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CADMIUM AND LEAD ACCUMULATION IN TWO LITTORAL PLANTS OF FIVE LAKES IN POZNAN, POLAND

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We measured cadmium and lead concentrations in two littoral plants (*Phragmites australis* Cav. Trin ex. Steudel and *Typha angustifolia* L.) collected in June and September 2007 from five selected lakes in the Poznan city area, and also in sediment and water samples from the same places. We determined the metal concentrations in rhizomes and leaves, and in sediment and water from the littoral and near the bank zone. Only low levels of the heavy metals were found. Pb and Cd concentrations were higher in water collected from the bank zone than from the littoral zone. Pb and Cd accumulation was noted in sediments. Heavy metal levels were higher in rhizomes than in stems and leaves. The studied aquatic macrophytes may be bioaccumulators and bioindicators of Pb and Cd in freshwater in natural conditions, even when concentrations are low.

Key words: Cadmium, lead, accumulation, *Phragmites australis*, *Typha angustifolia.*

INTRODUCTION

Water is a very important component of the biosphere. Water pollution originates from both natural and anthropogenic sources, but over 90% of Cd, Cu, Pb and Zn content in sediments and water is associated with human activity (Kabata-Pendias and Pendias, 1999).

Some water plants such as common reed (*Phragmites australis* Cav. Trin ex. Steudel) and narrow-leaved cattail (*Typha angustifolia* L.) can accumulate excessive levels of heavy metals (Kufel and Kufel, 1980). This feature makes it possible to use them for water, soil and sediment decontamination. It is necessary to develop methods to remove low concentrations of heavy metals economically (Hermle et al., 2006; Volesky, 2000). Many experiments have been done on removal of bulk amounts of heavy metals from water and sediments (Fourest and Roux, 1992; Holan and Volesky, 1994), but only a few at low concentrations of pollutants. Controlled experiments have used *Phragmites australis* (Ait Ali et al., 2004; Southichak et al., 2006). The possibility of using littoral plants to remove heavy metals from water bodies in natural conditions is an important area of research.

The main sources of heavy metals in plants are soil, water, ambient air and precipitation (Fillion et al., 2009). Trace elements can be absorbed through leaf surfaces or via the root system (Bose et al., 2008). A common feature of animals and plants is their tolerance to certain levels of elements (Yang et al., 2005). A toxic response is observed if the level of elements is too low or too high (Kabata-Pendias and Pendias, 1999).

Cadmium in water is connected with anthropogenic sources, and the level worldwide oscillates around 0.02 μg dm^{-3}. The main source of Cd is particle deposition and river loads brought with river flow (Kabata-Pendias and Pendias, 1999). Annual cadmium deposition in Poland ranges from 2 to 20 g ha^{-1}. Cadmium is actively absorbed as the cation Cd^{2+}, the hydrated ion and a metal-organic chelate. The quantity of absorbed cadmium depends on the soil pH. Cadmium content in plant organs varies, and the range in aboveground organs is usually from 0.05 to 0.22 mg kg^{-1}. A toxic response is

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observed in plants when the concentration exceeds 5-30 mg kg^{-1} (Das et al., 1997; Kabata-Pendias and Pendias, 1999).

Since lead is hardly a mobile element, Pb concentrations are highest in the upper soil horizon in humus (O'Neill, 1998). The natural background level of lead in water is very low, because its compounds are poorly soluble in water. The mean lead concentration in groundwater worldwide is 2 $\mu g\ dm^{-3}$. This element is highly bioaccumulated by plants, algae and fish (Kabata-Pendias and Pendias, 1999). Lead is accumulated mainly in roots, and a small amount is transported to aboveground organs of plants (Mleczek et al., 2009). Hence, aboveground parts of plants are endangered mainly by lead deposition from ambient air (Buczkowski et al., 2002). Toxic Pb concentrations in plant tissue are put at 30-300 $\mu g\ g^{-1}$ (Roos, 1994). The main sources of lead pollution are sludge from battery production, toy production, printing, the petroleum industry, waste water and exhaust gases (Demirezen and Aksoy, 2004).

In this study we determined cadmium and lead content in various parts of common reed (*Phragmites australis*) and narrow-leaved cattail (*Typha angustifolia*) collected from city lakes. We examined the possibility of using littoral plants as bioaccumulators of heavy metals in the city.

MATERIAL AND METHODS

CHARACTERISTICS OF LAKES

The investigations were carried out in Poznan, a city of about 560,000 inhabitants, where five lakes are located (Fig. 1). These bodies of water are very popular for summer recreation because of their proximity to the city center. Previous work revealed high nutrient pollution in four of the five investigated lakes. Little is known about heavy metal content in the area's littoral plants and their habitat.

The biggest body of water in the Poznan area is Kierskie Lake (285.5 ha), located in the northwest part of the city and constituting almost 50% of the town's surface water. Its maximum depth is 37.6 m and mean depth is 10.1 m. Wastewater from households and nutrients in runoff from fields are the main sources of water pollution in this lake. The highway next to the lake may be also a source of pollution.

Strzeszyńskie Lake is also in northwestern Poznan. The area of this natural reservoir is 34.9 ha, maximum depth 17.8 m and mean depth 8.2 m. It is a very popular recreation place during summer months. There are motels, restaurants, cottages and campgrounds at the lake shore (Pułyk and Tybiszewska, 1996).

Fig. 1. Location of the investigated water bodies in Poznan, Poland (1 – Kierskie Lake, 2 – Strzeszyńskie Lake, 3 – Rusałka Lake, 4 – Sołacz Pond, 5 – Malta Lake).

Rusałka Lake, an artificial reservoir 36.7 ha in area, is located in western Poznan (Buczyńska et al., 1995). Its maximum depth is 9.0 m and mean depth 1.9 m. During the summer a sport and recreation center operates. As this lake is very close to the city center, during the summer it is very popular among the residents of Poznan (Pułyk and Tybiszewska, 1996).

Sołacz Pond is a small body of water (3.6 ha) in Sołacz Park, and is a very popular place for walkers during the whole year.

Malta Lake is in the eastern part of the city. This artificial reservoir, covering 64 ha, is a destination for sport and recreation (Anders et al., 2002). A tourist boat has been running since 2000 on this lake (Maluśkiewicz, 2000). This place is very popular with residents and visitors for recreation and sports.

We collected plants and sediment from one site at each water body. Site selection was based on previous field studies.

PLANT MATERIAL

For our purposes we chose two common littoral zone plant species: common reed (*Phragmites australis*) and narrow-leaved cattail (*Typha angustifolia*). These two species grew in the littoral zone of all five investigated lakes.

Common reed is a large perennial grass which reaches 2–4 m in height, and in favorable conditions even 5 m. The root system is extensive, and the rhizomes are long (Kłosowski and Kłosowski, 2001). The leaves are long for a grass, 20-50 cm long and 2-3 cm wide. The flowers are produced in late summer in a dense, dark purple panicle 20-50 cm long. It is very widespread species in the littoral zones of Polish lakes and rivers. It occurs in peat and clay, soils, wetlands and boggy areas. Common reed usually populates oligotrophic and eutrophic water and usually forms a reed zone (*Phragmitetum communis*) (Kłosowski and Kłosowski, 2001; Polakowska, 1976).

Narrow-leaved cattail is also a perennial grass, reaching 2.5 m maximum height. The plant is unbranched, consisting of a flowering stalk and 4 or more leaves. The leaves are 25-150 cm long and 3-10 cm across. The inner side of each leaf is flat to slightly concave, while the outer side is convex. The stalk terminates in a spike of pistillate flowers and a spike of staminate flowers; the staminate spike is above the pistillate spike, and they are separated from each other by at least 1.5 cm and usually a few centimeters. It is a very common littoral plant in Poland. It populates oligotrophic and eutrophic rivers, lakes and moats with sandy, clay and loam soils. It usually forms a cattail zone (*Typhetum angustifoliae*) (Kłosowski and Kłosowski, 2001).

EXPERIMENTAL DESIGN

Plant material was collected twice during 2007, at the beginning of the growing period (June 5) and at the end of plant physiological activity (September 5). Five plants were gathered from each selected site and divided into parts, and samples for analysis of heavy metals content were prepared. Common reed was separated into leaves, stems and rhizomes, and narrow-leaved cattail was separated into leaves and rhizomes.

Simultaneously with plant collection, water samples were collected 50 cm below the water surface in the littoral zone (the plant zones were treated as biogeochemical barriers) and near the bank area. Collected water was acidified with nitric acid for fixation of interchangeable forms. Sediment samples were collected close to plants. As Malta Lake is an artificial lake, sediment was not collected from it.

PLANT PREPARATION FOR HEAVY METAL ANALYSIS

Material (±250 g fresh weight) was collected in 100 cm^3 polypropylene containers and dried in an electric drier for 48 h (or longer) at 105±5°C. Dry material was ground in an electric laboratory mill. The sawdust fraction (0.5–1 mm) was used for determination of cadmium and lead concentrations. Material was mineralized in a Mars 5 Xpress microwave sample mineralization system by CEM in a closed system using HNO_3 and H_2O_2.

HEAVY METAL ANALYSIS

Analysis of heavy metal content in material was conducted by flame atomic absorption spectrometry (FAAS) with an AA Varian Spectra 200 spectrometer. All analyses used hollow-cathode lamps (HCL) (Varian and Perkin Elmer); lamps were used for one element. Lead and cadmium content of the material was determined by procedures based on the guidelines for AAS 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 exhibiting concentrations within the range up to 75% of the standard curve were prepared. 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) and inductively coupled plasma mass spectroscopy (ICP-Mass Spec) with an UltraMass-700 instrument. Achieved results of selected heavy metals concentration level in samples were validated on the basis of certified reference materials: NIST 1575a (pine needles), NCS DC 73350 (leaves of poplar), Montana Soil S-1 (soil samples) and SRM 1643d (surface water) analyzed in every fifteenth assay system.

STATISTICAL ANALYSIS

Statistical analyses employed STATISTICA 8.1. Results were analyzed with factorial ANOVA, with term, lake and species as fixed factors. Tukey's test was used to analyze the differences between measured parameters. Shapiro-Wilk's test was used to check the normality of the data distributions and Levene's test for homogeneity of variance.

RESULTS

ANALYSIS OF SEDIMENTS

Heavy metal concentrations were determined in sediment of the Kierskie, Strzeszyńskie and Rusałka lakes and Sołacz Pond. Lead content in sediment averaged 22.73 mg kg^{-1} and ranged from 4.17 to 70.42 mg kg^{-1}. It was highest in Sołacz Pond in both periods. In three of these water bodies the lead concentrations were higher in sediment of the *Phragmites australis* zone; in the other one, Strzeszyńskie Lake, lead content was higher in sediment of the *Typha angustifolia* zone. In Sołacz Pond the lead concentration in sediment was higher in the second period of sampling (Fig. 2). The

TABLE 1. Factorial ANOVA for Cd and Pb content in two littoral plants species

	Pb				Cd			
	Term	Lake	Species	Interaction	Term	Lake	Species	Interaction
Leaves	***	***	***	***	***	***	***	***
Rhizomes	***	***	***	***	***	***	***	***
Sediment	***	***	***	***	***	***	***	***
Littoral water	***	***	ns	ns	***	***	ns	ns
Beach water	***	***	***	***	ns	**	ns	ns

*** $p < 0.001$, ** $p < 0.01$, ns – not significant

cadmium concentration in sediments at the two sampling periods was lowest in Kierskie Lake (0.495 mg kg^{-1}) and highest (2.984 mg kg^{-1}) in the Sołacz Pond. Cadmium concentrations were higher in sediments of the *Typha angustifolia* zone in Kierskie and Strzeszyńskie lakes, and in the *Phragmites australis* zone of Rusałka and Sołacz lakes. As in the case of lead, the cadmium concentration was higher in the second period in Sołacz Pond (Fig. 3).

ANALYSIS OF WATER

Heavy metal concentrations in water collected from littoral zones and near the bank were lower than those in sediments. The lead concentration in lake water was lowest in Malta Lake (3.478 mg m^{-3}) and highest in Sołacz Pond (4.795 mg m^{-3}). In contrast, the cadmium concentration in water was highest in Malta Lake (0.049 mg m^{-3}) and lowest in Sołacz Pond (0.028 mg m^{-3}). In the first period of measurement the lead concentrations were higher in the littoral zone than near the bank, except at Sołacz Pond. The situation changed during the next two months – lead concentrations were higher in the littoral zone in Kierskie, Strzeszyńskie and Rusałka lakes, and near the bank in Malta Lake and Sołacz Pond (Fig. 4). Cadmium concentrations in water did not vary between the littoral zone and near the bank in Strzeszyńskie, Rusałka and Sołacz lakes at the beginning of June. In the first period of measurement, in Kierskie Lake the cadmium concentration was higher in the bank zone, while in Malta Lake it was lower in that zone. Cadmium concentrations changed in water collected in the second sampling, and also were higher in the bank zone in all lakes, especially Malta Lake (Fig. 5).

ANALYSIS OF PLANTS

Lead and cadmium concentrations in the plants were closely related to their content in sediments. Heavy metal accumulation in plants was similar to that in sediments in each water body except the artificial Malta Lake. Lead concentrations were highest in *Typha angustifolia* at Sołacz Pond and Malta Lake in both harvesting periods. The lead concentration was also higher in *Typha angustifolia* in Strzeszyńskie Lake, while in Kierskie and Rusałka lakes the Pb concentrations were lower and similar. Lead concentrations were slightly higher in the second harvesting period in both plant species (Fig. 6).

The cadmium concentrations in plants were highest in samples from Sołacz and Rusałka lakes in both harvesting periods. Cadmium levels were higher in *Typha angustifolia* from Kierskie Lake and Sołacz Pond. As with lead, cadmium content in plants was slightly higher in the second harvesting period (Fig. 7).

The distribution of the measured elements in plant organs was also examined. The concentrations of both elements were highest in roots (Figs. 8, 9). Pb and Cd accumulation in rhizomes and leaves varied significantly between harvest periods, lakes and species, and also between sediments (not taken from Malta Lake, an artificial reservoir). Concentrations of measured elements in water (both for littoral zone and bank zone) were not connected with plant species (Tab. 1).

Analysis of the relationship between metal concentrations in biotic and abiotic elements of water ecosystems revealed a high linear correlation coefficient between accumulation in leaves, rhizomes and sediment, for both analyzed metals. Moreover, the correlation between concentrations in sediment and water from the littoral zone was significant at $\alpha=0.001$ for lead, and for cadmium at $\alpha=0.05$. There was no significant correlation between metal concentrations in plants and in sediment in relation to water near the bank, for Pb as well as for Cd (Tab. 2 and 3).

DISCUSSION

Littoral plants are commonly used in constructed wetlands to accumulate large amounts of heavy metals (Peverly et al., 1995; Southichak et al., 2006; Vymazal et al., 2009). There is still little data on the

TABLE 2. Linear correlation coefficients and significance levels for relation between selected parameters for lead concentration

Pb concentration	Sediment	Leaves	Rhizomes	Littoral water	Beach water
Sediment	1				
Leaves	r = 0.624 p < 0.001	1			
Rhizomes	r = 0.684 p < 0.001	r = 0.676 p < 0.001	1		
Littoral water	r = 0.610 p < 0.001	r = 0.432 p = 0.002	r = 0.458 p = 0.001	1	
Beach water	r = -0.151 p = 0.306	r = -0.006 p = 0.968	r = 0.016 p = 0.911	r = -0.424 p = 0.003	1

TABLE 3. Linear correlation coefficients and significance levels for relation between selected parameters for cadmium concentration

Cd concentration	Sediment	Leaves	Rhizomes	Littoral water	Beach water
Sediment	1				
Leaves	r = 0.901 p < 0.001	1			
Rhizomes	r = 0.596 p < 0.001	r = 0.791 p < 0.001	1		
Littoral water	r = 0.296 p = 0.041	r = 0.111 p = 0.451	r = 0.124 p = 0.401	1	
Beach water	r = -0.132 p = 0.370	r = -0.208 p = 0.155	r = -0.018 p = 0.903	r = 0.330 p = 0.022	1

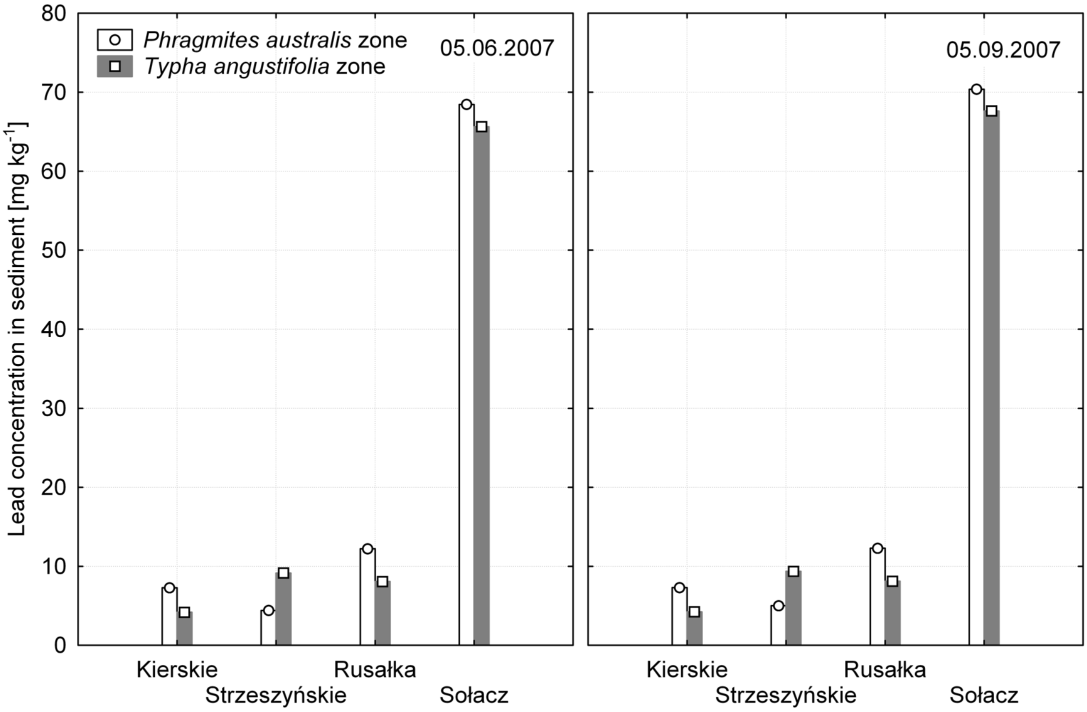

Fig. 2. Lead concentrations in sediments sampled twice from selected water bodies in *Typha angustifolia* and *Phragmites australis* littoral zones. Vertical bars represent 95% confidence intervals (too small to be visible at this scale).

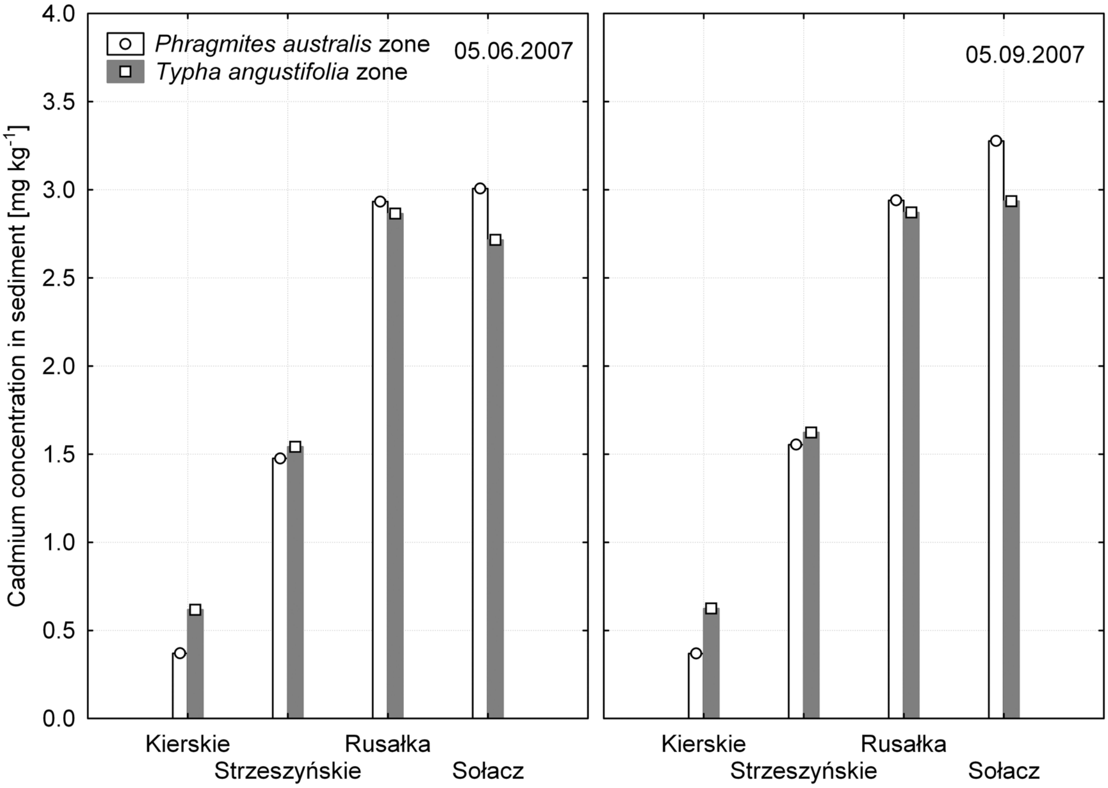

Fig. 3. Cadmium concentrations in sediments sampled twice from selected water bodies in *Typha angustifolia* and *Phragmites australis* littoral zones. Vertical bars represent 95% confidence intervals (too small to be visible at this scale).

usefulness of these plants as bioaccumulators under natural conditions where relatively low concentrations of heavy metals occur (Southichak et al., 2006), and very little research on the use of littoral plants as heavy metal bioindicators and/or as buffers against the spread of heavy metals over large areas in a freshwater environment.

Our work here is intended to help fill this gap. Although the lead and cadmium concentrations in sediments and water of the investigated city lakes were relatively low, some accumulation of these toxic elements by *Phragmites australis* and *Typha angustifolia* was observed. Concentrations were lower in water of the littoral and bank zones than in sediment. The finding that Pb and Cd concentrations were higher at the end of summer in bank zone water samples than in the littoral zone water samples from most of the studied lakes suggests that both plant species accumulated the investigated elements. That the heavy metal content of water of the littoral and bank zones was independent of the plant species means that both species influenced the decrease of Pb and Cd concentrations in littoral zone water.

This suggestion is supported by our analysis of heavy metal content in *Phragmites australis* and *Typha angustifolia*, which revealed an increase in the second period of measurement. Our findings show that these species can serve as good bioaccumulators and bioindicators of heavy metals in water bodies under natural conditions.

Belowground parts of plants generally seem to be good retaining filters for several heavy metals in littoral plants such as *Phragmites australis, Phalaris arundinacea* (Vymazal et al., 2007), *Typha angustifolia, Potamogeton pectinatus* (Demirezen and Aksoy, 2004), *Carex rostrata* (Stoltz and Greger, 2002), *Nuphar lutea* and *Potamogeton nodosus* (Mazej and Germ, 2009), although some authors have observed transport of Pb to the upper parts of plants, for example in *Phragmites australis* (Peverly et al., 1995; Liu et al., 2007) and *Eriophorum angustifolium* (Stoltz and Greger, 2002). The latter feature might be useful in constructed wetlands for removing heavy metals from sediments by harvesting shoots. In natural conditions, higher concentrations of toxic elements in aboveground parts of plants might be dangerous to animals feeding on these plants. The positive and statistically significant linear correlation between Pb and Cd concentrations in the studied plants and in sediments indicates bioaccumulation. Demirezen and

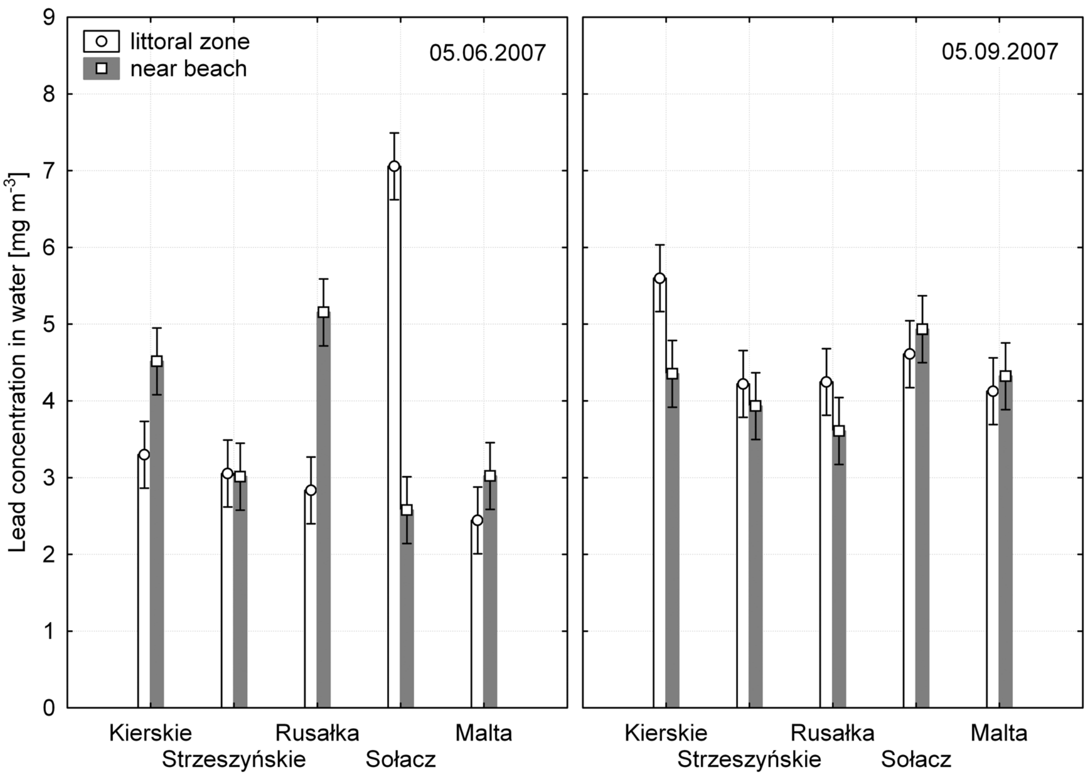

Fig. 4. Lead concentrations in water sampled twice from the littoral zone and the near bank. Vertical bars represent 95% confidence intervals.

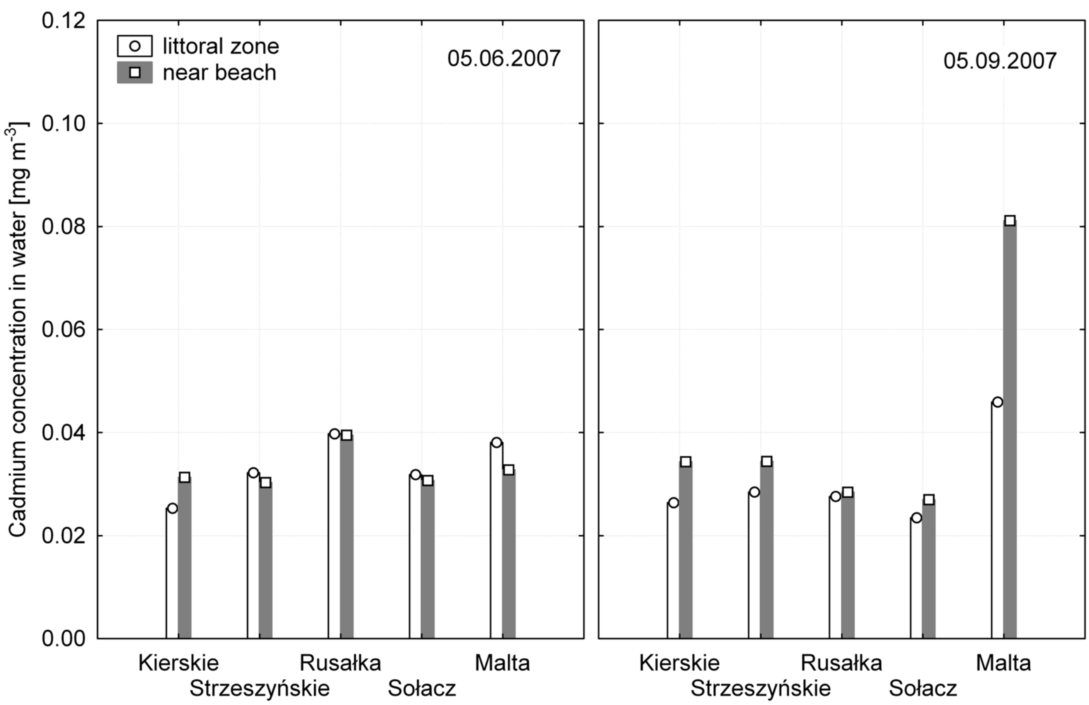

Fig. 5. Cadmium concentrations in water sampled twice from the littoral zone and near the bank. Vertical bars represent 95% confidence intervals (too small to be visible at this scale).

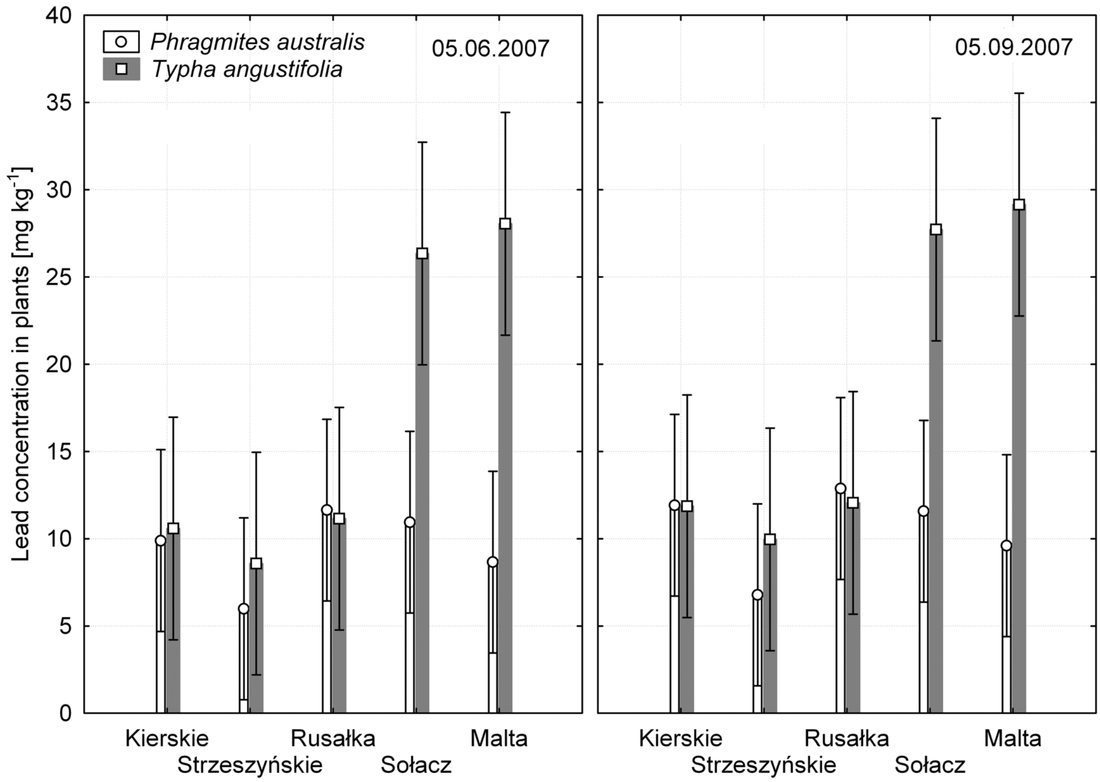

Fig. 6. Lead concentrations in *Typha angustifolia* and *Phragmites australis* sampled twice from selected lakes. Vertical bars represent 95% confidence intervals.

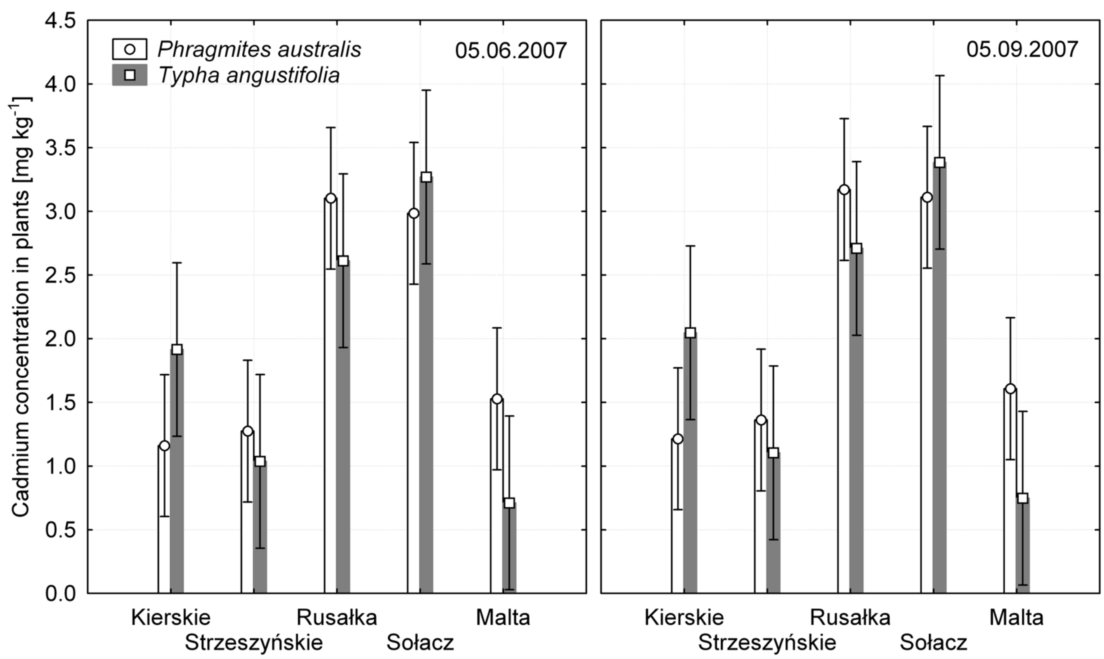

Fig. 7. Cadmium concentrations in *Typha angustifolia* and *Phragmites australis* sampled twice from selected lakes. Vertical bars represent 95% confidence intervals.

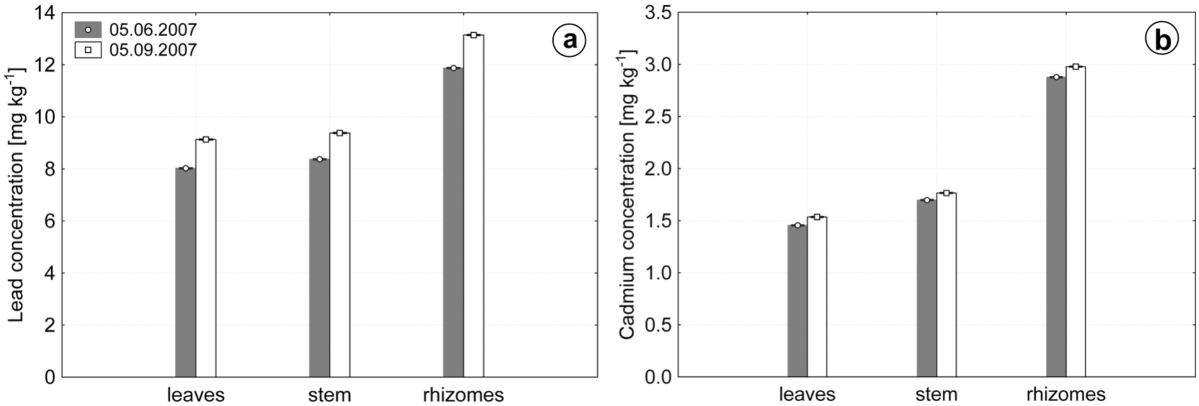

Fig. 8. Lead **(a)** and cadmium **(b)** concentrations in selected plant parts of *Phragmites australis* sampled twice. Vertical bars represent 95% confidence intervals.

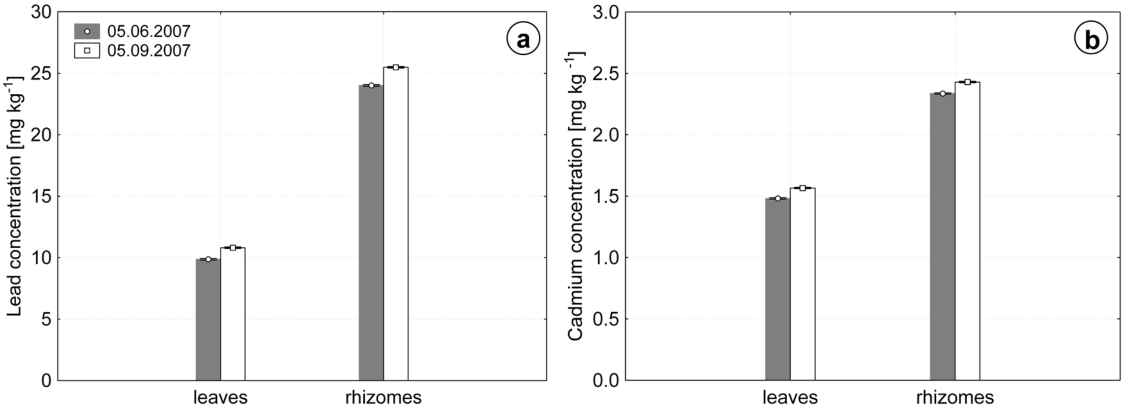

Fig. 9. Lead **(a)** and cadmium **(b)** concentrations in selected plants parts of *Typha angustifolia* sampled twice. Vertical bars represent 95% confidence intervals.

Aksoy (2004) reported similar results from research in the Sultan Marsh natural wetlands, where *Typha angustifolia* grew. On the other hand, investigations of aquatic macrophytes in rivers revealed higher absorption of heavy metals from water, especially in downstream river sections where heavy metals may accumulate (Lewander et al., 1996).

This study suggests that *Phragmites australis* and *Typha angustifolia* may be used as bioaccumulators and bioindicators of lead and cadmium at low metal concentrations in natural freshwater conditions. As accumulation of the analyzed elements was higher in rhizomes, there seems to be no danger to animals feeding on the aboveground plant parts. The littoral plants accumulated cadmium and lead, and the water samples from the littoral zone contained less heavy metals than water from the bank zone. Hence, these littoral plant species show potential for use as a biological barrier against the spread of heavy metal pollution in lakes.

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