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ACCUMULATION OF COPPER IN SELECTED ELEMENTS OF A FOOD CHAIN IN A POND ECOSYSTEM

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Abstract

The content of elements in an aquatic environment (water and bottom sediments) is not a reliable indicator of a potential threat of toxic compounds to living organisms. The amounts of elements accumulated in living organisms depend primarily on forms in which the elements occur in the environment. The measurement of the rate of uptake of trace elements by living organisms is known as a bioaccumulation coefficient. Copper is one of the most toxic metals to water organisms. In respect of its toxicity, it is the third (after mercury and silver) most toxic element among metals commonly present in the environment. The paper aimed to determine the copper accumulation in individual links of a food chain in a water ecosystem of a pond used for extensive carp aquaculture. Based on the copper concentration in the carps, the value of the copper bioaccumulation coefficient in the water ecosystem was calculated and the degree of contamination of the pond was estimated.

The study comprised a breeding fish pond situated in Mydlniki, fed with water from the Rudawa River. The following were sampled: pond water, sediment from the pond's bottom, benthos organisms represented by larvae of *Diptera* family *Chironomidae* and carps (*Ciprinus carpio* L.). Organs from the fish (gills, muscles, livers and gonads) most strongly connected with the metabolism of metals were excised and prepared. Copper concentrations were determined in all samples by means of atomic emission spectrometry on a JY 238 Ultrace apparatus (Jobin Yvon Emission) after wet mineralization in a closed system using microwave energy. The results enabled us to conclude that there was no hazard of copper contamination in the examined ecosystem, although the copper content in the pond's sediments and water suggest some enrichment from anthropogenic sources. A lower value of the copper enrichment factor was determined in the sediment than in water. The bioaccumulation coefficient for copper in benthos and fish muscles assumed higher values, being much lower in fish gills in comparison with the literature data. The values of the copper bioaccumulation coefficient in the livers of the examined carps in relation to its content in water and bottom sediments were 1,532 and 0.623, respectively. Literature references

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indicate that – regardless of the water pollution degree – the bioacummulation coefficient in this organ assumes a value approximately the same as obtained in the authors' own investigations. The copper concentration in the liver is a reliable indicator of the environmental pollution with copper compounds. The highest amounts of copper were found in the liver; less copper was in gills and gonads, and the lowest concentration of copper was detected in the carps' muscles.

Key words: copper, bioaccumulation, food chain, aquatic ecosystem.

AKUMULACJA MIEDZI W WYBRANYCH ELEMENTACH ŁAŃCUCHA POKARMOWEGO EKOSYSTEMU STAWOWEGO

Abstrakt

Zawartość pierwiastków w środowisku wodnym (w wodzie i osadach dennych) nie jest miarodajnym wskaźnikiem zagrożenia dla organizmów żywych. Ilość pierwiastków akumulowanych w organizmach żywych zależy przede wszystkim od form, w jakich występują w środowisku. Miarą intensywności pobierania pierwiastków śladowych przez organizmy żywe jest współczynnik bioakumulacji. Miedź jest jednym z najbardziej toksycznych metali dla organizmów wodnych. Pod względem toksyczności zajmuje 3 miejsce (po rtęci i srebrze) wśród metali powszechnie występujących w środowisku. Celem pracy było określenie akumulacji miedzi w poszczególnych ogniwach łańcucha pokarmowego ekosystemu wodnego w warunkach ekstensywnej hodowli karpi. Na podstawie zawartości miedzi w tych organizmach obliczono wartość współczynnika bioakumulacji miedzi w ekosystemie wodnym i oszacowano stopień zanieczyszczenia stawów.

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 (*Diptera*) z rodziny ochotkowatych (*Chironomidae*) oraz karpi (*Cyprinus carpio* L.). Z organizmów karpi wypreparowano narządy (skrzela, gonady, wątrobę i mięśnie) w największym stopniu związane z metabolizmem metali. We wszystkich próbkach oznaczono zawartość miedzi metodą emisyjnej spektrometrii atomowej w aparacie JY 238 Ultrace Jobin Yvon Emission, po uprzedniej mineralizacji metodą na mokro w systemie zamkniętym z wykorzystaniem energii mikrofalowej.

Stwierdzono, że w badanym ekosystemie nie ma zagrożenia zatrucia miedzią, chociaż zawartość miedzi w osadach i wodzie wskazuje na ich antropogeniczne wzbogacenie. Stwierdzono małą wartość współczynnika wzbogacenia osadów w miedź w stosunku do jej zawartości w wodzie. Współczynnik bioakumulacji tego pierwiastka w bentosie oraz w mięśniach ryb przyjmował większe wartości, natomiast w skrzelach znacznie mniejsze w porównaniu z danymi literaturowymi. Wartość współczynnika bioakumulacji miedzi w wątrobie badanych karpi w stosunku do jej zawartości w wodzie i osadach dennych wynosiła odpowiednio 1532 i 0,623. Dane literaturowe wskazują, że niezależnie od stopnia zanieczyszczenia wody, współczynnik bioakumulacji w tym organie przyjmuje wartość zbliżoną do uzyskanych w badaniach własnych. Zawartość miedzi w wątrobie jest najbardziej miarodajnym wskaźnikiem zanieczyszczenia środowiska związkami miedzi. Najwięcej miedzi stwierdzono w wątrobie, następnie w skrzelach, gonadach, a najmniej w mięśniach karpi.

Słowa kluczowe: miedź, bioakumulacja, łańcuch pokarmowy, ekosystem wodny.

INTRODUCTION

Complex determination of the threat to water ecosystems caused by trace elements is very difficult due to high temporal and spatial changeability of the chemical composition of water and bottom sediments in any water reservoir. Amounts of elements accumulated in living organisms above all depend on the form in which elements occur in the environment, which determines their bioavailability. Depending on the species of an aquatic organism species, which determines the type of food, the way of it is ingested, life activity and metabolic specificity, both amounts of accumulated copper and sources from which it is absorbed are different. Pelagic organisms take up mainly elements contained in water and in the seston. For benthic or benthic-foraging organisms, including carp, the basic source of heavy metals are bottom sediments (LIANG et al. 1999, ALAM et al. 2002, SCHJOLDEN et al. 2007). The best method of estimating environmental hazards posed by trace elements is by determining the bioaccumulation coefficient through an assessment of their accumulation in organisms at the subsequent trophic levels in an ecosystem. Determination of the environmental pollution with bioindicators is preceded by a selection of appropriate animal and plant species, which are distinguished by high capacity to accumulate a given xenobiotic. In the case of aquatic macrofauna, it is also necessary to choose an organ which accumulates the highest amounts of the analysed element.

Copper is one of the most toxic metals to aquatic organisms. In fact, it is the third (after mercury and silver) most toxic substance among metals commonly present in the environment (KHANGAROT 1991). The element may negatively affect fish even if present in small amounts in the environment (YUVANATEMIYA, BOYD 2006).

The aim of the paper was to determine the copper accumulation in individual links of of a food chain in an ecosystem in a pond ecosystem used for extensive carp (*Ciprinus carpio* L.) breeding. On the basis of conducted analyses the value of copper bioaccumulation coefficient in aquatic ecosystem was computed and the degree of pond pollution was estimated.

MATERIAL AND METHODS

In 2008, research on copper cycling was conducted in a fish pond, owned by the Experimental Station of the Department of Ichtyobiology and Fisheries, University of Agriculture in Krakow, situated in Mydlniki and fed with water from the Rudawa River. It was a commercial pond covering an area of about 4 ha. The analyses comprised copper assessments in water, bottom sediments, benthos and carp (*Cyprinus carpio* L.) organs.

Copper concentrations in water were assessed three times during the fish rearing season. The samples were collected at the beginning of the feeding season (in May), during the most intensive fish feeding (in July) and in September, by the end of the fattening period. Water was sampled from six points in the pond. Bottom sediments were collected from the topmost layer of the pond's bottom (0-5 cm) after emptying the pond. The pond was divided into 8 sections, and samples were taken from each one (two samples in the vicinity of the inlet box, 4 samples from the middle part of the pond and two close to the outlet box). The bottom sediments were dried, sifted through a sieve with 1mm mesh and ground in a mortar. Samples of benthic organisms (larvae of *Diptera* family *Chironomidae*) were collected in the same sites. The copper content in carp (*Cyprinus carpio* L.) was assessed in 25 randomly chosen fish reared for human consumption. The fish gender (by inspection), their age (fish rearing logbooks) and mass of the analysed carps (gravimetric method) were determined. The fish came from a three-year rearing period, and their weight ranged from 1,500 to 2,200 g. Carps were sacrificed by decapitation and their individual organs (gills, muscles, livers and gonads) were prepared. The laboratory samples were wet mineralized in a closed system using microwave energy. A weighted portion for analyses was *ca* 0.5 g in conversion to dry weight. Biological material was dissolved in a mixture of HNO_3 and H_2O_2 (5:1, v/v), whereas bottom sediments were dissolved in *aqua regia* in the quantitative ratio of sediment/reagent equal 1:10. Water samples for analyses were condensed tenfold. The copper concentration in the solutions was determined using atomic emission spectrometry in inductively coupled plasma, in a JY 238 apparatus (Ultrace Jobin Yvon Emission) at the wavelength of 327.393 nm. The limit of detection in the applied method was 0.0097 mg Cu dm^{-3}. The measurement uncertainty of the applied method was ±6 %. The limit of detection of the analyses was 0.291 μg g^{-1} of the biological material dry mass and 0.47 μg g^{-1} of the sediment dry mass. The correctness of copper analyses was verified by means of the certified reference material CRM 16-050. Moreover, the following properties of sediments were assessed: pH in water suspension (potentiometrically), grain-size composition (areometric method) and organic carbon content (oxidation method using acidified dichromate ($K_2Cr_2O_7$-H_2SO_4) solution) (Ostrowska et al. 1991).

RESULTS AND DISCUSSION

The average copper concentration in water of the analysed pond was 5.62 μg Cu dm^{-3} (Table 1). No statistically significant differences in this metal concentration were assessed in water collected on various dates. Water collected in July contained slightly more copper. Less copper was as-

Table 1

Statistical parameters of copper content in studied elements of ecosystem

Statistical parameter	Water	Sediment	Bentos	Organ of *Ciprinus carpio* L.			
				gills	gonads	muscle	liver
	(μg dm^{-3})	(mg kg^{-1} d.m.)					
Minimum	4.080	6.763	13.55	1.739	1.340	0.870	3.953
Maximum	8.080	21.38	16.48	4.492	9.369	3.701	29.32
Mean	5.618	13.83	14.66	2.880	2.888	1.763	8.612
Median	5.440	12.97	14.48	2.638	2.474	1.447	6.886
Standard deviation	1.064	4.649	1.096	0.667	1.641	0.843	5.174
Relative standard deviation (%)	18.94	33.61	7.476	23.14	56.81	47.84	60.08

sessed in samples collected from water flowing into fish ponds (ŁUSZCZEK--TROJNAR et al. 2011), which evidences slight enrichment of the pond water. WIŚNIOWSKA-KIELIAN and NIEMIEC (2004) recorded a similar content of this metal in a section of the Dunajec River flowing through agricultural and recreational land, with a moderate level of anthropopressure. In a section of the same river passing through an area where some municipal and industrial sewage was discharged, the copper concentration was higher than found in the present research. High water temperature causes higher copper toxicity, which is a result of the depressed oxygen content in water due to an increased concentration of dissolved forms of copper in water; it also limits the ability of living organisms for detoxication (ALLEN, BRISBI 1980, RUSSEL et al. 2009). NIEMIEC and WIŚNIOWSKA-KIELIAN (2011) state that mean copper concentrations in reservoirs holding water running off a road were 15.20 µg Cu dm^{-3}. In polluted reservoirs, a copper concentration reaching 35 µg Cu dm^{-3} may prove harmful to biological life. KAHLE and ZAUKE (2003) found copper concentrations from 0.1 to 0.2 µg Cu dm^{-3} in water from the Arctic Sea. In fresh waters from unpolluted areas, the copper content is usually below 1 µg Cu dm^{-3} (KABATA-PENDIAS, PENDIAS 1999).

Copper contained in water has a strong affinity for organic matter. The biodiversity of this element depends firstly on the content of its water-soluble forms, which is connected not only with this element's amount but also with physical, chemical and physicochemical properties of water (ALLEN, BRISBIN 1980).

Bottom sediments from the analysed pond revealed a small amount of organic matter, which depending on the sampling place ranged from 1.38 to 5.05%. In intensively utilized ponds, this parameter often exceeds 10% (YUVANATEMIYA, BOYD 2006). The small quantity of organic matter detected in the uppermost layer of the pond sediments is caused by a low amount of indigenous sediments due to the extensive fishery management and proper agrotechnical measures applied to the pond bottom. The grain-size composition of the analysed sediments revealed a considerable percentage of the silt fraction. Three of the analysed sediment samples were classified as ordinary silt, three belonged to the silt loam group and two corresponded to heavy silt loams. The content of floatable particles fluctuated between 25-54%. The grain-size composition of the analysed sediments is typical for water sediments. The pH value in the analysed sediments measured in water suspension ranged from 7.8 to 8.3.

The average copper content in bottom sediments from the analysed pond ecosystem was 13.83 mg Cu kg^{-1} (Table 1). WIŚNIOWSKA-KIELIAN and NIEMIEC (2005ab) reported similar copper content in bottom sediments of the Dunajec River and its tributaries. Similar data were presented by SKORBIŁOWICZ and SKORBIŁOWICZ (2009) for the Supraśl River and its tributaries. Differences in the content of this metal between individual samples reached 33%. According to the classification of BOJAKOWSKA and SOKOŁOWSKA (1998), the examined sediments presented the 1st degree of copper pollution. In the research of YUVANATEMIYA and BOYD (2006), bottom sediments from unpolluted fish ponds contained 7 mg Cu kg^{-1}. In the pond ecosystem analysed herein, a slight accumulation of copper in bottom sediments was noted in relation to its quantity in water. VINOT and PIHAN (2005) reported almost 20-fold higher copper concentrations in bottom sediments from Mirgenbach Lake in northern France than in its water. In our investigations, the factor representing the copper enrichment in sediments was about 2.5 thousand. It may have been caused by a low content of organic matter in pond sediments. Organic matter is the most important substance binding copper in bottom sediments and its amount is positively correlated with the value of the sediment copper enrichment coefficient (ALLEN, BRISBIN 1980, YUVANATEMIYA, BOYD 2006, VINOT, PIHAN 2005). The authors' own research revealed a statistically significant (at p<0.01) correlation coefficient between the organic matter content and copper concentration in sediments. The copper content in the analysed sediments was not high, being typical of bottom sediments from unpolluted ecosystems.

Copper bioaccumulation in living organisms is determined by two processes. One limits the absorption of the element from the environment by a given organism and the other one determines the intensity of copper excretion from the organism. Depending on the strategy adopted by an organism, one of these processes prevails, thus protecting it against poisoning (RUSSEL et al. 2009).

The copper content in benthic organisms of the examined ecosystem revealed the least changeability, ranging from 13.55 to 16.48 mg Cu kg^{-1} d.m., on average 14.66 mg Cu kg^{-1} d.m. (Table 1). The copper content in scuds (*Gammarus* sp.) from Mirgenbach Lake was 134 mg Cu kg^{-1} d.m., whilst the water Cu concentration was 35 µg dm^{-3} and the copper concentration in sediments was 744 mg Cu kg^{-1} (VINOT, PIHAN 2005). The copper bioaccumulation coefficient in larvae of *Diptera* family *Chironomidae* analysed in the present research was high, reaching 2,610 and 1.06 of the amounts in the water and the bottom sediments, respectively. The value of the bioaccumulation coefficient in polluted ecosystems is much lower. VINOT and PIHAN (2005) reported that this coefficient's value in relation to the copper concentration in water and sediments for scuds (*Gammarus* sp.) from polluted Mirgenbach Lake was about 3,800 and 0.18, respectively. Copper bioaccumulation coefficient for snails (*Gastropoda*) from this lake in relation to bottom sediments was about 1.0. LIANG et al. (1999) conducted research on copper bioacummulation in ponds to which sewage was disposed. Value of copper bioaccumulation coefficient in benthos from the ponds in relation to its content in the sediments was about 0.5, however this metal content was approximate to its amount assessed in the studied pond. Generally, metal bioacummulation coefficient in benthos of water ecosystems is adversely proportional to their concentration in the environment (DEFOREST et al. 2007).

The use of fish for bioindication of water environment pollution with heavy metals provides an answer concerning the element content in water ecosystem, but first of all allows estimate the element toxicological effect in the environment. Carp is the fish well suitable for an assessment of the environment pollution with copper due to high correlation between copper amount in the environment and this element content in its organism, in the first place in liver (DE BOECK et al. 2003).

Gills are an important organ of ionic exchange in fish organism. Fish take up metals from the water and remove them from the organism. Copper is absorbed by gills as free ions and most probably hydroxyl complexes of this element. Other water soluble compounds are not taken up by gills. On basis of an analysis of the forms in which copper occurs in water it is possible to predict its toxicity for living organisms (TAO et al. 2002). Excessive amount of copper causes an injury and oedema of gill lobes leading to impairment of mucus production. Healthiness of gills and their copper content are good indicators of the environment pollution with this element (REYNDERS et al. 2008, KUNWAR et al. 2009). Copper content in the analysed fish gills revealed little diversification and ranged from 1.739 to 4.492 mg kg^{-1} d.m., with an average of 2 880 mg kg^{-1} d.m. (Table 1). Copper content in the gills of carps living in unpolluted waters is about 1.0 mg Cu kg^{-1} f.m. (SCHJOLDEN et al. 2007), which in conversion to dry matter gives the contents similar to obtained in the presented investigations. The copper bioaccumulation coefficient in the analysed organs was 512 in relation to the water concentrations, and 0.208 in relation to the content in the sediments. The concentration of this element concentration in carp gills was fivefold smaller than in the benthos (Table 2). REDDY et al. (2006) stated that the copper bioaccumulation coefficient in gills of fish living in water containing 39 µg

Table 2

Bioaccumulation coefficients of copper in benthos and individual organs of *Ciprinus carpio* L. in studied ecosystem

Element of ecosystem	Benthos	Gills	Gonads	Muscle	Liver
Water	2610	512.7	514.1	313.8	1532
Sediments	1.060	0.208	0.209	0.127	0.623
Benthos	-	0.196	0.197	0.120	0.587

Cu dm^{-3} as copper sulphate reached the value of over 3,500. Such a high value of this coefficient is connected with the form in which this element occurs. In water with high calcium and magnesium concentrations, the copper bioaccumulation coefficient is lower, which may explain its low value reported for the analysed fish.

The copper content in carp muscles was highly variable, fluctuating from 0.870 to 3.701 mg Cu kg^{-1} (Table 1), and the average was 1.763 mg Cu kg^{-1}. LIANG et al. (1999) obtained similar values for muscles of carps living in ponds with approximately similar copper accumulation in sediments. The copper bioaccumulation coefficient in these organs of the fish tested in our experiment, in relation to this metal's concentrations in water, bottom sediments and benthos was 313.8; 0.127 and 0.120, respectively (Table 2). ALAM et al. (2002) reported copper contents in muscles of carps kept in ponds of 0.249 mg Cu kg^{-1} in f.m. in the case of a low concentration of this element in water (2.2 µg Cu dm^{-3}). Under these conditions, the copper bioaccumulation coefficient in relation to its concentration in water was 450 and fell down to 1.0 in relation to the content in bottom sediments. VINOT and PIHAN (2005) found similar copper contents in muscles of breams (*Abramis brama*) from the pond whose water contained over 7-fold more copper than the water of the pond analysed in our study, whereas the bottom sediments had 60-fold more copper than herein. A much lower value of the bioaccumulation coefficient for breams is connected with this species's biology (bream is a pelagic fish) and lower water hardness. LIANG et al. (1999) assessed a high copper content (about 4 mg Cu kg^{-1}) in mosquitofish (*Gambusia affinis*) in an ecosystem with copper concentrations approximately same as found in the investigated pond. These authors point to a high copper bioaccumulation coefficient in phytoplankton and zooplankton in relation to the copper concentration in water. When the binding of copper with sediments is limited, more copper is absorbed by phyto- and zooplankton and by pelagic fish. In ecosystems with large amounts of organic matter or with bicarbonate of calcium and magnesium, the copper uptake from water is lower owing to its fast binding in sediments by organic matter or precipitation as carbonates. The Rudawa River catchment, which feeds the analysed pond, is abundant in limestone.

The liver is the main site of copper accumulation in fish organisms. The concentration of copper in this organ is a sensitive indicator of the environmental pollution and degree of fish poisoning with copper. The content of copper accumulated in livers of the analysed carps revealed the highest changeability, fluctuating between 3.953 to 29.32 mg Cu kg^{-1} d.m. (Table 1), at an average content of 8.612 mg Cu kg^{-1} d.m. This element's bioaccumulation coefficient in relation to its amount in water was 1,532, whereas in relation to bottom sediments equalled 0.623. The copper content determined in carps' livers was almost half the amount observed in the benthos (Table 2). ALAM et al. (2002) reported values of the copper bioaccumulation coefficient in livers of wild carps in an unpolluted environment approximately same as presented in this paper (in relation to the concentration in water and sediments, the cited coefficients were about 2,000 and 0.288, respectively). Copper bioaccumulation coefficients in organisms of carps from aquacultures assumed lower values. VINOT and PIHAN (2005) obtained similar values of the copper bioaccumulation coefficient in livers of various fish species living in copper-polluted water.

The copper concentration in the liver of bream (*Abramis brama*) was 70 mg kg^{-1} d.m., of roach (*Rutilus rutilus*) – 50 mg kg^{-1} d.m. and of perch (*Perca fluviatilis*) – 30 mg kg^{-1} d.m., with the content of this element in water being 35 μg dm^{-3}, and in the sediments – 744 mg kg^{-1}. The value of copper bioaccumulation from sediments was much lower than in the presented investigations. MERSCH et al. (1993) reported the copper concentrations in bream's and roach's livers equal 56 and 36 mg Cu kg^{-1} d.m., respectively, with the concentration of this element in water amounting to 20.5 μg Cu dm^{-3}. The coefficient of copper bioaccumulation in lives of these fish species reached 2,700 and 1,750, respectively. The bioaccumulation coefficient of copper in fish livers from the ecosystem analysed in our experiment in relation to its water concentrations reached a similar level to the data quoted in literature. Irrespective of the degree of water pollution, it assumes values from 1,400 to 3,000. In the case of the bioaccumulation coefficient in the carp's liver computed in relation to the copper content in sediments, its value is high and characteristic for ecosystems unpolluted with copper. Thee results obtained by the authors imply a higher copper uptake from water than from bottom sediments.

Gills are organs which do not accumulate copper. The content of this element in gills was highly varied, fluctuating from 1.340 to 9.369 mg Cu kg^{-1} d.m., with the mean content of 2.89 mg Cu kg^{-1} d.m. (Table 1). No statistically significant differences in concentrations of this element were found in testicles or ovaries. VINOT and PIHAN (2003) reported similar quantities of copper, as observed in the authors' own studies, in gonads of carps caught from a lake unpolluted with this element, i.e. 1.264 mg Cu kg^{-1} f.m. in gonads of wild carps and 0.607 mg kg^{-1} f.m. in bred ones. The cited researchers determined that the copper bioaccumulation coefficient in gonads in relation to its content in water was 559, which is a value approximately same as obtained in the authors' own research. The values of the bioaccumulation coefficient in relation to bottom sediments found herein are characteristic for ecosystems in slightly polluted environments.

Considering all the studied organs, the highest amounts of copper were found in livers, then in gonads and gills, whereas the smallest quantities of Cu occurred in muscles of the analysed carps (Figure 1). The quantitative ratio of the copper content in these organs was 1:0.34, 34:0.19, respectively. No statistically significant differences were determined between the copper content in male and female organs. Quantitative ratios of trace elements in individual fish organs depend on availability of the said substances in the environment. In ecosystems polluted with copper, its higher concentrations appear in the liver and gills, whereas in the environments poor in copper, the biggest quantities of Cu may accumulate in gonads, which is connected with the physiological functions performed by copper in these organs (Moiseenko et al. 2008, Alam et al. 2002, Reddy et al. 2006, Reynders et al. 2008).

In soft waters and waters with a low content of organic matter, copper is taken up mainly from water, both by plankton and fish. In ecosystems with a high content of organic matter, organisms in a food chain have limited availability of copper from water, and the metal is taken up mainly from sediments.

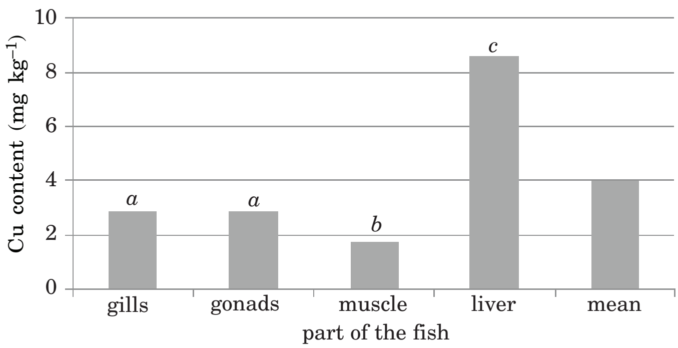

Fig. 1. Mean content of copper in studied organs of *Ciprinus carpio* L.

CONCLUSIONS

1. Both water and bottom sediments from the pond had copper concentrations normally observed in areas with a low degree of anthropopressure.

2. Copper concentrations in individual fish organs can be put in order from the highest: liver > gonads > gills > muscles. The copper content in the carp's liver is the most reliable indicator of copper hazard to the environment.

3. Copper concentrations in all the analysed organs were on a level observed in fish from unpolluted environments.

4. The coefficient of copper enrichment in the sediments was not high and characteristic for ecosystems poor in organic matter.

5. The calculated copper bioaccumulation coefficients in the benthos and fish muscles were high in relation to the content in water and sediments. Similar values of these coefficients are noted in unpolluted ecosystems.

6. Low values of the copper bioaccumulation coefficients were recorded in gills, which is connected with the limited availability of this element from water.

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