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THE BIOACCUMULATION OF HEAVY METALS BY THE MUSSELS *ANODONTA WOODIANA* (LEA, 1834) AND *DREISSENA POLYMORPHA* (PALL.) IN THE HEATED KONIN LAKES

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ABSTRACT. Determinations were made of the contents of heavy metals (Mn, Fe, Cu, Zn, Pb and Cd) in the soft tissues and shells of the mussels *Anodonta woodiana* and *Dreissena polymorpha* which inhabit the discharge channels of the Pątnów and Konin power plants and the heated Konin lakes. The studied mussels contained higher concentrations of metals, especially of Cu, Zn, and Pb, than did mussels of the family Unionidae and *D. polymorpha* which occur in fresh water reservoirs that are not polluted by dust fall-out from power plants. In the environments which were compared, the adult mussels of the genus *Anodonta* cumulate metals in greater concentrations than do *D. polymorpha*; this is due to their life span which is at least twice as long.

Key words: *ANODONTA WOODIANA*, *DREISSENA POLYMORPHA*, HEAVY METALS, BIOACCUMULATION, POLLUTION

INTRODUCTION

Pollutants emitted by the Pątnów and Konin power plants accumulate in the heated Konin lakes located in the Warta-Gopło channel watershed area of the Wielkopolskie Lake District in central Poland (Hillbricht-Ilkowska and Zdanowski 1988, Zdanowski 1994, Socha 1997). As indicated in a report by Barrett and Protheroe (1994), in 1990, the Pątnów power plant was included on a list of 100 enterprises with the highest SO_2 emissions in Europe. Following the installation of new electro-filters in both power plants in the late 1990s, the amounts of dust pollutants emitted into the atmosphere annually had decreased from 20 to four thousand tons (PAK Report, Konin Power Plant, unpublished data). Since the power plants utilize brown coal, the possibility exists that, in addition to SO_2 emissions, heavy metals and other inorganic and organic compounds are released into the atmosphere. Information concerning these types of emissions is rather scarce. The degree of environmental heavy metal contamination can either be indirectly assessed by emission coefficients (Hławiczka 1995), or it can be estimated directly by the amounts accumulated in organisms.

Mussels belong to a group of indicator organisms in contaminated aquatic environments. These animals may cumulate, without any distinct physiological effects, significant amounts of heavy metals in both soft tissues and shells (Jurkiewicz-Karnkowska 1994, 1998). The amounts of actual accumulation may not only be indicative of real heavy metal emissions, but they also may indicate the mobilization and transfer within the trophic webs of the long-term cumulations of pollutants that are contained in the bottom sediments of aquatic ecosystems. The Konin lakes are well buffered having a water pH of > 8.3. Due of the buffering properties, this environment limits the continuous occurrence in the water of labile, toxic and dissociated forms of metals (Hillbricht--Ilkowska and Zdanowski 1988, Zdanowski 1994).

Anodonta woodiana (Lea) is a newly-introduced mussel species in Europe (Kiss and Pekli 1988, Kiss 1992, 1995, Piechocki and Riedel 1997). It occurs in the natural environments of the Amur River . It was accidentally introduced in Poland in the mid 1980s when it arrived from Hungary together with silver carp *Hypophthalmichthys molitrix* (Val.) stocking fry (Protasov et al. 1993). On the basis of the morphological characteristics of shells, two phenotypes of the species occurring in the discharge channels of the power plant and in the lotic zones of the Konin lakes have been identified by J. I. Starobogatov (personal communication). These are *Sinanodonta orbicularis* (Hende) and *Sinanodonta gibba* (Benson). These two names, or *Anodonta* sp., have been used for the biodiversity characteristics of the benthic and periphyton fauna in the Konin lakes (Protasov et al. 1994, 1997). Genetic studies performed with the enzymatic electrophoresis technique showed that both phenotypes belong to one species (Soroka and Zdanowski 2001).

The purpose of the present work was to assess the heavy metal contents (Mn, Fe, Cu, Zn, Pb, and Cd) in the soft tissues and shells of two species of mussels *A. woodiana* and *Dreissena polymorpha* (Pall.). These mussels form the basic structural elements of the periphyton and benthic communities in the heated Konin lakes and channels. Both of the species occur at high densities, and their biomass in the channels reaches a value of more than ten kilograms per square meter of bottom surface area (Protasov et al. 1994, 1997).

MATERIAL AND METHODS

The mollusks *A. woodiana* and *D. polymorpha* used for the determination of metal contents were collected in August 1998 from the warm Licheński Channel. The channel belongs to the cooling system of discharge waters from the Pątnów and Konin power plants, and of Licheńskie Lake, which is the most intensively heated reservoir of the five Konin lakes. After the soft tissues were separated from the shells, they were dried at 60°C, weighed, and homogenized in an agate mortar. Sub-samples of tissues weighing 0.5 g and 1 g of shells were mineralized in 4 cm^3 of concentrated nitric acid and 2 cm^3 of perhydrol. Subsequently, they were transferred quantitatively to measuring flasks with a volume of 50 cm^3 which were filled with doubly distilled water. The metal contents in the samples were determined using the AAS technique (Carl-Zeiss Jena 30). The flame method was used to determine the contents of Mn, Fe, Cu, Zn, and, in some cases, Pb and Cd. A graphite couvette was used for low concentrations of Pb and Cd. Concentrations of individual elements (μg g^{-1}) in the total quantity of mussels were calculated from the percentage content of soft tissues in dry weight (d.w.) of the animals, as well as from the metal concentrations in tissues and shells.

RESULTS

A. woodiana cumulated distinctly greater amounts of metals in both the soft tissues and shells than did the other species. Biologically utilized metals, such as Mn, Fe, Cu, and Zn, were cumulated in higher concentrations in the soft tissues of both species (Fig. 1), while xenobiotic elements, Pb and Cd, occurred in greater amounts in the shells of *A. woodiana.* The average content in soft tissues comprised 15.2 and 6.1% of dry weight in *A. woodiana* and *D. polymorpha*, respectively.

Elements that play a role in metabolic processes (Mn, Fe, Cu, and Zn) were cumulated mainly in the soft tissues (Fig. 1). The concentration of Mn in the soft tissues of *D. polymorpha* from Licheńskie Lake was 62 μg g^{-1} d.w. It was 4,400 μg g^{-1} d.w. for *A. woodiana* from Licheńskie Lake, and 3,000 μg g^{-1} d.w. for the same species from the Licheński Channel. The Mn content in the shells of *A. woodiana* was 180 and 200 μg g^{-1} d.w. in the lake and channel, respectively. It was 90 μg g^{-1} d.w. for *D. polymorpha* from Licheńskie Lake.

Fe contents both in soft tissues and shells of the two phenotypes of *A. woodiana* from the lake and channel were similar at 1,050 and 1,000 μg g^{-1} d.w. (for soft tissues), respectively, and 50 and 70 μg g^{-1} d.w. (for shells), respectively. *D. polymorpha* contained Fe in the amounts of 350 and 140 μg g^{-1} d.w. in the soft tissues and shells, respectively.

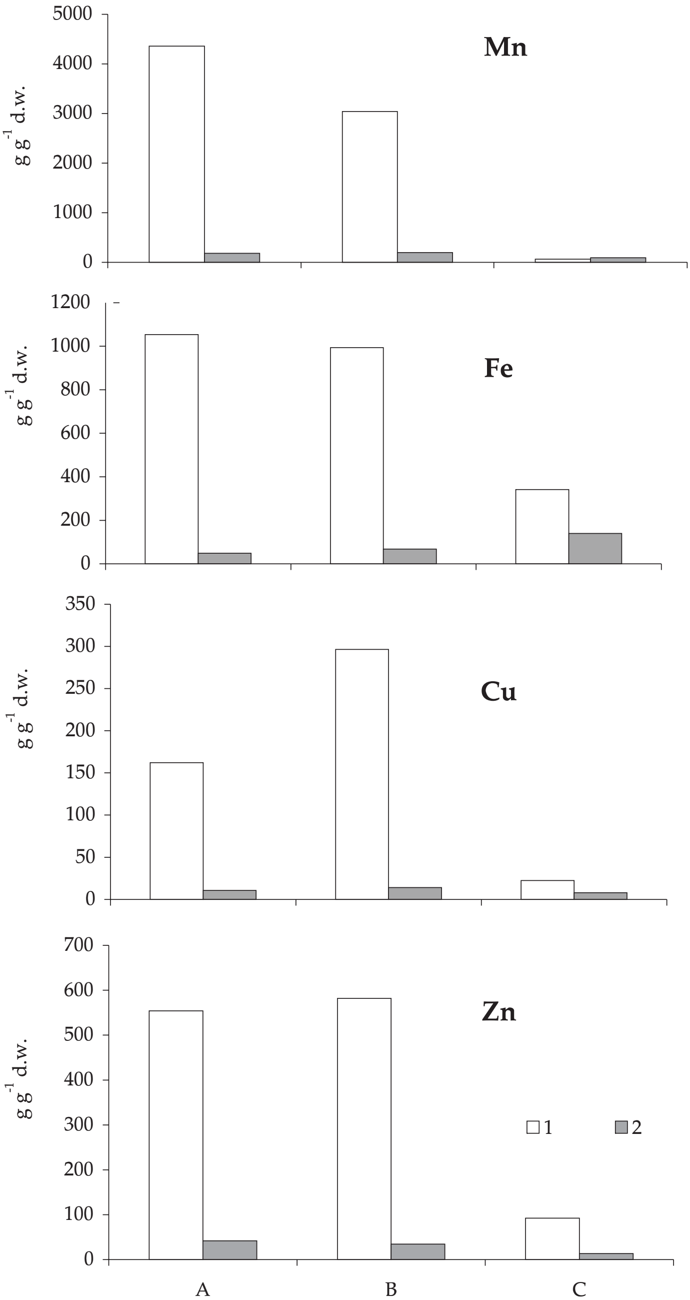

Figure 1. Average content of heavy metals (Mn, Fe, Cu, Zn) in the soft tissues (1) and shells (2) of the *Anodonta woodiana* phenotype from Licheńskie Lake (A) and from the warm discharge channel (B). Heavy metal content in tissues and shells of *Dreissena polymorpha* (Pall.) from Licheńskie Lake (C).

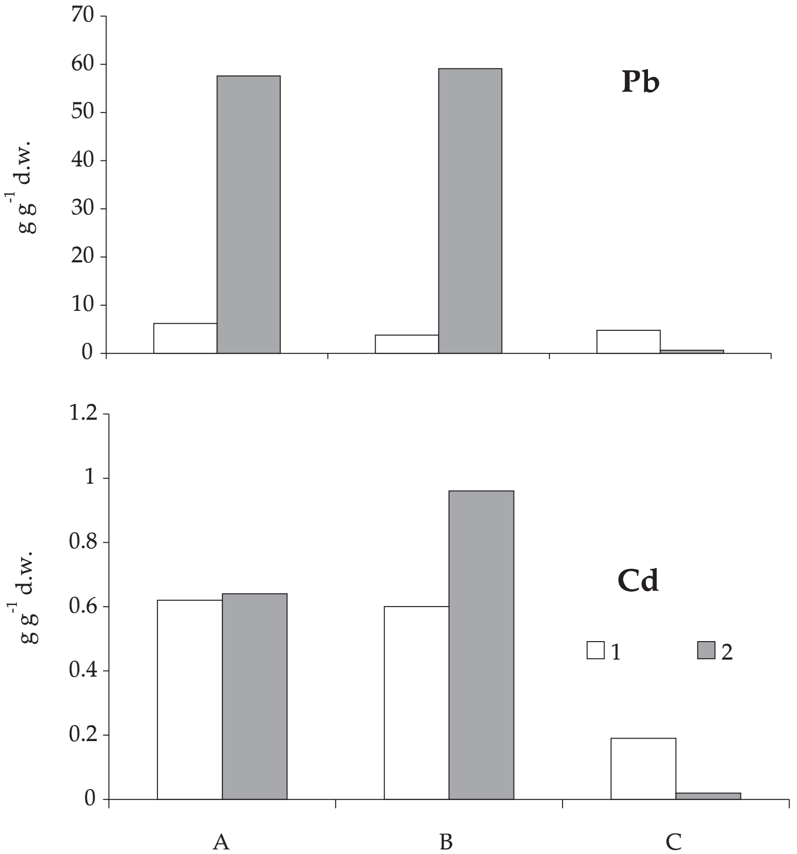

Figure 2. Average content of Pb and Cd in the soft tissues (1) and shells (2) of the *A. woodiana* phenotype from Licheńskie Lake (A), and from the warm discharge channel (B). The same data is presented for *D. polymorpha* from Licheńskie Lake (C).

Cumulations of Cu in the soft tissues and shells of the *A. woodiana* phenotype from Licheńskie Lake were 160 and 11 μg g^{-1} d.w., respectively. The values for the phenotype from Licheński Channel were 300 and 14 μg g^{-1} d.w. The respective values for *D. polymorpha* from the channel were 23 and 8 μg g^{-1} d.w.

The three mussels cumulated zinc in the shells and soft tissues in the amounts of 42, 35, and 13 μg g^{-1} d.w., and 550, 580, and 92 μg g^{-1} d.w., respectively.

Toxic elements (Pb and Cd) were cumulated in the soft tissues of the mussels in distinctly lower amounts (Fig. 2). Trace amounts of lead (4-6 μg g^{-1} d.w.) occurred in the soft tissues of both species and in the shells of *D. polymorpha* (0.6 μg g^{-1} d.w.). Lead was found in greater concentrations (~ 60 μg g^{-1} d.w.) in the shells of *A. woodiana*. The concentration of Cd in the soft tissues of *A. woodiana* was three times as high (0.6 μg g^{-1} d.w.) as that in *D. polymorpha*. In the shells of the phenotypes of *A. woodiana*, the concentration was 40 times as high (0.80 μg g^{-1} d.w.) as in the shells of *D. polymorpha*.

DISCUSSION

The ability to accumulate metals by mussels appears to be a taxonomic feature that depends on both individual requirements for bio-elements and behavior, as well as on the related metabolic processes in a given environment (Jurkiewicz--Karnkowska 1994). Differences in the metal concentration of individual species of mussels living in the same environment may result from the selective uptake of elements with food and the variable regulation of their concentration levels in soft tissues and shells (Brooks and Rumsby 1965, Parsons et al. 1973).

The continuous inflow of metals into the environment can result in a decrease in the size and weight of the mussels and a decline in fecundity (Willis 1983, Forbes 1991, Raj and Hameed 1991). This effect can be illustrated by the lower percentage of soft tissues in *D. polymorpha* from the Konin lakes as compared with individuals from less polluted environments (Królak and Stańczykowska 1999). The long-term exposure of mussels to even low concentrations of heavy metals may cause genetic changes in them (Baršytė Lovejoy 1999).

The level of the studied elements both in the soft tissues and shells of mussels from the Konin lakes was generally higher than the respective values recorded for mussels living in different freshwater reservoirs in Europe (Kraak et al 1991, Busch 1991, Baršytė Lovejoy 1999).

Heavy metals, mainly Zn, Cu, and Pb, are accumulated in the soft tissues and shells of the mussels inhabiting the Konin lakes in much greater concentrations than those of representatives of the families Unionidae and *D. polymorpha* living in the less-polluted lakes of the Masurian Lake District (Królak and Stańczykowska 1999) or in the Zegrzyński Reservoir (Jurkiewicz-Karnkowska and Królak 1999). *A. cygnea* from Inulec Lake (Masurian Lake District) accumulated the following amounts of metals in its soft tissues and shells: Mn - 11,430 and 503 μg g^{-1} d.w.; Fe - 1,528 and 14 μg g^{-1} d.w.; Zn - 301 and 3 μg g^{-1} d.w.; Cu - 7 and 4 μg g^{-1} d.w.; Pb - 1.2 and 0.3 μg g^{-1} d.w.; Cd - 0.8; 0.1 ug g^{-1} d.w., respectively. The concentrations cumulated by the same species in the Zegrzyński Reservoir were as follows (respective values in μg g^{-1} d.w. are given for tissues and shells): Mn - 6,112 and 461; Fe - 1,764 and 1,289; Zn - 235 and

5; Cu - 6 and 6; Pb - 18 and 6; Cd - 0.2 and 0.02. Similar levels of metal accumulation were noted for other species of mussels of the family Unionidae, e.g. *Unio tumidus* (Królak and Stańczykowska 1999), and *A. anatina* (Jurkiewicz-Karnkowska and Królak 1999).

Much lower concentrations of heavy metals, as compared with the levels from the Konin lakes, were noted in *D. polymorpha* from unpolluted freshwater reservoirs in Poland. In Inulec Lake and in Zegrzyński Reservoir this species cumulated the following amounts of metals in its soft tissues: Mn - 130 and 92 µg g^{-1} d.w.; Fe - 129 and 276 µg g^{-1} d.w.; Cu - 6.0 and 7.7 µg g^{-1} d.w.; Zn - 71 and 93 µg g^{-1} d.w.; Pb 1 and 14 µg g^{-1} d.w.; Cd - 1.4 and 0.2 µg g^{-1} d.w. In the shells, the Mn concentrations were 263 and 181 µg g^{-1} d.w., Fe - 36 and 362 µg g^{-1} d.w., Cu - 5.9 and 3.6 µg g^{-1} d.w., Zn - 8.5 and 6.4 µg g^{-1} d.w., Pb - 0.64 and 2.0 µg g^{-1} d.w. and Cd - 0.12 and 0.02 µg g^{-1} d.w., respectively.

It should be pointed out that mussels occurring in the lakes and discharge channels of the power plants in the Konin lake system contribute significantly to removing heavy metals from this aquatic environment. In the zones of abundant occurrence, both *D. polymorpha* and *A. woodiana* may reach about 15 kg m^{-2} (Protasov et al. 1994, 1997, Kraszewski and Zdanowski 2001). Based on the average metal concentrations in mussels (Table 1), it was calculated that they cumulate the following amounts of bio-metals for every square meter of bottom surface area in the lakes and channels: Mn - 1.3 and 12 g m^{-2}; Fe - 2 and 3 g m^{-2}; Cu - 0.12 and 0.9 g m^{-2}; Zn - 0.3 and 1.8 g m^{-2}. The values for the toxic metals are Pb - 13 and 750 mg m^{-2} and Cd - 0.4 and 1.3 mg m^{-2}.

TABLE 1

Average concentration of metals (µg g^{-1} d.w.) in the soft tissues and shells of mussels from the Konin lakes. A - phenotype of *A. woodiana* from Licheńskie Lake, B - phenotype of *A. woodiana* from the warm discharge channel, C - *D. polymorpha* from Licheńskie Lake

	A	B	C
Mn	821.5	625.6	88.3
Fe	202.0	211.3	132.9
Cu	33.6	57.5	8.4
Zn	119.2	117.8	17.8
Pb	49.8	13.1	0.85
Cd	0.8	0.9	0.03

A. woodiana, with its longer life span and its considerable accumulation of toxic metals in its shells, plays a significant role in the process of deactivation of metals in the Konin lakes. The deposition of metals in the shells is a long-lasting process, and it may contribute significantly to lowering the amounts of metals in an aquatic environment. The removal of toxic lead and cadmium by the mussels is especially important (Imlay 1982).

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STRESZCZENIE

BIOAKUMULACJA METALI CIĘŻKICH PRZEZ MAŁŻE *ANODONTA WOODIANA WOODIANA* (LEA, 1834) I *DREISSENA POLYMORPHA* (PALL.) W PODGRZANYM SYSTEMIE JEZIOR KONIŃSKICH

Jeziora konińskie ze względu na położenie w pobliżu elektrowni Konin i Pątnów są miejscem akumulacji zanieczyszczeń, w tym także metali ciężkich emitowanych z elektrowni. Wśród organizmów zasiedlających środowisko wodne szczególnie podatne na akumulację metali są małże *Anodona woodiana woodiana* (Lea, 1834) i *Dreissena polymorpha* (Pall.). *A. woodiana* jest nowym dla Europy gatunkiem, który został zawleczony z Chin z rybami roślinożernymi. Wyniki oznaczeń zawartości metali Mn, Fe, Cu, Zn, Pb i Cd w tkankach małży *A. woodiana* i *D. polymorpha*, zasiedlających podgrzane Jezioro Licheńskie i ciepły kanał zrzutowy, wykazały, że zarówno w tkankach miękkich, jak i muszlach, w większych ilościach gromadziła metale *A. woodiana* niż *D. polymorpha* (tabela 1, rys. 1 i 2). Odnotowano zdecydowanie wyższą zawartość Cu, Zn i Pb w zbadanych małżach niż w przedstawicielach rodziny *Anodonta* i *D. polymorpha* występujących w środowiskach nienarażonych na działanie pyłów z elektrowni. Wysokie biomasy obu gatunków małży, do kilkunastu kg m^{-2} decydują, że zwierzęta te istotnie przyczyniają się do usuwania metali ze środowiska wodnego. Odkładanie metali w muszlach *A. woodiana*, zwłaszcza Pb i Cd, może przyczyniać się do inaktywacji form toksycznych metali w środowisku.

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