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The relationships between fish heavy metal concentrations and fish size in the upper and middle reach of Yangtze River

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Abstract

Heavy metal (Cd, Cr, Cu, Hg, Pb, Zn) concentrations identified in the muscle tissue of seven fish species (silver carp *Hypophthalmichthys molitrix*, grass carp *Ctenopharyngodon idellus*, crucian carp *Carassius auratus*, carp *Cyprinus carpio*, *Coreius heterodom*, catfish *Silurus asotus*, and yellow-head catfish *Pelteobagrus fulvidraco*) from the Yangtze River were measured. Additionally, the relationships between fish size (length and weight), condition factor, and metal concentrations were investigated by linear regression analysis. Metal concentrations (mg/kg wet w.) were found to be distributed differently amongst the different types of fish. The highest concentrations of Cu (1.22) and Zn (7.55) were measured in yellow-head catfish. The catfish also showed strikingly high Cd (0.115) and Hg (0.0304) concentrations. The crucian carp and common carp showed highest levels of Pb (0.811) and Cr (0.239), respectively.
The results of comparisons made between metal concentrations and the fish size parameters demonstrated positive relationships between fish sizes and metal levels in most cases, with negative relationships found only between mercury and chromium levels in the size of catfish and yellow-head catfish. The variance observed in the relationships between metal concentration and fish size, as measured among different fish species, may be related to the differences in ecological needs, swimming behaviors, and metabolic activity.

Key words: Heavy metal; Fish; Size; Accumulation; Yangtze River

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1. Introduction

The rapid development of industry and agriculture has resulted in an increase in the pollution of rivers and lakes with heavy metals, which have been identified as a significant environmental hazard for invertebrates, fish, and humans [1]. Significant quantities of heavy metals in waster water are discharged into rivers. These metals can be strongly accumulated and biomagnified along water, sediment, and aquatic food chains, thus resulting in sublethal effects or death in local fish populations [2-5]. Heavy metals like copper and zinc are essential for fish metabolism, while others such as mercury, cadmium, and lead have no known role in biological systems [6]. For the normal metabolism of fish, the essential metals must be taken up from water, food, or sediment. However, similarly to the essential metals, non-essential metals are also absorbed by fish (where they ultimately accumulate in the tissues). Studies from field and laboratory experiments have shown that the accumulation of heavy metals in fish tissue is mainly dependent upon concentrations of the metals in surrounding water, in addition to the exposure period [7] (although some other environmental factors such as salinity, pH, hardness, and temperature are also found to play a significant role in metal accumulation). Ecological needs and the size of aquatic animals have also been found to affect their inclination towards metal accumulation [8-10].

Therefore, it is important to better understand the relationships between animal size and the concentrations of both essential and non-essential metals. Heavy metal pollution of water and sediment in the Yangtze River basin has attracted much attention from researchers [11-13]. However, to the best of our knowledge, existing studies have not examined the relationships between metal concentrations and fish size. Thus, the aim of this study is to determine heavy metal (Cd, Cr, Cu, Hg, Pb, Zn) levels in the muscle tissue of seven fish species (silver carp *Hypophthalmichthys molitrix*, grass carp *Ctenopharyngodon idellus*, crucian carp *Carassius auratus*, carp *Cyprinus carpio*, *Coreius heterodom*, catfish *Silurus asotus*, and yellow-head catfish *Pelteobagrus fulvidraco*) residing within the Yangtze River, and to investigate the relationships between fish size (length and weight), and condition factor with metal concentrations.

2. Materials and methods

2.1. Study sites

The Yangtze River, being the third longest river in the world, is also the longest and largest river in China. The Yangtze River is 6300 km long, and has a watershed of 1.80 million km^2. It is divided into several reaches. The upper reach consists of the region between the source and Yichang (the Three Gorges Dam), the middle reach runs between Yichang and Hukou (Poyang Lake mouth), and the lower reach runs between Hukou and Datong. All sections downriver from Datong are considered to be the estuary. In this study, the samples were collected at seven sites in the reach from Yibin to Hukou during 1996-2003 (Fig. 1). All sampling procedures were carried out according to internationally recognized guidelines [14].

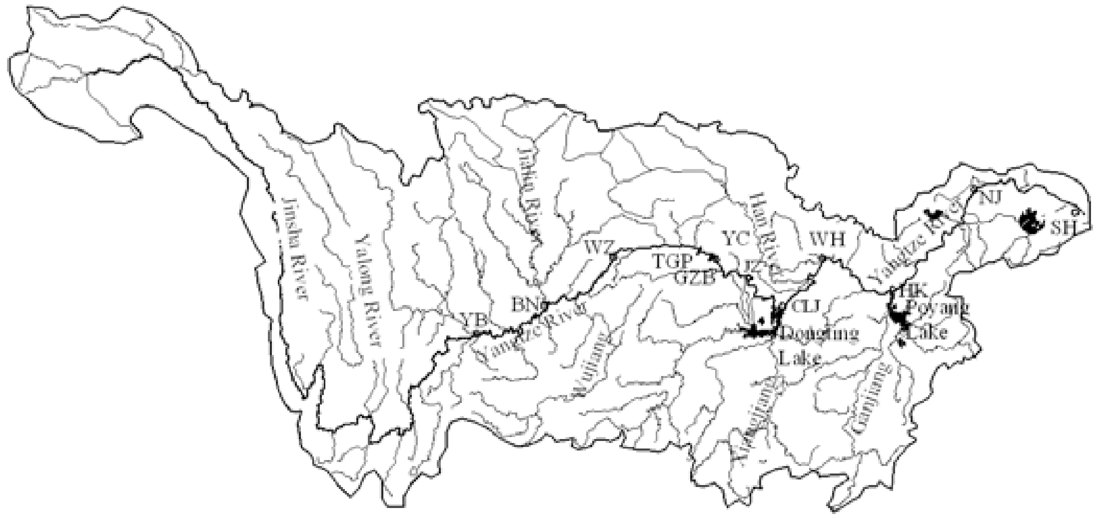

Fig. 1. Sample sites distribution. YB, Yibin; BN, Banan; WZ, Wanzhou; YC, Yichang; JZ, Jingzhou; CLJ, Chenlingji; WH, Wuhan; HK, Hukou; NJ, Nanjing; SH, Shanghai; TGP, Three Gorges project; GZB, Gezhouba dam.

2.2. Sample collection, analysis and data analysis

Sample collection and analysis methods see reference [7].

Data analysis was carried out by means of the statistical software package, SPSS 15.0. Chemicals showing concentrations under the limit of detection (LOD) were assumed to have a concentration equal to one-half of that value (ND= ½ LOD). The pearson correlation test was used to check for significant relationships between heavy metal concentrations and individual length, net weight, and the condition factor of fish studied. The level of significance was set at a probability lower than 0.05 ($p < 0.05$). To evaluate significant differences between groups, the Levene test was applied to verify the equality of variances. Subsequently, ANOVA or Kruskal Wallis tests were applied according to the distribution of the data (normal or not, respectively).

To study the effect of the condition of heavy metals on the load of fish, the individual condition factor of fish samples was determined using the Fulton's Condition Factor [15]: $K = 100\ w/l^3$(where w and l are the recorded net weight and total length of a fish, respectively).

3. Results

Table 1 shows fish species, the numbers of fishes sampled, length and weight ranges, and their relationships. The fish samples under study belonged to the 0 to 7 year age group. They ranged in length from 23 to 731 mm, and in net weight from six to 8048 g. Table 2 shows mean metal concentrations and their standard deviations. The highest copper and zinc concentrations were found in yellow-head catfish, while the highest cadmium and lead concentrations were found in crucian carp. The highest mercury concentrations were found in catfish. Chromium concentrations varied between the fishes, with the common carp showed the highest levels. Generally speaking, catfish and yellow-head catfish had relatively high metal concentrations, while silver carp and grass carp had relatively low metal concentrations.

Table 1. Size ranges and the relationships between weight (W) and total length (L) of the fishes silver carp *Hypophthalmichthys molitrix* (*HM*), grass carp *Ctenopharyngodon idellus* (*CI*), crucian carp *Carassius auratus* (*CA*), common carp *Cyprinus carpio* (*CC*), *Coreius heterodom* (*CH*), catfish *Silurus asotus* (*SA*), and yellow-head catfish *Pelteobagrus fulvidraco* (*PF*) caught from the Yangtze River

Species	n	L. ranges	W. ranges	Equation[a]	R value
HM	53	18-69.4	372-8048	$y = 3.0472x^{0.3633}$	0.93
CI	40	10.2-73.1	163-7227.5	$y= 0.1174x^{2.54}$	0.99
CA	20	2.3-20	9.1-211	$y = 0.0344x + 10.263$	0.93
CC	56	5.5-50.4	95-3154.4	$y = 2.9268x^{0.3536}$	0.95
CH	46	7-31.6	35-469.7	$y = 0.168x^{2.24}$	0.93
SA	37	3.6-39.8	20-7420	$y = 4.7675x^{0.324}$	0.93
PF	40	6.4-35.8	6-488	$y = 0.0576x + 11.484$	0.93

[a] *y* is total fish length (cm) and *x* is total fish weight (g).

Table 2. Mean concentrations of metals and standard deviations in the tissues of fish caught from the Yangtze River **(mg/kg** wet w.)

Species	Age	Copper	Zinc	Lead	Cadmium	Mercury	Chromium
HM	0-3	0.771±0.726	3.39±2.89	0.529±0.493	0.062±0.051	0.006±0.009	0.206±0.252
CI	0-3	0.834±0.655	2.8±3.17	0.21±0.236	0.0457±0.0449	0.006±0.013	0.121±0.0874
CA	0-5	0.934±0.406	6.445±6.72	0.811±0.763	0.132±0.144	0.0079±0.0114	0.19±0.16
CC	0-4	0.99±0.89	5.0±4.7	0.43±0.45	0.096±0.108	0.015±0.03	0.239±0.178
CH	0-4	0.97±1.09	3.45±3.82	0.53±0.62	0.085±0.164	0.005±0.01	0.123±0.074
SA	0-7	0.78±0.63	4.6±4.3	0.55±0.58	0.115±0.128	0.0304±0.0582	0.209±0.153
PF	0-2	1.22±1.11	7.55±6.89	0.607±0.83	0.1±0.15	0.017±0.029	0.10±0.076

[a] Metal concentrations among the tissues from different fishes were compared statistically using one-way ANOVA. All comparisons were statistically significant at P<0.01.

Tables 3 shows the relationship between metal concentrations and fish size (length and weight), and the relationship between metal levels and condition factor. There were no substantial differences noted in the effect of length or net weight on the tissue metal concentrations. Therefore, length was considered as the basic measure since it is less likely to be subjected to major fluctuations than weight, which is highly influenced by changes in the proximate composition of muscle tissue(most notably in lipid percentage [16]).

No significant relationships were found between fish length (weight) and copper. Positive correlations were found between fish size and zinc in grass carp ($p<0.05$), with lead in *coreius heterodom* ($p<0.05$), with cadmium in grass carp ($p<0.05$), and common carp ($p<0.05$). Between the fish size and mercury concentration measured for each species, positive correlations were found in grass carp ($p<0.0001$) and common carp ($p<0.05$), while negative correlations were found in catfish ($p<0.05$) and yellow-head catfish ($p<0.001$). Similar to the results for mercury, chromium had positive correlations related to size characteristics in grass carp ($p<0.0001$) and common carp ($p<0.01$), while having negative correlations in negative in yellow-head catfish ($p<0.0001$).

Similar correlations were found between the heavy metal concentrations of fish and the individual condition factors, with characteristically opposite trends compared to those related to length (Table 4). Positive relationship the between condition factor and copper concentration were found in silver carp ($p<0.01$) and common carp ($p<0.05$). For cadmium, negative associations of cadmium concentration related to the condition factor were characteristic were found in grass carp ($p<0.05$). Significant negative relationships were also found between the condition factor and mercury levels in silver carp ($p<0.0001$) and grass carp ($p<0.01$), and positive relationships were found in catfish ($p<0.05$) and yellow-head catfish ($p<0.05$). Negative correlations were found in relation to the condition factor in grass carp ($p<0.01$) and positive in yellow-head catfish ($p<0.0001$).

Table 3. Pearson correlation coefficient (R) and levels of significant (P) for the relationships between heavy metal concentrations and fish size (length and weight), in terms of condition factors associated with the fish caught from the Yangtze River **(mg/kg** wet w.)

Species	Data	Copper	Zinc	Lead	Cadmium	Mercury	Chromium
HM	DF	41	34	41	40	37	35
Length	R	-0.282	-0.248	-0.245	-0.149	-0.123	-0.151
	P	NS[a]	NS	NS	NS	NS	NS
Condition factor	R	0.404	0.463	-0.053	0.172	-0.616	0.061
	P	0.009	0.006	NS	NS	<0.0001	NS
CI	DF	28	25	30	30	27	27
Length	R	0.064	0.448	0.027	0.413	0.626	0.637
	P	NS	0.025	NS	0.023	<0.0001	<0.0001
Condition factor	R	-0.077	-0.389	-0.11	-0.399	-0.503	-0.485
	P	NS	NS	NS	0.029	0.008	0.01
CA	DF	13	11	13	13	13	13
Length	R	0.176	-0.338	-0.418	0.182	0.357	0.462
	P	NS	NS	NS	NS	NS	NS

Condition factor	R	0.193	0.344	0.162	0.278	0.01	0.145
	P	NS	NS	NS	NS	NS	NS
CC	DF	47	43	47	46	40	39
Length	R	-0.181	0.04	0.265	0.358	0.231(0.366)	0.425
	P	NS	NS	NS	0.014	NS(0.02)	0.007
Condition factor	R	0.358	0.29	-0.034	-0.184	0.232	-0.085
	P	0.014	NS	NS	NS	NS	NS
CH	DF	24	24	24	24	24	24
Length	R	-0.17	0.248	0.448	-0.116	-0.211	0.248
	P	NS	NS	0.028	NS	NS	NS
Condition factor	R	0.037	-0.105	0	0.375	0.341	0.115
	P	NS	NS	NS	NS	NS	NS
SA	DF	30	28	31	30	20	16
Length	R	-0.004	0.03	0.109	0.029	-0.542	-0.069
	P	NS	NS	NS	NS	0.014(NS)	NS
Condition factor	R	-0.047	0.058	0.025	-0.029	0.501	0.475
	P	NS	NS	NS	NS	0.024	NS
PF	DF	28	28	27	27	23	22
Length	R	0.073	0.114	-0.005	0.072	-0.648	-0.659
	P	NS	NS	NS	NS	0.001	0.001
Condition factor	R	-0.169	-0.167	0.049	-0.05	0.509	0.794
	P	NS	NS	NS	NS	0.013	<0.0001

[a] NS, not significant, P>0.05.

4. Discussion

This study mainly aimed to investigate relationships between heavy metal concentrations in fish with fish size.

Relatively low concentrations of heavy metals were identified in grass carp. While relatively high metal concentrations were identified in both yellow-head catfish (1.22 for Cu, 7.55 for Zinc, 0.607 for Lead, 0.1 for cadmium, and 0.017 for mercury) and catfish (0.78 for Cu, 4.6 for Zinc, 0.55 for Lead, 0.115 for cadmium, 0.304 for mercury, and 0.209 for chromium).

The relationships between metal concentrations and the fish size parameters are listed in table 3. Results show that there are positive relationships between fish sizes and metal levels in most cases, with negative relationships found only in the levels of mercury and chromium pertaining to catfish and yellow-head catfish size. According to previous studies, Al-yousuf et al. [17] found that the concentration of Zn, Cu, Hg, and Cd in *Lethrinus Lentjan* demonstrates a positive correlation with fish length and weight. An assessment of heavy metal contamination of marine biota (fish and various bivalves) was made in the

Gulf and Gulf of Oman, where total Hg concentrations were found to generally increase with the age and size of the fish [18]. The Hg content in both the liver and the muscle depended upon the size (wet weight) of the fish. This has been demonstrated previously only for Hg concentrations found in grouper muscle as a function of fish length [19-21]. Mercury is known to bioaccumulate in fish, and thus relatively high concentrations can be expected to be attained in top predators. Guo [22] found that for *Branchiostoma belcheri*, a positive correlation existed between concentrations of Cu and Zn with fish length, and concentrations of Hg and Cd with fish length and weight; however, no significant relationship was found between Pb and fish length and weight. Widianarko et al. [23] investigated the relationship between metal (Pb, Zn, Cu) concentrations and fish (Poecilia reticulata) size, and found that there was a significant decline in lead concentrations with the increase in size (whereas concentrations of copper and zinc did not depend on body weight). Some research has shown negative relationships between fish size and the metal concentrations found in those fish [6, 24, 25].

Despite these studies, there are no definite or established relationships between heavy metal concentration and fish size. Metal accumulation in fish has been found to reach a steady state after a certain age [26]. This indicates that concentrations of copper and zinc are regulated and maintained at certain concentrations. However, the dilution of tissue metal concentrations associated with growth and/or lowered metabolic activity in older individuals may not be seen if metal concentrations in the surrounding water are found to be higher than the capacity of these factors. In this case, the continued accumulation of metals may occur, and positive relationships may be seen between animal size and metal concentrations in tissues.

5. Conclusion

The results obtained from this study indicate that the concentration of trace metals in fish varies significantly; not only as a function of fish size and the pollution load of each respective site, but also as it is influenced to a remarkable degree by the sediment accumulation of each area.

Heavy metal levels of sediment in different reaches were not measured as a part of this study; however, it is necessary for future research to focus on sediment heavy metal concentrations. Research must also analyze the relationship between sediment heavy metals and metal levels detected in fish.

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References

[1] Uluturhan E, Kucuksezgin F. Heavy metal contaminants in Red Pandora (Pagellus erythrinus) tissues from the Eastern Aegean Sea, Turkey. *Water Res* 2007; 41: 1185-92.

[2] Megeer JC, Szebedinszky C, McDonald DG, Wood CM. Effect of Chronic Sublethal Exposure to Waterborne Cu, Cd, or Zn in Rainbow Trout 1: Iono-regulatory disturbance and metabolic costs. *Aquat Toxicol* 2000; 50(3): 231-43.

[3] Jones I, Kille P, Sweeney G. Cadmiun Delays Grouth Hormone Expression during Rainbow Trout Development. *J Fish Biol* 2001; 59: 1015-22.

[4] Almeida JA, Diniz YS, Marques SFG, Faine IA, Ribas BO, Burneiko RC, Novelli EIB. The Use of Oxidative Stress Responses as Biomarkers in Nile Tilapia (oreochromis niloticus) Exposed to in Vivo Cadmium Contamination. *Environ Int* 2002; 27, 673-9.

[5] Xu YJ, Liu XZ, Ma A J. Current Research on Toxicity Effect and Molecular Mechanism of Heavy Metals on Fish. *Mar Sci* 2004; 28(10): 67-70. (in Chinese)

[6] Canli M, Atli G. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. *Environ Pollut* 2003; 121: 129–36.

[7] Yi YJ, Yang ZF, Zhang SH. Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. *Environ Pollut* 2011; doi:10.1016/j.envpol.2011.06.011.

[8] Bryan G, Langston WJ. Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. *Environ Pollut* 1992; 76: 89–131.

[9] Canli M, Furness RW. Toxicity of heavy metals dissolved in sea water and influences of sex and size on metal accumulation and tissue distribution in the Norway lobster Nephrops norvegicus. *Mar Environ Res* 1993; 36: 217–36.

[10] Kalay M, Canli M. Elimination of essential (Cu, Zn) and nonessential (Cd, Pb) metals from tissues of a freshwater fish Tilapia zillii following an uptake protocol. *Tr J Zoology* 2000; 24: 429–36.

[11] Yi YJ, Wang ZY, Yu GA. Sediment pollution and its effect on fish through food chain in the Yangtze River. *Int J Sed Res* 2008; 23(4):338-47.

[12] Yang ZF, Wang Y, Shen ZY, Niu JF, Tang ZW. Distribution and speciation of heavy metals in sediments from the mainstream, tributaries, and lakes of the Yangtze River catchment of Wuhan, China. Journal of Hazardous Materials, 2009; 166: 1186–94.

[13] Zhang WG, Feng H, Chang JN, Qu JG, Xie HX, Yu LZ. Heavy metal contamination in surface sediments of Yangtze River intertidal zone: An assessment from different indexes. *Environ Pollut* 2009; 157: 1533–43.

[14] UNEP. Sampling of selected marine organisms and sample preparation for the analysis of chlorinated hydrocarbons. *Reference Methods for Marine Pollution Studies* No. 12, Rev. 2. UNEP, Nairobi, 1991. p. 17.

[15] Bagenal TB, Tesch FW. Age and growth. In: Bagenal TB, editor. *Methods for assessment of fish production in fresh waters, IBP Handbook, Oxford, London, Edinburgh,* Melbourne: Blackwell Scientific Publications; 1978, vol. 3, p. 101–36.

[16] Anno GH, Young RW, Bloom RM, Mercier JR. Dose response relationships for acute ionizing-radiation lethality. *Health Phys* 2003; 84:565–75.

[17] Karadede H, Oymak S A, Ünlü E. Heavy metals in mullet, Liza abu, and catfish, Silurus triostegus, from the Atatürk Dam Lake (Euphrates), Turkey. *Environ Int* 2004; 30: 183-8.

[18] de Mora S, Fowler SW, Wyse E, Azemard S. Distribution of heavy metals in marine bivalves，fish and coastal sediments in the Gulf and Gulf of Oman. *Mar Pollut Bull* 2004; 49:410-24.

[19] Al-Majed NB, Preston MR. Factors influencing the total mercury and methyl mercury in the hair of the fishermen of Kuwait. *Environ Pollut* 2000; 109: 239–50.

[20] Kureishy TW. Concentration of heavy metals in marine organisms around Qatar before and after the Gulf War oil spill. *Mar Pollut Bull* 1993; 27: 183–186.

[21] Sadiq M, Saeed T, Fowler SW. Seafood contamination. In: Khan, N.Y., Munawar, M., Price, A.R.G. (Eds.), *The Gulf Ecosystem: Health and Sustainability.* Bakhuys Publishers, Leiden, 2002. pp. 327–351.

[22] Guo JD. Assessment of heavy metal concentration in several ocean endangered fauna. Master thesis. *Shangdong University*. 2005 (in Chinese).

[23] Widianarko B, Van Gestel CAM, Verweij RA, Van Straalen NM. Associations between trace metals in sediment, water, and guppy, Poecilia reticulate, from urban streams of semarang, Indonesia. *Ecotox Environ Saf* 2000; 46:101-7.

[24] Farkas A, Salánki J, Specziár A. Age- and size-specific patterns of heavy metals in the organs of freshwater fish Abramis brama L. populating a low-contaminated site. *Water Res* 2003; 37: 959–64.

[25] García-Montelongo F, Díaz C, Galindo L, Larrechi MS, Rius X. Heavy metals in three fish species from the coastal waters of Santa Cruz de Tenerife (Canary Islands). *Sci Mar* 1994, 58: 179–83.

[26] Douben PE. Lead and cadmium in stone loaeh (Noemacheilus barbatulus L.) from three rivers in Derbyshire. *Ecotox Environ Saf* 1989; 18: 35-58.