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COPPER, ZINC, MANGANESE, LEAD AND CADMIUM IN PLANTS OF GARDNO LAKE

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MIEDŹ, CYNK, MANGAN, OŁÓW I KADM W ROŚLINACH JEZIORA GARDNO

W prezentowanej pracy przedstawiono wyniki badań zawartości cynku, kadmu, miedzi, manganu i ołowiu w wybranych roślinach *(Myriophyllum spicatun, Potamogeton natans, Acorus calamus, Nuphar lutea, Elodea canadensis, Phragmites australis, Typha latifolia, Sparganium ramosum hudds, Veronica anagallis)* jeziora Gardno w latach 2000–2001. Są to pierwsze doniesienia o akumulacji metali w makrofitach tego jeziora. Największą koncentrację badanych metali obserwowano w *Potamogeton natans* i *Elodea canadensis*, średnio: Zn – 34,9 μg g^{-1}, Pb – 2,77 μg g^{-1}, Cd – 0,62 μg g^{-1}, Cu – 3,24 μg g^{-1} i Mn – 257,4 μg g^{-1}. Rośliny te charakteryzowały się największymi współczynnikami koncentracji tych metali, a metale wykazywały największą zdolność kumulacji w tych roślinach. Stwierdzono, że części nadziemne badanych roślin kumulowały kilkakrotnie mniej metali niż ich korzenie. Wyznaczone współczynniki wzbogacenia wykazały, że miedź w badanych roślinach jest pochodzenia naturalnego, a mangan, kadm i cynk – pochodzenia antropogenicznego. Najwyższy poziom fitosorpcji metali w jeziorze Gardno wykazywał *Phragmites australis*: Zn – 13,22 mg m^{-2}, Pb – 2,16 mg m^{-2}, Cd – 0,15 mg m^{-2}, Cu – 0,95 mg m^{-2}, Mn – 130,53 mg m^{-2}.

Summary

In the present paper there have been shown the results of research on the content of zinc, cadmium, copper, manganese and lead in chosen plants *(Myriophyllum spicatun, Potamogeton natans, Acorus calamus, Nuphar lutea, Elodea canadensis, Phragmites australis, Typha latifolia, Sparganium ramosum hudds, Veronica anagallis)* of Lake Gardno in the years 2000–2001. The first data concerning the accumulation of those metals in the macrophytes of Lake Gardno has been provided. The biggest concentration of examined metals has been observed in *Potamogeton natans* and *Elodea canadensis*, on average Zn – 34.9 μg g^{-1}, Pb – 2.77 μg g^{-1}, Cd – 0.62 μg g^{-1}, Cu – 3.24 μg g^{-1} and Mn – 257.4 μg g^{-1}. They are also characterized by the biggest coefficients of concentration of those metals, and therefore they have the biggest abilities to cumulate in them. It has been found that the over-ground parts of the plants under analysis cumulate several times less of heavy metals than their roots. The determined enrichment factors enabled the researchers to state that copper in the examined plants is of natural origin while manganese, cadmium and zinc – of anthropogenic origin. The highest level of phytosorption of the metals under analysis in Lake Gardno was shown by *Phragmites australis*: Zn – 13.22 mg m^{-2}, Pb – 2.16 mg m^{-2}, Cd – 0.15 mg m^{-2}, Cu – 0.95 mg m^{-2}, Mn – 130.53 mg m^{-2}.

INTRODUCTION

Propagation of heavy metals in the aquatic environment leads to the increase of their concentrations in different ecosystems. Often, these concentrations are several times higher than the concentrations characteristic for the level of their natural occurrence in the environment. If, in given conditions, the content of particular elements exceeds the demand for macro and microelements of the food chain organisms in the aquatic ecosystem, then in consequence, they may exert a toxic influence on biocenoses and inhibit the processes of self-cleaning [21]. An important criterion of toxic action assessment seems to be the ability to penetrate and cumulate in different elements of the aquatic ecosystem (plants, animals, bottoms). A particularly harmful influence is characteristic for heavy metals among others, mercury, lead, copper and cadmium. Toxicity of metals depends on the concentration and solubility of their compounds in water, and also on their chemical reactivity, that is their ability to make complex components with fractions of organic matter and with inorganic compounds, and the ability to bond with living organisms. The ability to bond metals by organisms and to immobilize them partially has a harmful effect on the processes of cellular metabolism. Their influence manifests itself mainly in blocking SH, NH, NH_2 groups in enzymatic protein, which inhibits growth and physiological processes of organisms [21].

Aquatic and rush vegetation constitutes an essential component of inland aquatic ecosystems. It is considered to be a significant biotope-forming factor [10, 11] and, at the same time, a specific ecotone land/open water level [16, 31]. Concentrations of heavy metals in plants are frequently higher than in the water surrounding them. Andrzejewski [2] proved that the concentration of zinc in phytoplankton and zooplankton is 30 times higher than in water. Higher plants play a very important role in migration of those metals and they cumulate them in their tissues unevenly [7, 14, 19]. A lot of heavy metals show a high correlation between their content in the environment, including the aquatic environment, and the concentration in aquatic macrophytes [1, 4, 5, 15].

The purpose of this work was:

- to define participation and abilities of chosen aquatic plants in Lake Gardno to cumulate zinc, copper, lead, cadmium and manganese and to assess the correlation among metals in this process;
- to define to what degree sea water flowing into the lake influence the content of heavy metals in plants.

STUDY AREA

One of coastal lakes is Lake Gardno. It is situated in the central part of the southern coastal zone of the Baltic Sea and is an integral part of the Słowiński National Park (Fig. 1). The area of Lake Gardno is 2468.1 ha. Like most coastal lakes it is a very shallow lake with an average depth of 1.3 m. The bottom of the lake is generally flat, with the biggest depression (2.6 m) occurring in the south-eastern part. Almost the whole lake basin is covered with slimes and bottoms of various thicknesses. The biggest thickness of the bottom appears in the south-eastern part of the lake and comes up to 2.5 m. Only a small surface of the bottom has a hard sandy foundation. It appears in the north-eastern part of the lake within the 1.5 m isobath and by Kamienna Island. Kamienna Island, of the area of 0.6 ha is rich in boulders and is a breeding ground for many bird species.

Flat shores of Lake Gardno are covered with a wide belt of reeds which makes an access to water difficult and at the same time it constitutes a shelter for many bird species. The width of this belt in some places exceeds 100 m.

The Łupawa River flows through Lake Gardno. It falls into the lake in its eastern part and flows out in the north-western part. The section of this river joining the lake with the sea has the character of a channel of about 1500 m in length. It is characterized by a small drop facilitating periodic seawater silts into the lake. In the area of water outflow from the lake there appears salty seawater and also, sandy materials from coastal dunes.

The Łupawa brings into the lake significant amounts of rock waste and, as a result, at its mouth a big delta was formed which is steadily increasing its area. A younger part of this delta takes an area of about 8 km^2. In the course of silting up the shores, particular zones of vegetation are moving towards the center of the lake and the shores are being taken over by helophytes. Shoal patching, and also enriching with nutrients by the river, has created very beneficial conditions for reed to expand which, by depositing its remnants, was causing an increase of organogenic deposit every year and contributing efficiently to further shoal patching and changing the eastern part of the lake into land.

VEGETATION OF LAKE GARDNO

In Lake Gardno there appear three basic groups of aquatic vegetation. The first one grows mainly in sheltered lake bays and shallow waters among a wide belt of rushes around the lake and includes, first of all, duckweeds (*Lemna*): *Lemna minor, Lemna trisulca* and *Lemna gibba*. In the rushes reeds *Phragmites australis, Typha latifolia* and *Acorus calamus* dominate. Another group of aquatic vegetation occurs in deeper parts of coastal zone of the lake and consists mainly of water-lilies: *Nymphaea alba, Nuphar lutea, Hydrocharis morsus-ranae* and *Stratiotes aloides* and other plants: *Veronica anagallis, Sparganium ramosum hudds*. The most numerous group is constituted by plants which are totally submerged in the depths of the lake, namely: *Potamogeton crispus, Potamogeton natans, Elodea canadensis, Myriophyllum spicatum* and *Zannichellia palustris* [23].

MATERIAL AND METHODS

Considering content differentiation of heavy metals due to the stage of plants development, the authors limited themselves only to taking samples every year in summer, in the period of maximum vegetative development of plants at Lake Gardno in the years 2000–2001. The plants under examination were taken from two characteristic places in the lake. Station 1 was situated near the place where the Łupawa River flows into the lake in its eastern part, station 2 – near the outflow of this river in the north-eastern part of the lake (Fig. 1).

Nine plant species characteristic for this lake were included in the research. Primary samples of studied plants consisted of the following number of phytocenoses: *Sparganium ramosum hudds* – 50 in year 2000 and 42 in 2001, *Elodea canadensis* – 80 and 76, *Typha latifolia* – 33 and 35, *Phragmites australlis* – 38 and 38, *Potamogeton natans* – 76 and 72, *Myriophyllum spicatum* – 43 and 51, *Veronica anagallis* – 43 and 47, *Acorus calamus* 36 and 32, *Nuphar lutea* – 48 and 50. In the case of *Typha lafiolia, Acorus calamus, Phragmites australis, Veronica anagallis* and *Sparganium ramosum hudds* the over-ground portion

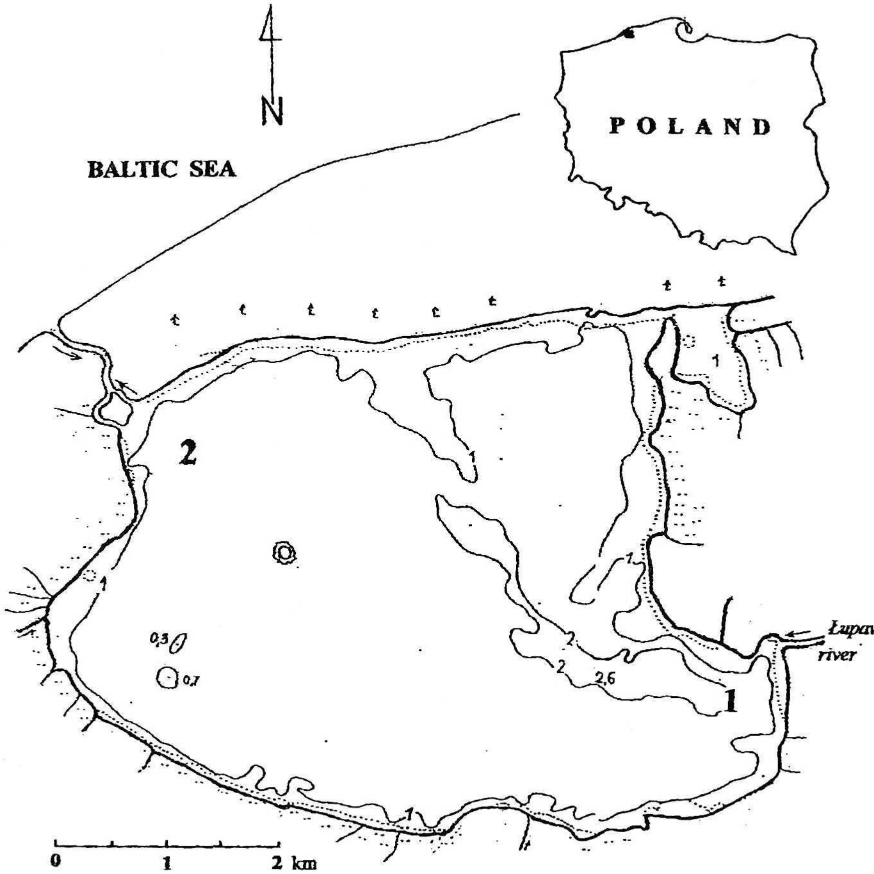

Fig. 1. Location of sampling stations in Lake Gardno

and root part were examined separately; in the remaining plants no such distinction was made. Their appearance was defined as an average percentage of the total biomass of all plants in reference to the covered area. The range of appearance of particular macrophytes and their biomass were defined with the use of Traczyk's method [27]. Collected plant samples were investigated separately every year.

After being collected, plant samples were washed with distilled water to remove bottoms and suspended solids, and then dried at the temperature of 100°C to get solid matter. The dried plant material was ground, homogenized and mineralized with the use of HNO_3 and $HClO_4$ mixture in the MAXIDIGEST MX 350 mineralizer. The content of heavy metals in the plant matter was defined with the use of a spectrophotometer of atomic absorption AAS-3. The results were subject to statistic analysis according to test-t.

Phytosorption was estimated as the content of a particular metal in the plant in the form of biomass expressed in mg m^{-2} [28].

On the basis of knowledge of trace elements concentration in the plants under analysis, enrichment factors with those metals were calculated for them in order to define their origin in the ecosystem [26]. The enrichment factor is defined as a ratio of a particular metal concentration (me) in the organism under analysis $(Cme)_S$ to its concentration in the lithosphere $(Cme)_{EC}$ [26]:

$$EF = \frac{(Cme / CFe)_s}{(Cme / CFe)_{EC}}$$

where: CFe stands for the concentration of iron.

Concentration of studied metals and iron in water and bottom sediments of Lake Gardno required to determine enrichment factors was taken from Trojanowski [29].

Results presented in tables are average values obtained from both studied periods.

RESULT AND DISCUSSION

The level of heavy metals in aquatic plant tissues is significantly influenced by the specificity of the environment. Rooted plants at the bottom of a water basin draw nutrition salts not only through the root system but also through the surface that is in the direct contact with an aqueous solution. Therefore, comparing them to land plants may be done only when they both come from the same area. Besides the specific character of species, the quality of the environment has a significant meaning too.

In Table 1 there have been compiled the average contents of heavy metals in the examined plants. Manganese is a dominating metal in them and its average content at the post 1 in the over-ground part ranged from 108.7 $\mu g\ g^{-1}$ in *Acorus calamus* to 322.0 $\mu g\ g^{-1}$ in *Elodea canadensis*. However, at the post 2 that range was smaller and amounted to 95.3 $\mu g\ g^{-1}$ in *Phragmites australis* and 238.0 $\mu g\ g^{-1}$ in *Potamogeton natans*. This level of manganese should rather be reckoned as low because according to Kabata-Pendias and Pendias [15] grasses in Poland contain from 20 up to 665 $\mu g\ g^{-1}$ of manganese, while Ozimek [24] on the basis of carried out research stated that the concentration of heavy metals in aquatic plants is much higher than in land plants. It results from better possibilities for aquatic plants which draw metals not only through the root system but also directly from water through the over-ground part [6]. In connection with that, in Lake Gardno there was observed a much higher concentration in submerged plants, such as: *Potamogeton natans, Elodea canadensis* and *Myriophyllum spicatun* than in emerged plants: *Phragmites australis, Acorus calamus* and *Typha latifolia*. A significantly higher concentration of manganese was observed in *Potamogeton natans* from the eutrophic Lake Wadąg [12], where the concentration of manganese (3197 $\mu g\ g^{-1}$) was about thirteen times higher than in the lake under examination, and in *Myriophyllum spicatun, Typha latifolia* and *Nuphar lutea* – over twice as high. While the concentration of manganese in the *Elodea canadensis* from Lake Gardno is twice as high as in Lake Wadąg, it is much lower than in the *Elodea canadensis* from Lake Piaseczno (1800 $\mu g\ g^{-1}$) [17]. In the case of *Acorus calamus, Phragmites australis* and *Sparganium ramosum hudds* the concentration of manganese was similar to that of Lake Wadąg [12]. Higher concentrations of that metal were observed in analogical plants (from 83.7 $\mu g\ g^{-1}$ in *Myriophyllum spicatun* up to 819.5 $\mu g\ g^{-1}$ in *Acorus calamus*) in Lake Dołgie Wielkie 2 km away from Lake Gardno [3].

A much higher concentration of manganese was observed in the root part of the plants under examination than in the over-ground part (Tab. 1). It was characterized by the

Table 1. Average content of zinc, in μg g^{-1} of dry mass, in the chosen plants of Lake Gardno in years 2000–2001 (x* – mean value, S_x – standard deviation, V_x – index of variation)

Species	Stations	x*	x_{min}	x_{max}	S_x	V_x	n
		μg g^{-1}				(%)	
Patamogeton natans	1 2	34.67 31.20	6.27 4.16	50.52 46.83	10.24 8.46	29.5 27.1	74 74
Elodea canadensis	1 2	40.67 33.67	5.25 3.89	66.17 54.63	6.68 6.32	16.4 18.8	78 78
Nuphar lutea	1 2	22.35 13.98	2.61 0.93	41.81 25.83	2.26 2.17	10.1 15.5	49 49
Myriophyllum spicatun	1 2	18.54 11.89	2.54 1.58	31.46 23.97	3.58 2.17	19.3 18.2	47 47
Sparganium ramosum hudds (over-ground part)	1 2	21.32 13.87	2.63 1.07	40.01 2348	6.58 2.17	30.9 15.6	46 46
Sparganium ramosum hudds (root part)	1 2	44.38 28.60	3.44 2.56	68.10 40.12	4.17 3.29	9.4 11.5	46 46
Phragmites australis (over-ground part)	1 2	17.07 10.76	0.94 0.75	31.41 20.27	2.26 1.58	13.2 14.7	38 38
Phragmites australis (root part)	1 2	48.25 14.83	5.63 1.27	69.62 29.05	7.26 1.31	15.0 8.8	38 38
Acorus calamus (over-ground part)	1 2	13.92 9.52	0.94 0.64	22.27 18.07	2.06 2.18	14.8 22.9	34 34
Acorus calamus (root part)	1 2	35.69 15.40	4.45 2.52	61.18 24.89	6.18 2.14	17.3 13.9	34 34
Veronica anagallis (over-ground part)	1 2	20.12 11.37	3.27 0.81	37.10 20.03	2.11 2.41	10.5 21.2	45 45
Veronica anagallis (root part)	1 2	37.87 17.89	4.05 1.78	59.16 28.25	11.4 1.16	30.1 6.5	45 45
Typha latifolia (over-ground part)	1 2	21.97 9.32	3.14 0.77	38.14 21.05	4.16 1.11	18.9 11.9	34 34
Typha latifolia (root part)	1 2	27.31 16.74	1.92 1.58	51.16 30.70	4.86 2.16	17.8 12.9	34 34

range from 276.4 μg g^{-1} in *Acorus calamus* up to 584.5 μg g^{-1} in *Typha latifolia*. A similar dependence was observed by Ozimek [24]. A demand for manganese in plants results from its participation in metabolic processes but in the case of its high concentrations in particular elements of the lake ecosystem metabolic barriers fail and manganese is absorbed in spite of the lack of demand [15].

Manganese phytosorption in the plants under examination ranged from 9.57 mg m^{-2} (*Sparganium ramosum hudds*) up to 130.53 mg m^{-2} (*Phragmites australis*) (Tab. 2). A much higher range of phytosorption was observed in Lake Wadąg from 16.14 mg m^{-2} (*Elodea canadensis*) up to 1051.27 mg m^{-2} (*Potamogeton natans*) [12]. However, phytosorption of that metal by *Phragmites australis* and *Sparganium ramosum hudds* in both lakes is similar.

Table 2. Average phytosorption, in mg m^{-2}, of Cu, Zn, Pb, Cd and Mn in dominating plants of Lake Gardno in years 2000–2001

Plants	Dry plants biomass	Cu	Zn	Pb	Cd	Mn
	(g m^{-2})	(mg m^{-2})				
Potamogeton natans	225.4	0.835	7.422	0.642	0.131	54.975
Elodea canadensis	198.2	0.549	7.308	0.533	0.,129	53.673
Nuphar lutea	123.4	0.208	2.240	0.227	0.043	21.200
Myriophyllum spicatun	344.2	0.499	5.239	0.606	0.079	79.702
Sparganium ramosum hudds	41.5	0.148	1.124	0.292	0.047	9.574
Phragmites australis	581.8	0.948	13.224	2.164	0.151	130.530
Acorus calamus	148.1	0.315	2.759	0.386	0.038	24.658
Veronica anagallis	72.2	0.183	1.575	0.398	0.046	17.862
Typha latifolia	170.1	0.415	3.203	0.668	0.054	48.036

The metal that appeared in the examined plants in significant amounts was also zinc. Its average content in the over-ground part of the plants at the station 1 ranged from 13.92 μg g^{-1} (*Acorus calamus*) up to 40.67 μg g^{-1} (*Elodea canadensis*), while at the station 2 from the value below 10 μg g^{-1} (*Typha latifolia, Acorus calamus*) up to the value above 30 μg g^{-1} (*Elodea canadensis, Potamogeton natans*). On the other hand, an average concentration of zinc in root parts of the chosen plants from the station 1 ranged from 27.31 μg g^{-1} (*Typha latifolia*) up to 48.25 μg g^{-1} (*Phragmites australis*), while from the station 2 it was lower with the range from 14.83 μg g^{-1} (*Phragmites australis*) up to 28.60 μg g^{-1} (*Sparganium ramosum hudds).*

The content of zinc in upper plants of the eutrophic Lake Dołgie Wielkie ranged from 9.19 μg g^{-1} in *Myriophyllum spicatun* up to 66.76 μg g^{-1} in *Nuphar lutea* [3]. These values are close to the values noted in Lake Gardno. Similar concentrations were observed in analogical plants in Lake Wadąg from 15.20 μg g^{-1} in *Sparganium ramosum hudds* up to 30.15 μg g^{-1} in *Potamogeton natans* [14]. The content of zinc in the plants of the Barycz River ranged widely from 7.2 μg g^{-1} in *Phragmites australis* up to 187.5 μg g^{-1} in *Elodea* *canadensis* [22]. In Lake Balaton the range of zinc concentration in *Phragmites australis* was 12.03–128.82 μg g^{-1}, and in *Typha latifolia* 32.4–316.5 μg g^{-1}. In comparison with this lake the *Phragmites australis* from Lake Gardno is close to the lower border, while the *Typha latifolia* is below the lower border of the macrophytes from Lake Balaton [18].

The level of zinc phytosorption in the plants under examination was much smaller than of manganese. Similarly, as in the case of manganese, the lowest zinc phytosorption was observed in *Sparganium ramosum hudds* (1.124 mg m^{-2}) and the highest in *Phragmites australis* (13.224 mg m^{-2}). The observed phytosorption of that metal in the plants of Lake Wadąg was characterized by a significantly wider range 0.172–44.383 mg m^{-2} [12].

The concentrations of zinc in the plants under analysis were several times higher than the concentrations of lead, copper and cadmium. The metal which appeared in much smaller amounts was lead. An average content of that metal in over-ground parts of the plants from the station 1 of the lake under examination ranged from 1.14 μg g^{-1} in *Phragmites australis* up to 3.17 μg g^{-1} in *Potamogeton natans*, and analogically, from the station 2 from 0.62 up to 2.54 μg g^{-1} (Tab. 1). Similarly, as in the case of manganese and zinc, the concentration of lead in the root portion of chosen plants was much higher than in the over-ground part, especially in the plants from the station 1 where average values ranged from 5.48 μg g^{-1} in *Acorus calamus* up to 19.40 μg g^{-1} in *Sparganium ramosum hudds*. In the plants from the post 2 this range was much smaller and ranged from 1.49 μg g^{-1} in *Phragmites australis* up to 4.79 μg g^{-1} in *Sparganium ramosum hudds*. An average level of lead in the tissues of the plants under examination was a dozen or so times smaller than in the analogical plants in the lakes located on the territory of the Tucholski Landscape Park [9]. In the examined plants of Lake Dołgie Wielkie [3] the lowest level of lead was observed in *Potamogeton natans* 0.72 μg g^{-1}, and the highest in *Nuphar lutea* – 2.60 μg g^{-1}, whereas in the analogical plants in Lake Gardno respectively 3.17 μg g^{-1} and 1.78 μg g^{-1}. The concentration of lead in the plants under examination was contained in the range of concentrations of that metal in the analogical plants from Lake Wadąg – 0.71–3.55 μg g^{-1} [11]. However, in the lakes of the Tucholski Landscape Park [9] the amount of lead cumulated in *Phragmites australis* (4.6–27.1 μg g^{-1}) and in *Nuphar lutea* (3.0–33.0 μg g^{-1}) was several or a dozen or so times bigger than in Lake Gardno. A still higher concentration of that metal was observed in the plants from Lake Piaseczno where, for example, a lead level in *Elodea canadensis* came up to 22 μg g^{-1} [17].

Lead phytosorption in the *Phragmites australis* from Gardno Lake (Tab. 2) was almost ten times higher than in the *Phragmites australis* examined by Kufel and Kufel [20]. The range of phytosorption of that metal in the plants of Lake Gardno (0.292–2.164 mg m^{-2}) was similar to that in Lake Wadąg (0.189–1.480 mg m^{-2}) [13].

From among heavy metals, cadmium appeared in the smallest amounts in the plants of the examined lake. Its concentration was the lowest in the over-ground part of *Phragmites australis* – 0.12 μg g^{-1} (st. 1) and in *Acorus calamus* – 0.06 μg g^{-1}, and the highest in the roots of *Veronica anagallis* – 1.87 μg g^{-1} (st. 1) and 0.31 μg g^{-1} (st. 2) (Tab. 1). However, *Elodea canadensis* from the station 1 was characterized by the highest concentration of cadmium in the over-ground part (0.88 μg g^{-1}), and *Potamogeton natans* at the station 2 (0.50 μg g^{-1}). Its concentration in the plants under analysis was a little higher than in the analogical plants of Lake Dołgie Wielkie, but a much higher content of cadmium was observed in the analogical plants of Lake Wadąg [8]. In spite of being necessary for plant development, cadmium is exceptionally easy for them to draw. Similarly to other analyzed metals, cadmium drawn by plants is accumulated mainly in roots. Its share in the roots increases in the course of growth of its concentration in the environment. The concentration of cadmium in the waters of Lake Gardno was several times lower than in *Potamogeton natans, Elodea canadensis, Nuphar lutea, Myriophyllum spicatun* and *Sparganium ramosum hudds* [29].

Cadmium phytosorption in the plants under analysis was the smallest in comparison with other metals and was characterized by the range from 0.047 mg m^{-2} in *Sparganium ramosum hudds* and *Veronica anagallis* up to 0.151 mg m^{-2} in *Phragmites australis*. A high phytosorption of this metal was shown by *Potamogeton natans* and *Elodea canadensis* (about 0.130 mg m^{-2}). Similar values of phytosorption of cadmium were observed in the analogical plants of Lake Wądąg [8].

Copper, which is an indispensable ingredient in plants for their normal development and growth, is drawn by plants in an active way connected with metabolic processes and in a passive way along with transpiration flow of water. The highest concentration of copper in the over-ground parts of the plants under examination was observed in *Potamogeton natans* 3.98 μg g^{-1} (st. 1) and 3.43 μg g^{-1} (post 2), and the lowest in *Phragmites australis* – 1.13 μg g^{-1} (st. 1) and 0.65 μg g^{-1} (st. 2) (Tab. 1). The latter, in turn, contained the least of copper in roots – 3.21 μg g^{-1} (st. 1) and 1.54 μg g^{-1} (st. 2). The most of that metal was contained in the roots of *Sparganium ramosum hudds* 8.75 μg g^{-1} (st. 1) and *Veronica anagallis* 5.38 μg g^{-1} (st. 1). The concentration of copper in the plants under analysis is small and is included in the lower borders of the range observed in the reception basin ponds of the River Barycz – 0.6–25.0 μg g^{-1} [22].

The highest values of copper phytosorption were observed in *Phragmites australis* – 0.948 mg m^{-2} and in *Potamogeton natans* – 0.835 mg m^{-2}, and the lowest in *Sparganium ramosum hudds* – 0.148 mg m^{-2}.

It has been found out that in particular parts of plants the degree of metal accumulation is different. From among the plants under examination, the over-ground parts of *Phragmites australis*, *Typha latifolia* and *Acorus calamus* were characterized by the smallest content of the analyzed metals (Tab. 1). The highest content of the analyzed metals was found in *Potamogeton natans* and *Elodea canadensis*. They could also be used for evaluation of the degree of contamination with heavy metals of the aquatic environment.

The roots of *Typha latifolia, Acorus calamus, Phragmites australis*, *Sparganium ramosum hudds* and *Veronica anagallis* contained much more analyzed heavy metals than their over-ground parts. Particularly big differences between these two parts were observed in the case of lead and cadmium. The roots of *Phragmites australis* accumulate ten times more lead and six times more cadmium than the over-ground part. However, the content of the remaining heavy metals under analysis in the root portion was only about two or three times higher. Such a distribution is known in scientific literature. For example, [25, 30], while examining physiological and biochemical functions of copper, found out that copper is drawn by plants in the form of Cu^{2+} ions. In the first phase those ions are subject to strong adsorption in cell walls of the root, and then, they undergo slow dissociation and get through the cell membrane. A significant part of copper drawn by a plant is bound in the root tissues by phytochelatines.

The examined plants from the station 1 (at the outlet of the River Łupawa into the lake) were characterized by a higher content of heavy metals both in the over-ground and root parts (Tab. 1) in comparison with the plants collected at the station 2. Most likely, the cause of that is a much lower concentration of those metals, both in water and bottoms at the station 2 [29]. An undoubted influence is also exerted by sea waters that periodically run into the lake close to that post and are characterized by much lower concentrations of those metals.

The metal that appeared in the largest quantities proved to be manganese. Its concentration exceeded several times the concentration of the next metal – zinc. Ten times lower content in the plants under examination, in relation to zinc, was shown by copper and lead whose concentrations in the over-ground parts were very close. On the other hand, in roots the level of lead was much higher, often more than a dozen, than that of copper. It results from metabolic needs of plants whose demand for copper is much higher than for lead, therefore it penetrates much faster to the over-ground part. There was the least of cadmium in the plants under analysis. So the content of the analyzed metals in the over-ground parts of the plants under examination came in the following sequence Mn > Zn > Pb = Cu > Cd, and in the roots – Mn > Zn > Pb > Cu > Cd.

In order to determine a concentration coefficient for the plants under analysis, they were divided into three groups depending on the concentration of heavy metals in the over-ground part. The first group comprised *Elodea canadensis* and *Potamogeton natans* because they contained the most of the metals under examination. Group II was formed by *Nuphar lutea, Myriophyllum spicatun* and *Sparganium ramosum hudds* – the plants with an intermediate concentration of metals, and plants like *Phragmites australis*, *Acorus calamus, Veronica anagallis* and *Typha latifolia* with the lowest concentration of metals constituted group III.

On the basis of determined concentration coefficients (Tab. 3) it has been found that the biggest accumulation abilities in the plants under analysis have manganese (on average K = 2.23), then zinc (K = 1.46) and cadmium (K = 1.26), while the smallest abilities has – lead (K = 0.20). Generally, the over-ground parts of plants are characterized by higher coefficients of concentration of the analyzed metals (K = 1.29), except lead, than the roots (K = 0.90), which shows their bigger ability to accumulate those metals. As values of the concentration of metals coefficients show, the division of the plants under analysis was not accidental. *Potamogeton natans* and *Elodea canadensis*, belonging to group I are characterized by the biggest abilities to cumulate the analyzed metals (on average K = 2.11), and group III (*Phragmites australis*, *Acorus calamus, Veronica anagallis* and *Typha latifolia*) – the smallest (K = 0.76). An average coefficient of concentration for plants from group II was 1.08.

The obtained enrichment factors are normalized in relation to iron (Tab. 4) and indirectly indicate the origin of metals cumulated by organisms. Enrichment factors determined in such a way do not account for a specific enrichment of organisms with a particular metal caused by physiological factors or perhaps by the effectiveness of organism's detoxification of different metals. It has been assumed that enrichment factors higher than 10 indicate anthropogenic origin of metals, while the values of EF below 3 indicate natural origin of metals [26]. In connection with that in the plants under analysis only copper is of natural origin, whereas cadmium, zinc and manganese – of anthropogenic origin. In the case of lead the values of enrichment factors ranged from 2.7 up to 9.8 depending on the place of sample collection or plant species. This variation may be attributed to different concentrations of lead in the environment, caused by local sources of this metal in Lake Gardno and individual species features of the analyzed plants. Generally, the values obtained for the plants from the station 1 were higher than those from the station 2. It shows that the region of Lake

Gardno where the Łupawa River flows into is much more polluted with the metals under analysis than the region where that river flows out of the lake.

Table 3. Coefficients of heavy metals concentration in over-ground and root parts of the analyzed water plants in Lake Gardno (I – *Potamogeton natans, Elodea canadensis*; II – *Nuphar lutea, Myriophyllum spicatun, Sparganium ramosum hudds*; III – *Phragmites australis, Acorus calamus, Veronica anagallis, Typha latifolia*).

Metals	Stations	Over-ground part*			Root**
		I	II	III	
Cu	1	2.14	0.40	0.29	0.52
	2	1.15	0.48	0.32	0.32
Zn	1	1.89	1.04	0.92	0.92
	2	3.58	1.48	1.14	0.71
Pb	1	0.28	0.21	0.15	0.37
	2	0.23	0.14	0.08	0.21
Cd	1	2.40	1.09	0.66	0.67
	2	3.07	1.33	0.47	0.37
Mn	1	2.68	1.84	1.43	1.27
	2	3.72	2.82	1.66	2.45

K = content of metal in the over-ground part * or in roots**/concentration of metal in water* (μg dm^{-3}) or bottoms** (μg g^{-1})

Table 4. Enrichment factors in the chosen plants of Lake Gardno with heavy metals (I – *Potamogeton natans, Elodea canadensis;* II – *Nuphar lutea, Myriophyllum spicatun, Sparganium ramosum hudds;* III – *Phragmites australis, Acorus calamus, Veronica anagallis, Typha latifolia*).

Metals	Stations	Plants		
		I	II	III
Cu	1	2.73	1.79	1.25
	2	2.28	1.01	0.70
Zn	1	145.6	86.8	74.2
	2	124.7	55.5	44.4
Pb	1	9.8	8.5	5.3
	2	8.4	4.2	2.7
Cd	1	239.6	117,7	72.9
	2	142.7	67.2	23.9
Mn	1	52.3	38.9	31.2
	2	41.9	34.3	20.9

CONCLUSIONS

The content of zinc, lead, copper, manganese and cadmium in chosen plants of Lake Gardno is comparable with the average values observed for eutrophic lakes. In those plants copper is of natural origin while zinc, manganese and cadmium are of anthropogenic origin. However, the origin of lead depends on the place of plant appearance and its species. Unequal space concentration of metals in the examined plants indicates the source of water pollution with these metals in Lake Gardno. The plants under examination collected at the station 1 (at the outlet of the River Łupawa into the lake) were characterized by several times higher content of heavy metals under analysis, both in the over-ground part and in the roots, than the analogical plants collected at the station 2 (at the outlet of the River Łupawa from the lake). It indicates a higher concentration of those metals in the region of the River Łupawa outlet into the lake than in the place of its outlet from the lake.

It has been found out that in particular parts of the plants under examination the degree of metal accumulation is different. The over-ground parts of *Phragmites australis*, *Sparganium ramosum hudds, Acorus calamus, Veronica anagallis* and *Typha latifolia* were characterized by a much smaller content of the analyzed metals in comparison with the root part. The over-ground part of *Phragmites australis* and *Acorus calamus* proved to be the part of the lowest concentrations of heavy metals with the narrowest range of their appearance. Particularly big differences between those two parts have been observed in the case of lead and cadmium in the plants from the region of the Łupawa outlet into Lake Gardno. The roots of *Typha latifolia* accumulate four times as much of lead as its over-ground portion whereas the roots of *Phragmites australis* – ten times more.

From among analyzed macrophytes *Elodea canadensis* and *Potamogeton natans* appeared to be the plants that cumulate the biggest amounts of metals under analysis. They were also characterized by the biggest abilities to cumulate heavy metals; therefore they can be used to assess the degree of aquatic environment contamination with heavy metals. Taking into consideration the area that the plants under analysis cover, their biomass and level of heavy metals phytosorption, they play a vital role in drawing those metals from the ecosystem of Lake Gardno.

The content of the analyzed metals in over-ground parts of the plants under examination appeared in the following sequence: Mn > Zn > Pb = Cu > Cd, and in the roots a little differently: Mn > Zn > Pb > Cu > Cd. From among those metals the biggest ability to cumulate in the examined plants showed manganese, zinc and cadmium.

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