ABSTRACT: Litovelské Pomoraví Protected Landscape Area (Czech Republic) was chosen as the study area of heavy metal pollution (Zn, Ni, Cu, Pb, Cd). Assessment of heavy metal concentration in the soil was performed at eleven sites along the water stream in the alluvial plain (Morava river) and compared with concentration in selected plant tissues. Heavy metal concentration in two plant species (*Urtica dioica* L., *Taraxacum* sp.) and soils were detected by atomic absorption spectrophotometry (AAS). The correlation between heavy-metal concentrations in plant tissues (roots, leaves, stems) and in soils was tested and the ability of plants for heavy-metals indication in the alluvial plain landscape ecosystem was observed. Differences in correlation and ability to accumulate heavy metals were found not only between species and heavy metals but also among various plant tissues. *Taraxacum* sp. as a whole closely followed concentration of Zn, Cu, Pb and Cd and seems to be much more suitable as bioindicator than *Urtica dioica* L. Nevertheless, there are plant parts of both species with better response to adequate metal. Some plant tissues of both species provide ambiguous results, which was discussed in terms of living forms, growth strategy and genotypic differences.

KEY WORDS: alluvial plains, heavy metals, plant tissues, accumulation, AAS, *Taraxacum* sp., *Urtica dioica* L.

I. INTRODUCTION

Man has influenced concentration levels of heavy metals in his environment by three main ways: 1) industrial exhalations and consequent deposits on soil and vegetation surface, 2) raising concentration of elements in soil due to artificial fertilisers, 3) release of industrial, agricultural and domestic sewage into water and river systems. These facts are the reason for monitoring of heavy metal impact on affected plant communities and soil, as the metal uptake from the soil and by plants is an introductory pathway for heavy metals to enter the foodchain. Nevertheless, natural and relatively unaffected areas remain apart of such a research. In this contribution we focused on floodplain ecosystem to test heavy metal pollution in plant and soil components in the floodplain ecosystem.

All three ways of man influence mentioned above may take part there and in addition the countryside close to river has their own peculiarities. The rivers of temperate climatic zones are characterised by typical water regimes. Thaw and rainfall flood-discharges are frequent and the highest concentrations of heavy metals usually occur in fine-grained deposits near river banks. Flood
accumulation often results in contaminated river deposits in overbank sediments. This process can lead to an increased concentration of heavy metals in overbank sediments in the course of time (Cisze wski 1998).

Numerous investigators have demonstrated that plant growth and vigour and, hence, nutrient build-up are correlated with some soil features (Ernst 1975, Cataldo and Wildung 1978). It also has been shown that trace metal uptake is controlled not only by the soil types and soil conditions, but also by plant species (Singh et al. 1995) and plant species differ in ability to absorb and allocate nutrients. Nutrient uptake is a selective process so that nutrients are not taken up in proportion to their relative concentrations in the soil nor in relation to the minimum nutrient requirements of plants (Borůvka et al. 1997). Moreover, some evidence indicates that the variability of metal content in a shoot can be influenced by phylogeny, habitat (Bednář 1979b, Broadley et al. 2001) and genotypic differences in the studied plants (Bednář 1979a).

It is known that some physiological barriers against heavy metal ions function in the plant body. Hence, the amount of some ions in the roots, stems, leaves and flowers may be different (Sawidis et al. 1995, Wierzbicka 1995) and the allocation in plant parts is highly dependent on particular species (Ernst 1975, Prasad and Freitas 2003). That is why only two common plant species with frequent occurrence on study area were chosen for study as bioindicator. A test for five heavy metals (Cd, Cu, Ni, Pb, Zn) allocation into plant parts and its connection to concentration in soil in the study area was established. A comparison among soil, leaves and the roots of dandelion (Taraxacum sp.) and leaves, stems and roots of nettle (Urtica dioica L.) was performed to evaluate their ability to reflect heavy metal pollution in the alluvial plain of the Morava river.

The area of this investigation was the Litovelské Pomoraví Protected Landscape Area (PLA) in the middle part of North Moravia (Fig. 1) in the Czech Republic. It includes 96 km² of alluvial plain of the
Morava river, north of Olomouc. The most important places, the naturally meandering Morava that branches into a complex system of permanent and temporary streams in the floodplain forest, have been proclaimed nature reserves. PLA Litovelské Pomoraví is included in the List of Significant International Wetlands of the Ramsar Convention (Bureš and Machar 1999). Gravel covered by flood sediments composes the Morava river floodplain, as sandy-loam and sandy soil dominate in major of that PLA (Duchoslav 1997). The level of pH was slightly acid, about 6.5–6.8 and did not differ dramatically among sites. This feature is typical for fluvisol, which is the main kind of soil in Litovelské Pomoraví PLA. Heavy metal incomes from artificial fertilisers and the transportation of industrial air emissions or sewage treatment from vicinity of the Litovelské Pomoraví PLA are possible to take into account (Šindelářová 1988, Po dlešáková and Němeček 1996).

The aim of this study was to determine the heavy metals concentration in selected parts of flood plain ecosystem mentioned above. Hence, soil and common herbs were chosen as indicators. A comparison of the usefulness of two plant species abilities for monitoring purpose was also performed. That means to quantify the uptake of selected heavy metals by different plant tissues growing on the same place and soil.

2. MATERIAL AND METHODS

Nettle (Urtica dioica L.) and dandelion (Taraxacum sp.) belong to common plants in central Europe and subsequently in Litovelské Pomoraví PLA. The genus Taraxacum is taxonomically too complicated to identify the proper species category. In the Czech Republic, the genus is represented by 8–10 sections (Vašut 2003). Hence, we define it in the following text only as Taraxacum sp. All our items of that genus probably belonged to sect. Ruderalia Kirschner, H. Øllgaard et Štěpánek.

Taraxacum and Urtica are not considered hyperaccumulators and do not exhibit heavy-metal tolerance sensu Prasad et Freitas (2003), but both species have been mentioned many times as good bioindicators in scientific and environmental studies (Kabata-Pendias and Dudka 1991, Tack et al. 1996, Normandin et al. 1999, Czarowska and Milewski 2000). Moreover, Urtica was considered a model plant in the floodplain forest in the inundation area of Danube (Uherčíková et Hajdúk 1998). These facts were the reason why Taraxacum and Urtica tissues were chosen as an appropriate matter for the analysis.

Eleven typical sites close to river bank were set in community of Querco-Ulmetum Issler 1926. Each site was situated near a tributary to detect potential source of pollution and across the PLA along a water stream (and hence in different altitude). The place of Morava river entrance into PLA is 250.5 m a.s.l. and after meandering about 40 km its water leaves the protected area at 212.5 m a.s.l. Nevertheless, the real length of PLA is only 30 km and width 2–7 km. The process of analysis was modified after Mursphy et al. (2000) and Carlosena et al. (1997) by the next way.

Because of a laboratory capacity five fresh plant items were collected from each site. Dust and soil was removed from each plant item by fresh water. Leaves, stems and roots were dried separately at 85°C. From fine crushed tissues of each item 0.5 g were weighed and mineralised by microwave (BM-IS/II) in 4 ml HNO₃. Digests were analysed for selected metals by flame atomic absorption spectrophotometry (GBC Avanta).

Together with each plant small amount of soil was taken from a rhizosphere. Sieved and air-dried soil was weighed (0.3 g) and mineralised by microwave in a mixture of H₂SO₄, HCl and HNO₃ (1:2:3 v/v). Filtered extracts, similarly as plant tissues, were then submitted to selected heavy metal analysis for Zn, Ni, Cu, Pb and Cd by flame atomic absorption spectrophotometry.

Heavy metal concentrations in the given plant tissue and soil were used for calculation of mean concentrations and the transfer factors for selected plant parts. It is one of the suitable ecological parameters for expression of heavy metal accumulation in plants (Brooks 1972). The transfer factor was calculated as a ratio of the concentration of metal in plant dry weight to the concentration of the same metal in the soil (Uherčíková et al. 1998).
and Hajdůk 1998). Hence, the higher value of transfer factor the higher amount of particular metal in plant tissue.

Significant differences between means in different groups of variables were tested by analysis of variance (ANOVA). The purpose of the ANOVA analysis is to test for differences between means in different groups of variables. Moreover, comparisons between transfer factors and concentrations in root and shoot (Root/Shoot ratio) for each species were performed. Transfer factors of both plant species were compared with each other as well. All statistical procedures were performed by StatSoft, Inc. (2001). STATISTICA Cz.

The relationship between concentration values, species, soil and each measured parameter with each other was assessed by linear unimodal gradient analysis. Data evaluation was performed in the CANOCO Version 4.5 P.C. February 2002 (Braak and Šmilauer 1998). Each chemical parameter

![Diagram showing average distribution of heavy metals in selected plant parts and in soil, recorded in the Litovelské Pomoraví Protected Landscape Area. Mean value of R/S ratio is presented by dots and standard error by hatched areas.](image-url)
Heavy metals in two herb species

was centered and standardized to zero mean and unit variance. Such the way there is possible to detect hidden correlations and dependence effects between variables.

3. RESULTS

This study was dedicated to five heavy metals (Cd, Cu, Ni, Pb, Zn) which showed different pattern of concentration in both plant species, in their tissues and in soil. We were stated in general, that concentration of each heavy metal in plant tissues slightly differs from each other and there are differences between plants and soil (Fig. 2).

The concentration of Cd in soil was relatively low, from 0.3 µg g$^{-1}$ and 1.2 µg g$^{-1}$ as well as in plant tissues. The minimum was found in Urtica roots (1.1 µg g$^{-1}$) and a maximum in Taraxacum leaves (2.7 µg g$^{-1}$). The decrease of Cd content was in the order: Taraxacum roots > Taraxacum leaves > Urtica stems > Urtica roots > Urtica leaves. Moreover, the uniformity of low concentrations was accompanied only by a slight correlation (Table 1). The amount of Cd in Taraxacum leaves and roots, as well as Urtica stems and leaves were slightly negatively correlated with Cd concentration in the soil. There was also slight positive correlation between Cd concentration in Urtica roots and soil. As for Cd, the heavy-metal-incorporation into plant tissues reached the highest values (Table 2). On the basis of transfer factor the best ability to accumulate Cd showed Taraxacum leaves. On the other hand, R/S ratio close to one demonstrates (Fig. 3), that has accumulation ability Taraxacum species as a whole.

The concentration of Cu in the soil was from 2.2 to 10.3 µg g$^{-1}$. The minimum content of this metal in plant tissues was in Urtica stems (1.3 µg g$^{-1}$) and the maximum was in Taraxacum roots (15.8 µg g$^{-1}$; Fig. 2).

### Table 1. The regression analysis output – correlations among concentration of heavy metals in plant parts and soil.

<table>
<thead>
<tr>
<th></th>
<th>Urtica</th>
<th>Taraxacum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>leaves</td>
<td>root</td>
</tr>
<tr>
<td>Cd</td>
<td>–0.38</td>
<td>0.14</td>
</tr>
<tr>
<td>Cu</td>
<td>0.71*</td>
<td>0.52</td>
</tr>
<tr>
<td>Ni</td>
<td>–0.60</td>
<td>0.50</td>
</tr>
<tr>
<td>Pb</td>
<td>0.44</td>
<td>0.06</td>
</tr>
<tr>
<td>Zn</td>
<td>0.55</td>
<td>0.38</td>
</tr>
</tbody>
</table>

* significant correlation ($P < 0.05$)

### Table 2. Mean values of transfer factors (ratio of the concentration of metal in plant dry weight to the concentration of the same metal in the soil) for particular metals.

<table>
<thead>
<tr>
<th></th>
<th>Urtica</th>
<th>Taraxacum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>leaves</td>
<td>root</td>
</tr>
<tr>
<td>Cd</td>
<td>2.01</td>
<td>2.46</td>
</tr>
<tr>
<td>Cu</td>
<td>1.15</td>
<td>1.11</td>
</tr>
<tr>
<td>Ni</td>
<td>2.97</td>
<td>1.23</td>
</tr>
<tr>
<td>Pb</td>
<td>0.69</td>
<td>0.61</td>
</tr>
<tr>
<td>Zn</td>
<td>0.40</td>
<td>0.74</td>
</tr>
</tbody>
</table>
An amount of Cu in *Urtica* leaves and roots showed relatively strong significant positive correlation with Cu concentration in soil (Table 1). Nevertheless, other tested plant tissues were only slightly (negatively or positively) correlated with Cu concentration in soil. Cu generally seemed to be not accumulated in excess in *Urtica* leaves and roots. On the other hand *Taraxacum* leaves and root accumulated this metal in excess. The transfer factor of shoots significantly differs among species, which means *Taraxacum* better accumulates Cu in tissues above ground in comparison with *Urtica* (Table 3). Values of R/S ratio also reflect this fact (Fig. 3).

In soil the concentration of Ni varied between 1.3 and 18.8 µg g⁻¹. The minimum (0.1 µg g⁻¹) was in *Urtica* stems and the maximum (19.7 µg g⁻¹) in its leaves (Fig. 2). The amount of Ni in roots of *Urtica* and in shoots and roots of *Taraxacum* was non-significantly positively correlated with its amount in soil. Ni-concentration in *Urtica* stems and, above all, leaves showed non-significant negative correlation. Ni seems to be accumulated in excess in all tissues of *Urtica*, in leaves above all, and only a little in *Taraxacum* leaves (Table 2). The *Taraxacum* root tissue which had not very high amount of Ni seemed to be specific. Both species strongly differ by root transfer factor (Table 4) and R/S ratio (Table 5).

The content of Pb was assessed between 3.3 and 23.1 µg g⁻¹ in the soil. A

![](image)

**Fig. 3.** The graphical presentation of the heavy-metal distribution between root and shoot by R/S ratio values for *Urtica dioica* and *Taraxacum* sp. The higher is the value R/S the higher concentration of particular metal in root. Mean value of R/S ratio is presented by dots and standard error by hatched areas.

### Table 3. The comparison of difference between shoot transfer factors of both plants by ANOVA. There are two significant differences between ability to accumulate Cu and Zn in shoot, when *Taraxacum* differs from *Urtica.*

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>F-ratio</th>
<th>Prob. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: R/S ratio of species</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td></td>
<td>3.59</td>
<td>0.07</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>16.82</td>
<td>0.0005*</td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>1.20</td>
<td>0.29</td>
</tr>
<tr>
<td>Pb</td>
<td></td>
<td>3.22</td>
<td>0.09</td>
</tr>
<tr>
<td>Zn</td>
<td></td>
<td>5.87</td>
<td>0.02*</td>
</tr>
</tbody>
</table>

* significant at alpha = 0.05.
minimum of Pb was found in *Urtica* leaves (0.1 µg g⁻¹) and its maximum in *Taraxacum* roots (15.8 µg g⁻¹). Roots and leaves of *Urtica* differed significantly (α=0.05) from *Urtica* stems in Pb accumulation. Similarly, a significant difference (α=0.05) was found between *Taraxacum* roots and leaves in the accumulation of this metal. Pb concentration in *Urtica* roots and *Taraxacum* leaves is slightly correlated with its concentration in the soil. There was also a positive correlation between Pb concentration in *Urtica* leaves, *Taraxacum* leaves and Pb concentration in soil (Table 1). *Urtica* stems showed a negative correlation with Pb concentration in the soil. The best ability to accumulate Pb from soil showed *Taraxacum* leaves and *Urtica* stems in contrast to other plant tissues such as roots or *Urtica* leaves. The R/S ratio belongs to the lowest one (Fig. 3). The mean R/S value of *Taraxacum* is 0.28 and of *Urtica* 0.52, which confirm the higher concentration of Pb in tissues above the ground for both species.

The concentration of Zn highly varied from 7.28 to 20.3 µg g⁻¹ in the soil and the minimum was 5.0 µg g⁻¹ in *Urtica* leaves. The maximum was 78.3 µg g⁻¹ in *Urtica* stems (Fig. 2). The values of transfer factor are relatively low, mainly in case of *Urtica*, to compare with transfer factors of other metals (Table 2). Nevertheless, a significant difference (α=0.05) was found between the shoot and leaves of *Taraxacum* in Zn accumulation. Higher concentrations were found in the *Taraxacum* shoot to compare with...
with *Urtica* shoot. The concentration of Zn in the roots and leaves of both plants are slightly positively correlated with its concentration in soil. The best ability to accumulate Zn is shown by *Taraxacum* leaves, in contrast to *Urtica* leaves (Table 2). *Taraxacum* prefers to accumulate Zn in leaves, but *Urtica* prefers tissues in the following order: stem > root > leaves. Ions of Zn in both plants are distributed differently (Fig. 3). *Urtica* prefers root but *Taraxacum* prefers shoot part.

The concentration dependence of Pb on altitude is significant and negative (Table 6). From this point of view seems that Pb ions are introduced into Litovelské Pomoraví PLA by water from higher parts of catchment area. Cd, Cu and Ni showed slight negative (non-significant) correlation with altitude as well. The scheme of pollution by these three metals seems to be similar. Yet pollution in Litovelské Pomoraví PLA do not reached critical values.

### 4. DISCUSSION

Both species studied differ in the accumulation features of heavy metals. There were some differences of transfer factor values among plant tissues of *Taraxacum* and *Urtica* as well. Generally, Cd is the most absorbed element in all plant tissues and the transfer factor of Zn belongs to lowest, which supported results of Uherčíková and Hajdúk (1998). Cu is generally mentioned as metal of “medium accumulating degree”, its transfer factor reaches 0.1–1.0 (Edwards et al. 1998). Our results confirmed this fact in case of *Taraxacum*, but transfer factors of copper for *Urtica* exceeded mentioned values. The ability of absorption grades down Cd > Ni > Cu > Zn > Pb in *Urtica* roots but roots of *Taraxacum* differ in this respect: Cd > Cu > Pb > Ni > Zn. There are also differences between elements absorption of *Urtica* leaves (Ni > Cd > Cu > Pb > Zn) and *Taraxacum* leaves (Cd > Cu > Pb > Zn > Ni). *Urtica* stems have specific absorption ability of heavy metals: Cd > Pb > Ni > Zn > Cu.

Leaves of *Taraxacum* seemed to be better accumulator of Pb and Zn. Roots of *Urtica* had higher ability to accumulate Ni. Moreover, shoots of *Taraxacum* allocate higher portion of Cu and Zn. Additional differences were also revealed by R/S ratios, by which both species are significantly distinguished (Table 5) and this fact is also supported by gradient analysis (Fig. 4). From this point of view leaves of *Taraxacum* showed the best response to heavy metal concentration in the soil. It is valid for four heavy metals with exception of Ni. Concentrations of Ni in environment were poorly reflected by response of *Taraxacum* leaves. Higher amount of Ni in the leaves of both plants may be connected with a specific function. Ni is hypothesised as an elemental defence against herbivores and pathogens in some cases (Martens and Boyd 2002). Other plant tissues of both species showed only slight correlation

### Table 6. Pearson correlation among heavy-metal concentrations in plant tissues and altitude of plant sites.

<table>
<thead>
<tr>
<th></th>
<th>Urtica leaves</th>
<th>Urtica root</th>
<th>Urtica stem</th>
<th>Taraxacum leaves</th>
<th>Taraxacum root</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>-0.33</td>
<td>-0.10</td>
<td>0.35</td>
<td>-0.07</td>
<td>-0.13</td>
<td>-0.51</td>
</tr>
<tr>
<td>Cu</td>
<td>-0.41</td>
<td>0.10</td>
<td>0.21</td>
<td>0.57</td>
<td>0.66</td>
<td>-0.53</td>
</tr>
<tr>
<td>Ni</td>
<td>0.35</td>
<td>-0.54</td>
<td>0.59</td>
<td>0.42</td>
<td>0.07</td>
<td>-0.57</td>
</tr>
<tr>
<td>Pb</td>
<td>-0.23</td>
<td>0.17</td>
<td>0.37</td>
<td>0.70</td>
<td>0.81</td>
<td>-0.71*</td>
</tr>
<tr>
<td>Zn</td>
<td>-0.26</td>
<td>-0.07</td>
<td>0.72</td>
<td>0.37</td>
<td>0.43</td>
<td>-0.36</td>
</tr>
</tbody>
</table>
or no response to concentration of heavy metals in soil.

The content of Pb in roots of both *Taraxacum* and *Urtica* were low to compare with shoot and correlation root-soil is also slight. This fact goes against Cibulka et al. (1991), who stated that Pb from soil is absorbed by roots and a huge amount remain just in the roots. Another explanation is air pollution by Pb, which affects only the green parts of plants.

It is important to point out that there were differences between soil – plant tissue correlations and the ability to accumulate metals in the tissues which is most apparent in the case of Cd. There is very little connection between the ability to excess accumulation of heavy metals and the value (high or low) of correlation coefficient. *Urtica* roots give the best resolution for Ni and Cu while *Urtica* leaves for Zn, Cu and Ni (negative correlation) and *Taraxacum* leaves for Pb.

![Fig. 4. The output of linear Unimodal Gradient analysis by CANOCO. The heavy metals are shown as arrows, which represent directions of concentration Fincrease. Measured plant parts and soil are shown as points. The relation among particular heavy metal and plant part is given by perpendicular projection of the point on the arrow. The axes of all metals are constructed relatively, not in absolute scale (in µg g⁻¹). Labelling: “A” presents gravity centre constructed from all points with a particular quality, “Urt” *Urtica*, “Tar” *Taraxacum*, “L” leaves, “S” stems, “R” roots.](image-url)
Other parts of plants have, in some cases, a better ability to accumulate metals, but their heavy-metal content only slightly depends on the metal quantity in the soil. It is reflected by gradient analysis which revealed hidden trends among heavy metals concentration in soil and responses of plant parts.

Plant tolerance and heavy metal management is based on multiple physiological mechanisms. The differences were confirmed not only among plant species, but also among plant tissues (Bezel et al. 1998, Kozanecka et al. 2002). The differences among tissue-metal-content indicate dissimilar genetic origin of both species which are determined by evolutionary processes as also stated Broadley et al. (2001). Moreover, both tested perennial plants strongly differ by kind of their growth. Taraxacum belongs to the apomictic polyploid species with hermaphrodite inflorescence and it is common rosette plant. On the other hand Urtica has another rooting system based on the rhizome and belongs to creeping plants. Moreover, it is often monoecious. Both Urtica and Taraxacum belong to common ruderals, which is one of marked common traits. Their growth strategy and hence their ability to absorb metal ions are influenced by life history and by specific evolution of tissue morphology, anatomy and physiology.

5. SUMMARY

Wetland biotopes have become rare and worthy of protection in the Middle Europe. The alluvial plain of the Morava river, Litovelské Pomoraví Protected Landscape Area (PLA) belongs among them (Fig. 1). We try to find simple method how to test heavy metals pollution in that important ecosystem.

Urtica (Urtica dioica L.) and Taraxacum (Taraxacum sp.) were chosen as model organisms because of their common presence throughout the tested area. Leaves, stems, the roots of Urtica and leaves, and the roots of Taraxacum were digested by microwave and processed by atomic absorption spectroscopy (AAS). The absolute concentration of heavy metals (Zn, Ni, Cu, Pb, Cd) was tested in soil and plant tissues (Tables 1 and 2). There were stated differences between concentrations in selected plant tissues. Correlations between the heavy-metal content in plant tissues and soil were also calculated (Table 1) and selected suitable plant tissues for biomonitoring. In addition, we also compared the transfer factors (Table 4) and performed linear unimodal Gradient analysis (Fig. 4) to see trends in the occurrence of selected elements in plant tissues and soil.

To summarise, only some plant tissues of Urtica and Taraxacum are suitable for heavy metal assessment in the Litovelské Pomoraví PLA. It could be caused by different life strategies of both plants as genotypic differences. So, there are other arrangements of next tests recommended for future tests.

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6. REFERENCES


(Received after revising January 2005)