The comparison of Cd, Cu, Fe, Mg, Mn, P, Pb, Zn concentrations in ash of the roots of some herbaceous plant species (*Filipendula ulmaria*, *Carex* species, *Urtica dioica*)

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Abstract A common problem in biogeochemical mapping and contamination studies is that the same plant species are not available everywhere. *Filipendula ulmaria* is a widely used indicator plant but it does not grow in dry and high altitude areas. We used different plant species (*F. ulmaria*, *Carex* species and *Urtica dioica*) and analysed the concentrations of Cd, Cu, Fe, Mg, Mn, Pb, Zn and P in the material from 19 sampling points in eastern Estonia. The geometric mean concentrations of Pb, Cd and Zn were similar in *F. ulmaria* and *Carex*, as were the dominating ranges of Cu, Mn and Zn. The geometric mean concentrations typically differ between *F. ulmaria* and *U. dioica*.
Simultaneous use of multiple indicator plants could generally not be recommended. Still, in case of urgent need the results could be amalgamated for the elements with more than 50% similarity of dominating ranges in different plants.

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INTRODUCTION

Biogeochemical mapping is based on the knowledge that plants, compared to soil, are more sensitive to pollution and have natural higher concentrations of many heavy metals. Plant tissues accumulate all macro- and micro-elements, both the elements essential to growth and reproduction and those without a definite role (Girling, Peterson 1980). Plants reflect a combination of background element concentrations and anthropogenic pollution in soils. Some elements that plants are able to assimilate are significant indicators of environmental pollution. Extensive root systems are capable of integrating the chemistry of a large volume of soil (Dunn *et al*. 1996). The correlation between the elemental compositions of plant samples and the composition of underlying bedrock is much stronger for roots than for aerial parts of the plants (Anand *et al*. 2007). Plant samples also provide information on bioavailable metal contents (Lax, Selinus 2005).

A major perceived advantage of biogeochemistry over soil sampling is that plants have a potential of providing sample material from greater depths and wider areas (Lintern *et al*. 1997). Biogeochemical sampling is commonly used when geochemical soil sampling is complicated or a low-cost method is required (Reid, Hill 2010). For example, in Sweden the biogeochemical sampling of aquatic plants was initially aimed to be used in areas where till sampling was difficult and where the stream sediments were hard to interpret due to large variations in mineral and organic content (Lax 2005b).

Aquatic plants have several advantages over sampling surface water. The composition of water is subject to daily, seasonal and annual variations, depending on precipitation and other factors, while plant samples can provide time-integrated information on the content of metals in water for a long period (several months or longer). Plants can also adsorb the elements that are dissolved in groundwater but do not readily precipitate on soil particles. However, a common obstacle in biogeochemical studies is that the species, which concentrate elements to the highest

levels, may not be the most abundant or widespread taxa in a study area (Dunn *et al.* 1996).

In Estonia, biogeochemical mapping has been applied in environmental studies only, for assessing anthropogenic and natural contamination with heavy metals and other hazardous elements (Enel 2003; Kannukene, Puurmann 1996; Kösta, Liiv 2011; Ots, Mandre 2012). In previous studies, root samples of an annual aquatic herbaceous plant species, *Filipendula ulmaria* (fam. Rosaceae, meadowsweet) (Enel, Mõttus 1998; Enel 2000a, 2000b, 2003), have been exclusively used due to its common occurrence, ease of collection and geometric mean concentrations of elements that do not depend on seasonal climatic variations (Brundin *et al.* 1987; Holmberg et al. 1999). Roots are sensitive to chemical variations in the environment related to different bedrock types, in addition to the effects of pollution (Brundin, Nairis 1972).

Although *F. ulmaria* is a widespread species, the pilot studies revealed that it is less frequent in the Pandivere Upland, a limestone plateau lacking ditches and streams. For this reason some other species had to be used.

Several investigations have applied more than one plant species in parallel (Cohen *et al.* 1999; Galuzka 2005; Girling, Peterson 1980; Lax 2005a; Lax, Selinus 2005; Reid, Hill 2010) but the results of this approach are seldom described in detail.

The aim of this investigation was to assess the possibilities of simultaneous use of roots of different plant species for biogeochemical mapping: *F. ulmaria*, *Carex* species (fam. Cyperaceae, sedge) and *Urtica dioica* (fam. Urticaceae, nettle). A comparative analysis of data obtained from different plants is given below.

F. ulmaria and *Carex* species share a similar wet habitat. This is an important feature inasmuch as each plant sample from a small brook likely represents a drainage area of about 4–6 sq. km. The pilot studies also showed that at least one of these species was typically present at each sampling site. The same plant taxa were used together for biogeochemical mapping in Sweden (Holmberg *et al.* 1999; Lax 2005a; Lax 2005b; Lax, Selinus 2005) but the validity of the results was not discussed in detail in these papers.

Urtica dioica was selected because of its prevalence in dry and elevated regions of the Pandivere Upland, where *F. ulmaria* and *Carex* species are far less common.

MATERIAL AND METHODS

The locations where the root samples were collected for this study are displayed in Figure 1. *F. ulmaria* and *Carex* species were typically found in low and wet areas overgrown with different grasses
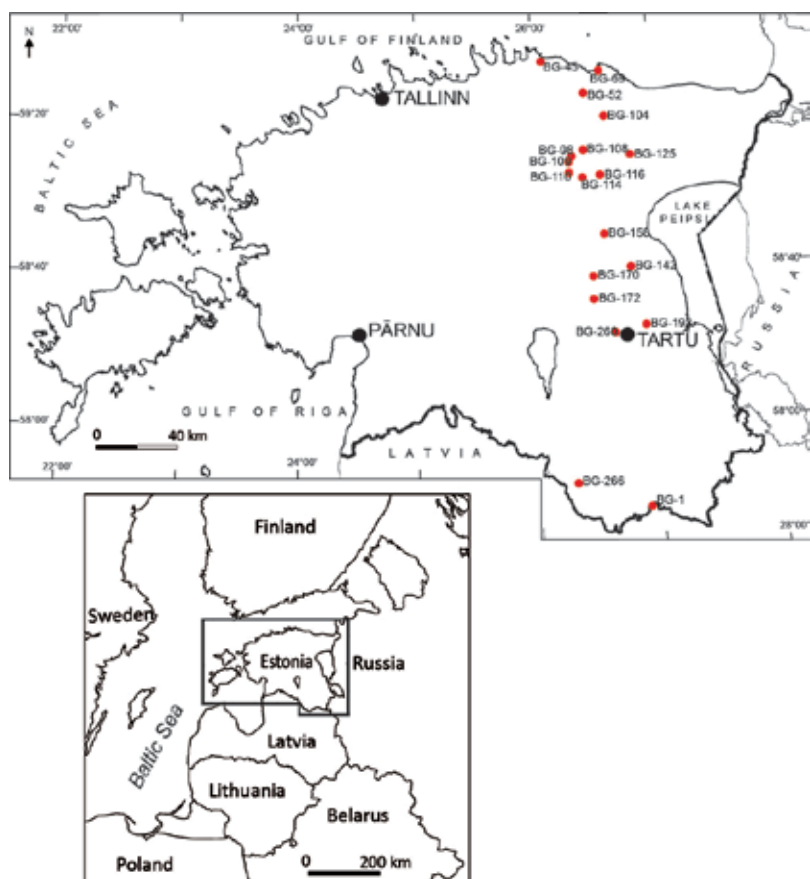

Fig. 1 Location of the study area. Sampling points are indicated by red dots

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and bushes, more rarely with small trees. The sites of *U. dioica* were generally drier and with more lush vegetation. Different plant species were collected as close to each other as possible at each location, at a distance of 10–30 m.

Data from the same location were compared. The element geometric mean (GM) concentrations were also compared for fourteen pairs of root samples of *F. ulmaria* and *Carex* species, coupled with data on six root samples of *U. dioica*.

To minimize the content of geogenic or dead organic matter and Fe-Mn oxides, the root samples were washed very carefully and soil and decayed material were removed. The samples were dried first, then ground and dried up to a constant weight at 105°C. Element concentrations were measured in the ashed material, after igniting the samples at 450°C. Cd, Cu, Fe, Mg, Mn, Pb and Zn, soluble in *aqua regia,* were measured by atomic-absorption spectrometry and P was quantified calorimetrically. The reliability of analytical data was checked against various international and local reference samples and also by partic-
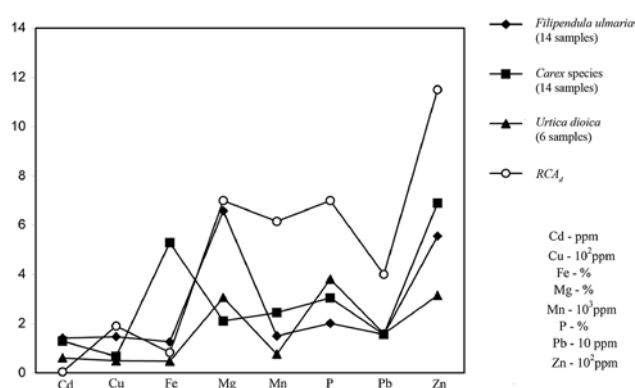

Fig. 2 Element geometric mean concentrations in *Filipendula ulmaria* and *Carex* species (14 sample pairs), *Urtica dioica* (6 samples), and reference concentration in ash of plants (RCA$_d$) based on Brooks (1972) and Maljuga (1963)

ipating in intercalibration. All analyses were made in the Laboratory of the Geological Survey of Estonia, accredited by the Estonian Accreditation Centre on 20 June, 2002 (certificate No. L093). Detection limits and analytical precision are presented in Tables 1 and 2.

This study makes use of the geometric parameters. The element geometric mean concentrations are calculated when it is assumed that the data follow a log-normal distribution. The geometric mean also eliminates the undue influence of occasional high concentrations on the mean value. The dominating range is defined as the interval between the geometric mean multiplied/divided by the standard deviation as a coefficient.

The GM values of element concentrations, calculated for the root samples of *F. ulmaria*, *Carex* species and *U. dioica* are presented in Table 4. The results of this study are also compared with average reference concentrations of elements in plant ash (Brooks 1972; Maljuga 1963). These concentrations in plant ash are calculated as arithmetic medians (AM) from direct data (RCA$_d$). Also comparison with recalculated reference concentrations by Lax (Lax 2005b) is given (RCA$_r$). RCA$_r$ that are based on 680 samples of three different species – *F. ulmaria*, *Carex* species and *Fontinalis antipyretica* were recalculated into concentrations in ash by using the average ash contents from our analytical results, keeping in mind that the methods and plants used are similar. For this the formula 100/7.85*(a + b + c) was used. Concentrations in oxides were recalculated into element concentrations.

The results are further presented in pairs (*F. ulmaria–Carex* species, *F. ulmaria–U. dioica* and *Carex* species–*U. dioica*) in order to assess the possibilities of parallel use of roots of different plant species.

Comparing the concentrations the expression 'similar' was used. If the ratio or inverse ratio was >2, then GM values were considered 'not similar'. The ratio or inverse ratio below 1.5 was characterized as 'very

Table 1 Elements, analytical methods and detection limits

Element	Detection limit, ppm		
	Atomic-absorption AAS-F analyses	Atomic-absorption AAS-Gr analyses	Colorimetric analyses
Cd		0.04	
Cu	2		
Fe	50		
Mg	50		
Mn	5		
P			40
Pb	2		
Zn	2		

AAS-F – flame atomic absorption spectrometry
AAS-Gr - electrothermal atomic absorption spectrometry

Table 2 Analytical precision

Reference sample BGK-1				
Element	Unit	n	X	s
Cd	ppm	30	0.33	0.048
Cu	ppm	30	38	6.96
Fe	%	21	0.86	0.2
Mg	%	30	0.69	0.07
Mn	ppm	20	2016	197
Pb	ppm	30	22.6	1.92
Zn	ppm	30	252	18

n – number of analyses
X – arithmetic mean
s – standard deviation
BGK-1 is a local reference sample (ashed leaves and branches).
Reference samples used for analytical quality control: SDPS – 1, SGHM – 4, SGD – 1a (Catalog of standards…, 1988).

similar', values in the interval 1.5–2 as 'rather similar'. For comparison of the dominating ranges, the relative width of the overlap of two species, with the narrower dominating range in the nominator, was calculated. The overlap was 'important' when exceeding 50%.

RESULTS

Filipendula ulmaria–Carex species

The ash concentration in *F. ulmaria* mainly varied between 6.24% and 8.70%; the GM was 7.37%

(Table 4). The GM of ash in *Carex* was slightly higher, 8.31%. The difference between the ash content of *F. ulmaria* and *Carex* species is considered insignificant, although some variation is present.

Figure 2 shows a comparison of the GM concentrations of elements in *F. ulmaria* and *Carex* species (14 sample pairs) with RCA_d of the same elements (Brooks 1972; Maljuga 1963). The GM concentrations of Cu, Fe, and Mg in *F. umaria* in this study were similar to RCA_d, but, GM concentrations in *Carex* species more than twice differed from RCA_d (Fig. 2; Table 4). However, the GM concentrations of

Table 3 Element concentrations in *Filipendula ulmaria*, *Carex* species and *Urtica dioica*

Number of sample	Plant species	Element, ppm								A_c*
		Cd	Cu	Fe*	Mg*	Mn	P*	Pb	Zn	
BG-1	*Filipendula ulmaria*	3.87	224	1.48	**7.63**	2844	3.21	16.5	854	5.56
	Carex species	3	148	1.21	1.96	2684	2.58	24.4	821	7.66
BG-45	*Filipendula ulmaria*	0.55	55	1.71	**3.08**	1170	2.1	9.9	145	6.59
	Carex species	1	50	**17.04**	1.11	**4813**	3.69	15.3	**535**	15.56
BG-52	*Filipendula ulmaria*	0.45	**360**	0.66	**4.86**	945	1.81	10	585	7.72
	Carex species	0.75	65	**4.12**	1.8	**2055**	1.29	18	510	6.22
BG-69	*Filipendula ulmaria*	0.43	**100**	2.91	**5.76**	1920	2.22	11	**290**	9.01
	Carex species	**1**	50	1.82	1.37	1255	4.37	9.8	140	10.6
BG-98	*Urtica dioica*	1.27	50.8	0.32	2.52	2188	3.51	19.6	496	7.31
BG-104	*Filipendula ulmaria*	0.92	32.5	1.53	5.59	3341	2.83	21	915	8.37
	Carex species	1.17	28.5	6.7	2.02	1796	4.66	9.4	1025	5.78
	Urtica dioica	0.27	46.5	0.49	0.27	296	4.79	9.3	255	8.5
BG-108	*Urtica dioica*	0.78	32.8	0.62	3.1	1291	2.81	16.5	229	6.04
BG-109	*Urtica dioica*	0.93	47.2	0.49	2.6	1449	2.71	16.5	295	4.25
BG-110	*Filipendula ulmaria*	**4.3**	71.5	0.27	6.34	339	2.63	35.6	**1558**	7.87
	Urtica dioica	0.66	86.8	0.27	3.3	276	4.83	24.4	436	5.9
BG-114	*Filipendula ulmaria*	1.41	79.1	0.11	**6.97**	245	2.35	17.3	634	6.69
	Carex species	2.17	40	**1.4**	2.86	**636**	2.2	11.1	778	4.69
BG-116	*Filipendula ulmaria*	**1.41**	**102**	0.98	8.68	535	3.83	12.3	555	6.57
	Urtica dioica	0.33	43.8	0.91	5.02	580	4.95	13.2	580	4.96
BG-125	*Filipendula ulmaria*	2.17	127	3.2	**7.23**	4114	1.09	13.2	485	9.72
	Carex species	1.32	**336**	2.47	2.56	2296	1.23	13.2	720	6.98
BG-142	*Filipendula ulmaria*	4.11	**216**	2.5	**8.17**	2094	3.06	11	574	5.67
	Carex species	2.38	69.3	**12.91**	2.43	3404	5.5	13.2	1025	9.25
BG-158	*Filipendula ulmaria*	0.24	**145**	1.82	**7.57**	1830	1.59	13.2	470	6.82
	Carex species	0.34	47.5	**21.06**	1.73	**6193**	**3.53**	13.2	695	13.43
BG-170	*Filipendula ulmaria*	1.78	**199**	1.39	6.2	1251	1.33	14	565	8.37
	Carex species	0.82	36.4	**7.32**	3.24	1981	**3.28**	13.3	922	7.25
BG-172	*Filipendula ulmaria*	**6.86**	333	1.44	**8.2**	3993	1.67	21	945	6.2
	Carex species	2	35.8	**8.02**	2.88	2591	**4.3**	32.7	905	9.6
BG-193	*Filipendula ulmaria*	**1.18**	248	1.78	**10.04**	1182	2.19	32.7	620	7.78
	Carex species	0.35	50.5	**11.14**	2.75	**3386**	4.4	32.7	635	6.08
BG-260	*Filipendula ulmaria*	13.1	318	1	**6.26**	432	1.65	40.5	1030	8.03
	Carex species	17.9	224	**4.02**	1.5	**1284**	2.31	22.8	1287	9.81
BG-266	*Filipendula ulmaria*	0.61	90.4	0.61	**7.87**	1471	2.43	10.1	491	8.03
	Carex species	0.55	83.2	**5.22**	2.75	**6588**	3.24	10.1	622	9.81

*concentrations in %
A_c ash content

Mn, P, Pb and Zn were appreciably lower, whereas the GM of Cd concentrations was higher.

The GM concentrations of some elements in different plants were similar. The GM concentrations of Pb were equal in *F. ulmaria* and *Carex* – 15.6 ppm. The correlation between the concentrations of Pb in *F. ulmaria* and *Carex* species is high (Fig. 3). Pb is one of the investigated elements having very similar concentrations in different plant taxa from the same locality (Table 3).

The concentrations of Cd and Zn in *F. ulmaria* and *Carex* species were comparable and dominating ranges of these elements were typically similar (Figs 3 and 4). The highest Cd and Zn concentration in *F. ulmaria* and *Carex* species was observed at the same location: BG-260 (Table 3). Fig. 3 demonstrates a generally positive correlation between Zn concentrations in *F. ulmaria* and *Carex* species, although a considerable variation occurred: the values were very similar in different plants from the locality BG-193 but differed by more than twice in the localities BG-45 and BG-69.

Almost opposite results were derived from a pairwise comparison of Fe and Mn concentrations in the same plant species. The concentration of Fe was mostly higher in *Carex* species (Table 3; Fig. 2) than in *F. ulmaria,* sometimes by a magnitude (BG-114, BG-158).

A tendency of higher concentrations of Cu and Mg in *F. ulmaria* was recognized. The corresponding values were often twice or even more higher than in *Carex* species (Table 3).

The concentrations of P, an essential plant nutrient element, were of a similar magnitude in a greater part of samples from the same location (Table 3), but always notably lower than RCA_d (Table 4; Fig. 2). P tended to concentrate a little more in *Carex*, but this difference was insignificant.

Filipendula ulmaria–Urtica dioica

The GM of ash in *U. dioica* was lower (6.00%) but the dominating range was wider (Table 4) (between 4.65% and 7.74%) than in *F. ulmaria* (GM 7.37%, dominating range 6.24–8.70%). Fig. 2 shows element GM concentrations in *U. dioica* (6 samples), other investigated species and RCA_d.

Like in case of *F. ulmaria* and *Carex* (above), the concentrations of Pb had the strongest correlation also in *F. ulmaria* and *U. dioica*. The GM values of Pb concentrations were equal in *F. ulmaria* and *Carex* species (15.6 ppm), and *U. dioica* also showed a very similar value – 15.9 ppm (Table 4).

The concentration of Cu in *U. dioica* was quite variable, but still much lower than RCA_d and RCA_r (Table 4). *Filipendula ulmaria* and *U. dioica* from the same localities sometimes also revealed similar concentrations of Fe (Table 3).

The only noticeable tendency in the behaviour of the essential nutrient element P was recognized in *U. dioica*. The concentrations in that species were in all cases higher than in *F. ulmaria*.

The comparison of Cd concentrations in *F. ulmaria* and *U. dioica* always gave higher (up to more than six times) values for *F. ulmaria*. A similar tendency

Table 4 Element geometric mean concentrations (ppm), standard deviations and dominating ranges in *Filipendula ulmaria*, *Carex* species and *Urtica dioica*

| Element | *Filipendula ulmaria* 14 | | | *Carex* species 14 | | | *Urtica dioica* 6 | | | Reference concentrations in ash of plants based on: | |
	GM	Standard deviation	Dominating range	GM	Standard deviation	Dominating range	GM	Standard deviation	Dominating range	direct data* (RCA_d)	recalculations of data** (RCA_r)
Cd	1.42	3.19	0.44–4.53	1.29	2.75	0.47–3.55	0.61	1.83	0.33–1.12	0.05	
Cu	147	2.06	71–303	67	2.07	32–139	49	1.37	36–67	190	153
Fe***	1.26	2.34	0.54–2.96	5.29	2.48	2.13–13.13	0.48	1.55	0.31–0.74	0.83	20.20
Mg***	6.58	1.33	4.95–8.75	2.11	1.38	1.53–2.92	3.06	1.31	2.34–4.01	7	3.83
Mn	1499	2.24	669–3358	2444	1.90	1284–4651	761	2.39	318–1819	6150	4.72
P***	2.02	1.37	1.47–2.76	3.05	1.58	1.93–4.84	3.81	1.32	2.89–5.03	7	2.17
Pb	15.6	1.56	10.0–24.3	15.6	1.53	10.2–23.9	15.9	1.39	11.4–22.1	40	200.2
Zn	556	1.70	327–945	689	1.69	408–1164	315	1.37	230–432	1150	1326
A_c	7.37	1.18	6.24–8.70	8.31	1.40	5.94–11.63	6.00	1.29	4.65–7.74		

*Filipendula ulmaria*14, – concentrations in 14 samples
Carex species14 – concentrations in 14 samples
Urtica dioica 6 – concentrations in 6 samples
GM – geometric mean
* From Maljuga (1963) and Brooks (1972)
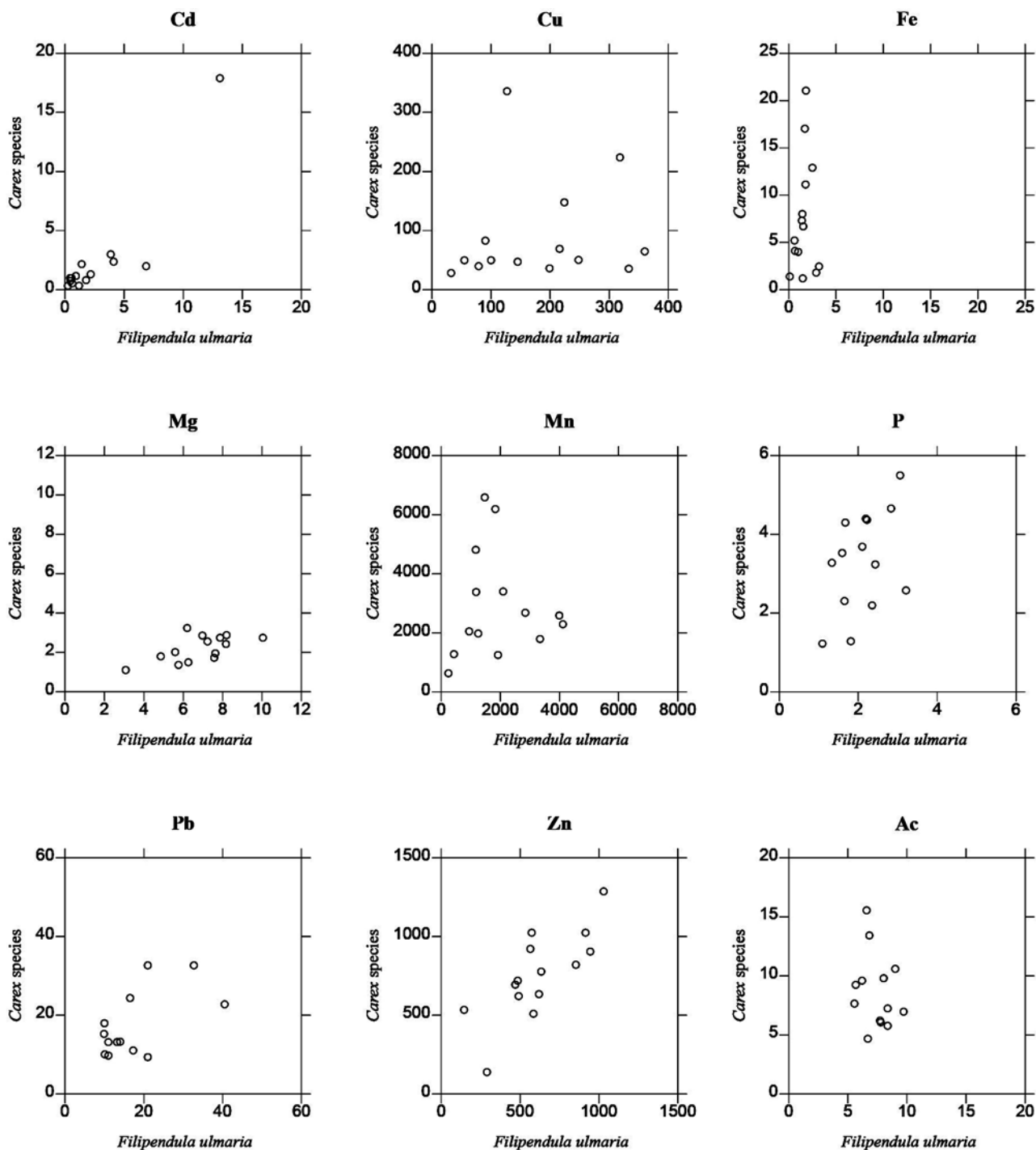**From Lax (2005b)
*** Concentrations in %

Fig. 3 Scatter plots of element concentrations in *Filipendula ulmaria* and *Carex* species

could be observed in the behaviour of Mg. No obvious trend was recorded for Mn, although its concentrations could occasionally be markedly higher in *F. ulmaria*. The same was valid for Zn.

Carex species–*Urtica dioica*

The comparison between the *Carex* species and *U. dioica* was based on data from one locality only. The GM of ash in *U. dioica* (6.00%) was lower than in *Carex* species (8.31%). The GM concentrations of Pb were very similar (the ratio or inverse ratio did not exceed 1.5) in these species (15.6 ppm in *Carex* and 15.9 ppm in *U. dioica*) and largely the same was valid for P (Table 4).

The concentration of Zn in the different plant species varied greatly, being higher in *Carex* species and lower in *U. dioica* (Table 3). Substantially lower concentrations of Cd, Fe, Mg and Mn (for Fe by a magnitude) were also characteristic of *U. dioica* (Table 3; Fig. 4).

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The GM concentration of Cu in *U. dioica* was rather similar (the ratio or inverse ratio of GM values is in the interval 1.5–2) to the GM concentration in *Carex* species.

Correlations between different element concentrations in the plant species

These correlations were both positive and negative (Table 5). A strong positive correlation existed in *F. ulmaria* between Zn, Cd and Pb with a weaker insignificant positive correlation between the listed elements and Cu. A significant correlation was also detected between Fe and Mn (Table 5). A significant negative correlation was observed between ash concentration and P.

An obviously positive correlation was found between Mn, Fe and ash concentration in *Carex* species. Also, Cd and Zn showed a significant positive correlation. A significant negative correlation was noted between Mg and ash concentration and also between P and Cu (Table 5).

U. dioica showed a strong positive correlation between Cd and Mn, between Mg and Fe, between Pb and Zn and between Pb and Cu. A strong negative correlation existed between P and Cd, between P and Mn and also between Fe and Zn.

DISCUSSION

This study was undertaken in the hope of recovering similar concentrations of individual elements in different plant species, *F. ulmaria*, *Carex* species and *U. dioica*, from the same locality, sharing a similar habitat. Such similarity of pairwise results was expected in more than 50% of sampling sites.

In general, element geometric mean concentrations in *F. ulmaria*, *Carex* species and *U. dioica* differed from RCA_d and $RCA_!$. Only Cu and Mg concentrations in *F. ulmaria* were similar to values calculated on the basis of previously reported results (Table 4).

Concentrations of Pb, Cd and Zn in *F. ulmaria* and *Carex* species were commonly similar (Table 3, Fig. 3), their GM concentrations were identical (Pb) or similar (Cd, Zn) (Table 4). These elements also featured significant positive correlation in case of *F. ulmaria* (Table 5).

We recorded a high correlation between concentrations in pairs of *F. ulmaria* and *Carex* in the same sampling site only for Pb. In some cases, the concentrations of Cu and Mn in *F. ulmaria* and *Carex* were similar, but in some pairs the ratio or inverse ratio exceeded 3 (Mn in BG-45 and BG-266) or even 9 (Cu in BG-172); this ratio for Cd and Zn in some localities exceeded 3. The concentrations of most of these
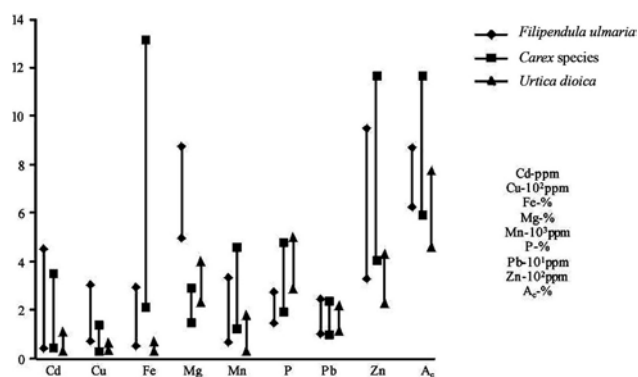

Fig. 4 Dominating ranges in *Filipendula ulmaria*, *Carex* species and *Urtica dioica*

elements were even more different in pairs with *U. dioica* (Table 3), the dominating ranges of these species were less similar (Fig. 4).

Although the GM concentrations of a few elements (Mn, Pb and Zn) were similar in *F. ulmaria* and *U. dioica*, the GM concentrations of other elements were significantly different (Table 4). The concentrations of Fe differed largely in *F. ulmaria* and *Carex* (Table 3), sometimes by a magnitude, but the same element behaved more similarly in the pairs of *F. ulmaria* and *U. dioica*. The similarity of Mg concentrations in pairs of different plant species was generally low, whilst the respective values were usually higher in *F. ulmaria*.

The results revealed no strongly anomalous concentrations of the elements, but relatively high Cd and Zn concentrations were still found in the locality BG-260 (Table 3), about 2 km from the west border of Tartu. These high values could likely be attributed to anthropogenic processes.

In specimens of one plant species and between different plant species, there were four significant positive correlation coefficients not only in *F. ulmaria* (Cd–Pb, Cd–Zn, Zn–Pb and Fe–Mn), but also in *Urtica diotica* (Cd–Mn, Pb–Cu, Pb–Zn, Fe–Mg) and only two – in *Carex* species (Cd–Zn, Fe–Mn).

The positive correlation between elements (Cd–Pb–Zn and partly also Cu) in a plant specimen might reflect natural high concentrations in soil, as these elements are taken up by plants and this uptake could be responsible for elevated concentrations in plant root ash. Their high concentrations might locally be indicative of polymetallic mineralization in deeper layers, known from the earlier studies (Sudov *et al.* 1973), or to anthropogenic atmospheric pollution.

The negative association between Cd (a well-known indicator of pollution) and P and partly Mn (important nutrient elements), may suggest that higher concentrations of Cd in the samples are likely to be caused by various anthropogenic pollution or atmospheric pollution.

The results may slightly be biased because the

Table 5 Pearson correlations between elements in *Filipendula ulmaria*, *Carex* species and *Urtica dioica*

	Cd	Cu	Fe	Mg	Mn	P	Pb	Zn	A_c
Filipendula ulmaria, n = 16									
Cd		**0.57**	-0.11	0.14	-0.01	-0.12	**0.7**	**0.69**	-0.16
Cu			-0.17	0.27	-0.06	-0.23	0.4	0.49	-0.23
Fe				0.08	**0.56**	-0.11	-0.19	-0.35	0.29
Mg					0.21	0.12	0.33	0.34	-0.17
Mn						-0.002	-0.17	0.21	0.07
P		Cd + (Cu) + Pb + Zn					-0.09	0.14	**-0.53**
Pb		Mn + Fe						**0.67**	0.07
Zn		P – A_c							-0.18
Carex species, n = 14									
Cd		0.46	-0.20	-0.06	-0.33	-0.22	0.23	**0.60**	0.06
Cu			-0.37	-0.08	-0.15	**-0.59**	0.04	0.23	-0.09
Fe				-0.20	**0.67**	0.45	0.04	0.01	**0.65**
Mg					-0.07	0.02	0.15	0.27	**-0.58**
Mn		A_c + Fe + Mn				0.22	-0.07	-0.19	**0.61**
P		Cd + Zn + (Cu)					0.05	0.04	0.27
Pb		A_c – Mg						0.21	-0.08
Zn		P – Cu							-0.22
Urtica dioica, n = 6									
Cd		0.02	-0.54	-0.48	**0.90**	**-0.71**	0.59	0.63	-0.12
Cu			-0.62	-0.20	-0.38	0.48	**0.71**	-0.07	-0.01
Fe				**0.76**	-0.21	0.13	-0.61	**-0.73**	-0.37
Mg		Cd + Mn + (Zn)			-0.38	0.47	-0.07	-0.25	-0.48
Mn		Cu + Pb + (Zn)				**-0.77**	0.22	0.37	-0.08
P		Fe + Mg					-0.14	0.09	0.31
Pb		Mn – P						**0.74**	-0.28
Zn		Fe – Zn							0.17

material of *F. ulmaria* and *Carex* species was mostly collected from very closely spaced plant specimens at a sampling point. It could also be assumed that the respective results reflect concentrations all over the drainage area as these species commonly grow in low-lying areas. The specimens of *U. dioica* were typically found at some distance from other species (not less than 10 m), and therefore the results might rather reflect a particular sampling point.

Most of the data from *U. dioica* are not very well comparable with data from other species. This could refer to different habitat preferences of this species. The calculated geochemical parameters, geometric mean concentration and standard deviation as a coefficient considerably differ in *U. dioica* from the same parameters of *F. ulmaria* and *Carex* species.

between *F. ulmaria* and *Carex* species was identified. This could be due to the fact that these species share a similar habitat, both occurring usually in low-lying areas, and the respective results could represent the entire drainage area. As the habitat of *U. dioica* is different, we assume that the respective results are more characteristic of a particular sampling point.

In spite of some similarity between *F. ulmaria* and *Carex* species, we may conclude that most of the elements accumulate differently in different plant species and therefore it is not recommended to employ multiple indicator plants in a single investigation. However, the data on elements that showed more than 50% similarity in dominating ranges among plant species from a similar habitat could be amalgamated. For *F. ulmaria* and *Carex* species, these elements are Cd, Cu, Mn, Pb, Zn and P.

CONCLUSIONS

The results show that in most cases the elements behave differently in different plant species, plants accumulate elements differently. Still, some similarity

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