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ORIGINAL PAPER

Risk to humans of consuming metals in anchovy (*Coilia* sp.) from the Yangtze River Delta

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Abstract Concentrations of metals were determined in four species of anchovy (*Coilia* sp.) from the Yangtze River, Taihu Lake, and Hongze Lake in Jiangsu Province, China. Concentrations of Cr in anchovy fish muscle ranged from 2.6×10^{-2} to 5.0 mg/kg ww, and *Coilia nasus taihuensis* in Jiaoshan, Taihu Lake contained the highest concentrations of Cr, which was almost 111-fold higher than the mean value at other locations. Concentrations of Pb ranged from 1.5×10^{-2} to 1.3×10^{-1} mg/kg ww. Comparisons of concentrations of lead (Pb) among the four species indicated that anadromous species contained higher concentrations of Pb than did freshwater species. However, concentrations of Pb in *C. nasus* from the Nanjing and Haimen locations in the Yangtze River were not significant higher than those of two freshwater species: *C. nasus taihuensis* from Taihu Lake and *C. brachygnathus* from Hongze Lake (Duncan's test,

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$\alpha = 0.05$). While concentrations of Cd and Zn ranged from 7.0×10^{-4} to 3.6×10^{-3} mg/kg ww and 3.4 to 4.8 mg/kg ww, respectively, there were no significant differences in concentrations among the eight locations. The only concentration of the metals studied that exceeded the Chinese National Standard was Cr in *Coilia* from Jiaoshan, Taihu Lake, which was 2.5-fold higher than the standard. These results indicate that people who consume the genus *Coilia* are not at risk due to concentrations of metals, except Cr in *C. nasus taihuensis* from Jiaoshan in Taihu Lake. Concentrations of all of the metals studied except for Cr were similar to or less than those of metals in most other areas in the world.

Keywords Health risk assessment · Metals · Coilia · Taihu Lake · Yangtze River Delta

Introduction

In 2004 the Yangtze River Delta (YRD) in Jiangsu Province, which includes downstream sections of the Yangtze River including Taihu and Hongze Lakes, had a population of 82.1 million (Tuan and Ng 2007), and is considered to be one of the most developed economic regions of China. The Yangtze River has the fifth largest discharge of water (9,200 Mt/year) in the world and the world's fourth largest discharge of sediment (480 Mt/year) (Yang et al. 2006). The Yangtze River is fulfilling an increasingly crucial role in the river valley's economic growth and has become a vital link for international shipping to inland provinces. Taihu Lake lies in the southern part of the YRD, and provides drinking water and fish for a population of 33 million people (Shen 1994). Due to rapid development of agriculture and industry, and a historical lack of enforcement of regulations, the YRD was become contaminated by metals including chromium (Cr), cadmium (Cd), lead (Pb), and zinc (Zn), which have been emitted into the environment through atmospheric deposition, solid-waste emissions, sludge applications, and irrigation with wastewater. Metals have been added to soils in the Taihu Lake region due to rapid industrial development and increased application of agrochemicals, particularly in the last 20 years (Shen et al. 2005). Enrichment of sediments with heavy metals has been found in northern Taihu Lake (Wang et al. 2004) and the Yangtze River estuary near Shanghai, especially in the intertidal zone (Feng et al. 2004). While studies of the occurrence of metals have been conducted elsewhere in China (Wang et al. 2005; Chi et al. 2007; Yang et al. 2007), few studies of metals have been conducted in this region and there was little information available on which to base a risk assessment of metals (Chi et al. 2007). Until now, no systematic sampling of typical species in the diets of people had been conducted in this region. Four species of anchovy, *Coilia nasus*, *C. mystus*, *C. nasus taihuensis*, and *C. brachygnathus* that live in the Yangtze River, Taihu Lake, and Hongze Lake are eaten by local people. *C. nasus* and *C. mystus* are anadromous, and migrate from saltwater (East China Sea) to freshwater (Yangtze River) for spawning (Xu et al. 1978). The other two species *C. nasus taihuensis* and *C. brachygnathus* live their entire life in the freshwaters of Taihu and Hongze Lakes. Results of previous studies have revealed that *C. nasus*, *C. brachygnathus*, and *C. nasus taihuensis* failed to form monophyletic clades and could not be separated clearly and should be considered as the same species (Tang et al. 2007), and that *C. mystus* is a separate species. Because of the similar feeding habits and close genetic relationships among the four species, concentrations of metals in these fishes represent the various life histories and time spent in the four water bodies: East China Sea-Yangtze River, Taihu Lake, and Hongze Lake.

Metals tend to accumulate in aquatic organisms, and concentrations of some metals can be magnified through the food chain. Humans can be exposed to metals through their diet, and over time metals can accumulate to potentially toxic concentrations (Klaassen 2001). The US Environmental Protection Agency (US EPA) has described the methodology for estimating target hazard quotients (THQ) for noncancer risk (US EPA 1989), which is applicable to assess the health risk of some metals. The objectives of this study were to measure concentrations of selected metals in the muscle of four species of genus *Coilia* from eight locations of the YRD and to assess the potential health risks of metals to local consumers of *Coilia* sp.

Materials and methods

Study area and sample collection

Four species of anchovy, *C. nasus*, *C. mystus*, *C. nasus taihuensis*, and *C. brachygnathus*, were collected in April, May, June, and August, 2007 from the Yangtze River, and Taihu and Hongze Lakes (Fig. 1). The locations and related information of the sites from which fish were collected are listed in Table 1. The eight locations included four in the lower Yangtze River, three in Taihu Lake, and one in Hongze Lake. All samples were immediately transported to the laboratory on ice at 4°C. Samples of muscle were homogenized and frozen at −20°C until analysis. All equipments used for sample collection, transportation, and preparation were free from contamination.

Materials

Prawn certified reference material (CRM, GBW08 572) was purchased from the National Research Center for Certified Reference Materials of China. Nitric acid and hydrogen peroxide were guarantee reagents (GR) purchased from the Institution of Beijing Chemical Reagent. The multi-element calibration standard (1,000 mg/l in 10% v/v nitric acid) was purchased from SPEX CertiPrep Group Co. Ltd., USA. All glass vessels were soaked in 1:1 nitric acid solution with ultrasonic cleaning for 20 min then rinsed with deionized water several times.

Sample preparation and digestion

Approximately 1 g (wet wt.) muscle tissues or 0.2 g CRM was weighed in a glassware digestion test tube and digested overnight at room temperature with 4 ml nitric acid. Thereafter the test tube was placed in ED36 Digital Block Sample Digestion System (Labtech Company, P.R. China) and digested for 12 h at 130°C. One milliliter of 30% hydrogen peroxide was added and when the solution appeared to be colorless, transparent, and almost dry, the digestion was stopped. After cooling, the solution was diluted with 2% nitric acid to 25 ml.

Instrumental analysis

Inductively coupled plasma-mass spectrometer (ICP–MS) Elan 9000 (PerkinElmer Co. Ltd., USA) was used for quantification of metals. The operation parameters for ICP-MS are given in Table 2. All analyses were

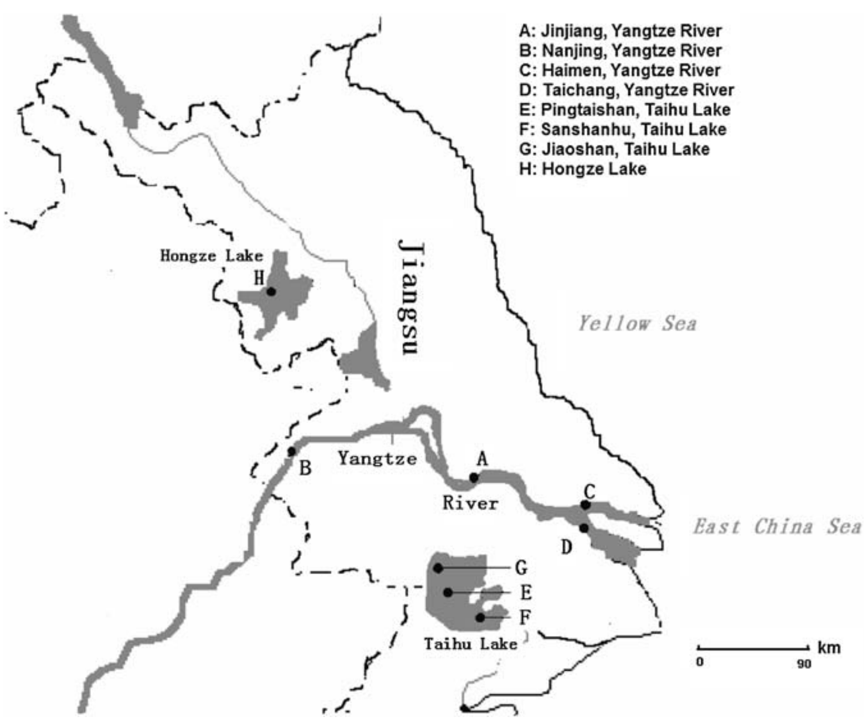


Fig. 1 Map of the lower Yangtze River showing sampling locations

Table 1 Sampling locations and basic characteristic of fish examined in the study

Sampling location	No. of individuals	Species	Sampling date (Y.M. D.)
Jingjiang, Yangtze River	5	*C. nasus*	2007.05.09
Nanjing, Yangtze River	5	*C. nasus*	2007.04.27
Haimen, Yangtze River	5	*C. nasus*	2007.04.22
Taichang, Yangtze River	10	*C. mystus*	2007.06.08
Pingtaishan, Taihu Lake	5	*C. nasus taihuensis*	2007.05.09
Sanshanhu, Taihu Lake	5	*C. nasus taihuensis*	2007.05.09
Jiaoshan, Taihu Lake	5	*C. nasus taihuensis*	2007.05.09
Hongze Lake	10	*C. brachygnathus*	2007.08.09

conducted in duplicate. The method was validated by quantification of metals in prawn CRM (GBW 08572), and observed values except Cd were in good agreement with the certified values, with recoveries ranging from 82.0% to 106.1% and relative standard deviations ranging from 2.8% to 13% (Table 3). Because the recovery of Cd was 47% and the concentrations reported were not corrected for recovery, the concentrations in the anchovy could be as much as two fold higher than those reported.

Target hazard quotients (THQ) were calculated based on the methods by Chien et al. (2002) (Eq. 1). The average adult male and female body weight in Jiangsu Province has been reported as 66.2 and 56.9 kg in 2004, respectively (Yuan et al. 2007). The average adult body weight of people consuming fish was assumed to be the arithmetic mean, which is 61.6 kg.

$$\mathrm{THQ} = \frac{E_{\mathrm{F}} \times E_{\mathrm{D}} \times F_{\mathrm{IR}} \times C}{R_{\mathrm{FD}} \times W_{\mathrm{AB}} \times T_{\mathrm{A}}} \times 10^{-3}, \quad (1)$$

where E_{F} is exposure frequency (365 days/year); E_{D} is exposure duration (70 years), equivalent to the average lifetime (Bennett et al. 1999); F_{IR} is food ingestion rate (g/person/day) (in this study we used the data which Yuan et al. reported in 2007 that the daily ingestion rate of fish was 69.1 g/person/day in 2004 for adult inhabitants in Jiangsu Province); C is metal concentration in food (mg/kg ww); R_{FD} is the oral reference dose (mg/kg/day); W_{AB} is the average adult body weight (61.6 kg); and T_{A} is the average exposure time for noncarcinogens (365 days/year × number of exposure years, assumed to be 70 years in this study). It was further assumed that cooking has no effect on the toxicity of metals in aquatic products (Cooper et al. 1991 and Chien et al. 2002). This algorithm is based on regulation of R_{FD}. When it comes to maximum residue limit (MRL), THQs were calculated with Eq. 2.

$$\mathrm{THQ} = \frac{C}{\mathrm{MRL}}, \quad (2)$$

where C is the metal concentration in food (mg/kg).

Table 3 Determination of heavy-metal contents (mg/kg, dry wt.) in prawn tissue of certified reference material (GBW 08572)

	Cr	Cd	Pb	Zn
Certified	2.4×10^{-1}	2.3×10^{-2}	3.0×10^{-1}	6.1×10^{1}
Found	2.0×10^{-1}	1.1×10^{-2}	3.0×10^{-1}	6.4×10^{1}
Recovery (%)	82	47	99	106
RSD ($n = 4$)	13%	10%	9.3%	2.8%

Table 2 Operation parameters for ICP-MS

RF power/(W)	1100	Scan mode	Peak hopping
Lens voltage	5.7	Plasma gas/(L min^{-1})	15
Analog stage voltage	−1680	Auxiliary gas/(L min^{-1})	1.2
Pulse stage voltage	1000	Sample uptake/(mL min^{-1})	1.0
Lens scanning	Enabled	Replicates	6
Detector mode	Pulse	Sweeps/reading	300
Nebulizer flow	0.95		

Results and discussion

Concentrations of the four metals in muscle of *C. nasus*, *C. nasus taihuensis*, *C. brachygnathus*, and *C. mystus* are summarized in Table 4. Concentrations of Cr in muscle of anchovy ranged from 2.6×10^{-2} to 5.0 mg/kg ww, and *C. nasus taihuensis* from the Jiaoshan location of Taihu Lake contained the highest Cr concentrations: almost 111-fold higher than the mean concentrations for the other locations. Concentrations of Pb at all locations ranged from 1.5×10^{-2} to 1.3×10^{-1} mg/kg ww. There were no large differences of Cd and Zn concentrations among the eight locations, ranging from 7.0×10^{-4} to 3.6×10^{-3} mg/kg ww and from 3.4 to 4.8 mg/kg ww, respectively.

Cr

C. nasus taihuensis from Jiaoshan, Taihu Lake contained the highest concentrations of Cr with a mean value of 5.0 mg/kg ww, followed by *C. nasus* in Haimen, Yangtze River ($5.9 \times 10^{-2} \pm 1.6 \times 10^{-2}$ mg/kg ww, $n = 5$), *C. brachygnathus* in Hongze Lake ($5.8 \times 10^{-2} \pm 1.4 \times 10^{-2}$ mg/kg ww, $n = 10$), and the samples from other locations (Fig. 2). Concentrations of Cr in *C. nasus taihuensis* of Jiaoshan, Taihu Lake were significantly higher than those in anchovy from all other locations (Duncan's test, $\alpha = 0.01$). There were no significant differences among the other seven locations (Duncan's test, $\alpha = 0.05$).

The average Cr concentration in samples from Jiaoshan Taihu Lake was significantly higher than that from the other two locations in Taihu Lake (Duncan's test, $\alpha = 0.01$) and was significantly higher than the concentrations of all the other locations (Duncan's test, $\alpha = 0.01$). Thus, sources of Cr contamination of the Jiaoshan location in Taihu Lake should be determined so that the situation can be improved. The toxicity of Cr is dependent on its valence state, i.e., Cr(VI) or Cr(III); Cr(VI) is a carcinogen, and is much more toxic than Cr(III) (Newman and Unger 2003). The solubility and mobility of Cr(III) are minimal in comparison with Cr(VI), and Cr(VI) usually exhibits a high degree of solubility and mobility (Robson 2003). Cr(VI) can be reduced to Cr(III) under the acidic conditions of the stomach (De Flora et al. 1997).

One source of Cr might be the cement factories that were in the area. When American cements were analyzed for total Cr content, and particularly for Cr(VI), it was detectable in 18 of 42 samples in concentrations varying from 0.1 to 5.4 g/kg cement, while the total Cr content ranged from 5 to 124 g/kg (Perone et al. 1974). Moreover, when Fregert and Gruvberger (1972) analyzed 59 samples of Portland cement from nine European countries it was found that contents of Cr(VI) extractable with sodium sulfate varied from 1 to 83 g/kg of cement, while total Cr concentrations ranged from 35 to 173 g/kg. Most of the cement factories on the islands and banks of Taihu Lake have been closed but some are still operating. There have been no previous studies of the concentrations of Cr in fishes from Jiaoshan, which is located in the north of Taihu Lake. Since concentrations of Cr were so high at the Jiaoshao location of Taihu Lake, it is suggested that further research into the sources and valence state of Cr should be conducted.

Cd

Concentrations of Cd at all eight locations were in the range of 7.0×10^{-4} to 3.6×10^{-3} mg/kg ww, with the highest concentrations in samples from the Taichang location in the Yangtze River with a mean concentration of 3.6×10^{-3} mg/kg ww, followed by samples from the Sanshanhu and Jiaoshan locations in Taihu Lake. Cd concentrations in anchovy from the Taichang location in the Yangtze River were significantly higher than those in samples from other locations except for the Sanshanhu and Jiaoshan locations in Taihu Lake (Duncan's test, $\alpha = 0.05$) (Table 5). *C. nasus taihuensis* from the Pingtaishan location in Taihu Lake contained the lowest Cd concentration, which was significantly less than the other locations except for two locations: Hongze Lake and the Nanjing location in the Yangtze River (Duncan's test, $\alpha = 0.05$).

Cd concentrations were compared among species (Table 6). *C. mystus* from the Taichang location in the Yangtze River contained the highest Cd concentration, followed by *C. nasus taihuensis* ($2.1 \times 10^{-3} \pm 1.4 \times 10^{-3}$ mg/kg ww, $n = 15$) from Taihu Lake, *C. nasus* ($2.0 \times 10^{-3} \pm 7.0 \times 10^{-4}$ mg/kg ww, $n = 15$) from the Yangtze River, and *C. brachygnathus* from Hongze Lake.

Seawater generally contains higher concentrations of Cd than does freshwater. The average concentration of Cd in seawater has been reported to be

Table 4 Concentrations of Cr, Pb, Cd, and Zn in the muscle of anchovy

Area	Species or population	Concentrations of heavy metals in fish (mg/kg ww)			
		Cr (mean, range, SD)	Cd (mean, range, SD)	Pb (mean, range, SD)	Zn (mean, range, SD)
Jinjiang, Yangtze River	*C. nasus*	5.1×10^{-2}, 3.0×10^{-2}–8.2×10^{-2}, 2.1×10^{-2}	2.3×10^{-3}, 1.7×10^{-3}–2.7×10^{-3}, 5.0×10^{-4}	1.4×10^{-1}, 1.0×10^{-1}–2.1×10^{-1}, 4.4×10^{-2}	4.1, 2.8–5.6, 1.0
Nanjing, Yangtze River	*C. nasus*	3.8×10^{-2}, 1.9×10^{-2}–7.9×10^{-2}, 2.6×10^{-2}	1.7×10^{-3}, 1.3×10^{-3}–2.7×10^{-3}, 6.0×10^{-4}	2.6×10^{-2}, 6.2×10^{-3}–5.2×10^{-2}, 2.2×10^{-2}	3.8, 3.2–4.3, 4.0×10^{-1}
Haimen, Yangtze River	*C. nasus*	5.9×10^{-2}, 3.4×10^{-2}–7.8×10^{-2}, 1.6×10^{-2}	1.9×10^{-3}, 1.1×10^{-3}–3.7×10^{-3}, 1.0×10^{-3}	3.5×10^{-2}, 1.8×10^{-2}–6.4×10^{-2}, 2.0×10^{-2}	4.4, 3.5–4.9, 5.6×10^{-1}
Taichang, Yangtze River	*C. mystus*	4.3×10^{-2}, 2.1×10^{-2}–1.3×10^{-1}, 3.3×10^{-2}	3.6×10^{-3}, 1.8×10^{-3}–6.1×10^{-3}, 1.2×10^{-3}	8.7×10^{-2}, 5.2×10^{-2}–1.8×10^{-1}, 4.0×10^{-2}	4.3, 3.8–4.8, 3.0×10^{-1}
Pingtaishan, Taihu Lake	*C. nasus taihuensis*	2.6×10^{-2}, 1.5×10^{-2}–3.6×10^{-2}, 1.0×10^{-2}	7.0×10^{-4}, 5.0×10^{-4}–8.4×10^{-4}, 2.0×10^{-4}	2.5×10^{-2}, 1.5×10^{-2}–3.2×10^{-2}, 9.0×10^{-3}	3.4, 3.1–3.7, 2.4×10^{-1}
Sanshanhu, Taihu Lake	*C. nasus taihuensis*	4.2×10^{-2}, 2.8×10^{-2}–6.4×10^{-2}, 1.4×10^{-2}	2.9×10^{-3}, 1.4×10^{-3}–5.2×10^{-3}, 1.6×10^{-3}	1.5×10^{-2}, 2.3×10^{-3}–3.7×10^{-2}, 1.5×10^{-2}	4.0, 3.6–4.4, 3.2×10^{-1}
Jiaoshan, Taihu Lake	*C. nasus taihuensis*	5.0, 1.6×10^{-1}–7.8, 2.9	2.7×10^{-3}, 1.6×10^{-3}–3.4×10^{-3}, 8.0×10^{-4}	1.7×10^{-2}, 3.0×10^{-3}–2.7×10^{-2}, 9.0×10^{-3}	3.6, 3.3–3.9, 3.0×10^{-1}
Hongze Lake	*C. brachygnathus*	5.8×10^{-2}, 3.1×10^{-2}–7.3×10^{-2}, 1.4×10^{-2}	1.1×10^{-3}, 6.4×10^{-4}–1.7×10^{-3}, 4.0×10^{-4}	2.5×10^{-2}, 2.3×10^{-3}–5.1×10^{-2}, 1.9×10^{-2}	4.8, 3.5–5.9, 7.8×10^{-1}

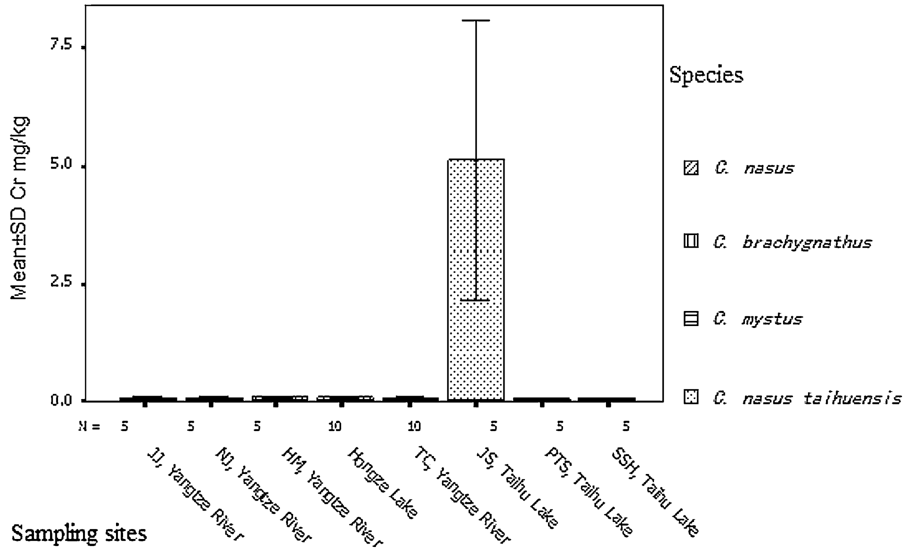


Fig. 2 Cr concentrations (mg/kg ww) in muscle of *Coilia* sp. from eight locations (JJ, Jinjiang; NJ, Nanjing; HM, Haimen; TC, Taichang; JS, Jiaoshan; PTS, Pingtaishan; SSH, Sanshanhu)

Table 5 Comparison of mean concentrations of Cd (mg/kg ww) in muscle of anchovy among sampling locations

Sampling locations	*N*	Subset for $\alpha = 0.05$			
		1	2	3	4
Pingtaishan, Taihu Lake	5	7.0×10^{-4}			
Hongze Lake	10	1.1×10^{-3}	1.1×10^{-3}		
Nanjing, Yangtze River	5	1.7×10^{-3}	1.7×10^{-3}	1.7×10^{-3}	
Haimen, Yangtze River	5		1.9×10^{-3}	1.9×10^{-3}	
Jinjiang, Yangtze River	5		2.3×10^{-3}	2.3×10^{-3}	
Jiaoshan, Taihu Lake	5			2.7×10^{-3}	2.7×10^{-3}
Sanshanhu, Taihu Lake	5			2.9×10^{-3}	2.9×10^{-3}
Taichang, Yangtze River	10				3.6×10^{-3}
Sig.		6.5×10^{-2}	5.6×10^{-2}	5.4×10^{-2}	8.5×10^{-2}

Table 6 Comparison of mean concentrations of Cd (mg/kg ww) among the four species of anchovy

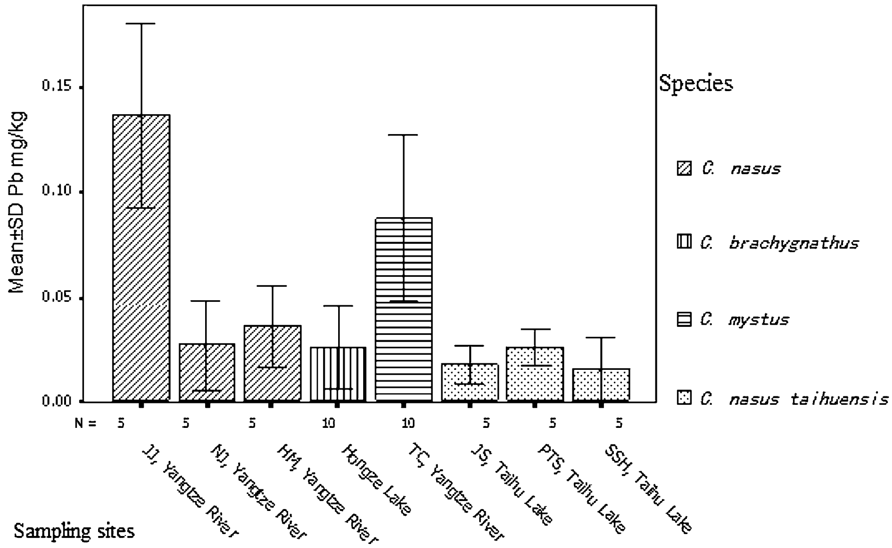
Species	*N*	Subset for $\alpha = 0.05$		
		1	2	3
C. brachygnathus	10	1.1×10^{-3}		
C. nasus	15	2.0×10^{-3}	2.0×10^{-3}	
C. nasus taihuensis	15		2.1×10^{-3}	
C. mystus	10			3.6×10^{-3}
Sig.		5.2×10^{-2}	8.3×10^{-1}	1.0

approximately 0.1 μg/l or less, while freshwaters contain <0.01 to 0.06 μg/l in unpolluted areas (WHO 1992). In this study the opposite situation was observed. *C. nasus taihuensis* from the Sanshanhu and Jiaoshan locations in Taihu Lake, which spend their entire life in freshwater, had relatively higher Cd concentrations than did most of the migratory species (East China Sea to Yangtze River) (Tables 4, 6).

Pb

The highest concentrations of Pb (1.4×10^{-1} mg/kg ww) were observed in *C. nasus* from the Jinjiang location in the Yangtze River. The lowest concentrations of Pb (0.015 mg/kg ww) were observed in *C. nasus taihuensis* from the Shanshanhu location in Taihu Lake (Fig. 3).

Fig. 3 Mean concentrations and ranges of Pb (mg/kg ww) in muscle of genus *Coilia* from eight locations (JJ, Jinjiang; NJ, Nanjing; HM, Haimen; TC, Taichang; JS, Jiaoshan; PTS, Pingtaishan; SSH, Sanshanhu)



The concentration of Pb in *C. nasus* from the Jingjiang location in the Yangtze River was significant higher than that of *C. mystus* from the Taichang location in the Yangtze River (Duncan's test, $\alpha = 0.01$). The latter was significantly higher than that of samples from other locations (Duncan's test, $\alpha = 0.01$). There was no significant difference among the remaining six samples.

Comparisons among the four species showed that *C. mystus* contained the highest Pb concentration, followed by *C. nasus* ($6.6 \times 10^{-2} \pm 5.9 \times 10^{-2}$ mg/kg ww, $n = 15$). Although the data showed that both of these anadromous species contained significant higher concentrations of lead than did *C. brachygnathus* ($2.5 \times 10^{-2} \pm 1.9 \times 10^{-2}$ mg/kg ww, $n = 10$) or *C. nasus taihuensis* ($1.9 \times 10^{-2} \pm 1.1 \times 10^{-2}$ mg/kg ww, $n = 15$) (Duncan's test, $\alpha = 0.05$), concentrations of Pb in *C. nasus* from the Nanjing and Haimen locations in the Yangtze River were not significant higher than those in *C. brachygnathus* and *C. nasus taihuensis* from four freshwater locations (Duncan's test, $\alpha = 0.05$).

Zn

Concentrations of Zn were similar among locations, ranging from 3.4 to 4.8 mg/kg ww (Fig. 4). The fact that Zn is a required element and homeostatically regulated, together with its relatively low toxicity in humans and the limited sources of human exposure, suggests that normal, healthy individuals not exposed to Zn in the workplace are at potentially higher risk from the adverse effects associated with Zn deficiency than from those associated with normal environmental exposure to Zn (WHO 2001).

The concentrations of Zn were highest in anchovy from Hongze Lake and these concentrations were significantly higher than those from the Pingtaishan location in Taihu Lake and the Jiaoshan location in Taihu Lake (Duncan's test, $\alpha = 0.01$).

Concentrations of Zn were statistically different among species. The concentration of Zn in *C. nasus taihuensis* ($3.7 \pm 3.5 \times 10^{-1}$ mg/kg ww, $n = 15$) was significantly less than those of *C. mystus* ($4.3 \pm 3.0 \times 10^{-1}$ mg/kg ww, $n = 10$) from the Taichang location in the Yangtze River and *C. brachygnathus* ($4.8 \pm 7.8 \times 10^{-1}$ mg/kg ww, $n = 10$) from Hongze Lake (Duncan's test, $\alpha = 0.05$), but there was no statistically significant difference between the concentrations of Zn in *C. nasus taihuensis* and *C. nasus* ($4.1 \pm 7.0 \times 10^{-1}$ mg/kg ww, $n = 15$) (Duncan's test, $\alpha = 0.05$).

No statistically significant differences in Zn concentrations were observed among the three locations in Taihu Lake and there were no statistically significant differences in mean Zn concentrations of *C. nasus* (Duncan's test, $\alpha = 0.05$) from locations in the Yangtze River.

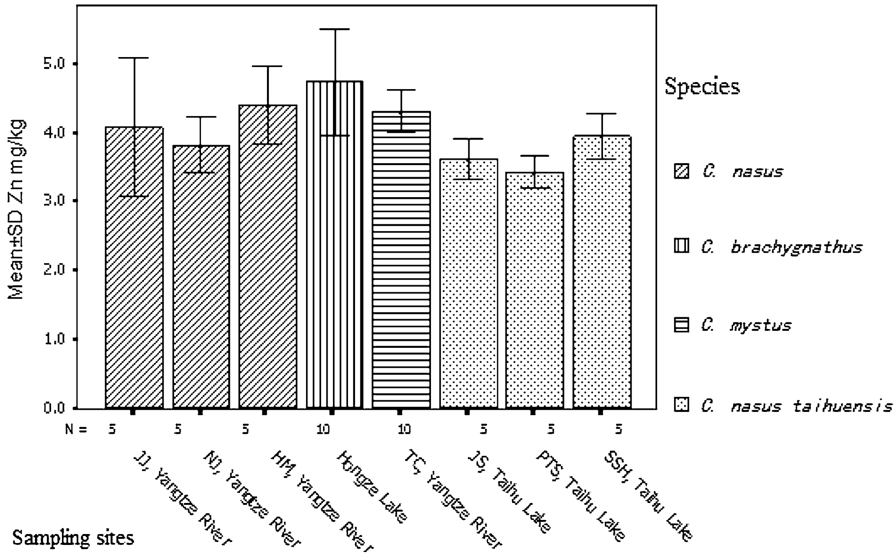


Fig. 4 Concentrations of Zn (mg/kg ww) in anchovy (JJ, Jinjiang; NJ, Nanjing; HM, Haimen; TC, Taichang; JS, Jiaoshan; PTS, Pingtaishan; SSH, Sanshanhu)

Comparison of concentrations of the four metals studied here to those in muscle of fishes from other areas of the world

Concentrations of metals in fish from YRD observed during this study were compared with those reported previously (Table 7). Concentrations of Cd, Pb, and Zn in fish from Meiliang Bay of Taihu Lake, which receives municipal and industrial wastewater from Wuxi City, were higher than those observed at the locations we studied, while concentrations of Cr were not. Mean values of Cr and Zn in our investigation, except for Cr in the Jiaoshan location in Taihu Lake, were less than those reported for Tianjin City, which has a long history of industrial contamination. Concentrations of Cd and Pb observed in our study were similar to those in fishes from Tianjin City. Concentration values of Pb and Zn observed in anchovy during our study were similar to those in fishes from the Tibet Plateau of China, but Cd concentrations in fish were higher in fishes from the Tibet Plateau.

The concentrations of Cr observed in this study except in Jiaoshan location were less than those in fishes of New Jersey in the USA and in *Liza aurata* of Lake Ganzirri in Italy. The concentrations of Cd observed in this study were less than those in fishes of the United Arab Emirates and, as for Zn, were less than those in fishes of the Masan Bay in Korea. The concentrations of Pb observed in this study were less than those in *Liza aurata* of Lake Ganzirri in Italy. Other results of heavy-metal concentrations in fish in different locations (Table 7) were similar to those observed in our study except for the concentration of Cr in anchovy from the Jiaoshan location in Taihu Lake.

Risk of consuming anchovy to humans

The health risks associated with consumption of metals in anchovy by local residents were assessed based on the THQ. A THQ value less than 1.0 means that the exposure population is unlikely to experience obvious adverse effects. Oral reference doses were based on 3.0×10^{-1} and 1.0×10^{-3} mg/kg/day for Zn and Cd, respectively (US EPA 2005, 1987), and 3.0×10^{-3} and 1.5 mg/kg/day for Cr(VI)and Cr(III), respectively (US EPA 1998a, b). The US Environmental Protection Agency has declined to set an R_{FD} for Pb because it has found no evidence of a threshold below which a nonharmful intake could be "allowed" (US EPA 2004). In several regions or countries MRLs in the human diet have been established for the studied heavy metals. For instance the MRLs set by the European Union for Cd and Pb in muscle meat of fish are 5.0×10^{-2} and 3.0×10^{-1} mg/kg ww, respectively (Commission Regulation 2006). In China, the MRL for Cd in fish is 1.0×10^{-1} mg/kg ww (Wu et al. 1994a), for Pb in fish and shrimp it is 5.0×10^{-1} mg/kg ww (Wu et al. 1994b), and for Cr in aquatic products it is 2.0 mg/kg ww (Pan et al. 2001). The

Table 7 Heavy-metal concentrations (mg/kg ww) in fish in other water areas

Location	Species or population	Cr	Cd	Pb	Zn	Reference
Meiliang Bay, Taihu Lake	*Cyprinus carpio*	ND	$2.1 \times 10^{-2} \pm 8.0 \times 10^{-3}$	$1.8 \times 10^{-1} \pm 3.0 \times 10^{-2}$	25 ± 4.0	Chi et al. (2007)
Meiliang Bay, Taihu Lake	*Carassius auratus*	$3.9 \times 10^{-1} \pm 1.1 \times 10^{-1}$	$1.3 \times 10^{-2} \pm 8.0 \times 10^{-3}$	$2.9 \times 10^{-1} \pm 1.0 \times 10^{-2}$	$1.3 \times 10^{2} \pm 7.0$	Chi et al. (2007)
Meiliang Bay, Taihu Lake	*Hypophthalmichthys molitrix*	ND	$3.0 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$1.8 \times 10^{-1} \pm 4.6 \times 10^{-2}$	21 ± 2.0	Chi et al. (2007)
Meiliang Bay, Taihu Lake	*Aristichthys nobilis*	ND	$4.0 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$1.8 \times 10^{-1} \pm 3.1 \times 10^{-2}$	16 ± 2.0	Chi et al. (2007)
Dong Li District, Tianjin	Fish	1.8×10^{-1} (7.0×10^{-2}–3.4×10^{-1})	2.0×10^{-3} (4.0×10^{-4}–5.0×10^{-3})	1.0×10^{-2} (2.0×10^{-3}–2.0×10^{-2})	9.4 (4.4–28)	Wang et al. (2005)
Xi Qing District, Tianjin	Fish	5.3×10^{-1} (1.1×10^{-1}–2.6)	6.0×10^{-3} (2.0×10^{-4}–3.0×10^{-2})	6.0×10^{-2} (1.0×10^{-3}–2.8×10^{-1})	19 (6.2–49)	Wang et al. (2005)
Jin Nan District, Tianjin	Fish	3.7×10^{-1} (4.0×10^{-2}–1.1)	8.0×10^{-3} (4.0×10^{-4}–3.0×10^{-2})	7.0×10^{-2} (3.0×10^{-3}–2.8×10^{-1})	22 (5.1–65)	Wang et al. (2005)
Bei Chen District, Tianjin	Fish	2.8×10^{-1} (2.6×10^{-1}–3.0×10^{-1})	2.0×10^{-3} (1.0×10^{-3}–3.0×10^{-3})	5.0×10^{-3} (3.0×10^{-3}–6.0×10^{-3})	14 (13–15)	Wang et al. (2005)
Nam Co Lake, Tibet Plateau	*Gymoncypris namensis*	–	2.5×10^{-2}	4.7×10^{-2}	6.9	Yang et al. (2007)
Yamdro Lake, Tibet Plateau	*Gymoncypris waddellii*	–	2.4×10^{-2}	7.9×10^{-2}	4.4	Yang et al. (2007)
Lhasa River, Tibet Plateau	*Ptychobarbus dipogon*	–	2.4×10^{-2}	2.4×10^{-2}	3.3	Yang et al. (2007)
Lhasa River, Tibet Plateau	*Schizopygopsis stoliczkae*	–	1.3×10^{-2}	2.6×10^{-2}	2.5	Yang et al. (2007)
Lhasa River, Tibet Plateau	*Schizopygopsis younhusbandi*	–	2.7×10^{-2}	6.5×10^{-2}	5.3	Yang et al. (2007)
Lhasa River, Tibet Plateau	*Schizopygopsis microphalus*	–	2.9×10^{-2}	5.5×10^{-2}	4.1	Yang et al. (2007)
Lhasa River, Tibet Plateau	*Oxygymnocypris stewartii*	–	2.3×10^{-2}	2.7×10^{-2}	3.0	Yang et al. (2007)
Adak Island, Alaska	*Myoxocephalus polyacanthocephalus*	$9.0 \times 10^{-2} \pm 1.6 \times 10^{-2}$	$4.0 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$1.4 \times 10^{-2} \pm 4.0 \times 10^{-3}$	–	Burger et al. (2007)
Adak Island, Alaska	*Hippoglossoides elassodon*	$9.5 \times 10^{-2} \pm 1.2 \times 10^{-2}$	$4.0 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$5.0 \times 10^{-2} \pm 8.0 \times 10^{-3}$	–	Burger et al. (2007)
Masan Bay, Korea	*Mugil cephalus*	2.0×10^{-2}	ND	4.0×10^{-2}	9.3	Kwon and Lee (2001)

Table 7 continued

Location	Species or population	Cr	Cd	Pb	Zn	Reference
Masan Bay, Korea	*Enedrias nebulosus*	3.0×10^{-2}	1.0×10^{-2}	5.0×10^{-2}	12.9	Kwon and Lee (2001)
Masan Bay, Korea	*Pleuronichthys cornutus*	3.0×10^{-2}	ND	1.1×10^{-1}	11.3	Kwon and Lee (2001)
Masan Bay, Korea	*Conger myriaster*	3.0×10^{-2}	ND	4.0×10^{-2}	9.2	Kwon and Lee (2001)
Masan Bay, Korea	*Acanthogobius flavimanus*	9.0×10^{-2}	3.0×10^{-2}	7.0×10^{-2}	12.7	Kwon and Lee (2001)
Masan Bay, Korea	*Hexagrammos otakii*	3.0×10^{-2}	1.0×10^{-2}	4.0×10^{-2}	7.0	Kwon and Lee (2001)
Masan Bay, Korea	*Sebastiscus marmoratus*	5.0×10^{-2}	1.0×10^{-2}	1.5×10^{-1}	6.3	Kwon and Lee (2001)
United Arab Emirates	*Lethrinus lentjan*	–	$1.1 \times 10^{-1} \pm 2.0 \times 10^{-2}$	–	$3.3 \pm 3.9 \times 10^{-1}$	Al-Yousuf et al. (2000)
New Jersey, USA	Bluefish	$2.5 \times 10^{-1} \pm 6.0 \times 10^{-2}$	$6.0 \times 10^{-3} \pm 2.0 \times 10^{-3}$	$6.0 \times 10^{-2} \pm 1.0 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Chilean sea bass	$8.0 \times 10^{-2} \pm 2.0 \times 10^{-2}$	$4.0 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$1.1 \times 10^{-1} \pm 1.0 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Cod	$3.4 \times 10^{-1} \pm 2.7 \times 10^{-1}$	$5.0 \times 10^{-4} \pm 3.0 \times 10^{-4}$	$1.2 \times 10^{-1} \pm 1.0 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Croaker	$1.1 \times 10^{-1} \pm 2.0 \times 10^{-2}$	$1.0 \times 10^{-3} \pm 4.0 \times 10^{-4}$	$9.0 \times 10^{-2} \pm 1.0 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Flounder	$3.1 \times 10^{-1} \pm 9.0 \times 10^{-2}$	$1.0 \times 10^{-2} \pm 2.0 \times 10^{-3}$	$6.0 \times 10^{-2} \pm 1.0 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Porgie	$1.4 \times 10^{-1} \pm 4.6 \times 10^{-2}$	$4.0 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$1.4 \times 10^{-1} \pm 1.7 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Red snapper	$1.5 \times 10^{-1} \pm 1.0 \times 10^{-1}$	$2.0 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$1.2 \times 10^{-1} \pm 1.0 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Whiting	$7.0 \times 10^{-2} \pm 1.4 \times 10^{-2}$	$9.0 \times 10^{-3} \pm 5.0 \times 10^{-3}$	$9.0 \times 10^{-2} \pm 1.1 \times 10^{-2}$	–	Burger and Gochfeld (2005)
New Jersey, USA	Yellow fin tuna	$2.0 \times 10^{-1} \pm 5.0 \times 10^{-2}$	$3.0 \times 10^{-2} \pm 5.0 \times 10^{-3}$	$4.0 \times 10^{-2} \pm 1.0 \times 10^{-2}$	–	Burger and Gochfeld (2005)
Lake Ganzirri, Italy	*Liza aurata*	$2.9 \times 10^{-1} \pm 8.0 \times 10^{-2}$	$6.1 \times 10^{-2} \pm 2.3 \times 10^{-2}$	$3.9 \times 10^{-1} \pm 1.0 \times 10^{-1}$	7.3 ± 0.9	Licata et al. (2004)
Coastal lagoons of Brazil	Fish	$8.0 \times 10^{-2} \pm 1.0 \times 10^{-2}$	–	–	4.6 ± 3.4	Fernandes et al. (1994)

Values in parentheses are the concentration range of metals

Table 8 MRL and R_{FD} published by different organizations or regions

	R_{FD} (US EPA) mg/kg/day	MRL (European Union) mg/kg	MRL (China National Standard) mg/kg
Cr	1.5 [Cr(III)]; 3.0×10^{-3} [Cr(VI)]	–	2.0
Cd	1.0×10^{-3}	5.0×10^{-2}	1.0×10^{-1}
Pb	–	3.0×10^{-1}	5.0×10^{-1}
Zn	3.0×10^{-1}	–	–

Table 9 Estimated target hazard quotients (THQ) for individual metals caused by consumption of fish for adults locally

Area	Based on US EPA R_{FD}		Based on EU MRLs		Based on China MRLs		
	Cd	Zn	Cd	Pb	Cr	Cd	Pb
Jinjiang, Yangtze River	2.6×10^{-3}	1.5×10^{-2}	4.0×10^{-2}	4.3×10^{-1}	2.6×10^{-2}	2.0×10^{-2}	2.6×10^{-1}
Nanjing, Yangtze River	1.9×10^{-3}	1.4×10^{-2}	3.4×10^{-2}	8.7×10^{-2}	1.9×10^{-2}	1.7×10^{-2}	5.2×10^{-2}
Haimen, Yangtze River	2.1×10^{-3}	1.7×10^{-2}	3.8×10^{-2}	1.2×10^{-1}	3.0×10^{-2}	1.9×10^{-2}	7.0×10^{-2}
Taichang, Yangtze River	4.0×10^{-3}	1.6×10^{-2}	7.2×10^{-2}	2.9×10^{-1}	2.2×10^{-2}	3.6×10^{-2}	1.7×10^{-1}
Pingtaishan, Taihu Lake	7.9×10^{-4}	1.3×10^{-2}	1.3×10^{-2}	8.3×10^{-2}	1.3×10^{-2}	7.0×10^{-3}	5.0×10^{-2}
Sanshanhu, Taihu Lake	3.3×10^{-3}	1.5×10^{-2}	5.8×10^{-2}	5.0×10^{-2}	2.1×10^{-2}	2.9×10^{-2}	3.0×10^{-2}
Jiaoshan, Taihu Lake	3.0×10^{-3}	1.4×10^{-2}	5.4×10^{-2}	5.7×10^{-2}	2.5	2.7×10^{-2}	3.4×10^{-2}
Hongze Lake	1.2×10^{-3}	1.8×10^{-2}	2.2×10^{-2}	8.3×10^{-2}	2.9×10^{-2}	1.1×10^{-2}	5.0×10^{-2}

relevant R_{FD} and MRL values are summarized in Table 8. Since the genus *Coilia* caught in this region are directly and randomly sold to residents, the average heavy-metal concentrations of fish in each location are used for calculation of THQ values (Table 9).

Except for the THQ for Cr in anchovy from the Jiaoshan location in Taihu Lake, which was 2.5 based on the China National Standard (Pan et al. 2001), no other THQs exceeded 1.0 (Table 9). This result suggests that the concentrations of the four heavy metals in anchovy at the eight locations studied, except Cr in anchovy in Jiaoshan location in Taihu Lake, would not present an unacceptable risk to humans.

Due to the difference in toxicity of the two valence states of Cr, the US EPA has set two separate R_{FD} values, one for Cr(III) and one for Cr(VI). In our study the total concentration of Cr was measured and not separated by the two valence states of Cr. Therefore, the THQ values for Cr based on R_{FD} values set by the US EPA will not be discussed here. Based on the concentration of Cr in *C. nasus taihuensis* from the Jiaoshan location in Taihu Lake which was 2.5-fold higher than the China National Standard value (MRL), people are probably at health risk due to eating *C. nasus taihuensis* from the Jiaoshan location of Taihu Lake, which is contaminated by Cr. THQ values for concentrations of Cr in anchovy from the other two locations of Pingtaishan, Taihu Lake and Sanshanhu, Taihu Lake were small relative to those of Jiaoshan, Taihu Lake ($THQ = 1.3 \times 10^{-2}$ and 2.1×10^{-2}).

Pb is a ubiquitous element detected in all environmental media. It has been estimated that the worldwide emission rates of lead are of the order of 19,000 tonnes/year (Nriagu and Pacyna 1988). Adults and older children receive the highest exposure to Pb from foods, whereas dust, soil, and food all make significant contributions to total Pb intake of young children (WHO 1995). Among the four metals studied, concentrations of Pb in anchovy had relatively greater potential health risk, particularly for people residing in Jingjiang (Table 9). In contrast, the concentrations of Cd and Zn in anchovy represent little potential health risks.

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