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METALS IN CHOSEN AQUATIC PLANTS IN A LOWLAND DAM RESERVOIR

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Abstract

The research involved Słup Dam Reservoir, which is used as a source of drinking water and for flood prevention. The research material was made up of aquatic plants and water collected in the littoral zone of the reservoir, in which copper, nickel, cadmium, lead and zinc contents were determined.

Ceratophyllum demersum L. turned out to be the best accumulator of nickel, cadmium and zinc, *Potamogeton crispus* L. – copper, and *Phragmites communis* Trin – zinc. The presence of plants in the backwater area of the dam reservoir definitely improves water quality, not only thanks to their metal accumulation properties but because of their ability to act as a filter of substances carried in the water.

Key words: aquatic plants, dam reservoirs, rivers, water, metals.

METALE W ROŚLINACH WODNYCH ZE ZBIORNIKA ZAPOROWEGO NA TERENIE NIZINNYM

Abstrakt

Badania prowadzono na terenie Zbiornika Zaporowego Słup, który jest rezerwuarem wody pitnej oraz stanowi rezerwę przeciwpowodziową. Materiałem badawczym były rośliny wodne oraz woda pobierane w strefie litoralu zbiornika, w których określono zawartość miedzi, niklu, kadmu, ołowiu i cynku.

Ceratophyllum demersum L. najsilniej spośród badanych roślin kumulował nikiel, kadm i cynk, *Potamogeton crispus* L. – miedź, a *Phragmites communis* Trin – ołów. Obecność roślin w rejonie tzw. cofki zbiornika zaporowego z pewnością wpływa na poprawę jakości wody nie tylko wskutek kumulacji metali, ale także działania filtracyjnego w stosunku do zawiesin wnoszonych z wodą dopływu.

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Słowa kluczowe: rośliny wodne, zbiorniki zaporowe, rzeki, woda, metale.

INTRODUCTION

Heavy metals are among the many chemical compounds regarded as harmful and present in atmospheric air, soil and water. The principal sources of heavy metals for aquatic plants are water, bottom deposits and direct dry or wet atmospheric deposition. Consequently, such plants are often used as environmental pollution indicators (KUFEL, KUFEL 1986). It is particularly important to know concentrations of metals in plants in Słup Dam Reservoir, as the facility is used for the intake of tap water for a big urban centre (SZULKOWSKA-WOJACZEK, MAREK 1984).

The reservoir is relatively poor in higher aquatic plants. Rare groups of macrophytes are only to be found in the Nysa Szalona River, its tributary, in the reservoir's backwater area and the Nysa Szalona below the reservoir. This scarcity of plants is a result of the structure of the bowl and the reservoir's functions (water storage and flood prevention). Because of constant fluctuations in water levels, the reservoir banks are not hospitable to higher aquatic vegetation.

The plants growing on the banks of the tributary and in the backwater area act as a filter for pollutants carried by the Nysa Szalona. The research described in this article sought answers to the following questions:
– Is metal accumulation in plant organisms dependent on their location?
– Is the metal concentration in aquatic plants a species characteristic?
– Is the presence of macrophytes in the upper part of the reservoir and their filtering characteristics helpful and beneficial to water quality in Słup Dam Reservoir?

MATERIALS AND METHODS

The research involved Słup Dam Reservoir and the Nysa Szalona River. The reservoir is located on the border of the Sudeten Foreland and the Silesian Lowland. The reservoir was created by constructing an earth dam across the valley of the Nysa Szalona River, 8.2 km from the river source, at the village of Słup. The facility was put into operation in 1986 and is used for flood prevention (mitigation of flood waves) and as a source of drinking and industrial water. The Nysa Szalona, classified as a grade II watercourse, is a right-bank tributary of the Kaczawa River; it collects urban and agricultural sewage from the cities of Bolków and Jawor (SZULKOWSKA-WOJACZEK, MAREK 1984).

Aquatic plant samples were collected at the following sites:

Site No. 1 – inflow into the reservoir; Site No. 2 – within the backwater area; Site No. 3 – 300 m below the reservoir. The following aquatic plant species were sampled: curly pondweed – *Potamogeton crispus* L., fennel-leaved pondweed – *Potamogeton pectinatus* L., slender-leaved pondweed – *Potamogeton filiformis* Pers., coontail – *Ceratophyllum demersum* L., narrowleaf cattail – *Typha angustifolia* L., common reed – *Phragmites communis* Trin., lakeshore bulrush – *Schoenoplectus lacustris* (L) Palla.

Five specimens of each species, without thizomes and roots, were collected for analysis. The plants were rinsed in water at the sampling site and then dried in room temperature until air-dry. The entire plants were pre-ground by crushing and then homogenized by pounding in a porcelain mortar. Mineralization was performed in concentrated nitric and perchloric acids at a ratio of 1 to 3 in a Mars 5 microwave oven. Concentrations of metals were determined by atomic absorption spectroscopy on a Varian Spectr AA-110/220 unit. The following metals were studied: copper, nickel, cadmium, lead and zinc.

Water samples were also taken at the same locations in order to establish metal accumulation rates (k) for plants. Each rate was computed as a ratio quotient of the concentration of a given metal in the plant to its concentration in water.

RESULTS

Copper contents in the specimens studied were within the limits established for plants from many lakes in various parts of Poland: Wojnowskie (Czupry-Horzela et al. 2001), Piaseczno (Kowalik et al. 1990), Łękuk (Smoleński 1999), Wadąg (Grzybowski 1996), lakes in the Suwałki region (Kwaśniak, Polechoński 2001) and other water reservoirs (Kufel, Kufel 1986, Dobicki et al. 1990, Samecka-Cymerman 1995, Samecka-Cymerman, Kempers 1996, Szymanowska et al. 1999), as well as carp ponds (Marek et al. 1986, Szulkowska-Wojaczek et al. 1992).

The lowest copper concentration (2.001 mg $Cu \cdot kg^{-1}$) was discovered in common reed at site 3 below the reservoir (Table 1). At the same site copper concentration in water was also the lowest (0.0038 mg $Cu \cdot dm^{-3}$) – Table 2. More copper was found in water samples from sites 1 and 2 (0.0045 mg $Cu \cdot dm^{-3}$); at the same sites the mean copper concentration in plants was higher than that at site 3.

The highest copper concentration (25.432 mg $Cu \cdot kg^{-1}$) was recorded for curly pondweed at site 2 in the backwater area (Table 1), where water flows more slowly. At the inflow and the outflow copper concentrations in the same plant species were lower.

Table 1

Heavy metal concentrations ($mg \cdot kg^{-1}$ of air-dry mass) in the aquatic plants of Słup Dam Reservoir and the Nysa Szalona River

Sampling site	Plant species	Cu			Ni			Cd			Pb			Zn		
		min max	mean	*k*	min max	mean	*k*	min max	mean	*k*	min max	mean	*k*	min max	mean	*k*
No. 1	Common reed *Phragmites communis* Trin.	3.000 7.005	5.632	1251	4.000 9.122	5.711	627	0.332 0.689	0.494	1235	2.909 7.010	4.859	1034	10.821 26.112	16.900	571
	Slender-leaved pondweed *Potamogeton filiformis* Pers.	6.014 13.980	9.738	2164	5.409 8.090	6.987	767	0.123 0.781	0.546	1365	3.776 8.010	5.586	1188	19.022 35.100	28.879	976
No. 2	Coontail *Ceratophyllum demersum* L.	6.917 18.910	10.783	2396	5.121 13.007	8.735	1432	0.992 2.997	2.154	5385	2.981 7.123	4.962	1306	35.026 80.101	59.115	2300
	Common reed *Phragmites communis* Trin.	6.132 17.000	12.380	2751	4.101 12.318	7.010	1149	0.090 0.682	0.364	910	7.021 13.010	9.996	2631	15.670 37.215	24.019	935
	Slender-leaved pondweed *Potamogeton filiformis* Pers.	5.421 16.541	10.958	2435	2.831 8.671	5.768	946	0.099 0.912	0.346	865	2.166 10.343	6.445	1696	16.110 34.090	25.899	1008
	Fennel-leaved pondweed *Potamogeton pectinatus* L.	5.999 12.440	8.695	1932	4.972 11.006	7.944	1302	0.337 1.440	0.760	1900	2.011 5.002	3.781	995	26.418 50.121	37.499	1459
	Curly pondweed *Potamogeton crispus* L.	10.799 25.432	17.489	3886	3.971 8.560	5.948	975	0.655 1.563	1.129	2823	3.001 8.439	5.379	1416	36.554 65.777	55.137	2145

cont. Table 1

No. 3	Common reed *Phragmites communis* Trin.	2.001 10.001	5.492	1445	3.541 14.002	8.065	2444	0.009 1.952	0.514	1285	0.521 7.098	2.683	706	8.000 32.015	18.119	681
	Lakeshore bulrush *Schoenoplectus lacustris* (L). Palla	5.884 10.329	7.553	1988	4.541 10.721	7.113	2155	0.995 2.153	1.655	4138	2.032 4.511	3.222	848	30.779 60.091	45.900	1726
	Narrowleaf cattail *Typha angustifolia* L.	2.898 6.488	4.645	1222	3.890 9.832	6.896	2090	0.890 3.090	1.474	3685	2.531 4.327	3.164	833	34.922 69.000	57.338	2155
	Slender-leaved pondweed *Potamogeton filiformis* Pers.	5.956 15.446	10.083	2653	5.540 9.995	7.851	2379	0.095 1.079	0.493	1233	4.365 12.959	7.934	2088	16.935 27.015	21.023	2156

k – accumulation rate = concentration in plant/concentration in water

The biggest amounts of copper had been accumulated by curly pondweed – accumulation rate *k*=3886, and coontail (*k*=2396) – Table 1 on each site. There were also large quantities of copper in slender-leaved pondweed on sites 1 (*k*=2164) and 3 (*k*=2653), and in on curly pondweed site 2 (k=3886). Also coontail contained much copper in (*k*=2396) – Table 1. Lower accumulation rates were discovered for the surface plants such as narrowleaf cattail, lakeshore bulrush and common reed at the inflow and outflow (Table 1). Unexpectedly, for the latter plant a very high accumulation rate of *k*=2751 was recorded at site 2. This resulted from nearly twice as much copper accumulated at this site as at the other sites.

Our results confirm that cooper accumulation in aquatic plants is correlated with aquatic plant species and with ecological class.

Nickel concentrations in the plants studied varied widely, from 2.831 mg $Ni \cdot kg^{-1}$ in slender-leaved pondweed (site 2) to 14.002 mg $Ni \cdot kg^{-1}$ in common reed (site 3) – Table 1. Similarly, the minimum nickel concentrations in individual species were sometimes over two-fold smaller than the maximum ones. No special susceptibility to nickel accumulation, as opposed to copper, especially no differences between submerged and surface plants, was discovered.

The increasing accumulation rates from site 1 to site 3 were rather a result of the falling nickel concentration in water, probably for reasons other than accumulation in plants. This is confirmed by the mean nickel concentration in plants at individual sites (Table 1). In general, the nickel concentrations in the plants of Słup Dam Reservoir did not deviate from the values quoted by various authors for reservoirs throughout Poland (KOWALIK et al. 1990, SAMECKA-CYMERMAN 1995, SAMECKA-CYMERMAN, KEMPERS 1996, SZYMANOWSKA et al. 1999, KWAŚNIAK, POLECHOŃSKI 2001).

The cadmium concentrations determined for plants from Słup Dam Reservoir fell within the limits established for plants from many lakes in various parts of Poland (KOWALIK et al. 1990, ENDLER, GRZYBOWSKI 1996, SMOLEŃSKI 1999, SZYMANOWSKA et al. 1999) and other water reservoirs in the country (KUFEL, KUFEL 1986, MAREK et al. 1986, SAMECKA-CYMERMAN, STUDNICKA 1986, DOBICKI et al. 1990, SZULKOWSKA-WOJACZEK et al. 1992, KEMPERS 1996, SAMECKA-CYMERMAN 1999).

Cadmium concentrations in water at all the sites were identical, at 0.0004 mg $Cd \cdot dm^{-3}$, although there were noticeable differences in the amounts of cadmium accumulated in plants at individual sites (Tables 1 and 2). The lowest concentrations, just like the accumulation rates, were determined for common reed. The highest mean concentrations were recorded for coontail (2.154 mg $Cd \cdot kg^{-1}$), lakeshore bulrush (1.655 mg $Cd \cdot kg^{-1}$), narrowleaf cattail (1.474 mg $Cd \cdot kg^{-1}$) and curly pondweed (1.129 mg $Cd \cdot kg^{-1}$) – Table 1. The calculated accumulation rates indicate a significant affinity between the examined plants and cadmium. No perceptible differences between the amounts of cadmium accumulated by plant specimens of the same species at various sites were discovered (common reed, slender-leaved pondweed).

Table 2

Heavy metal concentrations (mg·dm^{-3}) in water from the littoral zone in Słup Dam Reservoir and the Nysa Szalona River (mean values)

Sampling site	Cu	Ni	Cd	Pb	Zn
No. 1	0.0045	0.0091	0.0004	0.0047	0.0296
No. 2	0.0045	0.0061	0.0004	0.0038	0.0257
No. 3	0.0038	0.0033	0.0004	0.0038	0.0266

The water in Słup Dam Reservoir had very small concentrations of lead, which ranged from 0.0038 mg Pb·dm^{-3} at sites 2 and 3 to 0.0047 mg Pb·dm^{-3} at site 1 (Table 2). The examined plants had accumulated the metal in amounts comparable to those quoted by various authors for lakes (KOWALIK et al. 1990, SMOLEŃSKI 1999, KWAŚNIAK, POLECHOŃSKI 2001), carp ponds (SZULKOWSKA-WOJACZEK et al. 1992), and other reservoirs throughout Poland (KUFEL, KULEL 1986, STUDNICKA 1986, OZIMEK 1988, DOBICKI et al. 1990, SAMECKA-CYMERMAN 1995, SAMECKA-CYMERMAN, KEMPERS 1996, SZYMANOWSKA et al. 1999). Lead concentrations in the studied aquatic plants varied between 0.521 mg Pb·kg^{-1} in common reed at site 3 to 13.010 mg Pb·kg^{-1} also in common reed, but at site 2 (Table 1). The wide range between the minimum and maximum concentrations and the mean values makes it difficult to form any conclusions about the relationship between the species and lead accumulation. The mean lead concentration in common reed collected from site 2 amounted to 9.996 mg Pb·kg^{-1}, with the accumulation rate k=2631, and in common reed from site 3 – 2.68 mg Pb·kg^{-1} on average, with the accumulation rate k=706. With such a minimum difference in the lead concentrations between the above sites, one can cautiously presume that the reason for the discrepancy lies in the way in which lead is absorbed by reed, i.e. not directly from water, but mainly through the roots.

Zinc concentrations, similarly to those of the other examined metals, established for the aquatic plants from Słup Dam Reservoir did not deviate from the values given by numerous authors for aquatic plants in surface waters throughout Poland (MAREK et al. 1986, OZIMEK 1988, DOBICKI et al. 1990, KOWALIK et al. 1990, SZULKOWSKA-WOJACZEK et al. 1992, SAMECKA-CYMERMAN 1995, SAMECKA-CYMERMAN, KEMPERS 1996, SMOLEŃSKI 1999, SZYMANOWSKA et al. 1999, CZUPRY-HORZELA et al. 2001, KWAŚNIAK, POLECHOŃSKI 2001). Water contained very low concentrations of the metal, which were practically identical at all the sites. Although the concentration was slightly higher at the inflow, this was true for all of the examined metals (Table 2).

Zinc concentration in the plants ranged from 8.000 mg Zn·kg^{-1} in common reed at site 3 to 80.101 mg Zn·kg^{-1} in coontail. Common reed proved to have the weakest zinc accumulation potential. Its accumulation rates at all the three sites were the lowest among all the studied plants. Coontail turned out to be the most efficient zinc accumulator; the same was true for nickel and cadmium.

CONCLUSIONS

The research results enable us to draw only some specific conclusions, as only two plant species (common reed and slender-leaved pondweed) were present at all of the sites. Common reed was found to contain minimum concentrations of all of the examined metals as well as the lowest mean concentrations of nickel, lead and zinc. It was only in the backwater area that common red had accumulated the biggest amount of lead in absolute terms. It also had the highest mean lead concentration at site 2. Simultaneously, its accumulation rate reached a very high value.

Cootail was found to be the plant with the best accumulation capability. Although it grew at one site only, in the backwater area, it proved to be the best indicator organism for nickel, cadmium and zinc, as it not only accumulated the biggest amounts of these metals but also did it in the most efficient manner. This conclusion is supported by the calculated accumulation rates. Curly pondweed may be also regarded as a good indicator organism for copper.

Comparison of the accumulation capabilities of the plants examined indicates that the mean metal accumulation levels were higher in submerged plants. This may have been due to the fact that most of them grew in the backwater area, where a slower water flow was conducive to accumulation.

It is difficult to provide unambiguous answers to the questions behind the research. For instance, common reed, which occurred at all of the sites and seems to have shown an affinity with lead, had accumulated the highest amount of lead at site 2, while at site 1, with the highest lead concentration in water, did not behave in the same way. At site 3 lead concentrations in common reed were the lowest, while its concentration in water corresponded to that at site 2 (Tables 1, 2). Similarly, slender-leaved pondweed did not display any relationship between metal concentrations in plants and their position in the reservoir.

There are grounds, however, for claiming that metal concentrations depend on the plant species. Coontail proved to be the best accumulator of nickel, cadmium and zinc, curly pondweed – copper, and common reed – lead. This is attested both by the values of the calculated accumulation rates and the plants' response (the minimum and maximum concentrations) to individual metals. The presence of plants in the backwater area of the dam reservoir definitely improves water quality, not only thanks to their metal accumulation properties, but also to their ability to act as a filter of substances carried in the water.

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