# Distribution of heavy metals in stands of macrophytes along a cross-section gradient in the Elbe River lowland (near Poděbrady, Czech Republic)

**Distribuce těžkých kovů v porostech makrofyt rostoucích podél terénního gradientu napříč nivou Labe u Poděbrad**

Dedicated to František Procházka on the occasion of his 60th birthday

Pavel K o v á ř

*Department of Botany, Charles University, Benátská 2, 128 01 Praha 2, Czech Republic; E-mail: kovar@natur.cuni.cz*

Kovář P. (1999): Distribution of heavy metals in stands of macrophytes along a cross-section gradient in the Elbe River lowland (near Poděbrady, Czech Republic). – Preslia, Praha, 71: 249–256.

This case study aims to evaluate the degree of retention and removal of river pollutants by macrophytes. It was carried out in the Elbe river basin near Poděbrady, Czech Republic. Pollutant loads are evaluated through biomonitoring of species present in various biotopes on a transect across the floodplain: river banks, parts of the former river bed, i. e. oxbows, both connected and disconnected from the river. Pollutant-retention capacity of two species of different growth strategy and characteristics, *Glyceria aquatica* (L.)Wahlb. and *Acorus calamus* L., is also compared. Gradient of biomass pollution decreases with the distance from the river stream, depending on the "age" of the old oxbows and/or distance from the river. The level of biomass contamination with heavy metals (Pb, Cd, Cu, Mn, Zn) ranged from values common in the natural environment to values exceeding the legislative standards. Retention capacity of preserved vegetation in relation to heavy metals supports the self-purification ability of the Elbe river.

K e y w o r d s : Macrophytes, *Glyceria aquatica*, *Acorus calamus*, biomonitoring, retention capacity, surface deposit, heavy metals, Elbe River lowland

## Introduction

In general, macrophytes show differences both in uptake and tolerance to heavy metals (Pb, Cu, Cd, Mn, Zn – e. g. Abo-Rady 1980, Janauer 1985, Smith & Kwan 1989). The following questions have been raised frequently in ecotoxicological studies: Should the monitoring point be located in the rhizosphere, assimilating biomass, or on the retention surfaces? Which stands within the heterogeneous mosaics are representative enough for biomonitoring? Are there important differences between stands differing in structure and species composition within the reach of water?

Plants with ability to tolerate and even uptake and cummulate alien elements (Descy 1976) are used for purification of water environment, both passively (by allowing them to grow freely) and actively (in that case they are periodically removed from the river or used for biological purification of waste water).

Plant suitable as biomonitores should be (1) typical of the area concerned, (2) widespread and easy to collect, (3) highly tolerant to heavy metals and with a high factor of concentration, and, (4) easy to identify (Ray & White 1979). Criteria for including a species may be based on morphological, anatomical, physiological and biochemical features

(Kovář 1988, 1990). These may reflect the pollutant retention and/or deposition (Brabec & Kovář 1986), growth supression as well as changes in structure and functioning of plant communities (Kovář 1977, Kovář et al. 1987). The importance of biological monitors is reflected by our ability to quantify phytotoxical components in ecosystems and general knowledge of stress or risk imposed on other parts of the ecosystem (Guderian & Reidl 1982).

Resuspension of sediment from the river bottom induced by water movement is significantly higher in open waters than in a water body protected by vegetation (Dieter 1990). Microbial activity needed to maintain cycling of elements is restricted to transported benthic particles (Sinsabaugh & Linkins 1990); the indices of the quality of detritus increase with decreasing particle size. In northern Germany, sediments from four rivers, including Elbe river, were analyzed in 371 samples from 24 research plots, and a close positive correlation was found between the heavy metal contents and proportion of the fine fraction of deposited sediments (Lichtfuss & Brummer 1981). Relationships between plants and sediment particles used for transport of alien elements show a high variability with respect to biotopes. Unfortunately, the available data are scarce.

Biomonitoring attributes of particular stands could be assessed by relating the bioindicative information of particular species to the quality of sediment particles transported by water and deposited on plant surfaces.

## Study area

The study was carried out in the lowland of the Elbe river, in the area of the lock near Oseček (district of Poděbrady), before the inflow of the Cidlina river (Fig. 1). River banks dominated by *Glyceria aquatica* as well as other stands with the same species in the "young" river oxbow (Bajkal) and the "old" river oxbow (Volavčí) of the Elbe river were compared. Within the river bed, two types of stands dominated by species with different growth strategies (*Glyceria aquatica*, *Acorus calamus*) were compared. The data were collected in 1991.

## Material and methods

Samples of biomass from 0.25 × 0.25 m plots (4 replicates from each stand) were transported to the laboratory, washed for the deposit with distilled water and dried at 60 °C. Dry mass was finely ground in ball achate mill (Fritsch) and mineralized in a dry way (Apion). 1 g of the mineralized substance was dissolved in 1 ml $HNO_3$, diluted and the elements were measured by atomic absorption spectrophotometry (PU 9200 X, Philips). The deposit washed out from the plant surface was mineralized with $HNO_3$ under pressure. The values are given in $mg \cdot g^{-1}$ of dry material.

The following stands of *Glyceria aquatica* were tested: (a) submerged, i. e. in deeper water further in the river, (b) only sporadically overflown, i. e. on the river bank, (c) in stagnant water of the "young" river oxbow not completely isolated from the river bed (Bajkal), (d) in stagnant water of "older" oxbow (Volavčí). Besides, a series of samples of *Acorus calamus* was taken from the river. Analyses of the heavy metals (Pb, Cd, Cu, Mn and Zn) were made in both submerged and emerged biomass.


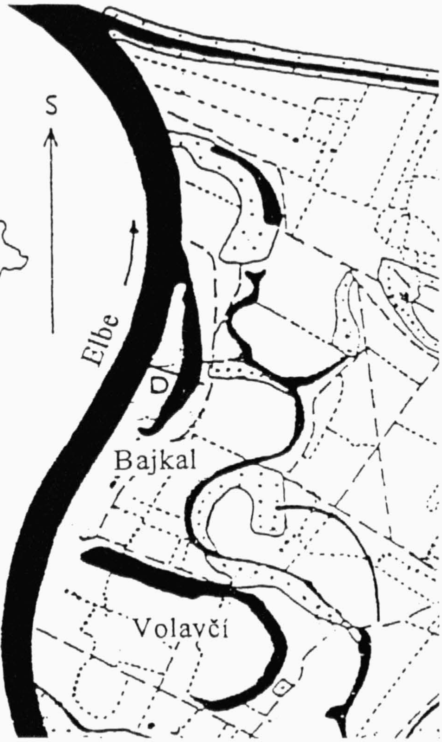


Fig. 1. – Location of the study area and situation plot.

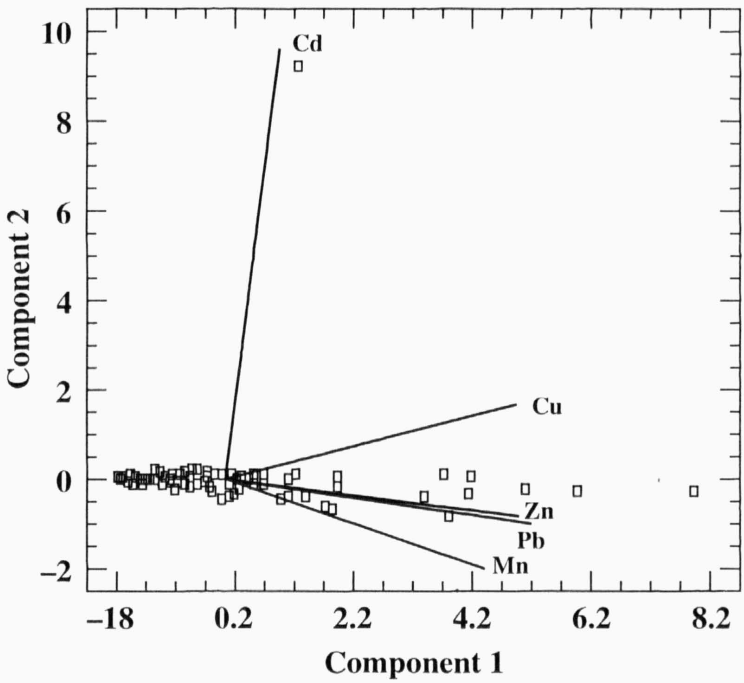


Fig. 2. – PCA ordination of the complete analytical data set along the two first variability componnets.

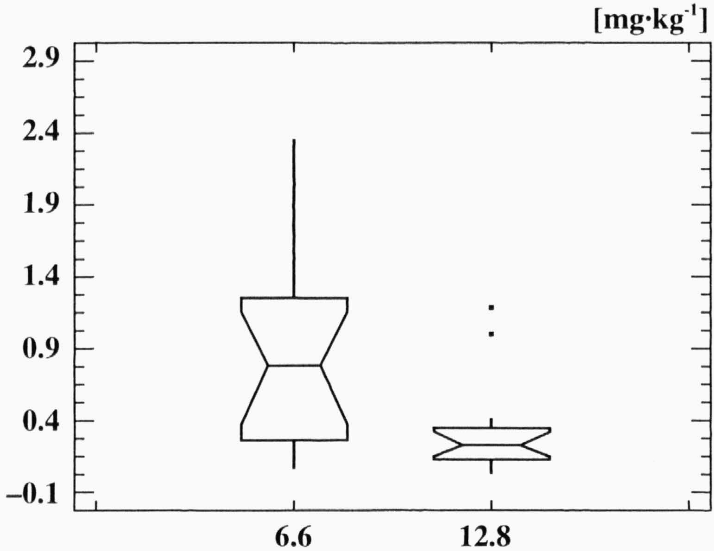


Fig. 3. – Comparison of the total metal content in plants as sampled on two different dates. The box-and-whisker plot gives following information: The central box encloses, between the upper and the lower quartile, the middle 50 % of the data values with median in the middle. The "whiskers" extend within 1.5 interquartile ranges from the quartile. Outliers are plotted as separate points. Notches correspond to 95 % confidence interval for the median, and the width of each box is proportional to the square root of the number of observations. Pairwise comparisons are performed by examining whether the two particular notches overlap. Two data sets are supposed to be significantly different if their confidence intervals do not overlap.

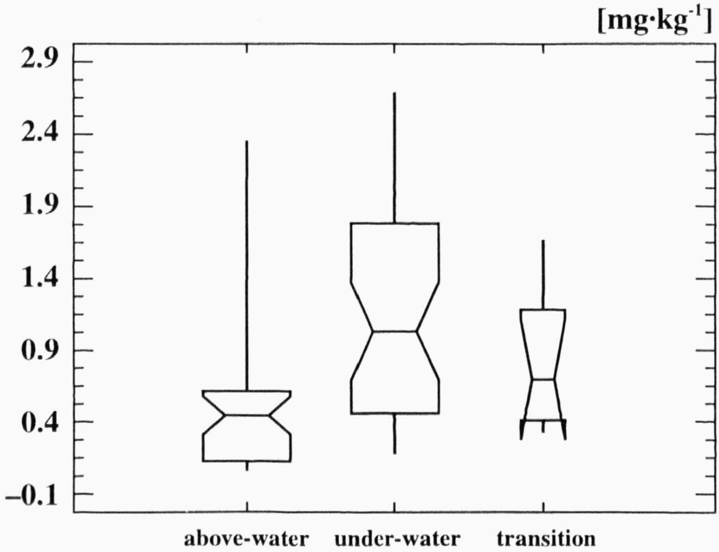


Fig. 4. – Comparison of the total content of metals in plants grown in different positions with respect to the water level. See Fig. 3 for description of box-and-whisker plot.

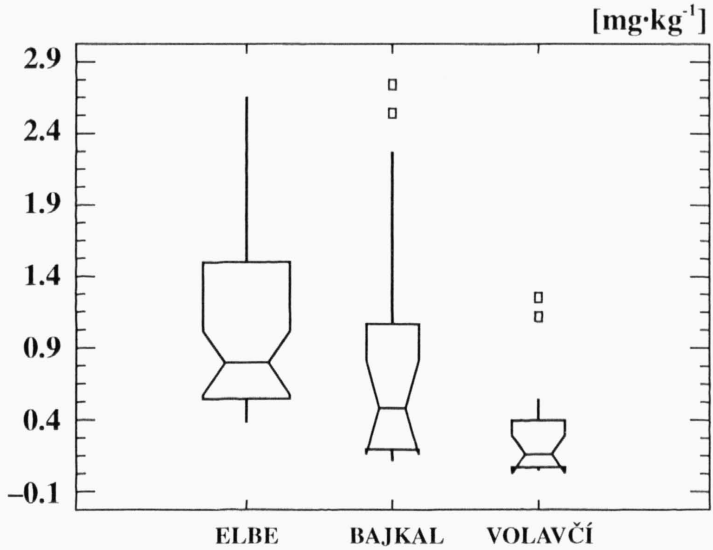


Fig. 5. – Comparison of the total content of metals in plants sampled in the three localities studied in the Elbe lowland. See Fig. 3 for description of box-and-whisker plot.

Results are summarized by using notched box-and-whisker plots. PCA was used for ordination of the heavy metals concentration in samples.

## Results and discussion

Introduction of water traffic (coal transport by tugboats) on the Elbe river to the Chvaletice power station in the 1970s changed the character of river banks. Before this traffic was introduced, continuous stands of *Glyceria aquatica* along the banks served as a buffer zone of a high sorption or retention capacity. It can be assumed (Haslam 1978, Kovář et al. 1995, Kovář 1996) that these, up to several meters wide vegetational strips at least temporarily immobilized the material carried by the river. There were, however, no local field measurements conducted then.

After the changes associated with traffic, the stands of *Glyceria* and other plants typical of the sedimentation lines along the non-regulated banks were gradually replaced by plants with a quite different adaptive strategy. These species are able to resist the wave action from busy coal-transport traffic. Spread of *Acorus calamus*, a species resistant to the increased wave action alongside the paved banks, can serve as a remarkable example. Its rhizomes are able to persist and develop in the slots between stones.

Stands in the river differ not only in the species composition; there are also differences in the monospecific stands of the same species in various sites of the floodplain such as in those of *Glyceria maxima* growing in the old river oxbows differing in age. These differences in stand structure may be due to shading (old river oxbows are fringed by tall trees) as well as to the changing water quality (decrease of pollution with increasing distance from the main river bed).

The river segment studied (near the Oseček lock) belongs to the river ecotype no. 3 of the five distinguished by landcape-ecological typology and management for the Elbe river in the Czech Republic (Kovář et al. 1991, Kovář & Hroudová 1995). For this part of the river between the towns Dvůr Králové and Mělník, flat and open niveau is typical, with fluvial deposition and alluvial forest ecosystems in a mosaic with mesic oakhorn and depauperate oakwoods. The target for the management in this segment is (1) to maintain the quality of surface and subsurface water (fishery, sources of drinking water), and in the zone of water transportation, (2) to maintain the retention and stabilization potential of the bank parts and the character of the river as biological corridor contributing to the landscape permeability both for humans and biota.

Value of the data collected in the area on two sampling dates, i. e. 6 June and 12 August, 1991, is increased by the fact that the concentration of heavy metals was measured both in plant biomass and in surface deposit retained by the biomass sampled. From the degree of correlation, it is possible to assess the relationship between the structural parameters of the vegetation and quantity of the pollutants retained. It may contribute to a more generally valid conclusions in management planning for the Elbe river.

Ordination of the complete data set can serve as an overall survey of pollution. Main areas of variability are indicated (Fig. 2). All heavy metals measured, except of Cd whose concentration values are near the limit of detectability, coincide. It is difficult to assess the source of Mn (either natural or anthropogenic). However, the Pb values were quite high. In the deposit, up to $10^2$ mg/kg of Pb was found suggesting the effect of water traffic (i. e. oil and gas pollution).

Correlation coefficients (Table 1) for the concentration values (either in biomass and deposit together, or using the biomass only) are high for Pb-Cu, Pb-Zn, Pb-Mn and Cu-Zn. Correlation between the concentration of particular elements in different components (biomass, deposit) is generally low and the respective values are not thus rerported here. Relative proportion of the metals in surface deposit to the total concentration of metals in the biomass are shown in Fig. 2. These are rather similar, ranging from 1/3 to 1/2, and the variation within one set of samples is high.

For the main dominant species of the river stream (*Glyceria aquatica*), the important factor seems to be the time of sampling (Fig. 3). Samples from August showed, compared to June, "dillution" of metals in both biomass and deposit. This may be related to the decay of leaf biomass produced in spring and the fast onset of the new biomass. When the two stream dominants, *Glyceria* and *Acorus*, were compared, the stand position with respect to the water level appears to be an important factor (Fig. 4). Both dominants were more polluted below the water surface than above it. Within the whole set of *Glyceria* stands stud-

Table 1. – Mutual correlation between contents of particular heavy metals in biomass (upper line) and in deposit (bottom line). Correlation coefficients are given (n = 84). Significant relationships (P < 0.05) are shown in bold.

| | Pb | Cd | Cu | Mn |
|---|---|---|---|---|
| Cd | 0.12 | – | | |
| Cu | **0.93** | 0.19 | – | |
| Mn | **0.70** | 0.15 | 0.10 | – |
| Zn | **0.60** | 0.09 | **0.80** | 0.13 |

ied, the locality brings about the main difference, the biggest pollution being in the main stream, the lowest in the longest isolated oxbow (Fig. 5). The presumption of different retention capacity of the two species compared (*Glyceria aquatica*, *Acorus calamus*) was not confirmed; no statistically significant differences were found. However, there is a difference between the formerly large stands of *Glyceria aquatica* along the old river banks and the contemporary sporadic occurrence (of both species) along the very narrow and sharp bank line on the paved stony banks. This suggests that with a similar retention capacity of *Glyceria* and *Acorus*, the overall amount of material retained by these stands would be one order of magnitude lower than before the river bank was paved. Obviously, it is not possible to extrapolate these results to other plant species and other combinations of ecological factors. However, it is possible to conclude, in accordance with, e. g. the survey made by Guilizzoni (1991), that the bioindication and monitoring value of species depends on competition between chemical elements, ecological factors and growth characteristics of plants.


## Souhrn

Gradient znečištění biomasy vybraných makrofyt klesá se vzdáleností od labského toku (okolí Osečku u Poděbrad), resp. se stářím vodního ramene. Úroveň kontaminace biomasy těžkými kovy (Pb, Cd, Cu, Mn, Zn) se pohybuje v pásmu od přirozených hodnot až k těm, které překračují normy. Byla zjištěna silná samočisticí schopnost řeky v těch partiích, kde zůstaly zachovány dostatečně husté a mocné porosty pobřežních makrofyt s vhodnou adaptivní strategií, resp. růstovou formou (*Glyceria aquatica*).



## Acknowledgement

Thanks are due to Ota Rauch and Karel Prach for their critical comments.


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Received on 30 April 1999
Accepted on 21 June 1999