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RESEARCH ARTICLE

# Essential mineral components in the muscles of six freshwater fish from the Mazurian Great Lakes (northeastern Poland)

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**Abstract**. The concentrations of nine mineral elements in the muscles of roach, *Rutilus rutilus* (L.), bream, *Abramis brama* (L.), vendace, *Coregonus albula* (L.), pike, *Esox lucius* L., Eurasian perch, *Perca fluviatilis* L. and burbot, *Lota lota* (L.) were measured. The microelement content in the muscle tissues of the fish was identified to have the following decreasing sequence: Zn > Fe > Cu > Mn, and the concentrations of macroelements in fish were noted in the following order: K > P > Na > Mg > Ca. Roach and bream had more iron than perch and pike ($P \leq 0.01$). There were no differences in the concentrations of copper between the species in the following groups: roach and bream; roach and perch; perch and pike ($P > 0.01$). The concentrations of the remaining elements did not differ among fish of different feeding types ($P > 0.01$). The only statistically significant differences were noted in the content of iron in the muscles of two fish groups: non-predatory (roach, bream and vendace) and predatory (perch, pike and burbot; $P \leq 0.01$).

**Keywords**: mineral elements, heavy metals, freshwater fish, non-predatory fish, predatory fish

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## Introduction

The macroelements calcium, magnesium, sodium, potassium, and phosphorus are essential to human health (Przybył and Koligot 1997a). Microelements such as zinc, iron, copper, and manganese, which occur in physiological concentrations, play key roles in living processes, and either an excess or deficit can disturb biochemical functions in both humans and animals (Przybył and Koligot 1997b, Śmigielska et al. 2005). The microelements mentioned above are heavy metals. According to Pourang (1995), heavy metals are important from the point of view of public health. These metals are also indicators of water pollution because they accumulate in aquatic animals. Szczerbowski (1995) contended that every living organism belongs to a definite level of the trophic chain. Consumers, including fish, comprise the second level. According to Szczerbowski et al. (1995), roach, *Rutilus rutilus* (L.), depending on its age, feeds on plankton, molluscs, and crustaceans, whereas vendace, *Coregonus albula* (L.), feeds on zooplankton. Bream, *Abramis brama* (L.), similarly to roach, feeds on plankton and crustaceans or insect larvae and oligochaets (mostly chironomids). These authors noted that the predatory fish pike, *Esox lucius* L., within a few weeks and perch, *Perca fluviatilis* L., larger than 10 cm feed on other smaller fish, while burbot, *Lota lota* (L.), feeds on invertebrates, fish eggs, and other fish (vendace and whitefish, *Coregonus lavaretus* (L.), are a predominant dietary element of this fish in vendace lakes).

Data from the literature indicate that the contents of macro- and microelements in fish depends on species and feeding type (Gladyshev et al. 2001a, 2001b, Łuczyńska et al. 2006). The bioaccumulation of heavy metals (Zn, Cu, Mn, Fe) also depends on fish weight and body length (Kostecki 2000, Anan et al. 2005, Łuczyńska and Tońska 2006) and age (Håkanson 1984, Berninger and Pennanen 1995, Farkas et al. 2003).

The aim of the current study was to investigate the concentrations of nine elements in the muscles of fish from the Mazurian Great Lakes and to verify whether or not interspecific differences in the contents of these elements among four species (roach, bream, perch, pike) and between two groups (non-predatory and predatory fish) are notable.

## Materials and Methods

Roach, bream, vendace, pike, Eurasian perch, and burbot were caught in June 1997 in lakes Kisajno, Dargin, and Niegocin. Fish samples were collected on the same day. The fish were euthanized, and then body weight and total length were measured. Muscle tissues extracted from the dorsal part were kept in plastic bags at -18°C until analysis. The analysis was performed on comprehensive samples that consisted of small and large specimens from the same lake. In the case of large roach, bream and perch from lakes Kisajno, Dargin, and Niegocin, burbot from Dargin, and pike from lakes Kisajno and Dargin (body weight >200 g), the samples were prepared from muscles taken from one to four specimens (Tables 1 and 2). Whereas for small roach from lakes Kisajno and Niegocin and perch from Kisajno and Dargin, samples were prepared from muscle tissue taken from nine to eleven and five to six fish, respectively. In the case of vendace from Lake Dargin, samples were prepared from muscles taken from five or six fish.

Duplicate samples of approximately 10 g each from all the muscle samples were dried to constant weight at 105°C. The samples were then ashed at 450°C for 12 h. The white ash was dissolved in 1M $HNO_3$. (Suprapur-Merck). Then each sample was quantitatively transferred into 25 ml volumetric flasks with deionized water. The concentrations of six elements (Fe, Mn, Cu, Zn, Mg, Ca) were measured with flame atomic absorption spectrometry (Unicam Solar 939) and corrected with a deuterium lamp. The absorption wavelengths were as follows: 248.3 nm for iron, 213.9 nm for zinc, 324.8 nm for copper, 279.5 nm for manganese, 285.2 nm for magnesium, 422.7 nm for calcium. The detection limits were 0.5 mg $kg^{-1}$ for Fe, 0.1 mg $kg^{-1}$ for Zn, 0.05 mg $kg^{-1}$ for Cu, 0.05 mg $kg^{-1}$ for Mn, 0.025 mg $kg^{-1}$ for Mg, 0.5 mg $kg^{-1}$ for Ca. Sensitivity was as follows: 0.05 mg $dm^{-3}$; 0.05 mg $dm^{-3}$; 0.02 mg $dm^{-3}$; 0.02 mg $dm^{-3}$; 0.01 mg $dm^{-3}$ ; 0.2 mg $dm^{-3}$, respectively. A solution of lanthanum chloride was added (in an amount that ensured a 0.5% concentration of $La^{+3}$ in the analyzed solutions) to all of samples and standards when determining calcium to eliminate the influence of phosphorus (Whiteside and Miner 1984). Sodium and potassium were assayed using flame photometry (Flapho 4, Carl Zeiss Jena) at 589.0 nm and 766.5 nm, respectively (Rutkowska 1981). Phosphorus was determined using the colorimetric method of Mattsson and Swartling (1954). The absorbance of phosphorus was determined at 610 nm (VIS 6000 Spectrophotometer). The detection limits were 1 mg $kg^{-1}$ for Na, 5 mg $kg^{-1}$ for K, and 0.01 mg $kg^{-1}$ for P. Sensitivity was 0.5 mg $dm^{-3}$, 2 mg $dm^{-3}$, and 0.005 mg $dm^{-3}$, respectively. The accuracy of the method was examined using standard reference materials CRM 422 cod muscle tissue (lyophilized sample) with a certified concentration of Zn, Fe, Cu, and Mn (Quevauviller et al. 1993). The standard reference material was analyzed with each batch of samples. The recovery rates of these elements were: 105% Zn, 96% Fe, 103% Cu, and 103% Mn. The microelements (Fe, Mn, Cu, Zn) concentration in muscles of fish is expressed in mg $kg^{-1}$ dry weight and the content of macroelements (Na, K, Mg, Ca, P) is expressed in mg 100 $g^{-1}$ dry weight. ANOVA one-way analysis of variance (Duncan's test) was used to test significant interspecific differences in the content of the elements studied among four species (roach, bream, perch, pike). The t-student test was used to qualify the significant differences in the concentration of these elements between the groups of non-predatory (roach, bream, vendace) and predatory fish (perch, pike, burbot). In both cases, the significance level of $P \leq 0.01$ was used.

## Results

There were no clear differences among species in the contents of zinc, iron, copper, or manganese in the muscles of the fish from different areas (Tables 1 and 2). However, differences in the concentrations of zinc in the muscle tissues of small and large roach in the same lakes (Kisajno and Niegocin) were noted. Small roach had higher values of zinc than large roach. The opposite was noted in pike from Lake Dargin. The body weights of perch and bream from Lake Dargin and perch from Lake Kisajno did not influence the content of zinc. The average zinc content in all the samples analyzed was 17.0-58.5 (roach), 17.0-18.7 (bream), 26.6-27.3 (vendace), 20.2-24.5 (perch), 27.1-53.6 (pike), and 41.5 (burbot). Small roach from Lake Kisajno had the highest values of zinc. The body weight of the selected fish species in the same lake had no impact on the concentration of iron, manganese, or copper. Exceptions were noted in roach from Lake Kisajno and perch from lakes Kisajno and Dargin, because the small roach contained more manganese, and the small perch had more copper than did large fish of the same species. The average contents of other microelements in the fish studied were as follows: 4.0-11.3 mg $kg^{-1}$ dry weight for iron; 0.4-1.2 mg $kg^{-1}$ dry weight for manganese; 0.6-2.7 mg $kg^{-1}$ dry weight for copper. The highest levels of copper were noted in burbot, while the highest contents of iron and manganese were noted in the vendace from Lake Dargin and the roach from Lake Kisajno, respectively.

Differences in the concentration of microelements in the muscles of four species (roach, bream, perch, pike) were examined (Table 3). Roach and bream had more iron than perch and pike ($P \leq 0.01$). There were no differences in the concentrations of copper between the species within the following groups: roach and bream; roach and perch; perch and pike ($P > 0.01$). The muscles of non-predatory fish (roach, bream, vendace) contained more iron (9.2 mg $kg^{-1}$ dry weight) than did those of the predatory fish ($P \leq 0.01$) (Fig. 1). The predatory fish (perch, pike, burbot) contained 5.3 mg Fe $kg^{-1}$ dry weight. Although concentrations of manganese, copper, and zinc varied among the different species, there were no clear differences in the values of these metals between groups of non-predatory and predatory fish ($P > 0.01$).

The contents of sodium (149.7 mg 100 $g^{-1}$ dry weight), potassium (1638.7 mg), magnesium (91.3 mg), and calcium (56.5 mg) in vendace were lower than in the other non-predatory roach and bream (Table 1). The level of phosphorus in the muscles of non-predatory fish ranged between 1047.8 and 1261.7 mg 100 $g^{-1}$ dry weight. The concentrations of potassium in the muscles of roach and bream were 1914.6-2387.0 and 1429.8-2268.3 mg 100 $g^{-1}$ dry weight, respectively, whereas the content of calcium in the muscle tissues of roach ranged from 61.5 (large roach from Lake Kisajno) to 103.6 (small roach from Lake Kisajno) and 53.5 (small bream from Lake Dargin) to 104.8 mg 100 $g^{-1}$ dry weight (small bream from Lake Niegocin). Lower concentrations of magnesium (84.9 mg 100 $g^{-1}$) were noted in the muscles of small bream from Lake Dargin. The highest values of magnesium were noted in the muscle tissue of large roach from Lake Kisajno (143.0 mg 100 $g^{-1}$ dry weight). In the group of predatory fish (perch, pike,burbot), perch from Lake Niegocin and pike from Lake Dargin had less sodium (169.0 and 181.8 mg 100 $g^{-1}$ dry weight [1], respectively) than did other fish from this group (Table 2). The concentrations of calcium and magnesium in the muscles of predatory fish were from 43.7 to 94.8, and from 82.7 to 108.6 mg 100 $g^{-1}$ dry weight, respectively. The values of phosphorus (1068.3-1265.4 mg 100 $g^{-1}$ dry weight) and potassium (1686.3-2366.8 mg 100 $g^{-1}$ dry weight) in predatory fish were close to the values for non-predatory fish ($P > 0.01$) (Fig. 3). The non-predatory fish contained more calcium (74.6 mg) than the predatory fish (59.5 mg), while the predatory fish had higher mean values of sodium (299.8 mg) than did non-predatory fish (243.4 mg) (Fig. 2), but the differences were not statistically significant ($P > 0.01$). There were no significant differences ($P > 0.01$) between the contents of magnesium in the muscles of non-predatory (101.5 mg) and predatory fish (98.3 mg) (Fig. 2). Similar differences among species in macroelement content (Ca, Mg, Na, K, P) in the muscle tissue of roach, bream, perch, and pike were not statistically significant ($P > 0.01$).

**Table1**

Weight and length of fish and the content of nine mineral elements in muscles of non-predatory fish

| Lake | Species | % | n | Weight (g) | | Length (cm) | | Fe | Mn | Cu | Zn | Na | K | Mg | Ca | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mean | min-max | mean | min-max | (mg kg$^{-1}$ dry weight) | | | | (mg 100 g$^{-1}$ dry weight) | | | | |
| Kisajno | Roach | 79.12 | 9 | 81.9 | 52.2-101.2 | 18.4 | 17.0-19.8 | 9.0 | 1.2 | 1.2 | 58.5 | 328.5 | 2108.1 | 107.7 | 103.6 | 1047.8 |
| Niegocin | Roach | 79.32 | 11 | 93.9 | 51.3-155.0 | 20.2 | 16.7-23.7 | 9.0 | 0.7 | 1.0 | 53.3 | 261.0 | 2246.6 | 99.9 | 61.8 | 1091.3 |
| Kisajno | Roach | 78.83 | 4 | 273.4 | 252.6-290.5 | 27.3 | 26.6-27.7 | 8.8 | 0.5 | 1.0 | 17.0 | 296.6 | 1914.6 | 143.0 | 61.5 | 1129.0 |
| Dargin | Roach | 80.99 | 3 | 328.3 | 282.6-389.4 | 30.3 | 29.5-31.2 | 9.3 | 0.5 | 1.1 | 20.7 | 198.8 | 2387.0 | 92.9 | 100.6 | 1174.6 |
| Niegocin | Roach | 79.08 | 3 | 419.0 | 413.1-425.7 | 29.6 | 29.1-29.9 | 9.7 | 0.6 | 1.1 | 23.1 | 157.6 | 2012.2 | 110.2 | 93.2 | 1261.7 |
| Niegocin | Bream | 80.04 | 4 | 361.3 | 279.7-461.5 | 31.6 | 26.5-36.7 | 10.7 | 0.7 | 1.2 | 18.7 | 193.4 | 2245.5 | 98.9 | 104.8 | 1110.7 |
| Kisajno | Bream | 78.76 | 2 | 444.1 | 440.3-447.9 | 33.2 | 32.5-34.0 | 8.0 | 0.5 | 1.7 | 18.5 | 273.5 | 2268.3 | 96.1 | 54.6 | 1131.3 |
| Dargin | Bream | 78.58 | 2 | 607.6 | 548.0-667.2 | 38.0 | 37.0-39.0 | 8.3 | 0.5 | 1.3 | 17.4 | 269.8 | 1429.8 | 89.5 | 53.5 | 1117.5 |
| Dargin | Bream | 78.46 | 2 | 1557.9 | 1485.2-1630.6 | 50.5 | 49.5-51.5 | 8.9 | 0.6 | 1.2 | 17.0 | 305.4 | 2082.4 | 84.9 | 56.2 | 1048.2 |
| Dargin | Vendace | 76.43 | 6 | 70.2 | 58.5-83.9 | 20.5 | 19.2-21.7 | 9.9 | 0.5 | 1.8 | 26.6 | 148.3 | 1621.3 | 89.3 | 53.6 | 1060.2 |
| Dargin | Vendace | 76.43 | 5 | 63.5 | 60.3-68.9 | 19.6 | 18.7-20.0 | 11.3 | 0.8 | 1.9 | 27.3 | 151.1 | 1656.1 | 93.3 | 59.4 | 1145.6 |

n – number of fish

% – content of water in samples

**Table 2**

Weight and length of fish and the content of nine mineral elements in muscles of predatory fish

| Lake | Species | % | n | Weight (g) | | Length (cm) | | Fe | Mn | Cu | Zn | Na | K | Mg | Ca | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mean | min-max | mean | min-max | (mg kg$^{-1}$ dry weight) | | | | (mg 100 g$^{-1}$ dry weight) | | | | |
| Dargin | Perch | 80.71 | 5 | 46.1 | 41.0-47.4 | 16.6 | 15.6-17.4 | 6.8 | 0.7 | 1.1 | 24.5 | 274.2 | 2278.4 | 102.5 | 94.8 | 1265.4 |
| Kisajno | Perch | 79.46 | 6 | 79.1 | 54.4-122.8 | 18.4 | 16.7-20.9 | 5.3 | 0.8 | 1.2 | 21.5 | 317.4 | 1686.3 | 108.3 | 84.1 | 1123.5 |
| Niegocin | Perch | 79.64 | 3 | 408.4 | 381.4-434.8 | 30.1 | 29.5-30.4 | 5.3 | 0.5 | 0.9 | 20.7 | 169.0 | 2191.2 | 93.2 | 50.1 | 1119.0 |
| Dargin | Perch | 79.87 | 3 | 501.4 | 406.4-637.7 | 33.3 | 31.1-36.2 | 4.6 | 0.5 | 0.7 | 20.3 | 312.0 | 2366.8 | 101.0 | 43.7 | 1250.9 |
| Kisajno | Perch | 80.10 | 1 | 1480.5 | | 42.5 | | 5.1 | 0.5 | 0.9 | 20.2 | 461.3 | 1858.7 | 87.6 | 55.8 | 1068.3 |
| Kisajno | Pike | 77.70 | 2 | 786.6 | 628.5-944.7 | 47.0 | 44.0-50.0 | 4.7 | 0.5 | 0.7 | 28.1 | 273.1 | 1907.5 | 102.0 | 53.3 | 1068.5 |
| Dargin | Pike | 77.35 | 2 | 885.1 | 824.7-945.5 | 50.7 | 49.5-51.9 | 4.7 | 0.5 | 0.6 | 27.1 | 379.7 | 1913.5 | 98.6 | 47.0 | 1068.4 |
| Dargin | Pike | 78.44 | 2 | 2511.7 | 2481.3-2542.1 | 67.8 | 65.3-70.3 | 4.0 | 0.4 | 0.7 | 53.6 | 181.8 | 1930.3 | 108.6 | 48.5 | 1084.4 |
| Dargin | Burbot | 80.18 | 1 | 524.7 | | 39.3 | | 7.4 | 0.9 | 2.7 | 41.5 | 329.9 | 2001.8 | 82.7 | 58.5 | 1094.8 |

n – number of fish

% – content of water in samples

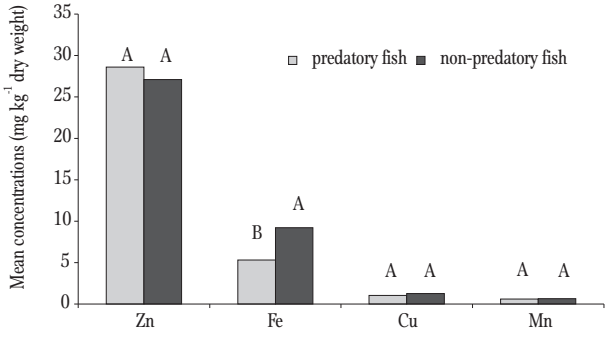


Figure 1. Concentrations of Zn, Fe, Cu and Mn in muscle tissue of predatory and non-predatory fish (mg $kg^{-1}$ dry weight). Values marked with the same letter do not differ significantly statistically (P > 0.01).

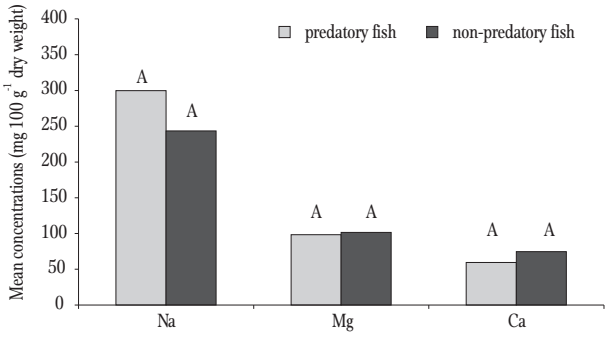


Figure 2. Concentrations of Na, Mg and Ca in muscle tissue of predatory and non-predatory fish (mg 100 $g^{-1}$ dry weight). Values marked with the same letter do not differ significantly statistically (P > 0.01).

## Discussion

The mean content of zinc in the muscles of pike from the Anzali wetlands connected to the Caspian Sea was 25.4 mg $kg^{-1}$ dry weight, whereas the mean amounts of manganese and copper was 5.3 and 2.8 mg $kg^{-1}$ dry weight, respectively (Pourang 1995). These values, with exception of zinc, were higher than those reported for the pike assayed (Table 2). This concurs with results of Radwan et al. (1990).

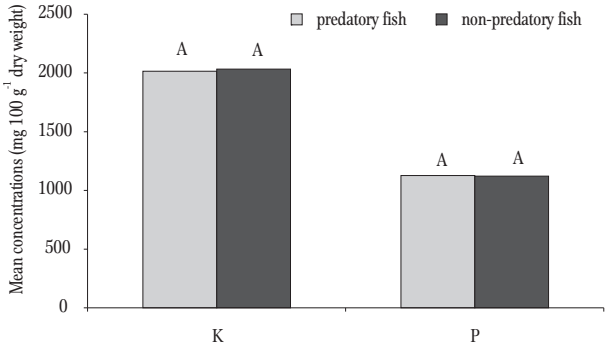


Figure 3. Concentrations of K and P in muscle tissue of predatory and non-predatory fish (mg 100 $g^{-1}$ dry weight). Values marked with the same letter do not differ significantly statistically (P >0.01).

These authors also reported higher concentrations of iron, manganese, copper, and zinc in the muscle tissues of perch (Table 2) and bream (Table 1) than in the case of the same fish species in the current study (with the exception of bream from Lake Niegocin). Likewise, Berninger and Pennanen (1995) found higher contents of zinc (36.0 mg $kg^{-1}$ dry weight) and iron (12.0 mg $kg^{-1}$ dry weight) in the muscles of perch (Finland) than in the perch in the current study (Table 2). According to Stanek et al. (2005), the contents of Fe, Mn, Cu, and Zn, expressed in mg $kg^{-1}$ fresh product, in the muscles of perch were 7.895, 1.206, 2.532, and 7.188, respectively. The roach assayed by these authors contained more Zn (11.720), Fe (10.050), and Mn (2.056), expressed in mg $kg^{-1}$ fresh product. Bream contained the following values of iron, manganese, copper, and zinc: 11.751; 1.450; 1.974; 6.862 mg $kg^{-1}$ fresh product. All the values published by the authors above were higher than in the fish assayed in the current study (Table 3), but the results of copper measured in the muscles of roach, bream, and perch from the Vistula Lagoon (Polak-Juszczak 2003) are comparable to those obtained in the present study. Decidedly lower amounts of Cu, Fe, Mn, and Zn were noted in perch (Table 2) and roach (Table 1) than in the same fish species from different sites in the River Seine (Paris) analyzed by Chevreuil et al. (1995), according to whom,

concentrations of these metals in the muscles of roach from Balloy were as follows: Cu – 1.9 mg $kg^{-1}$ dry weight; Fe – 64 mg $kg^{-1}$ dry weight; Mn – 4.8 mg $kg^{-1}$ dry weight; Zn – 72 mg $kg^{-1}$ dry weight, and in roach from Epinay the values were as follows: Cu – 1.8 mg $kg^{-1}$ dry weight; Fe – 99 mg $kg^{-1}$ dry weight; Mn – 5.6 mg $kg^{-1}$ dry weight; Zn – 120 mg $kg^{-1}$ dry weight. The content of Cu, Fe, Mn, and Zn in the muscle tissues of perch from Poses was 1.4, 66, 5.3, and 48 mg $kg^{-1}$ dry weight, respectively. In the case of bream from the Western basin of Lake Balaton (Hungary) caught in October 1999 and May 2000, the values for zinc (14.5 and 10.9 mg $kg^{-1}$ dry weight) were higher than those for copper (2.22 and 1.77 mg $kg^{-1}$ dry weight) (Farcas et al. 2003). These findings concur with the results of the current study, because the mean contents of microelements in the muscle tissue of bream and of other fish decreased in the following sequence: Zn > Fe > Cu > Mn, but these levels were higher than the contents of Zn and Cu in the muscles of the bream examined (Table 1). Łuczyńska et al. (2006) confirmed the decreasing order in all fish species (Zn > Fe > Cu > Mn). Only in the case of perch from Lake Piaseczno, was the content of zinc the highest followed by those of Fe, Cu, and Mn (Radwan et al. 1990). According to the same authors, the mean concentration of zinc, manganese, iron, and copper in pike and bream was in the following order: Fe > Zn > Cu > Mn and Zn > Cu > Fe > Mn, respectively. This does not concur with studies reported by Chevreuil et al. (1995). The essential amounts of copper, zinc, and cadmium in roach from the Dobczyce Reservoir (southern Poland) were probably consumed with food (Szarek-Gwiazda and Amirowicz 2003). The range of Cu, Zn, Mn, and Fe contents of roach muscles varied 1.5-5.3 mg $kg^{-1}$ dry weight, 24.3-69.6 mg $kg^{-1}$, 0.3-1.4 mg $kg^{-1}$, and 17.9-49.1 mg $kg^{-1}$ dry weight, respectively. These values, except with iron and copper, were measured in muscles of individual specimens of the fish examined (Table 1).

According to Pourang (1995), pike, as top predator, contained less manganese and zinc than *Carassius aureatus* (L.) which are at the lower trophic levels. The same author found that this is related to biopurification. Using fish caught in the vicinity of Włocławek, Stężycka et al. (2003) indicated that non-predatory fish contained 8.66 mg Zn $kg^{-1}$ wet weight and 0.32 mg Mn $kg^{-1}$ wet weight, whereas the content of zinc and manganese in predatory fish was 5.11 and 0.25 mg $kg^{-1}$ wet weight. These authors also noted that non-predatory fish had higher concentrations of copper (0.73 wet weight) than did predatory fish (0.35 wet weight). Řehulka (2002) suggested that with copper levels, there were no differences between predatory and non-predatory fish. Similarly, no distinct differences were noted in the concentrations of heavy metals (Cu, Mn, Fe and Zn) between predatory (pike and perch) and non-predatory fish (bream and tench, *Tinca tinca* (L.)) in from the mesotrophic Lake Piaseczno (eastern

**Table 3**
Interspecific differences in the content of nine mineral elements in muscles of four fish species

| Species (n) | Fe | Mn | Cu | Zn | Na | K | Mg | Ca | P |
|---|---|---|---|---|---|---|---|---|---|
| | mg $kg^{-1}$ dry weight (mg $kg^{-1}$ wet weight) | | | | mg 100 $g^{-1}$ dry weight (mg 100 $g^{-1}$ wet weight) | | | | |
| Roach (5) | 9.1±0.3$^{a}$ | 0.7±0.3$^{a}$ | 1.1±0.1$^{ab}$ | 34.5±19.7$^{a}$ | 248.5±70.0$^{a}$ | 2133.7±187.3$^{a}$ | 110.7±19.3$^{a}$ | 84.1±20.9$^{a}$ | 1140.9±82.2$^{a}$ |
| | (1.877±0.081) | (0.146±0.059) | (0.227±0.020) | (7.135±4.188) | (51.3±15.6) | (437.1±26.6) | (22.8±4.6) | (17.2±4.0) | (234.1±16.8) |
| Bream (4) | 9.0±1.2$^{a}$ | 0.6±0.1$^{a}$ | 1.4±0.2$^{a}$ | 17.9±0.8$^{a}$ | 260.5±47.5$^{a}$ | 2006.5±393.3$^{a}$ | 92.4±6.3$^{a}$ | 67.3±25.0$^{a}$ | 1101.9±36.8$^{a}$ |
| | (1.881±0.198) | (0.121±0.020) | (0.285±0.050) | (3.761±0.113) | (55.1±11.6) | (421.2±78.2) | (19.4±0.8) | (14.0±4.6) | (231.8±9.5) |
| Perch (5) | 5.4±0.8$^{a}$ | 0.6±0.1$^{a}$ | 0.9±0.2$^{bc}$ | 21.4±1.8$^{a}$ | 306.8±105.0$^{a}$ | 2076.3±290.6$^{a}$ | 98.5±8.1$^{a}$ | 65.7±22.4$^{a}$ | 1165.4±87.5$^{a}$ |
| | (1.083±0.141) | (0.119±0.024) | (0.185±0.036) | (4.290±0.291) | (61.4±20.9) | (415.7±54.9) | (19.8±1.8) | (13.1±4.3) | (233.4±15.2) |
| Pike (3) | 4.4±0.4$^{a}$ | 0.5±0.1$^{a}$ | 0.7±0.1$^{c}$ | 36.3±15.0$^{a}$ | 278.2±99.0$^{a}$ | 1917.1±11.8$^{a}$ | 103.1±5.1$^{a}$ | 49.6±3.3$^{a}$ | 1073.8±9.2$^{a}$ |
| | (0.987±0.117) | (0.111±0.015) | (0.153±0.012) | (7.984±3.092) | (62.0±23.4) | (425.0±8.6) | (22.8±0.6) | (11.0±0.8) | (238.0±4.1) |

(n) – number of fish samples
Values marked with the same subscript letter index in the same column did not differ significantly statistically (P > 0.01)

Poland) (Radwan et al. 1990). These findings concur with observations reported in the current study, with the exception of iron, because the non-predatory fish contained more iron than did predatory fish ($P \leq 0.01$) (Fig. 1). The smaller differences among species in the contents of Cu, Mn, and Fe in the fish from Piaseczno Lake were presented by Szarek-Gwiazda and Amirowicz (2006). The muscles of roach contained higher concentrations of copper than did those of silver bream, *Abramis bjoerkna* (L.), for example, while silver bream had lower iron contents than did roach or perch, and the content of manganese was lower than that in roach. According to the authors, there is an existing connection between the concentrations of metals (Mn, Fe, Cu, Cd, Pb, Sr) in some fish tissues and their trophic habits.

The concentrations of K, Na, Ca, and Mg in the muscles of perch from a Siberian pond (Russia) were 1703 mg, 284 mg, 202 mg, 136 mg in 100 $g^{-1}$ dry weight, respectively (Gladyshev et al. 2001b). The values of calcium and magnesium are superior to those noted in the current study (Table 2). The muscle tissue of perch examined in the current study had higher contents of potassium (with the exception of small fish from Lake Kisajno) and sodium (with the exception of small fish from Lake Dargin and large fish from Lake Niegocin) than did the same species assayed by the authors above. According to Łuczyńska et al. (2006), higher values of sodium were noted in the muscle tissue of perch (47.0 mg 100 $g^{-1}$ wet weight) than in other fish species (30.4-42.4 mg 100 $g^{-1}$ wet weight). The concentrations of sodium in the perch studied, which were expressed in mg 100 $g^{-1}$ wet weight, ranged from 34.4 to 91.8 and were higher (with the exception of perch from Lake Niegocin) than the values noted by the authors above. The amounts of potassium in vendace were lower than those in the other fish species examined (with the exception of small bream from Lake Dargin) (Table 1), which was confirmed by the study of these authors. The values of calcium in the muscles of the studied roach, bream, vendace, perch, pike, and burbot were 12.9-21.6, 11.5-20.9, 13.3, 8.8-18.3, 10.5-11.9 and 11.6 mg 100 $g^{-1}$ wet weight, respectively. Only the contents of calcium in the muscles of small perch from Lake Dargin ( Table 2) and in bream from Lake Niegocin (Table 1) were close to the values for perch and bream noted by the same authors. In pike from two reservoirs (Vermeulle and Dollier) studied by Belinsky et al. (1996), the contents of calcium (7 and 8 mg 100 $g^{-1}$ wet weight, respectively) were lower than in the pike examined (Table 2). Statistically significant differences between the concentrations of Ca in the muscles of perch and crucian carp, *Carassius carassius* (L.), which differ in food types, were noted by Gladyshev et al. (2001a). Kownacki and Doboszyńska (1976) reported that the concentrations of magnesium varied among species (carp, *Cyprinus carpio* (L.), pike-perch, *Sander lucioperca* (L.), pike and tench). Predatory pike contained more magnesium than non-predatory fish, but pike-perch had higher magnesium contents than did carp. The authors above noted that the values of magnesium in the edible parts of pike ranged from 80.6 to 128.4 mg 100 $g^{-1}$ dry weight. The content of this metal in the muscles of the pike examined (Table 2) was within the range mentioned by these authors. There were no significant differences between the concentrations of calcium and magnesium in the muscles of non-predatory and predatory fish ($P > 0.01$).

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## Streszczenie

### Zawartość składników mineralnych w tkance mięśniowej sześciu gatunków ryb słodkowodnych z wielkich Jezior Mazurskich (północno-wschodnia Polska)

Oznaczono zawartość dziewięciu składników mineralnych w tkance mięśniowej płoci, *Rutilus rutilus* (L.), leszcza, *Abramis brama* (L.), sielawy, *Coregonus albula* (L.), szczupaka, *Esox lucius* L., okonia, *Perca fluviatilis* L. i miętusa, *Lota lota* (L.). Zawartość mikroelementów w mięśniach badanych ryb malała w następującym szeregu: Zn > Fe > Cu > Mn. Koncentracja makroelementów w mięśniach badanych ryb malała według następującej kolejności: K > P > Na > Mg > Ca. W przypadku płoci i leszczy stwierdzono większe ilości żelaza niż w okoniach i szczupakach ($P \leq 0.01$). Nie zaobserwowano istotnych różnic zawartości miedzi w poszczególnych grupach ryb, tj.: płoć i leszcz; płoć i okoń; okoń i szczupak ($P > 0.01$). Ryby spokojnego żeru (płoć, leszcz i sielawa) zawierały więcej żelaza niż ryby drapieżne (okoń, szczupak i miętus) ($P \leq 0.01$) (rys. 1). W przypadku pozostałych pierwiastków nie stwierdzono różnic istotnych statystycznie ($P > 0.01$).