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Bioaccumulation of heavy metals in fishes from Taihu Lake, China

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Abstract

The Cr, Zn, Cu, Cd, Pb contents were determined in *Cyprinus carpio* Linnaeus, *Carassius auratus* Linnaeus, *Hypophthalmichthys molitrix* and *Aristichthys nobilis*, which were caught from Meiliang Bay, Taihu Lake, a large, shallow and eutrophic lake of China. The results showed that: (1) the Cr, Cu, Pb, Cd contents in the edible parts of the four fish species were much lower than Chinese Food Health Criterion (1994), but the Zn contents were higher than the Criterion; (2) Cd contents were the highest in the liver of fish, Pb contents were almost the same in all organs of fish, Cr contents mainly enriched in the skin and gonads, Zn contents were the highest in the gonad (♀), and Cu contents were the highest in the liver; (3) the total metal accumulation was the greatest in the liver and the lowest in the muscle. The total metal accumulation was the highest in *C. auratus* L. This investigation indicated that fish products in Taihu Lake were still safe for human consumption, but the amount consumed should be controlled under the Chinese Food Health Criterion to avoid excessive intake of Zn.

Key words: fish; heavy metals; bioaccumulation; food safety; Taihu Lake

Introduction

In freshwater systems, fish is one of aquatic products humans consume, and also provide a good indicator of trace element pollution (Rashed, 2001). Taihu Lake is a shallow eutrophic lake located in the south of the Yangtze Delta, China (30°55′–31°33′N, 119°55′–120°36′E), and has an area of 2428 km^2 and an average water depth of 1.89 m (Qin *et al*., 2007). Taihu Lake is the third largest freshwater lake in China (Chen *et al*., 2003), it plays an important role in water and fish supply (Qin, 1999; Li and Yang, 1995). The intensity of fish catches increased quickly since the 1950s. *Cyprinus carpio* Linnaeus, *Carassius auratus* Linnaeus, *Hypophthalmichthys molitrix* and *Aristichthys nobilis* have high market value and are the main fish products in Taihu Lake.

In the last five decades, industry and agriculture in Taihu area have been rapidly developed, and human activities have increased. During the years of 1991–1993, the mean content of total nitrogen (TN) in water was 2.96 mg/L, and total phosphorus (TP) was 0.107 mg/L. During the years of 2000–2002, the mean content of TN was 3.76 mg/L, and TP was 0.15 mg/L (Jiao and Li, 2005). In 2005, the mean content of TN was 5.12 mg/L, and TP was 0.15 mg/L in Meiliang Bay. River water from Wuxi, Huzhou and Changxing were the major sources of heavy metals according to the sediments investigation in 1988 (Sun and Huang, 1993). In 2005, it was found from sediment investigation that water in the northern part of Taihu Lake was moderately polluted by heavy metals. In addition, the intensity of fishing has rapidly increased. However, heavy metal contents in fish collected from Taihu Lake is still unknown. Heavy metals tend to accumulate in advanced organisms through bio-magnification effects in the food chain. Thus they can enter into human body, and accumulate in the human tissues to pose chronic toxicity. Chronic assimilation of heavy metals is a known cause of cancer (Nabawi *et al*., 1987).

Fishes are the main aquatic products of Taihu Lake. Heavy metal pollution in the lake must have influence on the quality of the fishes. There were a lot of studies concentrated on the heavy metal bioaccumulation of fishes. These researches showed that the accumulating extent of heavy metals in fishes were by far dependent on the different metals, fish species, and the tissues, respectively. For example, Zn and Cu were relative accumulated more than Pb, Cr and Cd during the investigation of *Esox lucius* and *C. auratus* in the Caspian Sea (Pourang, 1995). Different tissues of the fishes showed significant difference for heavy metal accumulation. Normally, the kidney and liver showed higher enrichment coefficients than gill, muscle and swim bladder (Ayö *et al*., 1999; Kargin, 1998; Liu *et al*., 2001). It was also found that gonad showed a high enrichment coefficient for Zn (Wong *et al*., 2001). Being the complexity of heavy metal bioaccumulation of fishes, it was important to study the heavy metal accumulation

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in different commercial fishes in Taihu Lake for the food safety.

The main objective of this study was to determinate the contents of heavy metals in different tissues of *C. carpio*, *C. auratus*., *H. molitrix* and *A. nobilis* collected from Taihu Lake; and to clarify metals accumulation in fish products in Taihu Lake, a seriously eutrophic lake. This could help us understand the enrichment behavior of heavy metals in shallow lake ecosystems and emphasize the need to discard the most polluted tissues of the fish.

1 Materials and methods

1.1 Site description

Samples were collected from Meiliang Bay (31°24′–31°32′ N, 120°04′–120°14′ E) located in the northern part of Lake Taihu. The Meiliang Bay, with a water surface area of 135 km^2, serves as the main water supply for Wuxi City, an industrial city located approximately 2 km northeast of Taihu Lake. However, with population rapidly rising, industrial and agricultural developments near the lake have required that the bay accommodate municipal and industrial wastewater from Wuxi City, resulting in the deterioration of water quality in Meiliang Bay (Qiao *et al*., 2006). In recent years, enrichment of heavy metals was found in the sediments collected in the northern parts of Taihu Lake (Wang *et al*., 2004).

1.2 Fish sampling

C. carpio, *C. auratus*, *H. molitrix* and *A. nobilis* were sampled from Meiliang Bay. The muscles, liver, gonads, skin, encephalon were isolated and weighed. Water content in the organs and tissues of all samples was determined.

1.3 Heavy metal determination

The samples of each fish were freeze-dried and ground. Approximately 0.2 g of the tissue samples of fish were weighed into polytetrafluoroethylene (PTFE) tubes, followed by 0.5 ml of H_2O_2, 0.5 ml of hydrofluoric acid, and 5.0 ml of concentrated nitric acid. The samples were then digested in Berghofmws-3 microwave system. The advantages of microwave digestion against the classical methods are the shorter time, less consumption of acid and containment of volatile compounds in the solutions (Gulmini *et al*., 1994; Krushevska *et al*., 1993; Sures *et al*., 1994). The completely digested samples were transferred to the PTFE beakers, 1.0 ml of 1:3 nitric acid and 2–3 ml distilled water were added and the mixture heated to melt the residue. All digested samples were allowed to cool to room temperature, diluted to 10 ml in 10 ml; volumetric flasks with distilled water. Cr, Zn and Cu of all digested samples were determined by ICP-AES, and Cd and Pb were determined by ICP-MS. Accuracy and precision of the analytical procedure were checked by standard reference material (GBW08573). The results indicated good agreement.

2 Results

2.1 Contents of heavy metals in edible parts of fishes

Table 1 summarizes the heavy metals concentrations in the edible tissues of *C. carpio*, *C. auratus*, *H. molitrix* and *A. nobilis*. Except for Zn, the Cr, Cu, Pb and Cd concentrations in edible tissues of fish were less than Chinese Food Health Criterion (1994). Contents of Zn in edible parts of fishes were several times higher than Chinese Food Health Criterion.

Contents of Zn and Cr in skin and gonad (♀) range from 141 to 907 mg/kg (Zn) and from 0.324 to 1.316 mg/kg (Cr), respectively. Zn and Cr contents in encephalon of fish were low, ranging from 21 to 130 mg/kg, and from 0.219 to 0.387 mg/kg, respectively. Contents of Cr in muscle and encephalon of *C. carpio* and *A. nobilis* were lower than the limit of detection.

Cd concentrations in *C. auratus* and *C. carpio* were higher than *H. molitrix* and *A. nobilis*. In *C. auratus* and *C. carpio*, the Cd results were in the 0.010–0.021 mg/kg range; in *H. molitrix* and *A. nobilis*, they were in the 0.003–0.032 mg/kg range.

2.2 Heavy metals content in different organs of fishes

Figure 1 shows the distribution of heavy metals in all tissues of *C. auratus*, *C. carpio*, *H. molitrix* and *A. nobilis*. All metals were mainly enriched in liver, skin and gonads

Table 1 Heavy metal content (mg/kg dw) in different tissues and species of fishes

Tissues	Fish	Cd	Pb	Cr	Zn	Cu
Skin	*C. carpio*	0.015±0.010	0.251±0.009	1.181±0.141	773±11	0.480±0.090
	C. auratus	0.018±0.010	0.491±0.050	0.939±0.090	447±12	1.152±0.101
	H. molitrix	0.009±0.003	0.308±0.007	0.324±0.019	141±7	0.869±0.079
	A. nobilis	0.007±0.001	0.296±0.009	0.366±0.030	157±6	0.909±0.069
Gonad	*C. carpio*	0.017±0.010	0.155±0.009	1.316±0.138	907±14	4.615±0.009
	C. auratus	0.010±0.000	0.201±0.013	1.038±0.120	249±9	13.617±0.128
Encephalon	*C. carpio*	0.011±0.000	0.332±0.026	ND	73±4	3.379±0.947
	C. auratus	0.013±0.006	0.191±0.010	0.219±0.089	76±5	4.762±0.901
	H. molitrix	0.005±0.000	0.294±0.010	0.379±0.120	47±3	3.500±0.900
	A. nobilis	0.032±0.001	0.171±0.017	ND	60±5	3.894±0.911
Muscle	*C. carpio*	0.021±0.008	0.177±0.030	ND	25±4	ND
	C. auratus	0.013±0.008	0.287±0.010	0.387±0.109	130±7	1.890±0.301
	H. molitrix	0.003±0.001	0.179±0.046	ND	21±2	0.331±0.072
	A. nobilis	0.004±0.001	0.177±0.031	ND	16±2	0.228±0.088
Criterion*		0.1	0.5	2.0	50	50

* Chinese Food Health Criterion (1994).

(♀).

Cd contents were the highest in liver, which were 5–10 times higher than other tissues. Cd contents were higher in *C. auratus* and *A. nobilis* than that in *C. carpio* and *H. molitrix*. Peak values of Pb contents occurred in skin of *C. auratus*, and did not vary in organs of other fish. Cr mainly was enriched in skin and gonads. Cr contents in the skin of *C. auratus* and *C. carpio* were 3–5 times higher than those in skin of *H. molitrix* and *A. nobilis*. Moreover, Cr contents in gonad (♀) were higher than that in gonad (♂). The Cr content was very low in encephalon and muscle of fish. Zn contents were higher in skin, gonad (♀) and liver than other tissues. Zn contents were the highest in skin, gonad (♀) and liver of *C. carpio*, more 3–5 times higher than in *C. auratus*, *H. molitrix* and *A. nobilis*. The copper content was the highest in liver, being more 10–65 times higher than in other organs. It was the lowest in muscle.

2.3 Whole organism accumulation in various fishes

The metal pollution index (MPI) was used to compare the total metals accumulation level in various tissues of different fish. The MPI values were calculated using the equation by Usero *et al*. (1997):

$$\text{MPI} = (C_{\text{f}_1} \times C_{\text{f}_2} \times \cdots \times C_{\text{f}_n})^{1/n} \quad (1)$$

where, C_{f_n} is the contents for the metal n in the sample.

All the results are given in Table 2. The sequence of MPI in different organs was as following: liver > gonad (♀) > skin > gonad (♂) > encephalon > muscle. Different organs of fish have different abilities to bind heavy metals. In the different species, the order was: *C. auratus* > *C. carpio* > *H. molitrix* and *A. nobilis*. This difference was related the different feeding habits of fish. *C. carpio* and *C. auratus* are bottom-feeding fish, whereas *H. molitrix* and *A. nobilis* are planktotrophic feeding pattern fish. Heavy metal contents in encephalon did not vary with different

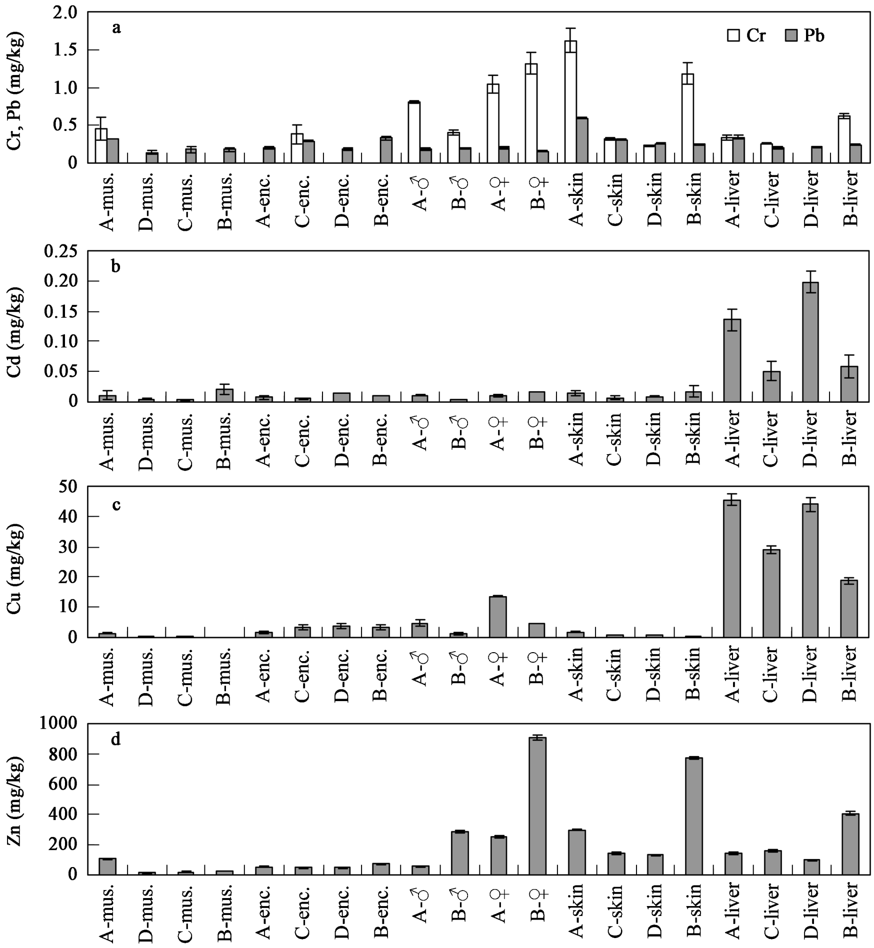

Fig. 1 Heavy metals contents in different organs of fish. A: *C. auratus*; B: *C. carpio*; C: *H. molitrix*; D: *A. nobilis*; mus.: for muscle; enc.: for encephalon; (♀, ♂) for gonads.

Table 2 Metal pollution index (MPI) value of the total metal accumulation level in fishes

Fish	Skin	Muscle	Encephalon	Liver	Gonad (♂)	Gonad (♀)
C. carpio	1.5	0.7	0.4	2.5	0.9	1.5
C. auratus	1.1	0.2	0.6	2.3	0.7	1.7
H. molitrix	0.6	0.2	0.6	1.7	–	–
A. nobilis	0.6	0.2	0.5	1.8	–	–

species, the highest contents in muscle were found in *C. auratus*.

3 Discussion

3.1 Public risk of consuming fish from Taihu Lake

Heavy metal bioaccumulation in fish can pose a health risk to the humans who consume them. Because muscle and skin constitute the greatest mass of the fish that is consumed, the research paid particular attention to these components. The percentage of dry/wet skin and muscle of fish were 20%. According to Table 2, the safe intake of fishes in Taihu Lake was calculated (Table 3).

Zn and Cu are recognized as essential elements, required by a wide variety of enzymes and other cell components having vital functions in all living things. But excessive Zn and Cu intake will damage human health. Excessive Zn intake will cause poisoning, nausea, acute stomach pains, diarrhea and fever, etc. The recommended dietary allowance (RDA) for zinc in humans is 15 mg/d for men, 12 mg/d for women, 10 mg/d for children, and 5 mg/d for infants (ATSDR, 1999) (Nord *et al*., 2004). The National Research Council has listed the estimated safe and adequate daily intake of Cu for adults as 1.5–3.0 mg; children 11 years and older as 1.5–2.5 mg; 1–2 mg for children between 7 and 10; 1.0–1.5 mg for children between 4 and 6; 0.7–1.0 mg for children between 1 and 3 and 0.4–0.7 mg for infants. Lead is a neurotoxin that causes behavioral deficits in vertebrates, decreases in survival and growth rates, causes learning disabilities, and metabolism. The World Health Organization has recommended that dietary Pb should not exceed 0.3 μg/g (wet weight basis), and with a recommended limit of 450 μg of Pb per day for adults. Cd is not an essential element, and the World Health Organization/Food and Agricultural Organization (WHO/FAO) has determined a maximum tolerable daily intake of 55 μg/(person·d). The estimated safe and adequate daily dietary intake of Cr is set at 50–200 μg/d.

According to the above recommended limits, the relation between the safe intake of fish in Taihu Lake and human health were evaluated (Table 4). Combining Tables 3 and 4, we know that fish products in Taihu Lake are basically safe for human consumption, but the people should control their intake of Zn.

3.2 Bio-accumulation of heavy metals in fishes

It is well known that heavy metals accumulated in substantially high levels can be very toxic for fish, especially for young and eggs which are very sensitive to the pollution. Target organs, such as liver, gonads, kidney and gills are metabolically active tissues and accumulate heavy metals of higher levels. Thus, it is not surprising that the liver, gonads of *C. auratus*, *C. carpio*, *H. molitrix* and *A. nobilis* had the highest levels of metals except in the case of chromium and zinc in the skin. Especially the zinc contents in the skin and gonads of fish were higher than Chinese Food Health Criterion.

Previous studies also indicated that different contents of heavy metals in different fish species might be a result of different ecological needs, metabolism and feeding patterns (Ayse, 2003). Romeo *et al*. (1999) pointed out that Cd, Cu and Zn contents in edible muscles of pelagic fish species were lower than for benthic fish species. Similarly, this study showed that the Cd, Cu and Zn contents in muscles of *H. molitrix* and *A. nobilis* (pelagic fishes) were lower than those in *C. auratus* and *C. carpio* (benthic fishes). The Pb and Cr contents in muscles showed no correlation with fish species. Perhaps this is due to heavy metal contents in different species depending on different feeding habits, age, size, and their habitats (Amundsen *et al*., 1997).

Taihu Lake has been polluted by heavy metals and has abundant fish products which people consume, but the contamination of fish products has been little studied. This study indicated that, except for Zn, concentrations of heavy metals in edible part of fish are safe for human consumption. In order to void excessively absorbing Zn, the gonads (♀) of fish should be removed before consumption. This study also indicated that except for Pb, concentrations of heavy metals in liver, gonads (♀) and skin samples were higher than in muscles and encephalon.

Table 3 Total contents of heavy metals in skin and muscle of fish from Taihu Lake

	Weight (g)		Weight (g)	Zn (mg)	Cu (μg)	Cr (μg)	Pb (μg)	Cd (μg)
C. carpio	63	Skin	2.43	0.20	0.56	0.46	0.24	0.02
		Muscle	22.40	0.58	8.50	1.75	1.28	0.06
C. auratus	400	Skin	18.8	2.90	1.80	4.41	0.94	0.07
		Muscle	144.48	0.72	–	–	5.11	0.61
H. molitrix	545	Skin	27.39	0.78	4.80	1.75	1.69	0.04
		Muscle	204.20	0.86	13.51	–	7.31	0.12
A. nobilis	705	Skin	39.48	1.24	7.22	2.92	2.34	0.65
		Muscle	249.80	0.80	11.50	–	8.84	0.20

Table 4 Number of safe daily intake of fish for humans

Fish	Weight (g)	Zn (ind/d)	Cu (ind/d)	Cr (ind/d)	Pb (ind/d)	Cd (ind/d)
C. auratus	63	< 10	< 150	< 90	< 300	< 688
C. carpio	400	< 2	< 750	< 45	< 75	< 80
H. molitrix	545	< 4	< 84	< 115	< 50	< 343
A. nobilis	705	< 3	< 83	< 66	< 40	< 64

4 Conclusions

The Cr, Cu, Pb, and Cd contents in the edible parts of fish were much lower than Chinese Food Health Criterion (1994). However, the contents of Zn were more than several times than Chinese Food Health Criterion, so human consumption should be limited. Other heavy metal levels (Cr, Cu, Pb, and Cd) are completely safe.

Cd contents were the highest in liver, Pb contents were the same in all organs of fish, the contents of Cr mainly enriched in skin and gonads, Zn contents were the highest in gonad (♀), and Cu contents were the highest in liver.

The total metals accumulation was the greatest in liver and was the lowest in muscle. The total metals accumulation level in *C. auratus* and *C. carpio* was the highest.

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References

Amundsen P A, Staldvik F J, Lukin A A *et al.*, 1997. Heavy metal contamination in freshwater fish from the border region between Norway and Russia[J]. The Science of the Total Environment, 201: 211–224.

Ay Ö, Kalay M, Tamer L *et al.*, 1999. Copper and lead accumulation in tissues of a freshwater fish *Tilapia zillii* and its effects on the branchial Na, K-ATPase activity[J]. Bulletin of Environmental Contamination Toxicology, 62: 160–168.

Ayse B Y, 2003. Levels of heavy metals (Fe, Cu, Ni, Cr, Pb, and Zn) in tissue of *Mugil cephalus* and *Trachurus mediterraneus* from Iskenderun Bay, Turkey[J]. Environmental Research, 92: 277–281.

Chen Y W, Fan C X, Teubner K *et al.*, 2003. Changes of nutrients and phytoplankton chlorophyll-*a* in a large shallow lake, Taihu, China: an 8-year investigation[J]. Hydrobiologia, 506–509: 273–279.

Chinese Food Health Griteria, 1994. GB 15201-94 for Cd, GB 15199-94 for Cu, GB 14935-94 for Pb and GB 13106-91 for Zn[S]. Minstry of Health of People's Republic of China.

Gulmini M, Ostacoli G, Zelano V *et al.*, 1994. Comparison between microwave and conventional heating procedures in Tessier's extractions of calcium, copper, iron and manganese in a lagoon sediment[J]. Analyst, 119: 2075–2080.

Jiao F, Li X, 2005. The relative discussion on eutrophication in Meiliang Bay of Lake Taihu[J]. Environment Pollution and Prevention, 27: 214–217.

Kargin F, 1998. Metal concentrations in tissues of the freshwater fish *Capoeta barroisi* from the Seyhan River (Turkey)[J]. Bulletin of Environmental Contamination Toxicology, 60: 822–828.

Krushevska A, Barnes M R, Chita A, 1993. Decomposition of biological samples for inductively coupled plasma atomic emission spectrometry using an open focused microwave digestion system[J]. Analyst, 118: 1175–1181.

Li W C, Yang Q X, 1995. Wetland utilization in Lake Taihu for fish farming and improvement of lake water quality[J]. Ecological Engineering, 5: 107–121.

Liu C, Tao S, Long A, 200l. Accumulations of lead and cadmium in goldfish, *Carassius auratus*[J]. Acta Hydrobiologica Sinica, 25(4): 344–349.

Nabawi A, Heinzow B, Kruse H, 1987. As, Cd, Cu, Pb, Hg, and Zn in fish from Alexandria Region, Egyption[J]. Bulletin of Environmental Contamination and Toxicology, 39: 889–897.

Nord L G, Craig D A, Bobby G W *et al.*, 2004. Lead, zinc, copper, and cadmium in fish and sediments from the Big River and Flat River Creek of Missouri's old lead belt[J]. Environmental Geochemistry and Health, 26: 37–49.

Pourang N, 1995. Heavy metal bioaccumulation in different tissues of two fish species with regards to their feeding habits and trophic levels[J]. Environmental Monitoring and Assessment, 35: 207–219.

Qiao M, Wang C X, Huang S B *et al.*, 2006. Composition, sources, and potential toxicological significance of PAHs in the surface sediments of the Meiliang Bay, Taihu Lake, China[J]. Environment International, 32: 28–33.

Qin B, 1999. Hydrodynamics of Lake Taihu, China[J]. Ambio, 28: 669–673.

Qin B, Xu P, Wu Q *et al.*, 2007. Environmental issues of Lake Taihu, China[J]. Hydrobiologia, 581: 3–14.

Rashed M N, 2001. Monitoring of environmental heavy metals in fish from Nasser lake[J]. Environmental International, 27: 27–33.

Romeo M, Siau Y, Sidoumou Z *et al.*, 1999. Heavy metal distribution in different fish species from the Mauritania coast[J]. The Science of the Total Environment, 232: 169–175.

Sun S C, Huang Y P, 1993. Lake Taihu[M]. Beijing: Ocean Publishing of China. 219–244.

Sures B, Tarschewski H, Haung C, 1994. Determination of trace metals (Cd, Pb) in fish by electro-thermal atomic absorption spectrometry after microwave digestion[J]. Analytica Chimica Acta, 311: 135–139.

Usero J, Gonzalez-Regalado E, Gracia I, 1997. Trace metal in the bivalve mollusks *Ruditapes decussates* and *Ruditapes philippinarum* from the Atlantic coast of southern Spain[J]. Environment International, 23: 291–298.

Wang H, Wang C X, Wang Z J *et al.*, 2004. Fractionation of heavy metals insurface sediments of Taihu Lake, East China[J]. Environmental Geochemistry and Health, 26: 303–309.

Wong C K, Wong P P K, Chu L M, 2001. Heavy metal concentrations in marine fishes collected from fish culture sites in Hong Kong[J]. Archives of Environmental Contamination and Toxicology, 40: 60–69.