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Toxicology

MERCURY IN FISHES AND IN SELECTED ELEMENTS OF THE ŚWIDWIE LAKE ECOSYSTEM

RTĘĆ W RYBACH I WYBRANYCH ELEMENTACH EKOSYSTEMU JEZIORA ŚWIDWIE

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The paper demonstrates concentration and distribution of mercury in selected elements of the Świdwie lake ecosystem: sediment, surface and rain water, fish tissues (gills, kidney, liver, muscles, alimentary tract and its contents—of rudd, perch, roach, white bream, and pike); duckweed, bladderwort; leaves, stems, and roots of reed and cattail.

INTRODUCTION

Mercury is a unique element due to its particularly high chemical and biological activity and variability in ionic state. Transformations of this element depend mainly on its oxidation-reduction potential and methylation processes (Kabata-Pendias 1992). From a toxicological point of view, these organic forms, especially methyl mercury, are important because they are known to be dangerous for organisms in aquatic ecosystems (Regnell 1995). Mercury concentration in fishes increases directly with size and age and accumulates mainly in the muscle tissue, gills, kidneys, liver and the brain (Spry et al. 1991). One of the main reasons that high mercury concentrations are found in predatory fish species is due to mercury's ability to accumulate in the food chain. Plants in an aquatic environment take up mercury in both organic and inorganic forms but more readily in the organic form (Ribeyre et al. 1991; Ribeyre and Bourdou 1994). An important factor influencing mercury accumulation by aquatic plants is also the source of acquisition. Water plants receive this metal from both water and sediment, although the uptake from a water source is about 10 times more efficient than that from a sediment. This is in contrast with the contamination levels, which are higher in sediments (Ribeyre and Bourdou 1994). Coquery et al. (1995) show that metal concentrations in plants is not easily correlated with concentration in sediments, because the presence of a high content of organic matter in sediments decrease metal availability.

Świdwie Lake is located 20 km north-west from Szczecin. Since 1963, the lake and surrounding areas have been protected by law. The Świdwie sanctuary is a valuable natural environment where many species of plants and animals exist, including rare and endangered species (Bacieczko et al. 1993; Zyska et al. 1994). The lake is small (125 ha), shallow with an average depth of 0.7 m (Jańczak et al. 1996), and its water is highly eutrophied (Tadajewski et al. 1987). To date, no research on concentrations of heavy metals in the lake has been conducted.

The aim of the study was to determine the concentration and distribution of mercury in selected elements of the Świdwie Lake ecosystem. An investigation into finding species that can be used as good bioindicators of mercury pollution was also conducted and this will allow future research to be limited to selected species.

MATERIAL AND METHODS

During 1995–96 samples of sediment cores, surface and rain water, fishes and plants were taken. Sediment cores, taken from depth of 0–20 cm, were acquired from 20 sites (Fig. 1) and were divided into 2.5 cm layers. Water samples were taken within 3 months of each other in 4 lake inlets and 1 outlet. Rain water samples were collected in Węgornik. Five fish species typical for this lake ichthiofauna were sampled: rudd, *Scardinius erythrophtalmus* L., perch, *Perca fluviatilis* L., roach, *Rutilus rutilus* L., white bream, *Blicca bjoerkna* L., and pike, *Esox lucius* L. Fish dimensions (length, weight) were within following ranges: rudd—8.1–13.0 cm, 5–26 g, perch—10.2–16.4 cm, 10–46 g, roach—14.3–21.7 cm, 39–96 g, white bream—8.8–16.2 cm, 7–45 g, pike—29.1–58.3 cm, 247–1250 g. Samples of muscles, kidney, liver, gills, alimentary tract, and its contents were collected from between five and ten individuals of each species. Samples of particular tissues, representative for each species were homogenised. Samples were also taken of two macrophytes (reed, *Phragmites australis* and cattail, *Typha augustifolia*) and two water plants (duckweed, *Lemna minor* and bladderwort, *Utricularia vulgaris*). Samples of the macrophytes and bladderwort were prepared by homogenising ten plants taken from five separate sample sites. Duckweed and bladderwort were analysed as a whole plant. Leaves, plant stems and roots of reed and cattail were analysed separately.

All the samples were analysed for total mercury content. In addition, in sediment samples, the percentage of organic matter content was measured. The pH values in surface waters were also determined. Sediment, fishes, and plant samples were prepared for analysis using Adrian's method (1971), and water samples using Sandell's method (1959). Mercury concentration was determined by cold vapour technique of atomic absorption spectrometry (CV AAS) in Varian Techtron A 1200.

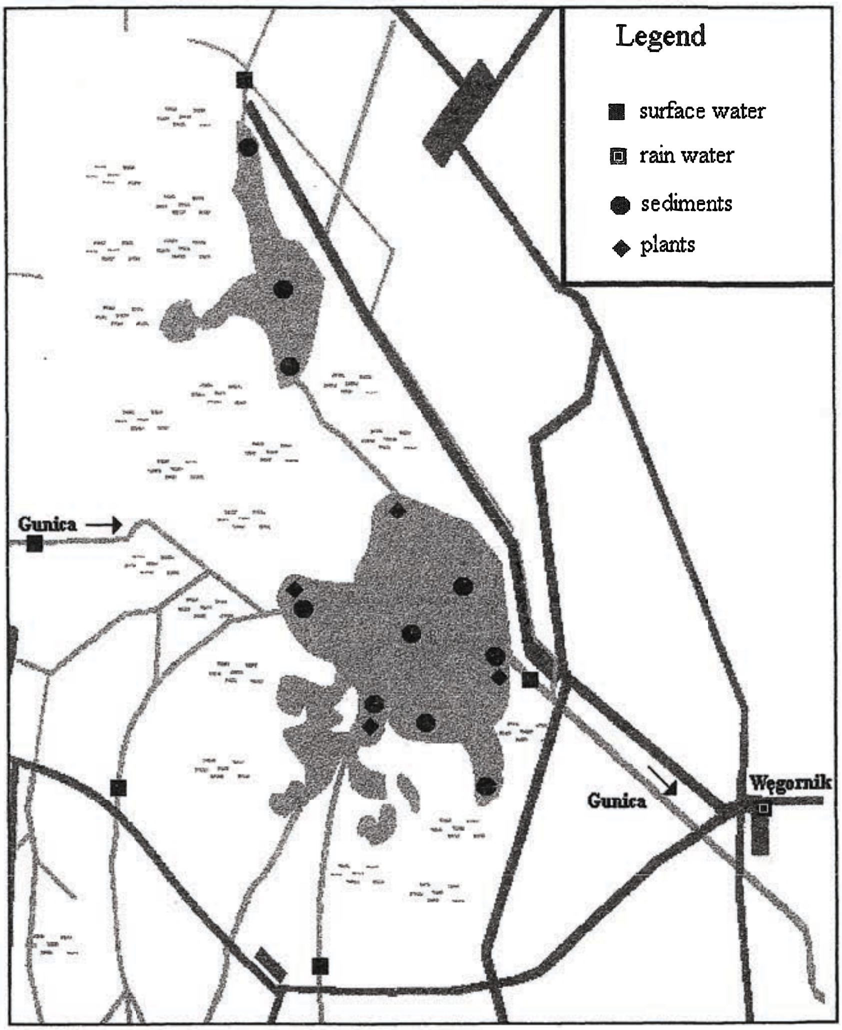

Fig. 1. Sampling sites

All samples were analysed in triplicate. Blank samples were analysed along with each analytical batch of samples. The mean value of the relative standard deviation within triplicate was 6.03%. Accuracy of the method was defined by adding standard solution. The mean recovery of the metal in water, sediment, fishes and plant samples ranged from 94 to 98%. Statistical analyses were performed using MS Excel 7.0. Significance level of 0.05 was used to judge all statistical tests.

RESULTS AND DISCUSSION

Table 1

Mercury concentration in water and plants from Świdwie Lake

Material	n	Range	Mean (SD)
Water [ng/dm^3]:			
inflows	32	<0.01–5.38	2.06 (1.55)
outflow	8	<0.01–4.47	1.69 (1.58)
rain	8	<0.01–5.29	2.51 (1.98)
Plants: [μg/g d.w.]			
Duckweed	8	0.068–0.156	0.113 (0.044)
Bladderwort	20	0.025–0.335	0.143 (0.086)
Cattail:			
leaves	20	0.009–0.090	0.033 (0.020)
stems	20	<0.001–0.068	0.028 (0.022)
reeds	20	0.049–0.377	0.141 (0.108)
Reed:			
leaves	20	<0.001–0.100	0.031 (0.030)
stems	20	<0.001–0.051	0.014 (0.013)
reeds	20	<0.001–0.377	0.141 (0.108)

SD—standard deviation

The results showed that mercury level (Tab. 1) in analysed surface waters was low, comparable with waters from unpolluted areas (Sorensen et al. 1990), although according to Wiener et al. (1996) concentration of the total mercury ranging from 0.6 to 4 ng Hg/dm^3 is typical for lightly contaminated lakes and streams (from 5 to 100 ng Hg/dm^3 for directly contaminated waters).

Average mercury concentration in surface waters taken from lake inlets was 2.06 ng/dm^3, and from the outlet 1.69 ng/dm^3. Although differences between averages were not statistically significant, the authors think that mercury is carried to the lake mainly by the Gunica River, because water samples were collected 8 times and in 6 of these 8 collecting the highest concentration of the metal was found in the river water. Mercury content in rain water (average 2.51 ng/dm^3) indicates that this is also the source of mercury in the Świdwie Lake environment. The Gunica River, which receives waters form the west part of the catchment area carries the biggest mass of water. Water comes to the lake from north and south by canals and ditches where minimum water flow is observed. The canals deliver water to the lake only during the period of higher rainfall and during the spring run off. The water level in the lake is very stable, and during summer months no efflux, and negative water balance is noticed (Kowalina et al. 1992).

On the basis of mercury levels and its distribution alone it is difficult to estimate how much of the metal remains in the lake environment. When analysing surface water influx and efflux one must remember that transfer of gaseous mercury from the lake to the atmosphere is also possible (Kabata-Pendias 1992; Rada et al. 1993) also, the metal concentration increases when negative water balance occurs in Świdwie Lake during summer months. The results give an insight into the inflow and outflow water quality. However, determination of the mercury content remaining in the lake is very difficult and only by determining the Hg accumulation in the sediments and biotic elements of the environment we could hopefully explain whether the metal might be dangerous for the organisms living there.

The highest average mercury concentration in the sediments amounting to 0.146 ±0.073 μg/g d.w. was found in the surface layer of 0–2.5 cm. According to Kabata-Pendias et al. (1993) the geochemical value for river sediments is 0.2 μg Hg/g. Förstner et al. (1974) estimate that value to be 0.3 μg/g. Therefore the mercury concentration in Świdwie Lake sediments remains within normal levels. Comparable amounts of the metal were found by Rada et al. (1993) in the north-central Wisconsin in lakes located in rural, mostly forested, watersheds with no identifiable, on-site antropogenic sources of mercury, in sediments rich in organic matter similar to those from Świdwie Lake. Also Sorensen et al. (1990) obtained similar results in north-east Minnesota. Sediments from mercury polluted lakes show much higher amount of this element in surface layers. Lacayo et al. (1991) in the sediments from Xolotan Lake (Nikaragua) received 0.62 ±0.42 μgHg/g.

Analysis of the sediment cores from Świdwie Lake showed that the biggest amount of mercury was present in the surface layer (Tab. 2), while the concentrations of the metal decreased with depth. Similar tendency was observed in the organic matter content, but relationship between mercury concentration and sediment depth was not statistically significant. The ratio of the highest to lowest average mercury content was 2.47, while this ratio for the organic matter—only 1.48. These data show that the vertical distribution of mercury in the Świdwie Lake sediments depends on sediments' structure and may be affected by antropogenic factors.

The assessment of the level of mercury content in the fishes was based on the metal concentration in the muscles. It is known that accumulation of heavy metals as well as their elimination from a muscle tissue proceeds slowly, therefore heavy metal levels in muscles are more stable and reflect better the environmental conditions. Mercury content in the predatory fish muscles can serve a widely accepted index of the metal level in lacustrine environment, that is the reason why it is analysed most frequently. The range of the natural values, according to different references, oscillates between 0.02 and 0.20 μg Hg/g muscles tissue wet weight (Mattheis 1992; Kozak et al. 1994). The average mercury level in the pike muscles from Świdwie Lake was low—in average 0.010 μg/g, while in rudd and perch muscles it was 0.004 and 0.005 μg/g respectively. Little more was found in roach (0.027 μg/g) and white bream (0.035 μg/g). These values are still much lower than these found in fishes from lakes polluted by metals. In Plunz-See, situated 50 km from Berlin, where there was no direct contamination by sewage, Mattheis (1992) found that even without direct exposure of lake to pollutants, the mercury content in the fishes was high. In pike muscles it ranged from 0.502 to 0.674 μg/g, and in roach from 0.272 to 0.393 μg/g. The problem of water contamination by mercury is known in Scandinavia. Out of 83 000 lakes in Sweden in about 40 000 the mercury levels in the muscles of 1-year-old pike exceeded 0.5 μg/g, and in about 10 000 lakes values were higher than 1 μg/g (Hakanson 1996). Rask et al. (1991) found that the concentration of mercury in the muscle tissue of pike from Finland's lakes ranging from 0.15 to 1.36 μg/g. It can be concluded that the mercury content values found in the fish muscle tissues from Świdwie Lake are characteristic for lakes where mercury pollution has not been recorded.

Table 2

Mercury and organic matter contents in Świdwie lake sediments at different dephts

Depth b.b. [cm]	Hg		Organic matter	
	Range n = 10 [μg/g d.w.]	Mean (SD) n = 10 [μg/g d.w.]	Range n = 10 [%]	Mean (SD) n = 10 [%]
0–2.5	0.061–0.235	0.146 (0.073)	1.49–47.66	31.57 (14.56)
2.5–5	0.011–0.317	0.145 (0.089)	3.32–47.09	28.60 (13.96)
5–7.5	0.031–0.274	0.124 (0.075)	1.66–39.26	26.20 (12.86)
7.5–10	0.026–0.227	0.104 (0.072)	3.20–41.82	25.45 (12.24)
10–12.5	0.020–0.236	0.102 (0.080)	2.24–34.95	24.23 (12.14)
12.5–15	<0.001–0.256	0.086 (0.085)	0.11–36.83	23.65 (14.59)
15–17.5	0.001–0.178	0.059 (0.061)	0.05–46.02	22.41 (15.43)
17.5–20	<0.001–0.146	0.061 (0.056)	0.04–47.49	21.27 (17.72)

SD—standard deviation
b.b.—below bottom

Mercury distribution between particular organs (Fig. 2) and the alimentary tract content was typical for fishes, however not always the biggest amounts were found in the kidneys and livers. In white bream and roach, higher amounts of the metal were found in the muscles than in other analysed organs. Probably this kind of distribution with low mercury level indicates that the fishes were not exposed to higher mercury level in the environment and the discharge of the mercury compounds proceeded more intensively than their uptake.

Taking all the analysed organs into consideration, in average the highest amount of mercury was accumulated by pike. Due to this fact it is proposed to use pike to control metal bioavailability for fishes in lacustrine environment. Using this fish species is motivated also by the fact, mentioned before, that pike is widely used for this kind of analyses. Also white bream and roach muscles fulfil the bioindicator requirements.

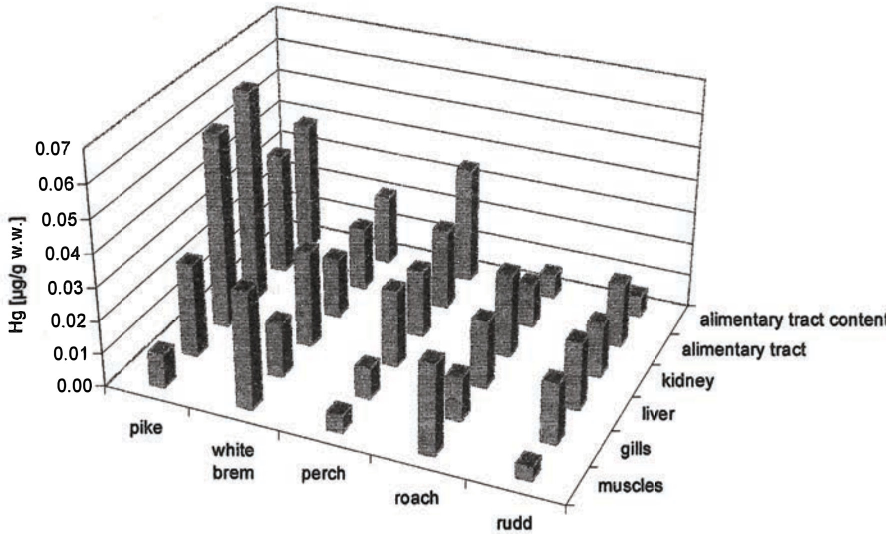

Fig. 2. Mercury contents in fishes

Kabata-Pendias et al. (1993) claim that the excessive (toxic) mercury concentration in plant leaves of moderated sensitivity and tolerance for redundancy of that metal ranged from 1 to 3 µg/g d.w. Our own results (Tab. 1) show that the mercury level in the plants from Świdwie Lake is many times lower than that given as toxic. The results are similar to those found by other researchers in the same or similar species in clean water (Nuorteva et al. 1986; Samecka-Cymerman et al. 1996).

The research proved that the roots of plants contained much bigger amounts of mercury than their leaves and stems. The submerged plants, as duckweed and bladderwort, examined as a whole, accumulated similar amounts of mercury as the roots of macrophytes. Despite the lack of substantial difference between the submerged plants and the roots of macrophytes, the former ones, duckweed and bladderwort, are more suitable for estimating and monitoring the mercury level in the plants of Świdwie Lake. Examination of these plants is less likely to lead to incorrect results, as in case of rush plants. When the macrophytes are analysed, there is a danger that the analysed roots are covered with sediment that would cause overestimation of the results.

Mercury distribution in the fish organs and alimentary tract content, and low level of the metal in fishes and plants, indicate that mercury occurring in abiotic elements of the lake is low available for organisms. As long as the metal exists in forms inaccessible for fishes and plant organisms does not pose a treat for them. Mercury being released from the sediments might be a cause of high growth of the mercury availability for organisms. Changes in the physical and chemical conditions, which effect transition of mercury forms and make them more mobile might be a result of natural processes, which occur in lacustrine environment. One of the most important factors influencing mercury availability in lakes is pH, which in Świdwie Lake varies from 6.5 to 8.5, and it is a factor limiting the metal uptake by organisms. As other researches demonstrated, mercury uptake by fishes is higher in acidic than in alkaline environment (Wiener 1987). Another important factor decreasing mercury availability in Świdwie Lake is organic type of the sediments. High chemical affinity of mercury to organic matter causes that its considerable amount remains bounded in sediments and it is unavailable to organisms. Occurrence of the phenomena is confirmed by the research of Coquery et al. (1995) who proved that there was no simple relationship between mercury concentration in *Eriocarion septangulare* and the metal content in the bottom sediments because of high organic matter content. Presence of the latter in the sediments reduces mercury availability to plants. One should, however, bear in mind that Świdwie Lake is a small, highly eutrophied, quickly warming up body of water. In such lakes higher mercury contents in fishes are observed due to increase of their ability to methylation (Bodaly et al. 1993), and as it known that methylmercury is easily taken up by organisms. Therefore it could be necessary to monitor, also in the future, the mercury levels in the lake.

CONCLUSIONS

1. The main source of mercury in the lake environment is an influx from the surface waters.
2. Surface sediments contained significantly more mercury than the deeper layers, which indicated that antropogenic sources of this metal have possibly played a role in its deposition. Despite it, the observed mercury content allow to qualify the lake sediments as not polluted with mercury.
3. Mercury distribution in fish organs, muscle tissue and alimentary tract content, and the low level of this metal concentration in the fishes and plants indicate that mercury existing in abiotic elements of the lake environment is of low availability to organisms.
4. The best indicators of mercury accumulation are: pike, *Esox lucius* L., duckweed, *Lemna minor*, and bladderwort, *Utricularia vulgaris*. White bream, *Blicca bjoerkna* L. is also a good bioindicator.

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RTĘĆ W RYBACH I WYBRANYCH ELEMENTACH EKOSYSTEMU JEZIORA ŚWIDWIE

STRESZCZENIE

Badano pionowe rozmieszczenie rtęci w osadach, jej zawartość w wodach powierzchniowych i opadowych; w narządach (skrzela, wątroba, nerki, mięśnie, przewód pokarmowy) i treści przewodów pokarmowych płoci, krąpia, wzdręgi, okonia i szczupaka; w rzęsie wodnej i pływaczu zwyczajnym; a także liściach, łodygach i korzeniach trzciny pospolitej oraz pałki wodnej. Zawartość rtęci w powierzchniowej warstwie osadów dennych (0,061–0,235 μg/g s.m.) oraz w wodach powierzchniowych (<0,01–5,38 ng/dm^3) pozostaje w zakresie uznawanym za naturalny, chociaż na podstawie badań osadów zwrócono uwagę na możliwość oddziaływań antropogenicznych. Rozmieszczenie rtęci w narządach i treści przewodów pokarmowych ryb, a zwłaszcza wykazany niski poziom tego pierwiastka w mięśniach ryb (0,006–0,032 μg/g m.m.) i roślinach (<0,001–0,355 μg/g s.m.) pozwala sądzić, że pierwiastek obecny w abiotycznych składnikach środowiska jeziora jest mało dostępny dla organizmów. Analiza wyników badań pozwala sądzić, że najlepszymi bioindykatorami przydatnymi w ocenie stopnia zanieczyszczenia ekosystemów rtęcią są: szczupak *Esox lucius* L, rzęsa drobna *Lemna minor* i pływacz zwyczajny *Utricularia vulgaris*.

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