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# Accumulation of Cd and Pb in water, sediment and two littoral plants (*Phragmites australis*, *Typha angustifolia*) of freshwater ecosystem

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**Keywords:** cadmium, lead, freshwater ecosystem, plants, sediment, water.

**Abstract:** Cd and Pb concentrations were measured in water, sediment and plant organs collected from selective sites located along the Bogdanka river (Poznań, Poland) in the 2012 growing season. The aim of the investigations was to monitor changes in heavy metal (HM) concentrations in different media over the periods, as well as to evaluate potential of two littoral plants, *Phragmites australis* and *Typha angustifolia*, for phytoremediation under natural conditions. Investigations revealed differences in HM concentrations in water and sediments. Higher values were observed in sediments than in water. The decrease in concentrations of both HMs in sediments was noted in two of the three selected water reservoirs during growing seasons, which suggests the possibility of their adsorption and accumulation by aquatic plants. Both investigated plant species accumulated ample amount of Cd and Pb in underground and aboveground plant tissues, however *T. angustifolia* revealed higher Cd translocation potential than *P. australis*. The latter revealed higher Pb accumulation in two lakes. Moreover, the translocation ratio was usually higher in spring, especially for Pb, in both plant species. Increasing level of pollution load index in sediment along the Bogdanka watercourse indicates accumulation of measured HMs.

## Introduction

Heavy metals (HMs) are introduced into the environment by both natural and anthropogenic sources. The main sources for freshwater ecosystems are agriculture due to extensive use of fertilizers (Milovanovic 2007), solid waste disposal and landfill leachates (Szyłak-Szydłowski 2012). Other sources are acid mine drainage (AMD) with a high concentration of metal-rich sulphides which are stored or abandoned (Concas et al. 2006, Rai 2008). The primary source of heavy metal pollution can be the burning of fossil fuels, coal mining (Finkelman and Gross 1999) and its allied industries (such as thermal power stations), chemical industries (Rai 2008), as well as sewage sludge (Kabata-Pendias 2006, Rai et al. 2007). Freshwater systems are a kind of sink for accumulative elements (Birch et al. 1996) and can play an important role in cleaning the environment. However, heavy metals can get accumulated in sediments and afterwards can be adsorbed by plants and released to the environment in the food chain. Moreover, heavy metals can affect biodiversity of the ecosystem and change the species combination due to the level of tolerance for certain elements. Human health is also endangered due to release of heavy metals from aquatic ecosystems (Rai 2009).

In natural water ecosystems, heavy metals can accumulate in sediments and concentrations of selected elements in water can decrease along the river flow. Many technologies are used to remove heavy metals from contaminated water, such as filtration, adsorption, chemical preparation and ion exchange (Horsfall and Alba 2003). However, in natural water ecosystems, plants can be the best solution due to their possibilities of absorption at lower concentrations, which usually occur in the environment, and due to low costs (Southichak et al. 2006). Aquatic plants can improve water quality in the ecosystem by accumulation of HMs in their organs (Stoltz and Greger 2002). Some species are more tolerant to higher concentrations of HM and can be widely used as phytoremediators in constructed wetlands, as well as play an important role in natural ecosystems. Common reed (*P. australis* Cav. Trin ex. Steudel) demonstrated a high capacity for HM accumulation due to its fast growth (Osmolovskaya and Kurilenko 2005, Zhulidov 1996) and suitable biochemical composition, i.e. high amounts of lignin and cellulose, which are known to adsorb HMs ions (Lenssen et al. 1999). Moreover, it is a widespread species occurring in a range of ecosystems ranging from very clean to highly polluted areas (Duman et al. 2007, Quan et al. 2007). Based on previous data, we can also predict that this species has a great ability to adsorb heavy metals at low concentrations (Southichak et al. 2006). The second plant chosen for the present investigations was narrow--leaved cattail (*T. angustifolia* L.), which previously also revealed some abilities to accumulate HMs (Demirezen and Aksoy 2004, Muhammad et al. 2009, Drzewiecka et al. 2010, Samecka-Cymerman and Kampers 2001). This species also revealed high productivity and can be used for wastewater treatment (Tsuchija 1991). Heavy metals mostly accumulate in belowground plant parts. However, transport to aboveground organs is also observed. In the case of Cd, usually a higher amount was noted in belowground parts (Vymazal et al. 2009), while in the case of Pb, mostly higher transport was recorded, hence a similar level as in belowground parts was observed (Peverly et al. 1995). Nevertheless, there is still some concern about Cd transport to aboveground plant parts.

Most investigations have been carried out for the examination of aquatic plants in constructed wetlands for further use in municipal wastewater (Liu et al. 2007, Vymazal et al. 2009) and landfill leachate treatment (Peverly et al. 1995). There are few investigations focused on possibilities of reduction of heavy metal concentrations by emergent plants in natural ecosystems, where usually lower levels occur. The present study attempted to address the question whether there is a relation between heavy metal concentrations in water and sediments and plants along the river watercourse. Hence, the aims of the study were as follows: (i) to examine spatial and temporal changes of Pb and Cd concentrations in water and sediments at selected investigation sites along the Bogdanka river during the growing season; (ii) to determine the accumulation of examined heavy metals in plant organs of *P. australis* and *T. angustifolia* grown in three lakes located on the course of the Bogdanka river; and (iii) to evaluate the relations between heavy metal concentrations in water, sediments and plants at the beginning and at the end of the growing season according to the possibility of potential phytoremediation. The results of HMs concentrations were related to pH and EC level in water. Moreover, contamination factor and pollution index of water and sediments were calculated to evaluate the level of pollution and indicate their potential sources.

## Materials and methods

### *Characteristics of the Bogdanka river catchment*

Investigations were carried out in the Bogdanka river catchment during the growing season of 2012. The Bogdanka river is 11.69 km long with a 51.95 km$^2$ catchment area. This is a class III watercourse and the Warta river is its recipient for 240.15 km of its course (Czarnecka 2005). The Bogdanka river runs through three water reservoirs. The first is Strzeszyńskie Lake, which is a natural flow reservoir, with 34.9 ha area, maximum depth 17.8 m and mean depth 8.2 m. Total lake catchment is 755.9 ha. The direct catchment area is 132.6 ha; 61% is covered by forests, 20% by rural area, and 16% by meadows (Buczyńska et al. 1995). The littoral zone includes mainly common reed (*Phragmites australis* Cav. Trin ex. Steudel), narrow-leaved cattail (*Typha angustifolia* L.), sedges (*Carex* sp.) and swamp sawgrass (*Cladiummariscus* (L.) Pohl). Low precipitation and high temperatures in summer cause a decrease of water level in the lake thus leading towards enhanced eutrophication. Next is Rusałka Lake, an artificial reservoir with 36.7 ha area. The maximum depth is 9.0 m, and the mean depth is 1.9 m. The shape of the lake is elongated; the maximum length is 1540 m and width is 330 m. The littoral zone is represented by common reed (*P. australis*), narrow--leaved cattail (*T. angustifolia*) and reed mannagrass (*Glyceria maxima* (Hartm.) Holmb.). The total catchment area of Rusałka Lake is 25.1 km$^2$, and direct 0.839 km$^2$. Forest covers 89% of the direct catchment and 10% is covered by meadows (Pułyk and Tybiszewska 1996). Sołacz Pond is the next water reservoir along the Bogdanka river course. It was created by damming of river water. It also has an elongated shape and has an irregular shoreline 1050 m long. The reservoir has a narrow part in the middle; hence it appears to consist of two smaller parts (Karolczak 1993). The total area of both parts is 3.6 ha. The pond is surrounded mainly by shrubs and deciduous trees. The number of plants in the pond is limited, and mainly common reed (*P. australis*), narrow-leaved cattail (*T. angustifolia*) and yellow floating heart (*Nymphoides peltata* S.G. Gmel.) are found (Janyszek et al. 2002).

### *Experimental design*

Water, sediments and plants were analysed. The water for further analyses was collected from seven sites along the Bogdanka river course, including three water reservoirs – Strzeszyńskie Lake, Rusałka Lake and Sołacz Pond – and the water stream before, between and after these reservoirs (Fig. 1). Water was sampled five times in the growing season of 2012, every month from April to September. Samples of water were placed in polypropylene bottles and acidified by nitric acid to obtain cation-exchangeable forms.

Sediments and plants were collected only from the lake's area at the beginning and at the end of the growing season – in May and September. Sediment samples were assembled with the aid of a "Heron" type tube near to plants. Two plant species were selected for the present investigations, due to their occurrence in all three water reservoirs, i.e. common reed (*P. australis*) and narrow-leaved cattail (*T. angustifolia*). Five plants of each species were selected and separated into plant organs. In the case of *P. australis* three plant organs *viz.* rhizomes, stem and leaves, while from *T. angustifolia,* rhizomes and leaves were collected.

### *Heavy metal and other analyses*

The samples were washed with Milli-Q Advantage distilled water A10 (Merck Millipore) – with the exception of soils – and dried in an electric drier at 105±1ºC for 72 h (analysis of plants/soils dry weight). Dry samples were ground to powder for 2 min in a laboratory Cutting Boll Mill. The material, as three representative samples (0.5 g each), was mineralized in a CEM Mars 5 Xpress microwave mineralization system (CEM Corp., USA) in a closed system using 65% $HNO_3$ (5 mL) and 30% $H_2O_2$ (1 mL). Digestion of the plant material was performed according to a microwave program composed of three stages: first stage – power 600 W, time 4 min, temperature 120°C; second stage – power 600 W, time 5 min, temperature 200°C; third stage – power 1200 W, time 6 min, temperature 200°C. Material after digestion was filtered through 45-mm filters and whole concentrations were made up to a final volume of 50 mL.

Analysis of heavy metal concentration in material was made by flame atomic absorption spectrometry (FAAS) using an Agilent Technologies AA Duo-AA280FS/AA280Z spectrometer

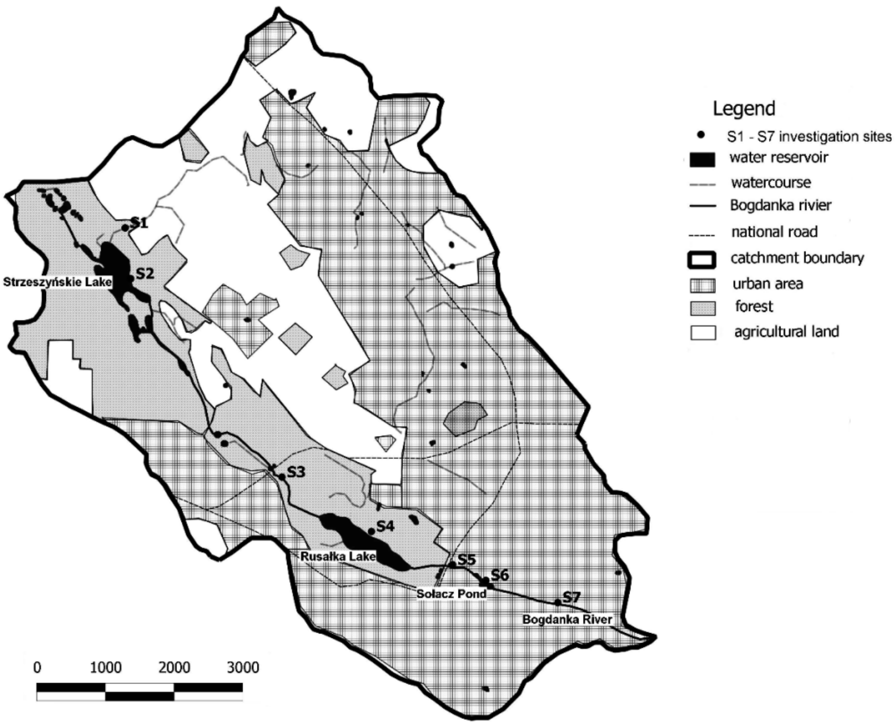


**Fig. 1.** Bogdanka river catchment with labelled investigation sites

(Agilent Technologies, Mulgrave, Victoria, Australia). All analyses used hollow-cathode lamps (HCL) (Varian and Perkin Elmer); lamps were used for one element. Pb and Cd concentration of the material was determined by procedures based on the guidelines for atomic absorption spectrometry analyses of environmental materials. To minimize the error of the complex matrix, deuterium background correction was applied. The standard curve was calibrated every day for the prepared standard solution and sample solutions (4). The results were validated by analyses of randomly selected samples by inductively coupled plasma optical emission spectrometry (ICP–OES) with a Vista MPX instrument (Varian). The achieved results of selected heavy metal concentrations in samples were validated on the basis of certified reference materials: NCS DC 73348 (Bush Branches and Leaves), NCS ZC 73003 (soil samples) and SRM 1643d (surface water) analysed in every tenth assay system. pH and electric conductivity of water were also measured using a microprocessor-based pH/mV/°C meter (pH 211) by Hanna Instruments according to PN-ISO 10390:1997 and Multi-range Portable EC Meter HI 8733 by Hanna Instruments (PN-ISO 1265+AC1:1997).

The obtained results were the basis to evaluation of water and sediments pollution degree. The contamination factor was calculated as follows:

$$C_f{}^i = \frac{C^i}{C_n{}^i} \qquad (1)$$

where $C^i$ is the mean concentration of substance in water or sediments, and $C_n{}^i$ is the reference level for the substance. The following criteria are used to describe the values of the contamination factor: $C_f{}^i < 1$, (LCF) low contamination factor; $1 \leq C_f{}^i < 3$, (MCF) moderate contamination factors; $3 \leq C_f{}^i < 6$, (CCF) considerable contamination factors; and $C_f{}^i \geq 6$, (VHCF) very high contamination factor (Zarei et al. 2014).

While Pollution load index (PLI) was calculated based on equation:

$$PLI = \frac{C_f{}^i(1) \cdot C_f{}^i(2) \cdot \ldots \cdot C_f{}^i(n)}{n} \qquad (2)$$

where *n* is the number of metals and $C_f{}^i\,(n)$ is the contamination factor analysed metals. The following criteria were used to describe the values of the pollution load index: PLI < 1, (NP) no pollution; 1 ≤ PLI < 2, (MP) moderate pollution; 2 ≤ PLI < 3, (HP) heavy pollution; and PLI ≥ 3, (EHP) extremely heavy pollution (Banerjee and Gupta 2012). The references values for water were as follows: cadmium – 2.4 μg $l^{-1}$ and lead – 3.0 μ $gl^{-1}$ (Kabata-Pendias 2006), and for sediments respectively 1.0 mg $kg^{-1}$and 7.0 mg $kg^{-1}$ (Lis and Pasieczna 2005).

### *Statistical analysis*

Statistical analysis employed STATISTICA 9.1. The results were analysed with factorial ANOVA, with period, site and plant species as fixed factors. Tukey's test was used to analyse the differences between measured parameters. For the determination of structure and rules in the relations between variables, principal component analysis (PCA) was used. In this analysis, the orthogonal transformation of observed variables to a new set of non-correlated variables (components) was performed.

## Results and discussion

### *Heavy metal concentration in water and sediments*

Two-way analysis of variance revealed the highly significant effect (α≤0.001) of period and site of investigation for Pb and Cd concentration in water and sediments (Table 1).

**Table 1.** Two-way analysis of variance of Cd and Pb concentrations in water, sediment and plant organs with period of measurement and site of measurement or period of measurement and plant organ fixed factors

| Parameter | Term of measurement | Site | | Interaction |
|---|---|---|---|---|
| Cd water | 171.9*** | 350.4*** | | 5.8*** |
| Pb water | 1362.3*** | 4293.4*** | | 532.9*** |
| Cd sediment | 66.8*** | 252.6*** | | 1.7ns |
| Pb sediment | 283.0*** | 4964.3*** | | 88.0*** |
| Accumulation in plants | | | | |
| Parameter | Water reservoir | Term | Plant's organ | Interaction |
| Cd in *P. australis* | Strzeszyńskie Lake | 125.9*** | 932.7*** | 10.1** |
| | Rusałka Lake | 14.8** | 33.2*** | 1.4ns |
| | Sołacz Pond | 125.9*** | 932.7*** | 10.1** |
| Pb in *P. australis* | Strzeszyńskie Lake | 1883.6*** | 3238.7*** | 246,3*** |
| | Rusałka Lake | 42.8*** | 335.1*** | 12.9** |
| | Sołacz Pond | 1883.6*** | 3238.7*** | 246.3*** |
| Cd in *T. angustifolia* | Strzeszyńskie Lake | 56.8*** | 100.7*** | 0.2ns |
| | Rusałka Lake | 28.9*** | 90.0*** | 3.5ns |
| | Sołacz Pond | 717.4*** | 1140.9*** | 395.2*** |
| Pb in *T. angustifolia* | Strzeszyńskie Lake | 622.3*** | 4027.6*** | 326.1*** |
| | Rusałka Lake | 298.9*** | 2605.5*** | 179.4*** |
| | Sołacz Pond | 704.9*** | 332.3*** | 404.3*** |

***α≤0.001; **α≤0.01; *α≤0.05; ns – not significant

The highest level of Cd was noted during April at the site (S1) located before Strzeszyńskie Lake; afterwards the level of Cd was maintained at a more or less similar level at this site. In Strzeszyńskie Lake (S2), the level of Cd concentration was lower in comparison to its inflow throughout the growing season. An increase of Cd concentration was observed between Strzeszyńskie Lake (S2) and Rusałka Lake (S3). This was valid for all investigation periods. Afterwards, a significant decrease in Cd concentration was observed in all periods and again a decrease was noted in the outflow of Sołacz Pond (S7). Overall, the highest values were noted in April in all investigation sites and an increase was observed in June, while during September and August, the level of Cd remained at a constant level. A different pattern of Pb concentration in water was noted. The highest levels were observed in Sołacz Pond (S6) in September and August. In the first period of investigations, an increase of Pb concentration was recorded in Strzeszyńskie Lake (S2), followed by a decrease in four sites (S3–S6), and a sudden increase at the outflow of Sołacz Pond (S7). An increase in Rusałka Lake (S4) and Sołacz Pond (S6) was observed in May, while in June, a decrease in Pb concentration was noted along the Bogdanka river course (S3–S7). A totally different pattern was noted in August, when a significant increase of Pb level was observed in Sołacz Pond (S6). Higher Pb concentrations were noted in all three water reservoirs in September in comparison to their in- and outflows (Fig. 2).

According to the values recorded for heavy metals in unpolluted surface water, none of the investigation sites revealed values of Cd and Pb above the upper limits, which were 0.2 and 25 µl $l^{-1}$, respectively (Drzewiecka et al. 2010).

Cd concentrations in sediments varied between sites. The highest level was noted in Strzeszyńskie Lake in September. A decrease during the growing season was noted in Rusałka Lake and Sołacz Pond, while an increase was observed in Strzeszyńskie Lake. A similar trend was observed in the case of Pb. However, a 5-fold decrease of Pb concentration was observed in two lakes during the growing season, while the increase in Strzeszyńskie Lake was not as high as in the case of Cd (Fig. 3). In non-contaminated soils, Cd concentration was in the range of 0.02–2 mg $kg^{-1}$, while the toxic level for plants is dependent on the plant growth phase and is assessed at the level of 3–8 mg $kg^{-1}$ (Kabata-Pendias 2006).

In our investigations, the Cd level in sediment was above that of contaminated soils in Strzeszyńskie Lake and Sołacz Pond, while in Rusałka, it was below 2 mg $kg^{-1}$ at the end of the growing season. However, sediments in all the water reservoirs revealed the Cd concentration to be below the toxic level for plants (Fig. 3). Sediments are the most important reservoir or sink of metals and other pollutants in the aquatic environment, because HMs released into aquatic systems are generally bound to particulate matter, which eventually settle and become incorporated into sediments (Peng et al. 2008). Hence, much higher values of Cd and Pb in sediments compared to water were observed in our investigations which are in agreement with those reported in other studies (Bonanno and Lo Guidice 2010, Peng et al. 2008). Moreover, the levels of Cd and Pb in recorded sediments in our investigations in all examined reservoirs were at least twice as high as in comparable water reservoir located near smaller city (Sojka et al. 2013). However, the decrease at the end of the growing season might suggest release to the environment or adsorption by aquatic plants.

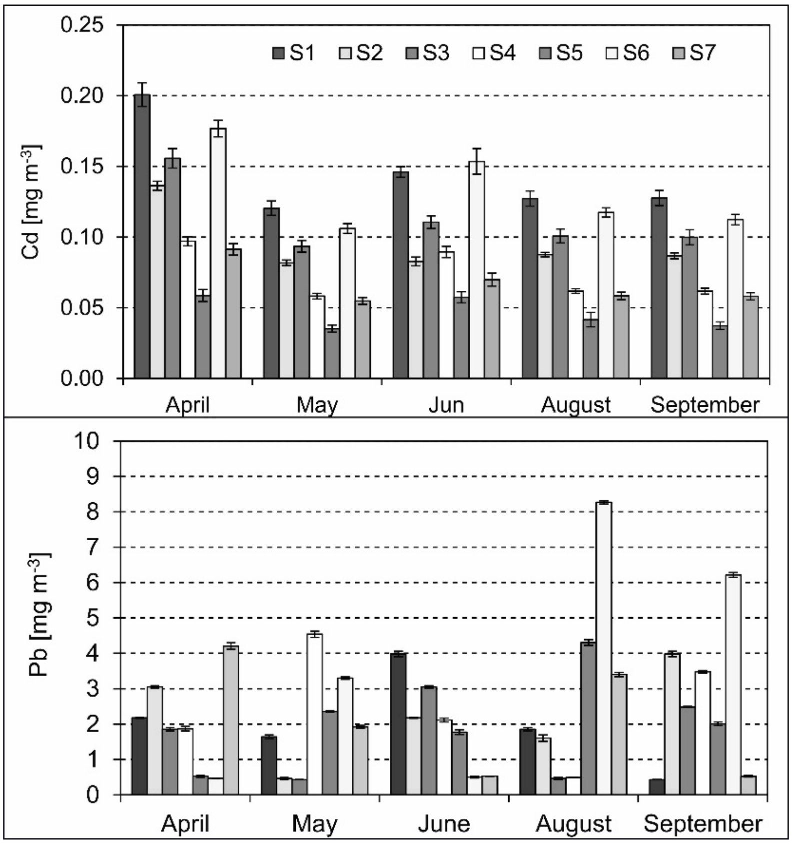


**Fig. 2.** Cd and Pb concentrations (means ±SE) in water samples collected from seven sites during five intervals

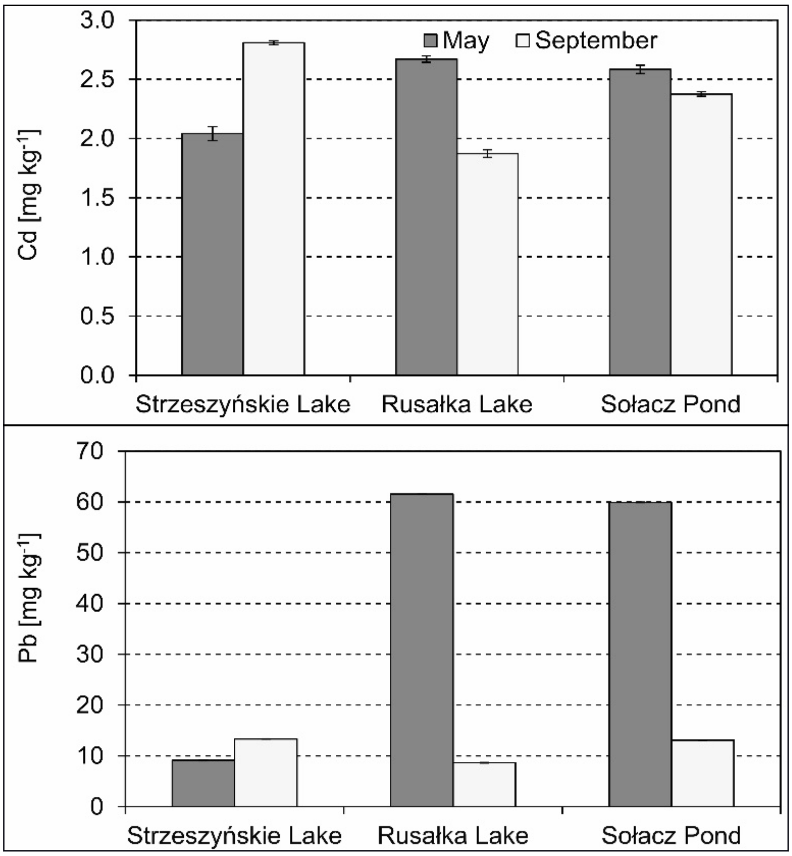


**Fig. 3.** Cd and Pb accumulation (means ±SE) in sediment samples of three water reservoirs during two measurement periods

### *Heavy metal concentrations in plant organs*

Two-way analysis of variance revealed a highly significant effect ($\alpha \leq 0.001$) of the period of investigations and plant organ on Cd and Pb concentrations in *P. australis* and *T. angustifolia* (Table 1). The highest accumulation of Cd and Pb was noted in rhizomes of plants from Strzeszyńskie Lake and Sołacz Pond at the end of the growing season. Increase in Cd and Pb concentrations in *P. australis* was noted in all plant organs during the growing season in all the three water reservoirs. In the case of Cd, lower values were noted in leaves in comparison to rhizomes and stems. This was especially true for plants collected from Strzeszyńskie Lake and Sołacz Pond (Fig. 4).

*P. australis* was found to be a good indicator and hyperaccumulator of heavy metal concentrations in a freshwater ecosystem (Bonanno and Lo Guidice 2010). Transport of Cd from belowground plant organs has been found previously. $Cd^{+2}$ ions were readily taken up by roots and translocated to leaves in many plant species, which can affect photosynthesis and nutrient uptake by plants (Mendelssohn et al. 2001). However, investigations by Stoltz and Greger (2002) revealed that Cd transport is mainly dependent on plant species. Also, some investigators found that Cd remains in roots, which act as good and effective filters (Peverly et al. 1995). Vymazal et al. (2009) found low Cd concentrations in shoots of *P. australis* growing in constructed wetland for treatment of municipal wastewater. On the other hand, some research revealed low transport of both heavy metals to leaves (Mazej and Germ 2009) or Pb as more portable element than Cd (Damodharan and Reddy 2015). In our investigations, Pb accumulation in leaves of common reed was higher than in stems of plants grown in Strzeszyńskie and Rusałka Lake.

The accumulation pattern for Pb in Sołacz Pond was similar as for Cd in this water reservoir (Figs 4 and 5). An increase in accumulation of Cd and Pb in narrow-leaf cattail during the growing season was observed. However, this tendency was not as high as observed in common reed, especially in leaves, for Pb concentrations. The transport of Pb to aboveground organs of *P. australis* was previously observed by Peverly et al. (1995). Among the two plants, higher accumulation of Cd in rhizomes of *T. angustifolia* was noted in Rusałka Lake and Sołacz Pond. In Rusałka Lake, higher transport of Cd to aboveground plant parts was also noted. In the case of Pb, higher accumulation in rhizomes of *T. angustifolia* was noted in Rusałka Lake and the transport to aboveground plant organs was slightly higher in comparison to *P. australis* (Figs 6 and 7). Transport of Pb to shoots was found in many other aquatic plant species, such as *Eriophorum angustifolium* (Stoltz and Greger 2002). However, Vymazal et al. (2009) found very low translocation of this element to aboveground plant organs in constructed wetlands.

### *Relationship between heavy metals in different media and other water parameters*

Mean pH values ranged between 8.190 and 8.452, while electric conductivity was in the range of 572.0–811.6. The highest pH levels were noted in the water collected from inflow to Rusałka Lake and in this lake, while the lowest was noted in Sołacz

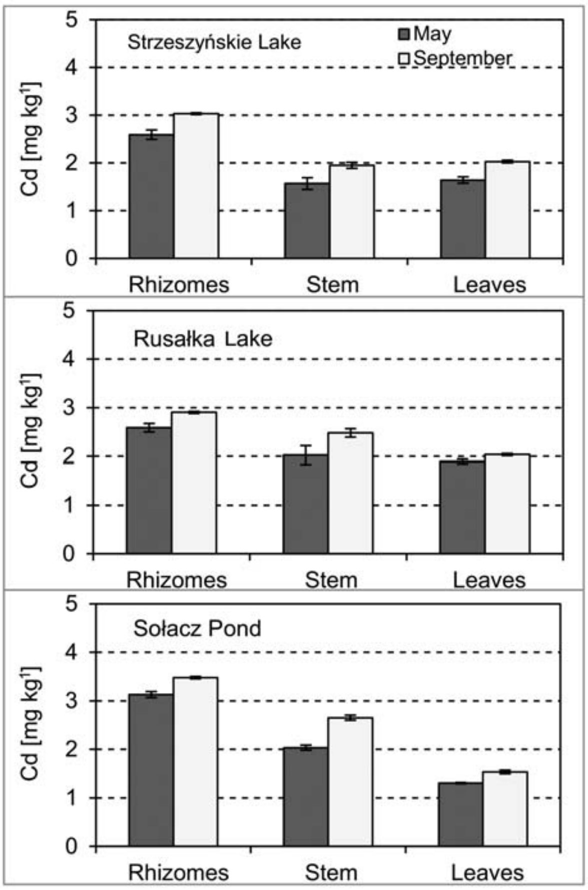


**Fig. 4.** Cd accumulation (means ±SE) in *P. australis* organs collected from three lakes during May and September

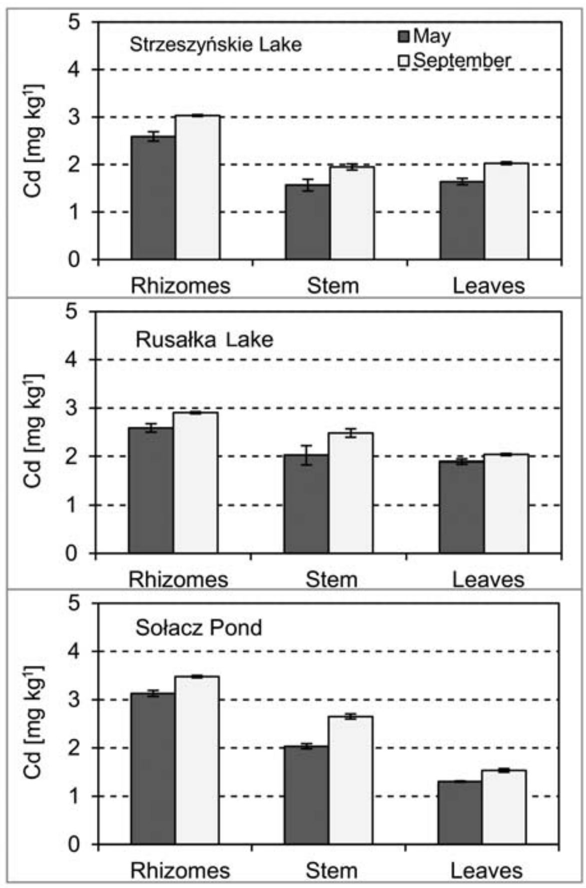


**Fig. 5.** Pb accumulation (means ±SE) in *P. australis* organs collected from three lakes within two periods

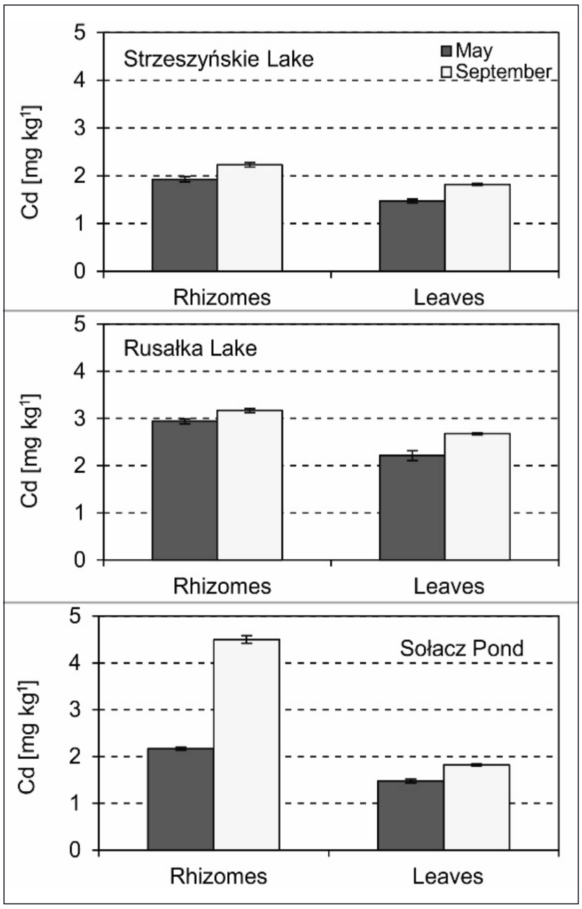


**Fig. 6.** Cd accumulation (means ±SE) in plant organs of *T. angustifolia* in three lakes in two periods

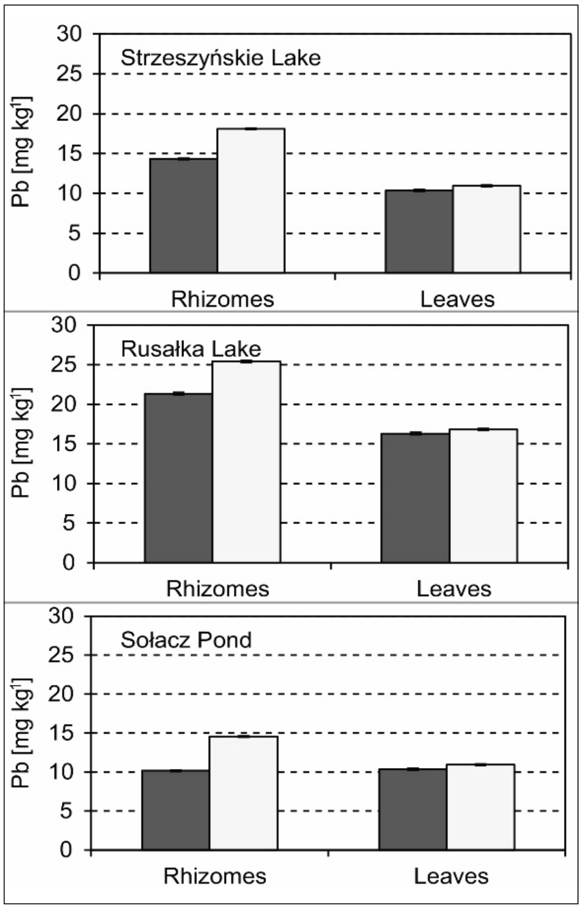


**Fig. 7.** Pb accumulation in (means ±SE) plant organs of *T. angustifolia* in three lakes in two periods

Pond. The highest EC values were recorded in the inflow to Sołacz Pond and the lowest in the inflow to Strzeszyńskie Lake (Table 2). The level of pH was relatively high in comparison to river affected by brown coal mine waters, where higher heavy metal concentrations were observed (Staniszewski and Jusik 2013, Staniszewski 2014).

A relationship between pH and heavy metal sorption was previously observed in many aquatic plant species. Southichak et al. (2006) noted the maximum $Cd^{2+}$ ion adsorption by *P. australis* at near neutral to higher pH values, while $Pb^{2+}$ ions were maximally adsorbed starting from acidic pH. In our study, we did not observe acidic pH, so it is hard to confirm these results. Positive and statistically significant (α=0.05) correlations between EC and Cd and Pb concentrations in sediments were noted. The similar tendency was previousely notted by Staniszewski (2014), who examined sediments in rives affected by brown coal mine waters. Negative relations of pH and EC with Cd concentrations were noted in *P. australis* rhizomes. Negative relation of Pb in sediments and sediment pH was found here, which is in agreement with the results previously noted by Ibragimow et al. (2013) in their investigations in the middle Odra river. Positive relations of pH with Cd and Pb concentration in *T. angustifolia* rhizomes and leaves were noted (Fig. 8).

A positive and statistically significant relation (α=0.05) was noted for Cd concentration in water and accumulation in *P. australis* rhizomes, while a negative relation was observed with leaves of both plant species and rhizomes of *T. angustifolia* (Fig. 8). A statistically significant positive correlation (α=0.05) was observed between Pb concentration in water and *P. australis* rhizomes, as well as between sediment concentration and *P. australis* stem accumulation, while a negative correlation was noted between Pb concentration in sediment and *P. australis* leaf accumulation and *T. angustifolia* rhizome concentration (Fig. 8). Previously positive relations between leaf Cd and Pb accumulation with water and sediments were noted (Bonanno and Lo Giudice 2010). In our investigations, various relations might be connected with low variability of pH, which is one of the factors affecting the adsorption of HMs by plants (Szyłak-Szydłowski 2012).

Cd translocation was higher than that of Pb in *P. australis* plants in all three water reservoirs. Moreover, higher Cd transport was noted in spring in plants collected from Rusałka Lake. This tendency was also true for Pb in all three lakes. In the case of *T. angustifolia,* a higher Cd translocation ratio was found in autumn in Strzeszyńskie and Rusałka Lake, while Pb transport was higher in spring in all water reservoirs (Table 3). This was in agreement with Duman and Obali (2008), who carried out an investigation on heavy metal accumulation in yellow pond lily. Summarizing, maybe both examined plant species are not widely treated as hyperaccumulators, however due to their fast growth, deep roots system and their tolerance to HMs in their aerial part, they can be a solution for trace elements removal in natural water systems (Copper et al. 1996), such presented in this paper.

**Table 2.** Values of pH and electrical conductivity (EC) measured in selected sites in five periods

| Site | Parameter | Term of measurement | | | | | |
|---|---|---|---|---|---|---|---|
| | | IV | V | VI | VIII | VIII | Mean |
| S1 | pH | 8.34 | 8.20 | 8.18 | 8.21 | 8.29 | 8.244 |
| | EC | 621 | 705 | 798 | 743 | 569 | 687.2 |
| S2 | pH | 8.24 | 8.27 | 8.25 | 8.30 | 8.21 | 8.254 |
| | EC | 524 | 594 | 645 | 626 | 471 | 572 |
| S3 | pH | 8.61 | 8.41 | 8.38 | 8.32 | 8.54 | 8.452 |
| | EC | 684 | 784 | 834 | 902 | 695 | 779.8 |
| S4 | pH | 8.61 | 8.41 | 8.38 | 8.32 | 8.54 | 8.452 |
| | EC | 684 | 784 | 834 | 902 | 695 | 779.8 |
| S5 | pH | 8.37 | 8.32 | 8.3 | 8.26 | 8.46 | 8.342 |
| | EC | 698 | 831 | 902 | 921 | 706 | 811.6 |
| S6 | pH | 8.31 | 8.17 | 8.16 | 8.06 | 8.25 | 8.190 |
| | EC | 674 | 795 | 874 | 838 | 652 | 766.6 |
| S7 | pH | 8.30 | 8.20 | 8.19 | 8.11 | 8.26 | 8.212 |
| | EC | 683 | 785 | 858 | 820 | 637 | 756.6 |

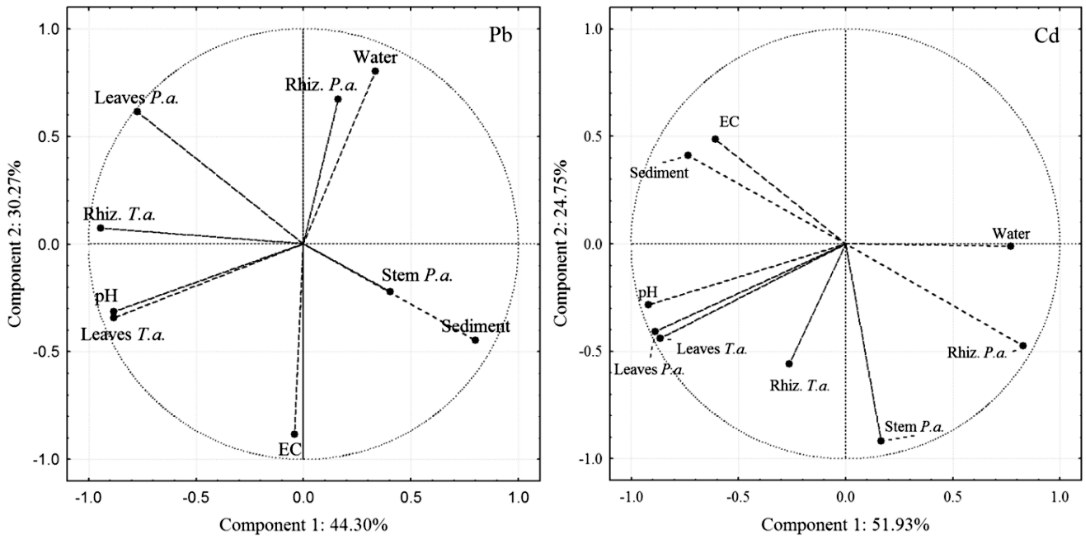


**Fig. 8.** Principal component analysis of Pb and Cd concentrations in plant organs, water sediments together with pH and EC (Rhiz. – *rhizomes; P.a. – P. australis; T.a. – T. angustifolia*)

**Table 3.** Leaf/rhizome translocation ratios for Cd and Pb in *P. australis* and *T. angustifolia* plants

| Plant species | Time of measurement | Strzeszyńskie Lake | Rusałka Lake | Sołacz Pond |
|---|---|---|---|---|
| Cd | | | | |
| *P. australis* | May | 0.634 | 0.733 | 0.416 |
| | September | 0.669 | 0.701 | 0.442 |
| *T. angustifolia* | May | 0.765 | 0.752 | 0.680 |
| | September | 0.816 | 0.845 | 0.404 |
| Pb | | | | |
| *P. australis* | May | 0.756 | 0.873 | 0.661 |
| | September | 0.698 | 0.856 | 0.553 |
| *T. angustifolia* | May | 0.722 | 0.765 | 1.017 |
| | September | 0.605 | 0.662 | 0.753 |

***Evaluation of water and sediments pollution degree by HMs***

Cadmium contamination factors in water values were noted below 1.000 in all examined water reservoirs, which indicates low contamination levels. In the case of lead the moderate contamination levels (1.017–1.160) were observed only in Sołacz Pond, while in the rest of the lakes, low contamination levels were noted (Table 4). Based on Banerjee and Gupta (2012), Zarei et al. (2014) who recorded Pollution Load Index (PLI) below 1.000 and concluded that the most of pollutants derived from natural processes.

The analysis of sediments pollution degree revealed moderate contamination levels of cadmium (1.873–2.809) in all examined water reservoirs. In the case of lead the moderate contamination levels (1.236–1.903) were noted for sediments collected from Strzeszyńskie Lake and Rusałka Lake, while very high contamination levels (8.555–8.792) were recorded in Sołacz Pond (Table 5). High level can be connected with relatively close distance to city highway from the East side of the pond. The values of PLI indicated the lowest sediments pollution in Strzeszyńskie Lake, while the highest was noted in Sołacz Pond. Spatial distribution of PLI indicates an increasing level of sediments pollution together with watercourse of the Bogdanka river. According to Sekabira et al. (2010) and Banerjee and Gupta (2012) if PLI values exceed 1.000 the human activities are the main sources of pollution.

## Conclusions

The Cd concentrations varied along the Bogdanka river course, while Pb concentration increased along the watercourse. An increased pollution load index (PLI) for sediments along the Bogdanka watercourse indicates accumulation of measured elements. Moreover, the values of PLI indicate anthropogenic sources of sediments pollutions. Moreover, Pb accumulation in the last water reservoir was observed at the end of the growing

**Table 4.** Contamination factors ($C_f^i$) and pollution load index (PLI) of Bogdanka river waters

| Month | Water reservoir | Contamination factor ($C_f^i$) | | Pollution load index (PLI) |
|---|---|---|---|---|
| | | Cd | Pb | |
| April | Strzeszyńskie Lake | 0.057 (LCF) | 0.546 (LCF) | 0.016 (NP) |
| May | Strzeszyńskie Lake | 0.034 (LCF) | 0.534 (LCF) | 0.009 (NP) |
| June | Strzeszyńskie Lake | 0.034 (LCF) | 0.623 (LCF) | 0.011 (NP) |
| August | Strzeszyńskie Lake | 0.037 (LCF) | 0.591 (LCF) | 0.011 (NP) |
| September | Strzeszyńskie Lake | 0.036 (LCF) | 2.071 (MCF) | 0.037 (NP) |
| April | Rusałka Lake | 0.040 (LCF) | 0.618 (LCF) | 0.012 (NP) |
| May | Rusałka Lake | 0.024 (LCF) | 0.618 (LCF) | 0.007 (NP) |
| June | Rusałka Lake | 0.037 (LCF) | 0.705 (LCF) | 0.013 (NP) |
| August | Rusałka Lake | 0.026 (LCF) | 0.669 (LCF) | 0.009 (NP) |
| September | Rusałka Lake | 0.026 (LCF) | 0.641 (LCF) | 0.008 (NP) |
| April | Sołacz Pond | 0.074 (LCF) | 1.017 (MCF) | 0.037 (NP) |
| May | Sołacz Pond | 0.044 (LCF) | 1.017 (MCF) | 0.022 (NP) |
| June | Sołacz Pond | 0.064 (LCF) | 1.160 (MCF) | 0.037 (NP) |
| August | Sołacz Pond | 0.049 (LCF) | 1.100 (MCF) | 0.027 (NP) |
| September | Sołacz Pond | 0.047 (LCF) | 1.134 (MCF) | 0.027 (NP) |

LCF – low contamination levels, MCF – moderate contamination levels,
NP – no pollution

**Table 5.** Contamination factors ($C_f^i$) and pollution load index (PLI) of Bogdanka river sediments

| Month | Water reservoir | Contamination factor ($C_f^i$) | | Pollution load index (PLI) |
|---|---|---|---|---|
| | | Cd | Pb | |
| May | Strzeszyńskie Lake | 2.041 (MCF) | 1.300 (MCF) | 1.326 (MP) |
| September | Strzeszyńskie Lake | 1.873 (MCF) | 1.236 (MCF) | 1.157 (MP) |
| May | Rusałka Lake | 2.809 (MCF) | 1.903 (MCF) | 2.673 (HP) |
| September | Rusałka Lake | 2.583 (MCF) | 1.866 (MCF) | 2.411 (HP) |
| May | Sołacz Pond | 2.671 (MCF) | 8.792 (VHCF) | 11.740 (EHP) |
| September | Sołacz Pond | 2.375 (MCF) | 8.555 (VHCF) | 10.161 (EHP) |

MCF – moderate contamination levels, VHCF – very high contamination levels,
MP – moderate pollution, HP – heavy pollution, EHP – extremely heavy pollution

season. Freshwater ecosystems are a kind of sink for heavy metals emitted from different sources. Sediments accumulated more HMs than water which can release them to further plants. A decrease of both HM concentrations in sediments was noted at the end of the growing season in the last two water reservoirs. Release to the environment or adsorption by aquatic plants could occur. High accumulation of Cd and Pb in plant organs was noted at the end of the season. Moreover, a higher leaf/rhizome translocation ratio was noted in the case of Pb in *P. australis*. The translocation of measured parameters was also mostly higher in *T. angustifolia* plants. Overall, plants revealed potential for phytoremediation in natural conditions, when relatively low Cd and Pb concentration occurred.

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## Akumulacja Cd i Pb w wodzie, osadzie i dwóch gatunkach roślin szuwarowych (*Phragmites australis*, *Typha angustifolia*) ekosystemów wodnych

**Abstrakt**: Stężenie Cd i Pb mierzono w wodzie, osadach, jak również w organach roślin zebranych z wybranych stanowisk zlokalizowanych wzdłuż biegu rzeki Bogdanka (Poznań, Polska) w sezonie wegetacyjnym 2012 roku. Celem badań był monitoring zmian zawartości metali ciężkich w różnych mediach w określonym czasie, jak również ocena dwóch gatunków roślin szuwarowych, *Phragmites australis* i *Typha angustifolia*, pod kątem zastosowania do fitoremediacji w warunkach naturalnych. Badania wykazały zróżnicowanie w stężeniach metali ciężkich w wodzie i osadach. Wyższe wartości zanotowano w osadach w porównaniu do wody. Zmniejszenie stężenia obu badanych pierwiastków zanotowano w osadach w dwóch z trzech badanych zbiorników w ciągu sezonu wegetacyjnego, co sugeruje możliwość ich absorpcji i akumulacji przez rośliny wodne. Oba badane gatunki zakumulowały pewne ilości Cd i Pb w częściach podziemnych i nadziemnych, jednakże *T. angustifolia* wykazała wyższy potencjał do translokacji Cd w porównaniu do *P. australis*. Ta ostatnia wykazała z kolei wyższy poziom akumulacji Pb w dwóch jeziorach. Współczynnik translokacji był w większości przypadków wyższy w okresie wiosennym, w szczególności dotyczy to Pb dla obu badanych gatunków. Zwiększający się poziom indeksu ładunku zanieczyszczeń w osadach wzdłuż biegu rzeki Bogdanka wskazywał na akumulację badanych pierwiastków.