	0.02	0.3	0.01	0.01	1	0
Na	2	3	1	0.1	0.4	0.3	3	2	1	
Mg	1	0.2	1	0.05	0.1	0.4	0.2	1	0.3	
Al	0.5	0.1	1	0.0004	0.01	1	0.2	0.02	**12**	10
P	3	3	1	1	3	0.4	12	2	6	
S	2	3	1	1	1	1	0.1	0.4	0.2	
K	3	1	1	0.2	1	0.3	1	1	1	

Ca	1	1	1	0.2	0.4	0.4	1	7	0.1	
Ti	0.4	0.1	0.4	0.01	0.04	0.1	0.01	0.02	0.4	0
Mn	0.4	0.1	0.4	0.03	0.1	0.3	0.02	0.1	0.2	10
Fe	0.4	0.04	1	0.0003	0.02	0.1	0.005	0.03	0.2	0
GM_f[4]	0.61	0.26	0.78	0.04	0.12	0.40	0.08	0.17	0.46	

[1] – factors > 1 (marked in bold) may suggest hyperaccumulation; [2] – trace elements plus Al, Ti, Mn and Fe are considered; [3] – element division as that for the soil samples; [4] – geometrical-mean translocation factors for trace elements (including Al, Ti, Mn,and Fe)

APPENDIX TABLE 9

Kendall correlation statistics for joint new soil and vegetation samples

	Na	Mg	Al	S	P	K	Ca	Ti	Mn	Fe	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	As	Se	Sr	Mo	Ag	Cd
Na		**0.77**	**0.73**	**0.59**	**0.64**	**0.59**	**0.68**	**0.47**	**0.68**	**0.73**	-0.21	**0.63**	**0.39**	0.18	**0.42**	**0.63**	**0.62**	-0.08	-0.06	-0.23	**0.77**	0.11	**-0.40**	-0.07
Mg	**0.77**		**0.75**	**0.60**	**0.70**	**0.63**	**0.79**	**0.55**	**0.77**	**0.81**	-0.03	**0.73**	**0.42**	0.32	**0.55**	**0.70**	**0.60**	0.03	0.04	-0.13	**0.86**	0.10	**-0.38**	-0.12
Al	**0.73**	**0.75**		**0.49**	**0.53**	**0.65**	**0.62**	**0.63**	**0.68**	**0.87**	0.12	**0.70**	**0.48**	**0.36**	**0.57**	**0.66**	**0.57**	0.20	0.00	-0.17	**0.72**	0.02	**-0.49**	-0.19
S	**0.59**	**0.60**	**0.49**		**0.47**	**0.45**	**0.61**	**0.39**	**0.56**	**0.56**	-0.25	**0.42**	0.20	0.05	**0.31**	**0.54**	**0.59**	-0.22	-0.14	-0.23	**0.59**	-0.07	**-0.42**	-0.12
P	**0.64**	**0.70**	**0.53**	**0.47**		**0.69**	**0.65**	**0.30**	**0.61**	**0.56**	-0.26	**0.43**	0.21	0.09	**0.31**	**0.49**	**0.55**	-0.20	-0.15	-0.37	**0.65**	-0.03	**-0.41**	-0.15
K	**0.59**	**0.63**	**0.65**	**0.45**	**0.69**		**0.52**	**0.29**	**0.53**	**0.52**	-0.05	**0.46**	0.19	0.10	**0.29**	**0.40**	**0.41**	-0.05	-0.28	-0.34	**0.55**	-0.21	**-0.57**	-0.22
Ca	**0.68**	**0.79**	**0.62**	**0.61**	**0.65**	**0.52**		**0.46**	**0.79**	**0.68**	-0.18	**0.55**	**0.33**	0.21	**0.45**	**0.66**	**0.76**	-0.09	0.11	-0.20	**0.81**	0.05	-0.27	-0.01
Ti	**0.47**	**0.55**	**0.63**	**0.39**	**0.30**	0.29	**0.46**		**0.51**	**0.69**	0.05	**0.73**	**0.66**	**0.38**	**0.64**	**0.58**	**0.40**	0.19	0.24	0.03	**0.57**	**0.31**	-0.21	-0.07
Mn	**0.68**	**0.77**	**0.68**	**0.56**	**0.61**	**0.53**	**0.79**	**0.51**		**0.78**	-0.10	**0.69**	**0.39**	**0.34**	**0.57**	**0.72**	**0.79**	-0.01	0.06	-0.12	**0.79**	0.07	-0.29	0.04
Fe	**0.73**	**0.81**	**0.87**	**0.56**	**0.56**	**0.52**	**0.68**	**0.69**	**0.78**		0.00	**0.76**	**0.55**	**0.43**	**0.67**	**0.78**	**0.68**	0.12	0.09	-0.09	**0.78**	0.13	**-0.36**	-0.08
Sc	-0.21	-0.03	0.12	-0.25	-0.26	-0.05	-0.18	0.05	-0.10	0.00		**0.32**	0.07	**0.49**	0.15	-0.11	-0.27	**0.76**	**0.36**	**0.45**	-0.07	0.15	0.20	-0.06
V	**0.63**	**0.73**	**0.70**	**0.42**	**0.43**	**0.46**	**0.55**	**0.73**	**0.69**	**0.76**	**0.32**		**0.72**	**0.72**	**0.76**	**0.60**	**0.48**	**0.38**	**0.37**	0.16	**0.64**	**0.49**	-0.18	-0.07
Cr	**0.39**	**0.42**	**0.48**	0.20	0.21	0.19	**0.33**	**0.66**	**0.39**	**0.55**	0.07	**0.72**		**0.33**	**0.68**	**0.47**	**0.32**	0.17	**0.32**	0.06	**0.36**	**0.45**	-0.03	-0.03
Co	0.18	**0.32**	**0.36**	0.05	0.09	0.10	0.21	**0.38**	**0.34**	**0.43**	**0.49**	**0.72**	**0.33**		**0.63**	**0.35**	0.22	**0.50**	**0.40**	**0.44**	**0.30**	**0.34**	0.04	0.13
Ni	**0.42**	**0.55**	**0.57**	**0.31**	**0.31**	0.29	**0.45**	**0.64**	**0.57**	**0.67**	0.15	**0.76**	**0.68**	**0.63**		**0.53**	**0.46**	0.29	0.23	0.17	**0.52**	**0.33**	-0.11	0.06
Cu	**0.63**	**0.70**	**0.66**	**0.54**	**0.49**	**0.40**	**0.66**	**0.58**	**0.72**	**0.78**	-0.11	0.60	**0.47**	**0.35**	**0.53**		**0.69**	-0.06	0.18	-0.10	**0.72**	0.19	-0.28	0.02
Zn	**0.62**	**0.60**	**0.57**	**0.59**	**0.55**	**0.41**	**0.76**	**0.40**	**0.79**	**0.68**	-0.27	**0.48**	**0.32**	0.22	**0.46**	**0.69**		-0.19	0.10	-0.20	**0.67**	0.03	-0.17	0.19
Ga	-0.08	0.03	0.20	-0.22	-0.20	-0.05	-0.09	0.19	-0.01	0.12	**0.76**	**0.38**	0.17	**0.50**	0.29	-0.06	-0.19		**0.49**	**0.43**	0.00	**0.33**	0.25	-0.10
As	-0.06	0.04	0.00	-0.14	-0.15	-0.28	0.11	0.24	0.06	0.09	**0.36**	**0.37**	**0.32**	**0.40**	0.23	0.18	0.10	**0.49**		**0.37**	0.12	**0.60**	**0.51**	0.20
Se	-0.23	-0.13	-0.17	-0.23	**-0.37**	**-0.34**	-0.20	0.03	-0.12	-0.09	**0.45**	0.16	0.06	0.44	0.17	-0.10	-0.20	**0.43**	**0.37**		-0.15	**0.41**	**0.53**	**0.34**
Sr	**0.77**	**0.86**	**0.72**	**0.59**	**0.65**	**0.55**	**0.81**	**0.57**	**0.79**	**0.78**	-0.07	**0.64**	**0.36**	**0.30**	**0.52**	**0.72**	**0.67**	0.00	0.12	-0.15		0.14	**-0.34**	-0.08
Mo	0.11	0.10	0.02	-0.07	-0.03	-0.21	0.05	**0.31**	0.07	0.13	0.15	**0.49**	**0.45**	**0.34**	**0.33**	0.19	0.03	0.33	**0.60**	**0.41**	0.14		**0.38**	0.07
Ag	**-0.40**	**-0.38**	**-0.49**	**-0.42**	**-0.41**	**-0.57**	-0.27	-0.21	-0.29	**-0.36**	0.20	-0.18	-0.03	0.04	-0.11	-0.28	-0.17	0.25	**0.51**	**0.53**	**-0.34**	**0.38**		**0.42**
Cd	-0.07	-0.12	-0.19	-0.12	-0.15	-0.22	-0.01	-0.07	0.04	-0.08	-0.06	-0.07	-0.03	0.13	0.06	0.02	0.19	-0.10	0.20	**0.34**	-0.08	0.07	**0.42**	
Sb	0.23	0.23	0.25	0.16	-0.03	-0.01	0.26	**0.56**	0.24	**0.33**	0.00	**0.44**	**0.56**	0.15	**0.42**	**0.42**	**0.30**	0.13	**0.47**	0.11	0.28	**0.41**	0.13	0.19
Te	**-0.44**	**-0.36**	**-0.44**	**-0.49**	**-0.40**	**-0.48**	**-0.51**	-0.25	**-0.40**	**-0.40**	0.28	-0.18	**-0.33**	0.07	-0.27	**-0.42**	**-0.57**	**0.37**	0.10	**0.38**	**-0.39**	0.13	**0.52**	0.17
Ba	**0.71**	**0.69**	**0.69**	**0.49**	**0.47**	**0.42**	**0.66**	**0.64**	**0.72**	**0.75**	-0.09	**0.66**	**0.53**	0.24	0.55	**0.65**	**0.62**	0.10	0.22	-0.15	**0.77**	0.26	-0.22	-0.04
La	0.04	0.03	0.27	-0.17	-0.16	0.03	-0.06	**0.36**	-0.04	0.14	**0.58**	**0.57**	**0.45**	**0.53**	**0.36**	0.04	-0.14	**0.69**	**0.51**	**0.31**	0.04	**0.44**	0.10	-0.14
W	-0.22	-0.08	-0.14	-0.22	-0.35	**-0.38**	-0.04	-0.04	0.06	-0.03	**0.35**	0.18	0.07	**0.44**	0.13	0.00	-0.09	**0.41**	**0.70**	**0.53**	-0.05	**0.54**	**0.51**	0.28
Au	**-0.41**	**-0.43**	**-0.45**	**-0.60**	**-0.37**	**-0.61**	**-0.37**	-0.22	**-0.36**	-0.34	0.17	-0.28	-0.14	0.05	-0.21	-0.31	-0.23	0.15	0.28	**0.45**	**-0.43**	0.20	**0.73**	**0.43**

Hg	**-0.51**	**-0.46**	**-0.42**	**-0.30**	**-0.60**	**-0.47**	**-0.48**	**-0.30**	**-0.49**	**-0.48**	**0.43**	**-0.30**	-0.11	-0.14	**-0.31**	**-0.41**	**-0.53**	0.27	0.21	**0.46**	**-0.47**	0.11	**0.48**	0.04
Tl	-0.25	-0.19	-0.29	**-0.46**	-0.25	**-0.33**	-0.21	-0.23	-0.11	-0.22	**0.37**	-0.04	-0.17	0.18	-0.17	-0.16	-0.22	0.25	0.24	**0.53**	-0.22	0.18	**0.54**	0.33
Pb	0.14	0.15	0.15	0.09	-0.01	-0.13	0.25	**0.38**	0.27	0.26	-0.01	0.29	**0.49**	**0.35**	**0.49**	**0.34**	**0.42**	0.12	**0.56**	0.20	0.19	**0.39**	0.29	**0.41**
Bi	-0.20	-0.21	-0.11	**-0.38**	**-0.35**	-0.29	-0.25	0.10	-0.21	-0.14	**0.48**	0.18	0.21	0.24	0.05	-0.17	**-0.33**	**0.56**	**0.39**	**0.43**	-0.12	**0.47**	**0.33**	-0.10
Th	**-0.32**	-0.22	-0.01	**-0.43**	**-0.38**	0.11	-0.36	-0.09	**-0.31**	-0.22	**0.53**	-0.04	-0.19	0.02	-0.19	**-0.33**	**-0.45**	**0.30**	-0.20	**0.32**	-0.24	-0.16	0.08	-0.18
U	0.01	0.02	0.12	-0.12	-0.19	-0.11	-0.06	**0.37**	-0.09	0.06	**0.44**	**0.48**	**0.35**	**0.31**	0.25	0.04	-0.21	**0.60**	**0.40**	0.26	0.05	**0.52**	0.10	-0.28

Appendix Table 3 — continued

	Sb	Te	Ba	La	W	Au	Hg	Tl	Pb	Bi	Th	U
Na	0.23	**-0.44**	**0.71**	0.04	-0.22	**-0.41**	**-0.51**	-0.25	0.14	-0.20	**-0.32**	0.01
Mg	0.23	**-0.36**	**0.69**	0.03	-0.08	**-0.43**	**-0.46**	-0.19	0.15	-0.21	-0.22	0.02
Al	0.25	**-0.44**	**0.69**	0.27	-0.14	**-0.45**	**-0.42**	-0.29	0.15	-0.11	-0.01	0.12
S	0.16	**-0.49**	**0.49**	-0.17	-0.22	**-0.60**	**-0.30**	**-0.46**	0.09	**-0.38**	**-0.43**	-0.12
P	-0.03	**-0.40**	**0.47**	-0.16	**-0.35**	**-0.37**	**-0.60**	-0.25	-0.01	**-0.35**	**-0.38**	-0.19
K	-0.01	**-0.48**	**0.42**	0.03	**-0.38**	**-0.61**	**-0.47**	**-0.33**	-0.13	-0.29	0.11	-0.11
Ca	0.26	**-0.51**	**0.66**	-0.06	-0.04	**-0.37**	**-0.48**	-0.21	0.25	-0.25	**-0.36**	-0.06
Ti	**0.56**	-0.25	**0.64**	**0.36**	-0.04	-0.22	**-0.30**	-0.23	**0.38**	0.10	-0.09	**0.37**
Mn	**0.24**	**-0.40**	**0.72**	-0.04	0.06	**-0.36**	**-0.49**	-0.11	0.27	-0.21	-0.31	-0.09
Fe	**0.33**	**-0.40**	**0.75**	0.14	-0.03	**-0.34**	**-0.48**	-0.22	0.26	-0.14	-0.22	0.06
Sc	0.00	0.28	-0.09	**0.58**	**0.35**	0.17	**0.43**	**0.37**	-0.01	**0.48**	**0.53**	**0.44**
V	**0.44**	-0.18	**0.66**	**0.57**	0.18	-0.28	**-0.30**	-0.04	0.29	0.18	-0.04	**0.48**
Cr	**0.56**	**-0.33**	**0.53**	**0.45**	0.07	-0.14	-0.11	-0.17	**0.49**	0.21	-0.19	**0.35**
Co	0.15	0.07	0.24	**0.53**	**0.44**	0.05	-0.14	0.18	**0.35**	0.24	0.02	**0.31**
Ni	**0.42**	-0.27	0.55	**0.36**	0.13	-0.21	**-0.31**	-0.17	**0.49**	0.05	-0.19	0.25
Cu	**0.42**	**-0.42**	**0.65**	0.04	0.00	**-0.31**	**-0.41**	-0.16	**0.34**	-0.17	-0.33	0.04
Zn	**0.30**	**-0.57**	**0.62**	-0.14	-0.09	-0.23	**-0.53**	-0.22	**0.42**	**-0.33**	**-0.45**	-0.21
Ga	0.13	**0.37**	0.10	**0.69**	**0.41**	0.15	0.27	0.25	0.12	**0.56**	0.30	**0.60**
As	**0.47**	0.10	0.22	**0.51**	**0.70**	0.28	0.21	0.24	**0.56**	**0.39**	-0.20	**0.40**
Se	0.11	**0.38**	-0.15	**0.31**	**0.53**	**0.45**	**0.46**	**0.53**	0.20	**0.43**	0.32	0.26
Sr	0.28	**-0.39**	**0.77**	0.04	-0.05	**-0.43**	**-0.47**	-0.22	0.19	-0.12	-0.24	0.05
Mo	**0.41**	0.13	0.26	0.44	**0.54**	0.20	0.11	0.18	**0.39**	**0.47**	-0.16	**0.52**
Ag	0.13	**0.52**	-0.22	0.10	**0.51**	**0.73**	**0.48**	**0.54**	0.29	**0.33**	0.08	0.10
Cd	0.19	0.17	-0.04	-0.14	0.28	**0.43**	0.04	**0.33**	**0.41**	-0.10	-0.18	-0.28
Sb		-0.26	**0.43**	0.24	0.11	0.02	-0.03	-0.13	**0.57**	0.10	-0.23	0.25
Te	-0.26		**-0.43**	0.03	**0.38**	**0.47**	**0.42**	**0.63**	-0.24	**0.39**	**0.38**	0.17
Ba	**0.43**	**-0.43**		0.19	0.06	**-0.36**	**-0.35**	-0.25	**0.33**	-0.03	-0.32	0.15
La	0.24	0.03	0.19		**0.35**	0.03	0.17	0.04	0.23	**0.57**	0.24	**0.64**

W	0.11	**0.38**	0.06	**0.35**		0.24	**0.33**	**0.44**	**0.38**	**0.47**	-0.11	0.34
Au	0.02	**0.47**	**-0.36**	0.03	0.24		**0.35**	**0.62**	0.15	0.24	0.17	-0.02
Hg	-0.03	**0.42**	**-0.35**	0.17	0.33	**0.35**		**0.33**	-0.08	**0.37**	**0.41**	0.14
Tl	-0.13	**0.63**	-0.25	0.04	0.44	**0.62**	**0.33**		0.00	0.28	0.32	0.04
Pb	**0.57**	-0.24	**0.33**	0.23	**0.38**	0.15	-0.08	0.00		0.10	**-0.44**	0.10
Bi	0.10	**0.39**	-0.03	**0.57**	**0.47**	0.24	**0.37**	0.28	0.10		**0.49**	**0.61**
Th	-0.23	**0.38**	**-0.32**	0.24	-0.11	0.17	**0.41**	**0.32**	**-0.44**	**0.49**		**0.33**
U	0.25	0.17	0.15	**0.64**	0.34	-0.02	0.14	0.04	0.10	**0.61**	**0.33**	

Explanations as for Appendix Tables 3 and 4

APPENDIX TABLE 10

Kendall correlation statistics, joint three accumulation/translocation factors

	Na	Mg	Al	S	P	K	Ca	Ti	Mn	Fe	B	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	As	Se	Sr	Mo	Ag	Cd
Na		0.32	0.09	0.45	0.14	0.34	0.13	0.16	0.08	0.08	-0.16	-0.01	0.15	0.19	0.01	0.15	0.37	0.22	0.07	0.19	-0.09	0.31	0.59	-0.10	0.22
Mg	0.32		0.34	0.13	0.07	-0.01	0.31	0.51	0.61	0.46	0.17	0.47	0.53	0.50	0.53	0.53	0.58	0.52	0.43	0.42	0.43	0.46	0.67	0.42	0.35
Al	0.09	0.34		-0.28	0.19	-0.25	0.25	0.75	0.43	0.87	0.10	0.67	0.76	0.71	0.58	0.67	0.33	0.37	0.90	0.78	0.32	0.26	0.35	0.47	0.15
S	0.45	0.13	-0.28		-0.26	0.45	0.05	-0.27	-0.11	-0.27	-0.10	-0.31	-0.21	-0.18	-0.32	-0.23	0.08	-0.01	-0.32	-0.23	-0.19	0.24	0.37	-0.08	0.06
P	0.14	0.07	0.19	-0.26		-0.10	-0.20	0.14	-0.12	0.18	0.20	0.31	0.11	0.11	0.01	0.07	0.10	-0.05	0.21	0.06	0.15	-0.19	0.13	-0.03	-0.15
K	0.34	-0.01	-0.25	0.45	-0.10		-0.12	-0.21	-0.21	-0.26	-0.07	-0.20	-0.20	-0.24	-0.32	-0.18	0.07	-0.03	-0.29	-0.10	-0.24	0.09	0.12	-0.22	0.05
Ca	0.13	0.31	0.25	0.05	-0.20	-0.12		0.22	0.53	0.19	0.14	0.04	0.21	0.25	0.45	0.19	0.36	0.61	0.18	0.37	-0.14	0.59	0.28	0.30	0.55
Ti	0.16	0.51	0.75	-0.27	0.14	-0.21	0.22		0.50	0.79	0.18	0.72	0.82	0.72	0.63	0.75	0.38	0.33	0.74	0.67	0.39	0.30	0.38	0.35	0.21
Mn	0.08	0.61	0.43	-0.11	-0.12	-0.21	0.53	0.50		0.52	0.12	0.36	0.56	0.56	0.66	0.54	0.57	0.66	0.48	0.54	0.21	0.45	0.37	0.61	0.45
Fe	0.08	0.46	0.87	-0.27	0.18	-0.26	0.19	0.79	0.52		0.18	0.76	0.86	0.75	0.61	0.79	0.39	0.39	0.92	0.76	0.41	0.26	0.36	0.56	0.14
B	-0.16	0.17	0.10	-0.10	0.20	-0.07	0.14	0.18	0.12	0.18		0.29	0.16	0.13	0.21	0.09	-0.04	0.12	0.14	0.01	0.22	0.26	-0.01	0.19	0.01
Sc	-0.01	0.47	0.67	-0.31	0.31	-0.20	0.04	0.72	0.36	0.76	0.29		0.70	0.59	0.52	0.67	0.27	0.23	0.74	0.52	0.55	0.20	0.30	0.45	0.11
V	0.15	0.53	0.76	-0.21	0.11	-0.20	0.21	0.82	0.56	0.86	0.16	0.70		0.82	0.65	0.87	0.48	0.40	0.83	0.72	0.39	0.29	0.41	0.55	0.18
Cr	0.19	0.50	0.71	-0.18	0.11	-0.24	0.25	0.72	0.56	0.75	0.13	0.59	0.82		0.65	0.77	0.46	0.46	0.76	0.66	0.39	0.32	0.45	0.54	0.23
Co	0.01	0.53	0.58	-0.32	0.01	-0.32	0.45	0.63	0.66	0.61	0.21	0.52	0.65	0.65		0.65	0.44	0.61	0.61	0.69	0.32	0.46	0.29	0.49	0.44
Ni	0.15	0.53	0.67	-0.23	0.07	-0.18	0.19	0.75	0.54	0.79	0.09	0.67	0.87	0.77	0.65		0.51	0.41	0.77	0.69	0.41	0.29	0.46	0.54	0.24
Cu	0.37	0.58	0.33	0.08	0.10	0.07	0.36	0.38	0.57	0.39	-0.04	0.27	0.48	0.46	0.44	0.51		0.58	0.38	0.49	0.17	0.34	0.50	0.38	0.52
Zn	0.22	0.52	0.37	-0.01	-0.05	-0.03	0.61	0.33	0.66	0.39	0.12	0.23	0.40	0.46	0.61	0.41	0.58		0.36	0.59	0.02	0.49	0.37	0.50	0.60
Ga	0.07	0.43	0.90	-0.32	0.21	-0.29	0.18	0.74	0.48	0.92	0.14	0.74	0.83	0.76	0.61	0.77	0.38	0.36		0.73	0.47	0.25	0.36	0.53	0.13
As	0.19	0.42	0.78	-0.23	0.06	-0.10	0.37	0.67	0.54	0.76	0.01	0.52	0.72	0.66	0.69	0.69	0.49	0.59	0.73		0.18	0.37	0.36	0.50	0.30
Se	-0.09	0.43	0.32	-0.19	0.15	-0.24	-0.14	0.39	0.21	0.41	0.22	0.55	0.39	0.39	0.32	0.41	0.17	0.02	0.47	0.18		0.14	0.18	0.21	0.07
Sr	0.31	0.46	0.26	0.24	-0.19	0.09	0.59	0.30	0.45	0.26	0.26	0.20	0.29	0.32	0.46	0.29	0.34	0.49	0.25	0.37	0.14		0.48	0.25	0.48
Mo	0.59	0.67	0.35	0.37	0.13	0.12	0.28	0.38	0.37	0.36	-0.01	0.30	0.41	0.45	0.29	0.46	0.50	0.37	0.36	0.36	0.18	0.48		0.28	0.21
Ag	-0.10	0.42	0.47	-0.08	-0.03	-0.22	0.30	0.35	0.61	0.56	0.19	0.45	0.55	0.54	0.49	0.54	0.38	0.50	0.53	0.50	0.21	0.25	0.28		0.14
Cd	0.22	0.35	0.15	0.06	-0.15	0.05	0.55	0.21	0.45	0.14	0.01	0.11	0.18	0.23	0.44	0.24	0.52	0.60	0.13	0.30	0.07	0.48	0.21	0.14	
Sb	0.33	0.12	0.24	0.03	-0.17	-0.01	0.43	0.17	0.39	0.19	-0.22	-0.06	0.25	0.33	0.28	0.29	0.47	0.52	0.22	0.42	-0.14	0.31	0.26	0.16	0.36
Te	0.05	0.45	0.35	-0.01	-0.08	-0.41	0.37	0.31	0.59	0.44	0.11	0.27	0.45	0.51	0.48	0.43	0.32	0.46	0.42	0.41	0.23	0.33	0.36	0.64	0.14
Ba	0.34	0.53	0.71	-0.02	0.12	-0.18	0.31	0.69	0.53	0.72	0.07	0.51	0.76	0.70	0.52	0.72	0.49	0.41	0.71	0.64	0.29	0.38	0.66	0.47	0.19
La	0.00	0.23	0.90	-0.38	0.26	-0.37	0.16	0.61	0.37	0.81	0.05	0.60	0.65	0.62	0.54	0.57	0.29	0.33	0.84	0.71	0.28	0.16	0.22	0.44	0.10
W	0.27	0.22	0.28	0.04	0.02	-0.37	0.35	0.18	0.29	0.25	-0.16	0.07	0.29	0.36	0.33	0.23	0.33	0.34	0.30	0.26	0.13	0.29	0.33	0.18	0.23
Au	0.09	0.41	0.56	-0.12	0.28	-0.14	0.10	0.47	0.36	0.56	0.20	0.58	0.49	0.54	0.47	0.53	0.29	0.32	0.61	0.46	0.51	0.30	0.43	0.48	0.13

Hg	-0.19	0.26	**0.36**	**-0.43**	**0.49**	**-0.33**	-0.03	**0.34**	**0.31**	0.42	**0.32**	**0.50**	**0.36**	**0.39**	0.28	**0.31**	0.21	0.19	**0.46**	0.21	**0.37**	0.00	0.03	**0.37**	-0.08
Tl	**0.37**	0.29	0.13	0.16	0.17	**0.43**	0.06	0.16	0.10	0.13	-0.23	0.14	0.15	0.03	0.05	0.15	**0.40**	0.17	0.12	0.26	-0.03	0.08	**0.31**	-0.04	0.21
Pb	0.04	**0.39**	**0.72**	**-0.35**	0.10	-0.26	**0.34**	**0.62**	**0.63**	**0.77**	0.12	**0.55**	**0.73**	**0.73**	**0.68**	**0.70**	**0.52**	**0.60**	**0.75**	**0.79**	**0.30**	0.28	0.25	**0.57**	**0.34**
Bi	-0.07	0.21	**0.62**	**-0.34**	0.14	**-0.51**	0.29	**0.42**	**0.42**	**0.62**	0.10	**0.42**	**0.51**	**0.54**	**0.57**	**0.48**	0.22	0.34	**0.62**	**0.57**	0.21	0.23	0.20	**0.50**	0.04
Th	0.05	**0.35**	**0.59**	**-0.35**	**0.35**	-0.10	-0.08	**0.71**	**0.30**	**0.64**	0.11	**0.75**	**0.66**	**0.55**	**0.38**	**0.64**	**0.32**	0.10	**0.66**	**0.45**	**0.43**	0.05	0.27	0.29	0.02
U	-0.14	0.23	**0.78**	**-0.45**	0.22	**-0.50**	0.25	**0.55**	**0.41**	**0.72**	0.11	**0.56**	**0.61**	**0.57**	**0.64**	**0.56**	0.24	**0.32**	**0.76**	**0.61**	0.29	0.21	0.19	**0.46**	0.12

Appendix Table 4 — continued

	Sb	Te	Ba	La	W	Au	Hg	Tl	Pb	Bi	Th	U
Na	**0.33**	0.05	**0.34**	0.00	0.27	0.09	-0.19	**0.37**	0.04	-0.07	0.05	-0.14
Mg	0.12	**0.45**	**0.53**	0.23	0.22	**0.41**	0.26	0.29	**0.39**	0.21	**0.35**	0.23
Al	0.24	**0.35**	**0.71**	**0.90**	0.28	**0.56**	**0.36**	0.13	**0.72**	**0.62**	**0.59**	**0.78**
S	0.03	-0.01	-0.02	**-0.38**	0.04	-0.12	**-0.43**	0.16	**-0.35**	**-0.34**	**-0.35**	**-0.45**
P	-0.17	-0.08	0.12	0.26	0.02	0.28	**0.49**	0.17	0.10	0.14	**0.35**	0.22
K	-0.01	**-0.41**	-0.18	**-0.37**	**-0.37**	-0.14	**-0.33**	**0.43**	-0.26	**-0.51**	-0.10	**-0.50**
Ca	**0.43**	**0.37**	**0.31**	0.16	**0.35**	0.10	-0.03	0.06	**0.34**	0.29	-0.08	0.25
Ti	0.17	**0.31**	**0.69**	0.61	0.18	**0.47**	**0.34**	0.16	**0.62**	**0.42**	**0.71**	**0.55**
Mn	**0.39**	**0.59**	**0.53**	**0.37**	0.29	**0.36**	**0.31**	0.10	**0.63**	**0.42**	**0.30**	**0.41**
Fe	0.19	**0.44**	**0.72**	**0.81**	0.25	**0.56**	**0.42**	0.13	**0.77**	**0.62**	**0.64**	**0.72**
B	-0.22	0.11	0.07	0.05	-0.16	0.20	**0.32**	-0.23	0.12	0.10	0.11	0.11
Sc	-0.06	0.27	**0.51**	**0.60**	0.07	**0.58**	**0.50**	0.14	**0.55**	**0.42**	**0.75**	**0.56**
V	0.25	**0.45**	**0.76**	**0.65**	0.29	**0.49**	**0.36**	0.15	**0.73**	**0.51**	**0.66**	**0.61**
Cr	**0.33**	**0.51**	**0.70**	**0.62**	**0.36**	**0.54**	**0.39**	0.03	**0.73**	**0.54**	**0.55**	**0.57**
Co	0.28	**0.48**	**0.52**	**0.54**	**0.33**	**0.47**	0.28	0.05	**0.68**	**0.57**	**0.38**	**0.64**
Ni	0.29	**0.43**	**0.72**	**0.57**	0.23	**0.53**	**0.31**	0.15	**0.70**	**0.48**	**0.64**	**0.56**
Cu	**0.47**	**0.32**	**0.49**	0.29	**0.33**	0.29	0.21	**0.40**	**0.52**	0.22	**0.32**	0.24
Zn	**0.52**	**0.46**	**0.41**	**0.33**	**0.34**	**0.32**	0.19	0.17	**0.60**	**0.34**	0.10	**0.32**
Ga	0.22	**0.42**	**0.71**	**0.84**	**0.30**	**0.61**	**0.46**	0.12	**0.75**	**0.62**	**0.66**	**0.76**
As	**0.42**	**0.41**	**0.64**	**0.71**	0.26	**0.46**	0.21	0.26	**0.79**	**0.57**	**0.45**	**0.61**
Se	-0.14	0.23	0.29	0.28	0.13	**0.51**	**0.37**	-0.03	0.30	0.21	**0.43**	0.29
Sr	**0.31**	**0.33**	**0.38**	0.16	0.29	**0.30**	0.00	0.08	0.28	0.23	0.05	0.21
Mo	0.26	**0.36**	**0.66**	0.22	**0.33**	**0.43**	0.03	**0.31**	0.25	0.20	0.27	0.19
Ag	0.16	**0.64**	**0.47**	**0.44**	0.18	**0.48**	**0.37**	-0.04	**0.57**	**0.50**	0.29	**0.46**
Cd	**0.36**	0.14	0.19	0.10	0.23	0.13	-0.08	0.21	**0.34**	0.04	0.02	0.12
Sb		**0.34**	**0.34**	0.23	**0.48**	0.02	-0.03	0.05	**0.43**	0.27	0.00	0.17
Te	**0.34**		**0.55**	**0.33**	**0.50**	0.43	0.28	-0.23	**0.49**	**0.57**	0.11	**0.38**
Ba	**0.34**	**0.55**		**0.58**	**0.38**	**0.59**	0.25	0.12	**0.58**	**0.53**	**0.48**	**0.53**

La	0.23	**0.33**	**0.58**		**0.33**	**0.47**	**0.45**	0.06	**0.70**	**0.67**	**0.53**	**0.85**
W	**0.48**	**0.50**	**0.38**	**0.33**		0.15	0.11	-0.12	**0.31**	**0.45**	-0.03	**0.39**
Au	0.02	**0.43**	**0.59**	**0.47**	0.15		**0.33**	0.05	**0.46**	**0.45**	0.42	**0.45**
Hg	-0.03	0.28	0.25	**0.45**	0.11	**0.33**		-0.11	**0.39**	**0.35**	**0.50**	**0.43**
Tl	0.05	-0.23	0.12	0.06	-0.12	0.05	-0.11		0.09	-0.16	0.27	-0.04
Pb	**0.43**	**0.49**	**0.58**	**0.70**	**0.31**	**0.46**	**0.39**	0.09		**0.63**	**0.49**	**0.62**
Bi	0.27	**0.57**	**0.53**	**0.67**	**0.45**	**0.45**	**0.35**	-0.16	**0.63**		0.26	**0.76**
Th	0.00	0.11	**0.48**	**0.53**	-0.03	**0.42**	**0.50**	0.27	**0.49**	0.26		**0.43**
U	0.17	**0.38**	**0.53**	**0.85**	**0.39**	**0.45**	**0.43**	-0.04	**0.62**	**0.76**	**0.43**	

Explanations as for Appendix Tables 1, 2 and 9

APPENDIX TABLE 11

Summary of element behaviour at the soil-vegetation interface (BAF, BCF) and root-to-shoot transfer (TF) on the heaps studied

	no. of records ≥10			no. of records ≥2			no. of records ~1			plant species with highest factors[1]			affinity[2]
	BAF (soil→leaf)	BCF (soil→root)	TF (root→leaf)	BAF (soil→leaf)	BCF (soil→root)	TF (root→leaf)	BAF (soil→leaf)	BCF (soil→root)	TF (root→leaf)	BAF (soil→leaf)	BCF (soil→root)	TF (root→leaf)	
B	1			11	1	6	1	6	1	***S. canadensis***	*S. canadensis*	*E. cannabinum*	leaf
Sc						3	2		5			*S. nigrum*	leaf
V						2	2		4			*Verbascum*	leaf
Cr						2	2	1	4			(*Verbascum*)	leaf
Co						1	2	1	6			*Verbascum*	leaf
Ni						1	3	1	5			*Verbascum*	leaf/var.
Cu				3	2		2	2	7		*S. nigrum*, (*Verbascum*)		leaf/var.
Zn				2	1	1	5	2	6		*S. nigrum*	(*Verbascum*)	leaf/var.
Ga						4	2		2			(*Verbascum*)	leaf
As						3	2	1	2			(*Verbascum*)	leaf
Se				2	2	5	7	1	2	*S. canadensis*	*S. canadensis*, (*Verbascum*)	different species	leaf/var.
Sr				7	2	3	3	4	4	*S. nigrum*, (*Verbascum*)	*S. nigrum*	*E. cannabinum*	leaf/var.
Mo	1			5	2	1	4	2	6	***S. nigrum***	*S. nigrum*	*S. nigrum*	leaf/var.
Ag			1	2		4	2	3	3	*S. gigantea*		***S. gigantea***	leaf
Cd	1	1		2	4	2	5	2	4	***S. nigrum***	***S. nigrum***	*E. cannabinum*, *S. nigrum*	root/var.
Sb				2	1	1	6	4	3	(*Verbascum*)	*S. nigrum*	(*Verbascum*)	leaf/var.
Te				1		3	4	2	4	*S. gigantea*		*S. gigantea*	leaf
Ba				1		2	3	2	4	*A. tomentosum*		*S. nigrum*, (*Verbascum*)	leaf
La						4	1		1			*S. nigrum*	leaf
W				3	1	2	7	4	5	*C. mollis*	*C. mollis*	*C. mollis*	leaf/var.
Au				4		6	7	3	1	*S. nigrum*		(***Verbascum***)	leaf
Hg			2	2		7	4	1		(*Verbascum*)		(*Verbascum*)	leaf

Tl			1	5	4	1	3	1	2	(*Verbascum*)	*S. nigrum*	(***Verbascum***)	root/var.
Pb						2	1		3			(*Verbascum*)	leaf
Bi						2	2		4			(*Verbascum*)	leaf
Th				1		2	2	1	4	*A. tomentosum*		*S. nigrum,* (*Verbascum)*	leaf
U						3	1		2			*S. nigrum*	leaf
Al						4	2		1			*S. nigrum*	leaf
Ti						3	3		2			*S. nigrum,* (*Verbascum)*	leaf
Mn	1			1	1	4	3	1	2	***S. nigrum***	*S. nigrum*	*S. gigantea*	leaf/var.
Fe						4	1		1			*S. nigrum,* (*Verbascum)*	leaf

[1] – species with factors ≥10 are given in bold; parentheses denote cases of single-specimen anomalies; [2] – dominant plant preference of accumulation of a particular element (var. – variable)