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IRON ACCUMULATION IN SELECTED ELEMENTS OF POND ECOSYSTEM FOOD CHAIN

AKUMULACJA ŻELAZA W WYBRANYCH ELEMENTACH ŁAŃCUCHA POKARMOWEGO EKOSYSTEMU STAWOWEGO

Abstract: The aim of this study was to determine the accumulation of iron in the individual links of aquatic ecosystems food chain under extensive farming of carp. Based on ascertained in these organisms the contents of this element calculated value of bioaccumulation in the aquatic system and evaluated the degree of contamination. The study was performed in the breeding pond, located in Mydlniki, supplied with water from the river Rudawa. From the study pond collected: water, sediment from the bottom of the pond, benthic organisms represented by the larvae of flies of the chironomid family organs in, and carps from which were dissected the most associated with metals metabolism organs (gills, gonads, liver and muscle). In all samples determine the content of iron by atomic emission spectrometry in the camera JY 238 Ultrace Jobin Yvon Emission. Digestion of the samples were made by the wet method in a closed system with the use of microwave energy. Based on the results concluded that in the studied ecosystem, there is no risk of iron poisoning. The contents of this element in the water and bottom sediments are comparable to other reservoirs, of anthropogenic and natural origin. Was found a high value of the sediments enrichment factor sediments with iron in relation to its content in the water. The content of iron in the benthic organisms have taken high values, from 1189 to 1997 mg · kg^{-1} d.m. The iron content in organisms of the examined fish ranged from 2.951 to 395.9 mg · kg^{-1} d.m. Most of this element was found in the gills, then in liver, gonads and the least iron is accumulated muscles. Literature data show that regardless of the amount of iron in the environment, bioaccumulation factor in fish organs takes a value close to those obtained in own research. The content of iron in the liver and gills of fish is the most authoritative indicator of environmental contamination by iron compounds.

Keywords: iron, bioaccumulation, food chain, aquaculture, carp

Intruduction

Comprehensive determining the extent of hazard to aquatic system posed by trace elements is very difficult due to considerable changeability of water and bottom

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sediments chemistry in the reservoir in time and spatial approach. Chemical elements supplied to the aquatic environment from anthropogenic or natural sources undergo various chemical and biochemical transformations in result of which they may accumulate in living organisms or bind bottom sediments. Determination of the total element concentrations in individual elements of the aquatic ecosystem does not provide information about the actual threat from xenobiotics. Contemporary approach to the environmental monitoring requires the use of the environment. Determining the environment pollution using bioindicators requires selection of appropriate animal and plant species, characterized by high abilities to accumulate a given xenobiotic. In case of water macrofauna it is also necessary to choose the organ in which an element accumulates in greatest quantities. The amount of elements accumulated in living organisms in first place depends on the forms in which they occur in the environment, which determines their bioavailability. In case of the elements which are microelements it is necessary to pay attention of their physiological role, the consequence of which is their increased accumulation in individual organs. The best method for an assessment of the threat posed to the environment by trace elements is determining bioaccumulation coefficient through an assessment of their accumulation in the organisms of subsequent trophic levels of the ecosystem [1]. Determining the environment pollution using bioindicators necessitates a selection of appropriate animal and plant species which are characterized by considerable abilities for a given xenobiotic accumulation. In case of water macrofauna it is also important to choose the organ in which an element accumulates in the biggest quantities [2, 3].

The paper aimed at determining iron accumulation in individual links of pond ecosystem food chain in conditions of intensive carp husbandry. On the basis of conducted research, the degree of pond pollution with this element was estimated and the element bioaccumulation coefficients were computed.

Material and methods

In 2008 research on iron cycling was conducted in a pond belonging to the Experimental Station of the Department of Ichtiobiology and Fisheries, University of Agriculture in Krakow, localized in Mydlniki, fed by the Rudawa river water. This is a commercial pond with an area of 4 ha. The investigations comprised determining iron content in water, bottom sediments, benthos and organs of carps (*Cyprinus carpio* L.).

Iron content in water was assessed thrice during the vegetation season. Samples were collected at the beginning of feeding season (in May), during the period of the most intensive fish feeding (in July) and in September by the end of fattening period. Water was taken from six points in the pond, whereas bottom sediments from the top layer of the pond bottom (0–5 cm) after the pond emptying. The pond was divided into eight zones and laboratory samples were collected from each one (two samples close to the outlet box, 4 samples from the central part of the pond and two in the vicinity of the outlet box). Bottom sediments were dried, sifted through a sieve with 1mm mesh and crumbled in a mortar. Samples of benthos organisms (*Diptera Chironomidae* larvae) were collected in the same spots. Iron concentrations in carp (*Cyprinus carpio* L.)

organisms were assessed in 25 randomly selected fish destined for consumption. The fish gender was determined (by organoleptic method), their age (insight into production documents) and mass of the analyzed carps (by gravimetric method). Fish originated from a three-year period of rearing, the weight fluctuated from 1500 to 2000 g. Carps were killed by decapitation and their organs (gills, muscles, livers and gonads) were prepared.

Obtained laboratory samples were subjected to wet mineralization in a closed system in a microwave mineralizer. The weighted portion for analyses was *ca* 0.5 g in conversion to dry mass. Biological material was dissolved in a mixture of HNO_3 and H_2O_2 (at 5:1 v/v ratio) of the acid, while bottom sediments in aqua regia (1:10). Water samples for analyses were condensed ten times. Iron concentrations in the obtained solutions were assessed by means of inductively coupled plasma atomic emission spectrometry (ICP-AES), on JY 238 ULTRACE apparatus (Jobin Yvon emission) at 238.04 nm wavelength. Iron limit of determination in the applied method was 0.0046 $mgFe \cdot dm^{-3}$. Uncertainty of measurement of applied methods was ±4 %. The limit of determination of the analyses was 0.155 $\mu g \cdot g^{-1}$ d.m. of biological material and 0.24 $\mu g \cdot g^{-1}$ d.m. of sediments. The correctness of iron analyses was verified using certified reference material CRM 16-050.

Result and discussion

Iron is an essential element for vertebrate animals. This element, being involved in oxygen transfer, respiratory chain reactions, DNA synthesis, and immune function. However, excess free iron promotes the formation of reactive oxygen species that are damaging to the host. The mechanisms of Fe uptake across the gills and intestine, is influence on geochemical prosperities of abiotic elements of ecosystem and life strategies of fish. Since there appears to be no regulated mechanism for iron excretion through the liver or kidney, to maintain iron balance both uptake by intestinal epithelial cells and recycling by macrophages are tightly controlled. Affect iron metabolism downloads on other elements. Ferric iron (Fe^{3+}) is first reduced to the ferrous (Fe^{2+}) form to the apical ferric reductase. Iron influenced of capable of transporting several other divalent metals, essential copper, zinc cobalt, nickel and manganese. A diet poor in iron can lead to excess accumulation of cadmium in organisms. If lead is not aware of such relationships [4]. Iron is an element, which is increasingly the subject of research related to aquatic ecosystems. Many research points to an important role of this element in the formation and development of the primary production of phytoplankton but only in seawater environments [5, 6]. Despite the propensity for iron oxidation in the freshwater environment it is not a limiting factor in lotic or lentic phytoplankton growth. The bioavailability of iron to organisms in freshwater is far greater than that of seawater.

Average iron content in surface waters fluctuates from 61 to 2680 $\mu gFe \cdot dm^{-3}$ Guarzu et al [7]. Its content in water is connected both with the intensity of its leaching from the parent rock and with industrial and municipal sewage discharge into the water bodies. An important source of iron in the environment are runoffs from roofs and hard surfaced areas. Mean content of iron in water of the analyzed pond was 988.2 $\mu gFe \cdot dm^{-3}$ (Table 1). No statistically significant differences were determined in water collected on various dates (Fig. 1). Water collected in August contained slightly smaller amounts of this element. Wisniowska-Kielian and Niemiec [8] assessed similar content of this metal in agricultural and recreational part of the Dunajec river catchment and only in the area of municipal and industrial sewage discharge iron concentrations were higher than obtained in the presented investigations. Fish [9] states that optimal iron content for the aquaculture animals remains within the range below 150 $\mu gFe \cdot dm^{-3}$.

Table 1

Statistic parameters of the results

Statistic parameters	Water	Sedi-ments	Larvae	Organs of fish			
				Gills	Gonads	Muscle	Liver
	$[\mu g \cdot dm^{-3}]$	$[mg \cdot kg^{-1}$ d.m.]					
Minimum	778.5	5088	1189	99.76	21.05	2.951	67.89
Maksimum	1305	9863	1997	395.9	354.5	70.76	207.8
Mean	988.2	8004	1583	192.8	95.70	37.62	114.1
Standard deviation	192.9	1602	319.7	70.13	76.82	20.00	35.63
Median	998.5	8533	1482	172.1	78.59	30.70	104.9
Deviation coefficient [%]	19.52	20.01	20.20	36.36	80.27	53.16	31.22

Oberholster et al [1] report that iron concentrations in the water of Loskop Lake in southern Africa range from 110 to 260 $\mu gFe \cdot dm^{-1}$. At iron concentrations in water exceeding 800 $\mu gFe \cdot dm^{-1}$, its compounds may start accumulating in bronchial epithelium in fish leading to possible changes of steroid hormone concentrations in blood plasma [10]. In aquatic environments where high iron concentrations, exceeding 1000 $\mu g \cdot dm^{-3}$ persist permanently, fish may develop defence mechanisms owing to which they are able to live and reproduce without toxicity symptoms [11], therefore the signals of negative effect of iron on aquaculture organisms are observed rarely. Iron bioavailability depends in the first place on its forms dissolved in water, which is

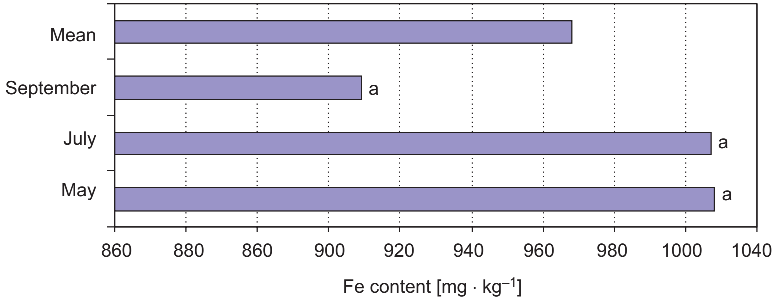

Fig. 1. Content of iron in water

associated not only with the total amount of this element but also with physicochemical, chemical and physical properties of water. Water pH and oxidation reduction conditions have the greatest effect on iron availability to fish. Increasing water pH causes precipitation of water insoluble iron carbonates which results in its immobilizing [12]. In fresh water processes of bivalent iron oxidation occur more intensively than in sea water, therefore its biodiversity in inland waters is much higher in comparison with seawaters. In high seas waters, deficiency of bioavailability iron often limits the amount of primary production [13]. Iron does not belong to toxic elements, but it affects the uptake of other elements which may cause their secondary deficiency [1]. It water it persists for a short time in an insoluble form. It precipitates to the sediments as hydroxides or insoluble trivalent iron salts. Ions of Fe^{3+} iron reveal a strong affinity to organic matter. In reservoirs with high content of seston organic fractions, faster processes of iron immobilization are observed in bottom sediments [14]. In the close to the bottom zone under conditions of oxygen deficiency, Fe^{3+} iron undergoes reduction forming water insoluble compounds. In this way it becomes available to benthos organisms. This element effect on the natural environment is observed among others as a change of physicochemical properties of bottom sediments, worsening the conditions of benthos organisms development. Liming the benthos and periphyton development leads to worsened biodiversity of the whole aquatic ecosystem and diminishes food resources for fish [15]. Iron plays an important role in processes of element cycling in aquatic ecosystem, particularly sulphur, phosphorus and heavy metals. Iron is of major importance for phosphorus sorption in aquatic environments. The element is important for binding heavy metals and sulphur released during organic matter mineralization, which may limit their toxicity [16].

In the sediments found to be very high iron content. The source of this element in aquatic sediments eroded from the debris basin and the precipitation of this element in the sediments as a result of self-purification processes. In the conditions of high oxidation-reduction potential is iron oxidation and their unsoluble compounds is precipitated as a salt be trivalent iron. Iron precipitates in the sediments in the form of carbonates, sulfides, phosphates. Mean content of iron in bottom sediments from the investigated pond ecosystem was 8004 mgFe $\cdot$ kg^{-1} (Table 1). Wisniowska-Kielian and Niemiec [8] noted higher iron concentrations in bottom sediments of the Dunajec river, reaching 7–25 g $\cdot$ kg^{-1}. Slight differences were registered in this element contents in samples collected from various parts of the pond. Iron in bottom sediments originates in the first place from processes of catchment erosion, whereas anthropogenic sources of this element are of minor importance. In research of Yuvanatemiya and Boyd [2], bottom sediments from unpolluted fish ponds contained only 150 mgFe $\cdot$ kg^{-1}. The authors registered much lower coefficient of sediment enrichment in relation to its content in water in comparison with the results obtained in the Authors' own studies. On the other hand, iron concentrations in the sediments from ponds which are receiving waters in Czech Republic, fluctuate from 100 to 1300 mg $\cdot$ kg^{-1} [17]. Iron content in the studied sediments was high and is characteristic for bottom sediments of basins whose catchments are developed from geological formations rich in this element or reservoirs intensively used antropogenically.

The most important representatives of benthic invertebrates in the studied ecosystem are the larvae of the chironomidae. These organisms are widespread in eutrophic reservoirs in the northern hemisphere, in mid-latitudes and can be found both in the environment of flowing and standing water. Because of its ecological functions associated with the decomposition of detritus and the most important item in the diet of benthos-eating fish, chironomidae larvae are a common subject of research in freshwater ecology interesting because they are the predominant part of benthic [18]. Chironomidae are a valuable group of organisms used in biological monitoring of environmental pollution [19]. Iron concentrations in benthos organisms of the investigated ecosystem fluctuated from 1189 to 1997 mgFe $\cdot$ kg^{-1} d.m., reaching average value on the level of 1583 mgFe $\cdot$ kg^{-1} d.m. (Table 1). Bioaccumulation coefficient of this element in *Diptera Chironomidae* larvae was respectively 1602 and 0.198 in relation to its level in water and bottom sediments (Table 2). Nurhasan et al [20] report iron concentrations in water insect larvae on rice fields in China on the level of 590 mgFe $\cdot$ kg^{-1} d.m. at much lower content of this element in the abiotic elements of the ecosystem. Contents approximate to obtained in the presented investigations the authors quoted above found in snails. Iron bioaccumulation coefficient in benthos organisms was over twice higher in the Authors' own research than presented by Nurhasan et al [20]. On the other hand, Foxall et al [21] stated iron content between 9170 and 12980 mgFe $\cdot$ kg^{-1} d.m. in endemic snail species from Tanganica Lake. High iron concentrations in water sediments and bottom fauna are specific for reservoirs in warm climate. Very high iron content in benthos organisms is the consequence of high accumulation of this element in sediments. Changes of oxidation-reduction conditions or changes of reaction in above-the-sediments water may lead to an immobilization of this metal or its accumulation in living organisms. Iron contents in benthos organisms of the analyzed ecosystem are high, which at high share of natural feed for carps may lead to a higher supply of this metal for fish.

Table 2

Bioaccumulation coefficients of iron in biotic part of environment

Parts of environment	Larvae	Gills	Gonads	Muscle	Liver
Water	1602	1951	96.84	38.07	115.5
Sedimets	0.198	0.024	0.012	0.005	0.014
Larvae	—	0.122	0.060	0.024	0.072

Iron is an element with strongly bioconcentration , especially in aquatic organisms that are at low levels of the trophic chain. The value of this coefficient in the fish can be even more than 1500. Very easy is captured through the skin, gills and epithelium. Accumulated mainly in the liver [22]. There is no documented studies in the literature demonstrating that this element is biomagnification. Iron deficiency is often observed that organisms inhabiting the ecosystems of the poor in this element, or in conditions of artificial breeding. Iron is routinely added to fish feeds in aquaculture. The concentrations of iron in the diet required to prevent signs of iron deficiency. for salmon required iron concentration in the feed is 60–100 mgFe · kg^{-1} for channel catfish 30 mgFe · kg^{-1}, and puffer fish 90–140 mgFe · kg^{-1}. A daily loss of iron by the freshwater fish is about 10–18 μg · kg^{-1} · day^{-1}. The uptake efficiency of iron from fish diet required to balance iron loss would have to be in the order of 0.7–1.2 %.

Bivalent form of iron Fe^{2+} is more available than $Fe^{3+,}$ but in oxic aquatic environments and at pH between 6.5–7.5 Fe^{2+} is oxidized to Fe^{3+}. In freshwater the oxidation rate of Fe^{2+} is considerably slower compare with than in seawater [23], and in these oxic environments iron is found as colloidal hydrous iron oxides that are not biologically available. The physio-chemical characteristics of seawater makes easier the formation of colloid aggregation. Fe^{3+} oxyhydroxide colloids, which may also be complexed with organic matter [24], settle out and the reducing environs of the anoxic zone or sediment results in Fe^{3+} reduction and Fe^{2+} leaches from the sediment generating an iron cycle. In the warm tine stratification of eutrophic reservoirs may result in an oxic zone extending only a few metres below the surface, and during the autumn or winter the breakdown of the thermocline as the lake cools results in the mixing of the bottom nutrient and iron rich waters. Based on these observations it would appear that there is a greater potential for iron uptake by the gills of freshwater fish compared to marine fish, but that the diet is probably the most important source of iron in both environments.

Carps are considered as organisms useful in the research on bioavailability of pollutants in the environment. They are organisms resistant to high concentrations of pollutants and reveal considerable abilities for these substances accumulation [23, 25].

Gills are important organ of ionic exchange in fish organism. Fish absorb and release metals from water through these organs. Iron is taken up by gills as free ions and chelates of this element. The other way of iron absorption by fish organism is alimentary canal. The ratio between iron absorption by gill and from alimentary canal determine the amounts of this metal in water and feed [26]. Iron uptake by fish gill epithelium is the most affected by water pH and its oxidation-reduction potential. In strongly alkaline and oxidative environment a limited iron uptake by fish gill epithelium is observed [27]. Precise regulation mechanism of iron quantity entering through gills and with feed has not been identified yet [28]. If iron occurs in aquatic environment in large quantities, its insoluble compounds (oxides or hydroxides and sulphites) may accumulate in gills, inhibiting gaseous and ionic exchange in fish [29]. In many aquatic environments, particularly saltwater bodies deficiencies of this element are observed [14]. In such environments fish often develop mechanisms of iron uptake from hardly available sources. Fish gill epithelium may produce substances which allow to absorb iron bound in insoluble compounds, *eg* as iron sulphites [30]. Iron content in gills of the analyzed fish was highly diversified and ranged from 99.76–395.9 mg · kg^{-1} d.m. with mean 192.8 mg · kg^{-1} d.m. (Table 1). Relative standard deviation was 36.6 %. No statistically significant differences of iron concentrations were observed in male and female gills (Fig. 2). High concentrations of this element in gills result from considerable blood supply in these organs. Uysal et al [31] report iron content in gills of various fish migrating from the area of Beymelek Lagoon in Turkey on a similar level

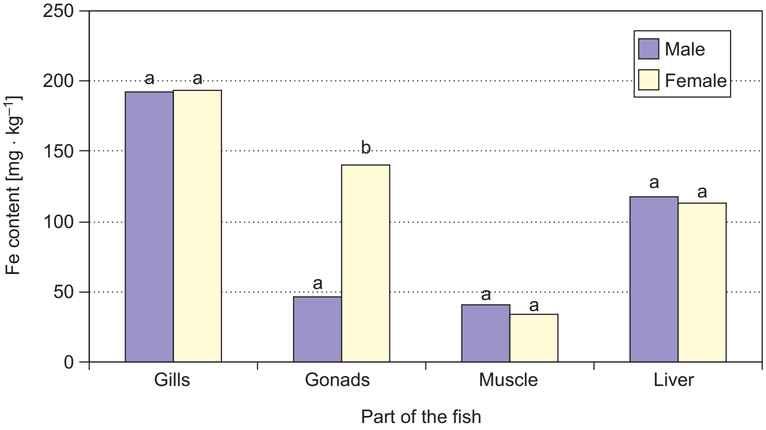

Fig. 2. Content of iron in following organs depending on sex

as the results obtained in the Authors' own investigations, however iron concentrations in fish muscles stated by these authors were several times lower. Under conditions of high iron concentrations in water, its increased concentrations in gills are observed connected with precipitation of this metal hydroxides in gill flakes. This element content in carp gills was over ten times lower than in benthos organisms. The metal bioaccumulation coefficient in relation to its concentrations in water and sediments was respectively: 195 and 0.024, while in relation to its content in benthos, the value of bioaccumulation coefficient was on the level of 0.122 (Table 2).

Iron content in carp muscles revealed high changeability fluctuating from 2.951 and 70.76 mgFe · kg^{-1} (Table 1). Mean content was 37.62 mgFe · kg^{-1} d.m. Relative standard deviation was 53.16 %. Muscles of male fish contained slightly more of this element. The differences were not statistically significant (Fig. 2). Nurhasan et al [20] assessed iron content in muscles of carps kept on rice fields and obtained results similar to presented in this paper despite much lower content of this element in abiotic environment components. Roos et al. [32], who report iron content in muscles of various fish species in fresh waters of Cambodia, point to a considerable diversification of this element content depending on fish species, ranging from 20 to over 360 mgFe · kg^{-1} d.m. The animal living environment has a lesser influence on iron concentrations [32]. Cooper at al [27] registered very high contents of iron, ranging from about 80 mg to over 150 mgFe · kg^{-1} d.m., in Danio rerio fish carcasses depending on this element quantity in feed. Foxall et al [21] report iron contents in muscles of 6 fish species from Tanganica Lake on the level from 29 to 38 mgFe · kg^{-1} d.m. Iron level in snails from this lake was much higher than noted in *Diptera Chironomidae* analysed in presented research. No effect of sampling localization was observed on iron accumulation level in fish tissues. Iron content in fish muscles is an important criterion of their usability for human consumption. Luczynska et al [33] report much lower amounts of this element in muscles of carps available in shops in Olsztyn.

Liver is the main place of iron accumulation in fish organism. This element concentration in this organ is a sensitive indicator of its availability in the environment but also health condition of fish [7, 34, 35]. The content of iron accumulated in livers of the analysed carps revealed the lowest changeability and fluctuated from 67.89 to 207.8 mgFe · kg^{-1} d.m. (Table 1) at an average content of 114.1 mgFe · kg^{-1} d.m. Male livers contained slightly bigger amounts of this metal, but the differences between males and females were not statistically significant. Coefficient of variation for all analyzed samples was 31 %. Iron bioaccumulation coefficient in the analysed fish livers was 115 in relation to its amount in water; 0.014 in relation to iron concentration in the sediments and 0.072 in relation to its content in benthos organisms.

Gonads are the organs where iron accumulation does not occur. Its concentrations in these organs is connected with their physiological functions. This element content in gonads showed a considerable changeability, fluctuating from 21.05 to 345.5 mgFe · kg^{-1} d.m. Mean content of this element was 95.7 mgFe · kg^{-1} d.m. (Table 1). A significant statistical differences were observed in this element content in testicles and ovaries. About thrice bigger amounts of iron were found in ovaries than in testicles.

Among all analysed organs, the highest amounts of iron were registered in gills, then in ovaries, in the liver and testicles, whereas the lowest content in muscles of the analysed carps. The ratio of iron content in these organs was 1 : 0.70 : 0.59 : 23 : 0.20. No statistically significant differences were registered between iron content in male and female organs, except its concentrations in gonads.

Conclusions

1. Water and bottom sediments from the ponds were characterized by high iron content.
2. Iron concentrations in individual fish organs was in the following order from the highest: gills > ovaries > liver > testicles > muscles.
3. Coefficient of iron enrichment was high in bottom sediments and characteristic for the ecosystems abundant in this element.
4. Iron content in benthos was very high, characteristic for the environments abundant in this element.
5. Iron bioaccumulation coefficient assumed much higher values in *Diptera* larvae organisms in comparison with the literature data, whereas in carp organisms its value was lower than presented in the subject literature.

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AKUMULACJA ŻELAZA W WYBRANYCH ELEMENTACH ŁAŃCUCHA POKARMOWEGO EKOSYSTEMU STAWOWEGO

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Abstrakt: Celem pracy było określenie akumulacji żelaza w poszczególnych ogniwach łańcucha pokarmowego ekosystemu wodnego w warunkach ekstensywnego chowu karpi. Na podstawie zawartości tego pierwiastka w biotycznych i abiotycznych elementach ekosystemu oszacowano stopień jego zanieczyszczenia. Badania wykonano w stawie hodowlanym, położonym w Mydlnikach, zasilanym wodą z rzeki Rudawa. Z badanego stawu pobrano: wodę, osad z dna stawu, organizmy bentosu reprezentowane przez larwy muchówek z rodziny ochotkowatych, a także karpie, z których wypreparowano narządy w największym stopniu związane z metabolizmem metali (skrzela, gonady, wątroba i mięśnie). We wszystkich próbkach oznaczono zawartość żelaza metodą emisyjnej spektrometrii atomowej w aparacie JY 238 ULTRACE Jobin Yvon Emission. Mineralizację próbek wykonano metodą na mokro w systemie zamkniętym z wykorzystaniem energii mikrofalowej. Na podstawie uzyskanych wyników stwierdzono, że w badanym ekosystemie nie ma zagrożenia zatrucia żelazem. Zawartości tego pierwiastka w wodzie i osadach dennych są porównywalne do innych akwenów, pochodzenia antropogennego i naturalnego zasobnych w ten pierwiastek. Stwierdzono dużą wartość współczynnika wzbogacenia osadów w żelazo w stosunku do jej zawartości w wodzie. Zawartość żelaza w organizmach bentosu przyjmowała duże wartości, od 1189 do 1997 mg · kg^{-1} s.m. Wartości współczynnika bioakumulacji żelaza w larwach ochotkowatych w stosunku do jego ilości w wodzie i osadach wynosiły odpowiednio 1602 i 0,198. W organizmach badanych ryb zawartość żelaza kształtowała się w zakresie 2,951 do 395,9 mg · kg^{-1} s.m. Najwięcej tego pierwiastka stwierdzono w skrzelach, następnie w wątrobie, gonadach, a najmniej żelaza akumulowały mięśnie. Dane literaturowe wskazują, że zawartość żelaza w rybach zależy od ilości tego pierwiastka w środowisku, ale w większym stopniu od właściwości abiotycznych elementów środowiska. Sumaryczna zawartość żelaza w osadach dennych i wodzie nie pozwala ocenić zagrożenia środowiska zanieczyszczeniem żelazem, dlatego tak ważne jest stosowanie bioindykacji. Zawartość żelaza w skrzelach i wątrobie ryb jest najbardziej miarodajnym wskaźnikiem zanieczyszczenia środowiska związkami żelaza. Wartość współczynnika bioakumulacji żelaza w skrzelach badanych karpi wynosiła w stosunku do jej zawartości w wodzie i osadach dennych odpowiednio 195,1 i 0,024 natomiast w stosunku do jego zawartości w larwach owadów wartość tego parametru wynosiła 0,122. Dane literaturowe wskazują, że poziom akumulacji żelaza w organizmach żywych jest uzależniony od środowiska w którym żyją.

Słowa kluczowe: żelazo, bioakumulacja, łańcuch pokarmowy, akwakultura, karp