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Phragmites australis and *Typha angustifolia* as Potential Accumulators of Zinc and Copper in Water Ecosystem at City Area

Jolanta Kanclerz, Klaudia Borowiak, Mirosław Mleczek, Ryszard Staniszewski, Marta Lisiak
Poznań University of Life Sciences

1. Introduction

Metal accumulation in wetland plants depends on many factors, such as oxic/anoxic conditions, pH, dissolved and particulate organic carbon contents, concentration of organic and inorganic ligands, which control the balance of heavy metal exchange between sediments and water, as well as bioavailability of trace elements to plants (Greger 2004).

Zn and Cu are very specific trace elements due to their dual function in plants. Hence, it is quite difficult to determine their positive or negative effect. It has been found that both have an essential effect on plant metabolism function, such as enzymatic activity (Marchner 1995, Zayed & Terry 2003). There are some mechanisms developed by plants to avoid the negative effect of high levels of these elements on photosynthesis activity, such as accumulation in roots. Most studies revealed translocation of Zn to above-ground parts of plants (Aksoy et al. 2005, Vymazal et al. 2009), while Cu seems to be a more stationary element, and only in the case of very high levels was higher accumulation noted in leaves and stems (Southichak et al. 2006, Baldantoni et al. 2004, Bragato et al. 2006).

The aims of this study were as follows: (i) to examine zinc and copper accumulation by two littoral plant species in artificial lake located in the city area; (ii) to evaluate time course of zinc and copper concentrations in water and selected plant species during the growing season; (iii) to examine the translocation of analysed trace elements in the plant organs.

2. Materials and methods

Characteristics of survey site

According to the physical and geographical classification of Poland, the Cybina river lies in Wielkopolska Lakeland (Kondracki 2009). This river is a third order river, and the right tributary of the Warta river. The river catchment area is 190.61 km^2 (Fig. 1). According to the code system of the European Union, the river received the code 1858 (Czarnecka 2005).

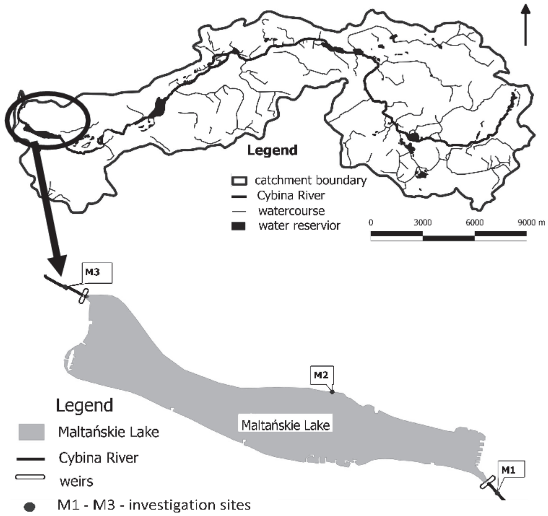

Fig. 1. Cybina river catchment with labeled investigation sites
Rys. 1. Zlewnia rzeki Cybiny wraz z zaznaczonymi punktami pomiarowo-kontrolnymi

Malta Lake is located in the lower part of the Cybina catchment. The reservoir covers a maximal area of 65.5 ha, with a length of 2.2 km, which makes it the biggest artificial water reservoir in the city of Poznan. The mean depth is over 3.13 m, while the maximum is 5 m. This water reservoir was built for water sports, active and passive recreation and fire-protection purposes (Bogucki & Staniewska-Zątek 1996). Once every four years the water is drained and the lake is deepened together with conservation activities.

Collection of samples

The water samples were analysed from three sites – along the Cybina river course (inflow and outflow of Malta Lake) and from Malta Lake (Fig. 1). Measurements were performed every month from April to September, excluding July.

Plants were collected only from the lake area at the beginning and at the end of the growing season – in May and September. Common reed (*Phragmites australis* Cav. Trin ex. Steudel) and narrow-leaved cattail (*Typha angustifolia* L.) were chosen for heavy metal concentration investigations. Five plants of each species were selected, and divided into plant organs. In the case of *Phragmites australis* three plant organs, rhizomes, stem and leaves, while from *Typha angustifolia* rhizomes and leaves were collected. The water and plant zinc and copper analysis were performed according methodology previously described by Borowiak et al. (2016).

Accumulation and translocation indices

The follow indexes were calculate to analysed water and plant contamination, bioaccumulation and translocation in plant organs.

The contamination factor was calculated as follows:

$$C_{f}{}^{i} = \frac{C^{i}}{C_{n}{}^{i}} \tag{1}$$

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

The accumulation efficiency of analysed trace elements in plant organs was described using bioaccumulation factor (BAF) values calculated according to Cohen et al. (1998) as the ratio of a trace element concentration in individual plant (rhizomes, stems and leaves) organs and trace element concentrations in water:

$$BAF = \frac{trace\ element\ concentration\ in\ plant\ organ\ (\mu l\ l^{-1})}{trace\ element\ concentration\ in\ the\ water\ (\mu l\ l^{-1})} \quad (2)$$

BAF values greater than 1 indicate accumulation, while those lower than one indicate a lack of accumulation.

Additionally, in order to describe trace elements' transport from water to the plants, the translocation factor (TF) was calculated according to Yu & Zhou (2009) applying the following formula:

$$TF = \frac{trace\ element\ concentration\ in\ leaves\ or\ stem\ of\ plants\ (\mu l\ l^{-1})}{trace\ element\ concentration\ in\ root\ or\ stem\ of\ plants\ (\mu l\ l^{-1})} \quad (3)$$

Wherein TF>1 indicates that the plant translocates metals effectively.

Statistical analyses employed STATISTICA 9.1. Results were analyzed with factorial ANOVA, with period, site and plant species as fixed factors. Tukey's test was used to analyze the differences between measured parameters. For 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) is performed.

3. Results and discussion

Heavy metal concentration in water

Site and date of sampling significantly ($\alpha \leq 0.001$) influenced on both measured heavy metal concentrations in water (Table 1).

Copper concentration in water was the highest in the Cybina river inflow to Malta Lake. Moreover, at all measurement points the highest values were noted in July and afterwards the level of this element decreased. However, it did not reach the level at the beginning of the season (Fig. 2).

Additionally, the Cu concentration in water at the Malta outflow was almost twice as low as that at the inflow. Zinc concentrations revealed similar tendencies at sites and during the season as copper. However, there was not such a large decrease at the outflow point (Fig. 2).

Table 1. Two-way analysis of variance of Cu and Zn concentrations in water and plant organs with period of measurement and site of measurement or period of measurement and plant organ fixed factors (***α ≤ 0.001; **α ≤ 0.01; *α≤0.05; ns – not significant)
Tabela 1. Dwuczynnikowa analiza wariancji stężenia Cu i Zn w wodzie i organach roślin z okresem oraz miejscem pomiarowym albo okresem pomiarowym i organem rośliny jako czynnikami wpływającymi na badany parametr (***α ≤ 0.001; **α ≤ 0.01; *α ≤ 0.05; ns – nieistotne statystycznie)

Trace element	Term of measurement	Site of measurement	Interaction
Water concentrations			
Cu	31.8***	1872.7***	0.9ns
Zn	12.4***	233.7***	0.04ns
Accumulation in plants			
	Term of measurement	Plant's organ	Interaction
Phragmites australis			
Cu	560.9***	2864.8***	41.1***
Zn	1986.4***	7584.1***	17.5***
Typha angustifolia			
Cu	206.4***	1618.9***	0.16ns
Zn	1061.1***	4241.8***	77.9***

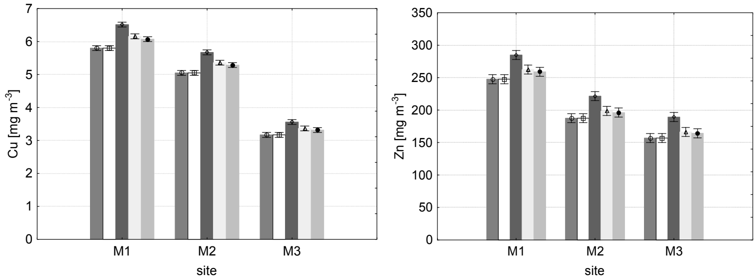

Fig. 2. Cu and Zn concentrations in water collected from three sites within five periods
Rys. 2. Stężenia Zn i Cu w wodzie pobranej z trzech stanowisk pomiarowych w pięciu terminach

Cu concentrations were determined as a medium level of C_{fi}, while Zn was identified as a very high level of C_{fi}. The pollution load index revealed non-polluted water (Table 2).

The contamination factor of Cu was at relatively low levels in comparison to the industrial area of river water collected near to the industrial area of Kosovo, while Zn reached very high values several times higher than those observed in the industrial area (Ferati et al. 2015). The pollution load index was three times lower than that recorded by Ferati et al. (2015), although in both cases the pollution level was not reached. Cu and Zn were noted at higher or equal levels as for our samples in comparison to water collected from a coastal port area of Malaysia (Sany et al. 2013) and the Maharlu saline lake in Iran (Moore et al. 2009).

Table 2. Contamination factor of all measured trace elements and Pollution Load Index of water in measurement sites and terms;
MCF – $1 \leq C_f^i < 3$ – moderate contamination factors;
VHCF – $C_f^i \geq 6$ – very high contamination factor.
Tabela 2. Współczynnik zanieczyszczenia cynku i miedzi w wodzie we wszystkich punktach i terminach badawczych.
MCF – $1 \leq C_f^i < 3$ – umiarkowany współczynnik zanieczyszczenia;
VHCF – $C_f^i \geq 6$ – bardzo wysoki współczynnik zanieczyszczenia

Month	site	Contamination factor (C_f^i)	
		Cu	Zn
April	M1	1.934 (MCF)	82.526 (VHCF)
May		1.934 (MCF)	82.526 (VHCF)
July		2.172 (MCF)	94.966 (VHCF)
August		2.053 (MCF)	87.477 (VHCF)
September		2.025 (MCF)	86.362 (VHCF)
April	M2	1.683 (MCF)	62.496 (VHCF)
May		1.683 (MCF)	62.496 (VHCF)
July		1.891 (MCF)	73.858 (VHCF)
August		1.787 (MCF)	66.246 (VHCF)
September		1.763 (MCF)	65.401 (VHCF)
April	M3	1.056 (MCF)	52.315 (VHCF)
May		1.056 (MCF)	52.315 (VHCF)
July		1.186 (MCF)	63.129 (VHCF)
August		1.121 (MCF)	55.454 (VHCF)
September		1.106 (MCF)	54.746 (VHCF)

Accumulation of trace elements in plant organs

Two-way ANOVA revealed a highly ($\alpha \leq 0.001$) significant effect of plant organ on concentrations of both elements in plants, similarly as the period of sampling (Table 1). There was noted an increase of both analysed elements during the growing season considering plant organs of both plant species. Similarly as findings of Vymazal et al. (2007) in constricted wetlands as well as Drzewiecka et al. (2011) and Duman et al. (2007) in natural water ecosystems.

Zinc and copper also revealed an increase of concentration during the growing season. Higher accumulation was noted in *P. australis* rhizomes, while accumulation in leaves varied between species. Higher accumulation of zinc at the beginning of the growing season was observed in *P. australis*, while Cu concentration was slightly higher at the end in *T. angustifolia* leaves (Fig. 3). The bioaccumulation factor was above 1 only for Cu in rhizomes and stems of *P. australis* and rhizomes of *T. angustifolia*, while Zn was always lower than 1 (Table 3).

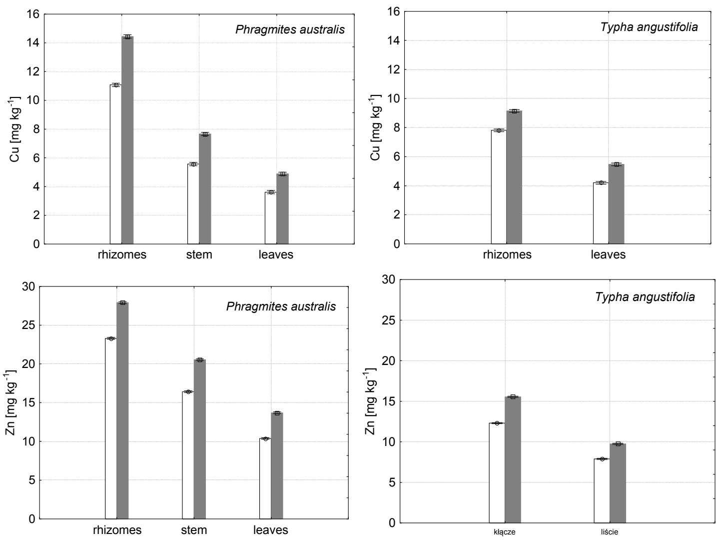

Fig. 3. Cu and Zn accumulation in *Phragmites australis* and *Typha angustifolia* organs collected from Malta Lake within two periods
Rys. 3. Poziom akumulacji Cu i Zn w organach *Phragmites australis* i *Typha angustifolia* zebranych z Jeziora Malta w dwóch terminach badawczych

The higher translocation factor values were noted for *P. australis* from rhizomes to stems for Zn concentrations (Table 4). High transport of Zn to above-ground plant parts was previously noted by Saraswat & Rai (2009) in six species cultivated in heavy metal contaminated soils, Windham et al. (2003) in two dominant salt marsh macrophytes, and

Lesage et al. (2007) in *P. australis* grown in a wetland constructed for treating domestic wastewater. Meanwhile, Marques et al. (2007) recorded poor translocation of zinc to aboveground sections.

Table 3. Bioaccumulation factor (BAF) values for plant organs from water in two measurement terms in *P. australis* and *T. angustifolia*
Tabela 3. Wskaźnik bioakumulacji (BAF) w organach roślin *P. australis* i *T. angustifolia* badanych w dwóch terminach

Term of measurement	BAF values					
	Cu	Zn	Cu	Zn	Cu	Zn
	P. australis					
	rhizomes		stems		leaves	
May	2.19	0.12	1.1	0.09	0.72	0.06
September	2.73	0.14	1.45	0.1	0.93	0.07
	T. angustifolia					
May	1.55	0.07	–	–	0.83	0.04
September	1.73	0.08	–	–	1.03	0.05

Table 4. Translocation factor (TF) values for plant organs
Tabela 4. Wskaźnik translokacji (TF) dla organów roślin

Term of measurement	Plant organs	Translocation factors	
		Cu	Zn
	P. australis		
May	rhizomes → stems	0.50	0.70
September		0.53	0.74
May	rhizomes → leaves	0.33	0.45
September		0.34	0.49
	T. angustifolia		
May	rhizomes → leaves	0.54	0.64
September		0.60	0.63

Relations between parameters

Principal component analysis revealed a positive relation between water concentration of Zn and Cu and accumulation in plant organs. However, in the case of Cu this relation was highly significant

($p \leq 0.001$). Inthe case of zinc correlation between water and leaves of both species was relatively weak (Fig. 4).

Zinc and copper are closely related elements. When in the environment Zn content is higher than Cu, it can reduce Cu uptake by plants (Bose et al. 2008). Other investigators also found an effect of Cu on higher uptake of Zn (Luo & Rimmer 1995).

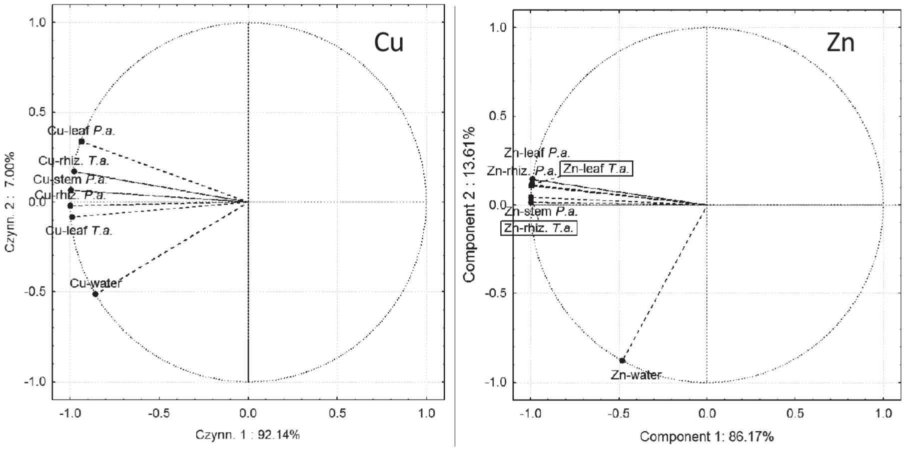

Fig. 4. Principal component analysis of Cu and Zn concentrations in plant organs and water (*Rhiz. – rhizomes; P.a. – P. australis; T.a. – T. angustifoli*a)
Rys. 4. Analiza składowych głównych dla cynku i miedzi zakumulowanych w roślinach i wodzie

4. Conclusions

A decrease of Zn an Cu along the Cybina watercourse was recorded. Moreover, the contamination factor of Cu and Zn was at a medium and very high level. Very high C_{fi} of zinc did not result in a high level of BAF, while Cu of the three elements revealed a high level of BAF. Moreover, Zn revealed the higher translocation to upper parts of plants of both analysed species in comparison to Cu. Uptake and transport to upper parts of plants of all elements was positively correlated with water concentration. However, the lowest relation was found for Zn. Zn uptake is usually closely related to Cu concentration in the environment; hence here there were noted some disturbances.

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Phragmites australis i *Typha angustifolia* jako potencjalne rośliny akumulujące cynk i miedź w ekosystemie wodnym zlokalizowanym na terenie miasta

Streszczenie

Dwa gatunki wodne były analizowane pod kątem akumulacji cynku i miedzi ze zbiornika wodnego zlokalizowanego na terenie miejskim. Przeprowadzono również badania zawartości tych pierwiastków w wodzie w celu odniesienia uzyskanych wyników w roślinach. Stężenia Zn i Cu były mniejsze na odpływie z jeziora Malta. Współczynnik zanieczyszczenia wykazały bardzo wysoki poziom Zn w wodzie, podczas gdy Cu na niskim i średnim poziomie. W ciągu sezonu wegetacyjnego zauważono zwiększenie stężenia w organach roślin obu gatunków. Stwierdzono niższy poziom akumulacji cynku aniżeli miedzi w roślinach. Wykazano ponadto wyższy poziom akumulacji obu pierwiastków w podziemnych częściach roślin. Wskaźnik translokacji wskazuje na większy transport do części nadziemnych cynku aniżeli miedzi.

Abstract

Two water plant species were analysed as potential accumulators of zinc and copper in water reservoirs in city areas. Moreover, water analysis were performed during the growing season to find some relations. Zn and Cu concentrations in water decreased at the outflow of Malta Lake. The contamination factor revealed very high values for Zn concentration in water, while Cu was at a low or medium level. Accumulation of both trace elements in plant organs was observed during the growing season in all plant organs. Zn bioaccumulation was found at lower level than Cu. Higher levels of both heavy metals were noted for belowground organs However, the translocation factor indicated that Zn were transported in the higher amounts to the above-ground parts of plants.

Słowa kluczowe:
ekosystem wodny, cynk, miedź, rośliny wodne

Keywords:
water ecosystem, zinc, copper, water plants