Environmental Pollution 158 (2010) 1334–1342

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Trace elements in two marine fish cultured in fish cages in Fujian province, China

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As levels in two marine caged fish from China exceeded the permissible standards, whereas the levels of others trace elements did not exceed the permissible concentrations.

ARTICLE INFO

Article history:
Received 14 October 2009
Received in revised form
16 December 2009
Accepted 11 January 2010

Keywords:
Trace elements
Cultured marine fish
Fish cages
Seafood safety

ABSTRACT

Two cultured marine fish, the Japanese seabass (*Lateolabrax japonicus*) and red seabream (*Pagrus major*) were collected from eight fish cage sites along the coast of Fujian province in China. The concentrations of Ag, As, Cd, Co, Cu, Fe, Mn, Se, and Zn in their muscle, stomach and liver tissue were quantified. The risk of these trace elements to humans through fish consumption was then assessed. The highest concentrations of As, Cd, Se and Zn in fish feed from fish cages were found in Dongshan Station. Moreover, the As levels in the muscles of both species at all sites were generally higher than China's national standard (>1.0 μg/g). Trace element concentrations in two marine fish followed the order of livers > stomachs > muscles. Although the As levels in two marine caged fish exceeded the permissible standards, the estimated daily intake of As did not exceed the reference dose guideline established by US EPA. For other trace elements examined in this study, their concentrations did not exceed the permissible concentrations of the international standards.

1. Introduction

Marine fish farming in China has been experiencing dramatic growth over the past decade as a result of increasing domestic fish consumption and foreign exports. Due to the low investment and easy routine management required, marine cage culture has grown tremendously in recent years along the east coast of China, especially in Fujian province, which has the largest number of marine fish cages in China (Chen et al., 2006; Chang and Chen, 2008). Based on aquaculture statistics data from the U.N.'s Food and Agricultural Organization (FAO), total aquaculture production in China in 2006 reached 34.4 million tons. The Japanese seabass *Lateolabrax japonicus* and the red seabream *Pagrus major* are the common carnivorous species cultured in the East China Sea, especially in Fujian province (Chang and Chen, 2008). The world production of *L. japonicus* increased from 800 tons in 1999 to 260 kilotons (a 320-fold increase) in 2006, suggesting a high demand for this species worldwide (FAO, 2006). Moreover, the government is now planning to support fishermen to develop offshore cage culture; for example, Shandong, Zhejiang and Guangdong provinces have planned to install >10,000 offshore fish cages, and Fujian and Hainan provinces will install 5000 offshore cages by 2010 (Chen et al., 2006).

Since 1980, the establishment of Xiamen in Fujian province as a special economic zone has led to a dramatic rise in pollution in this region (Klumpp et al., 2002). Inevitably, inshore pollution has contaminated the marine fish cage culture area. Such contamination is further exacerbated by feeding practices. Two types of fish feed are generally used. One type involves trash fish (e.g., anchovy or clupeids), fish viscera, and squid viscera which have low commercial values, are small and for which there is little consumer demand (Guo et al., 2009). The supply of trash fish is not stable in terms of either quality or quantity, and the fish viscera and squid viscera can contain high trace element concentrations. Another type of fish feed is pelleted artificial feed produced in factories, which is now commonly used. Feeding caged fish results in a great quantity of feces and food residues accumulating on the sea floor, which can potentially pollute the entire area (Chang and Chen, 2008; Mai et al., 2006). There have been some reports of trace element contamination in seawater (Cao and Wong, 2007; Meng et al., 2008), in sediment (Zhang et al., 2007; Yu et al., 2008; Meng et al., 2008), and in marine fish (Wong et al., 2001; Zheng et al., 2007; Cheung et al., 2008) from China. In recent years there has been a growing concern for public health in connection with the human consumption of marine fish. Weekly marine fish consumption in China averages 0.021 kg/person (FAO, 2008), but it can be much higher in coastal cities. Trace element contamination of seafood may thus be a legitimate safety concern.

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doi:10.1016/j.envpol.2010.01.012

However, there has not been any report of trace elements concentrations in caged fish.

In this study, the concentrations of Ag, As, Cd, Co, Cu, Fe, Mn, Se and Zn were determined in *L. japonicus* and *P. major* collected from eight marine fish cages in Fujian province. Trace element concentrations at different cage stations (from the south to the north of Fujian's coastal waters, all are in rural areas), between the two species, as well as among the different fish tissues (muscle, liver, and stomach) were compared. In addition to the muscle, the liver and stomach may occasionally be consumed by humans, and be recycled by the fishermen to feed the fish. Based on these trace element concentration measurements, human risk assessments for average Chinese people consuming cage-reared fish were performed. The hazard quotient ratio was calculated and compared with the provisional tolerance weekly intakes (PTWIs), average daily intakes (ADIs), and reference doses (RfDs) established by a Joint FAO/WHO Expert Committee on Food Additives (JECFA) (Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives, 2003) and America's Environmental Protection Agency (United States Environmental Protection Agency, 2005).

2. Materials and methods

2.1. Samples

In May 2008, sample Japanese seabass (*L. japonicus*) and red seabream (*P. major*) were collected from eight marine fish cages along the Fujian coastline (all in rural areas). From south to north, the sampling stations were at Dongshan (23°44.539′N, 117°31.081′E), Xiamen Bay (24°21.353′N, 118°04.342′E), Tongan (24°34.735′N, 118°11.021′E), Xinghua (25°18.335′N, 119°14.303′E), Meizhou (25°11.526′N, 118°58.782′E), Fuqing (25°41.169′N, 119°35.167′E), Luoyuan (26°21.615′N, 119°43.163′E), and Sandu-ao (26°37.906′N, 119°47.016′E) (Fig. 1). A total of 10 fish of marketable size for each species were sampled from each cage station. No gender difference was considered in this study. Similar sized fish were collected to minimize any differences in trace element concentrations resulting from size. The sizes and weights of the fish (0.58–0.77 kg in weight, 36.4–44.6 cm total length for *L. japonicus*, and 0.43–0.93 kg in weight, 29.1–39.2 cm total length for *P. major*) are shown in Table 1. Both species of fishes are commercially grown in marine fish cages in Fujian province, but when the samples were taken, seabass were not available at Dongshan, and seabream were not found in the Xinghua fish cage, thus only seven sites were sampled for both fish species.

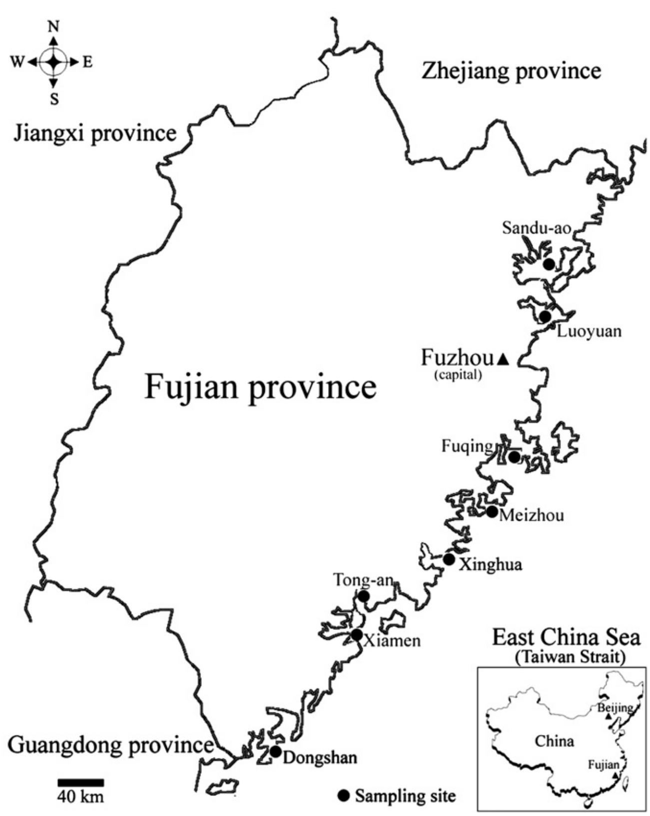

Fig. 1. Map of Fujian province showing the cage sampling sites.

The fish were immediately dissected using a precleaned stainless steel knife and approximately 5 g of each tissue of interest (muscle, stomach and liver) were first rinsed with double-distilled water, and then packed in acid-precleaned polyethylene bottles. The stomach did not include any of the stomach contents. The tissues were placed in liquid nitrogen and transported back to the laboratory, before being stored at −20 °C until chemical analysis. In addition, fish feed was collected from the farmers. At the Xiamen and Tongan cage sites, the farmers used pelleted artificial feed (Hai Long®) to feed both species, whereas in the other cages (at Xinghua, Meizhou, Fuqing and Sandu-ao) trash fish were being used at the time of sampling. The trash fish (anchovy, clupeoid and pony fishes) were ground and fed directly to the fish being raised. At Luoyuan, both types of feed were being used, and in Dongshan, only ground up fish viscera were collected.

2.2. Chemical analysis

All the glassware used for sample preparation was soaked in 10% HNO_3 for several days, then rinsed four times with deionized distilled water and dried at 80 °C for 24 h prior to use. The wet weights of all the fish tissues were recorded, and all the samples were transferred to preweighed acid-precleaned glass bottles and dried at 80 °C for 24 h, after which their dry weights were recorded. A 10 ml of ultrapure nitric acid (65%) was added to the samples, which were digested within a heat block at 80 °C for 1 h. Since lipid (oil) was a significant fraction of most tissues, 1–2 ml of 35% hydrogen peroxide was added for lipid digestion. The samples were further digested at 150 °C for 3 h. After cooling, the samples were transferred to 50 ml volumetric flasks and diluted with deionized water to 50 ml. Sample blanks were prepared in the same manner as the fish tissue samples.

The samples were analyzed for nine trace elements: Ag, As, Cd, Co, Cu, Fe, Mn, Se and Zn using inductively coupled plasma-atomic emission spectroscopy (ICP-AES, Thermo model-IRIS Intrepid II XSP). The standard solution was prepared from a stock solution (National China Standard (NCS), National Institute of Metrology, China). A standard reference material oyster tissue (1566a, National Institute of Standards and Technology, Gaithersburg, MD, USA) was used simultaneously for tissue digestion and AES measurements. Recoveries were 88–109% (Table 2). All specimens were run in batches that included blanks, a certified reference material, and 30 specimens. All trace element concentrations were expressed as μg/g wet weight.

2.3. Statistical analysis

The average trace element concentrations in each tissue of the two fish species and differences between tissues among the different cage sites were tested for statistical significance with one-way ANOVA and post-hoc Tukey tests using SPSS (version 16.0, SPSS Inc, Chicago, IL, USA). The significance of differences in trace element concentration in each tissue between the two fish species was tested using Student's *t*-test.

2.4. Human risk assessment analysis

The human risk assessment for Chinese people was calculated using the provisional tolerance weekly intake (PTWI), average daily intake (ADI), and reference dose (RfD) previously established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives, 2003) and the United States Environmental Protection Agency (2005). The daily intake (μg/kg bw/day) was estimated using the following equation:

$$EDI = C_{fish} \times \left[dc_{fish}/bw \right]$$

where C_{fish} = average trace element concentration in fish muscle (μg/g wet weight), dc_{fish} = daily fish consumption (g/day) per capita as recorded by the FAO (2008), and bw = the average body weight (kg) of the target population. The Chinese average body weight was 58.1 kg based on measurements of 158,666 Chinese from all provinces (Gu et al., 2006). The hazard quotient (HQ) was calculated by dividing the estimated daily intake (EDI) by the established RfD to assess the health risk from fish consumption. There would be no obvious risk if the HQ were less than 1.

3. Results and discussion

3.1. Comparison among cages, trace elements, and species, and the relationship with fish feed

The two fish (*L. japonicus* and *P. major*) from the Fujian fish cages were fed pellet artificial feed or fresh trash fish and fish viscera; the

Table 1
The mean weight, body length and tissue wet/dry weight ratio of the two farmed fish. Data are mean ± SE.

Species/site	n	Weight (kg)	Length (cm)	Wet/dry ratio		
				Muscle	Stomach	Liver
Lateolabrax japonicus						
Xiamen	10	0.78 ± 0.02	41.35 ± 0.35	4.46 ± 0.04	4.38 ± 0.10	3.00 ± 0.21
Tongan	10	0.79 ± 0.05	44.61 ± 0.85	4.39 ± 0.08	4.47 ± 0.09	2.65 ± 0.11
Xinghua	10	0.58 ± 0.02	37.90 ± 1.05	4.36 ± 0.67	4.79 ± 0.09	2.61 ± 0.09
Meizhou	10	0.59 ± 0.02	36.41 ± 0.56	4.11 ± 0.09	4.07 ± 0.17	3.99 ± 0.04
Fuqing	10	0.72 ± 0.02	39.22 ± 0.48	4.43 ± 0.08	4.39 ± 0.10	2.61 ± 0.09
Luoyuan	10	0.77 ± 0.03	41.72 ± 0.65	4.39 ± 0.08	4.57 ± 0.09	2.37 ± 0.10
Sandu-ao	10	0.66 ± 0.04	37.88 ± 1.03	3.55 ± 0.10	4.10 ± 0.19	2.42 ± 0.10
Pagrus major						
Dongshan	10	0.61 ± 0.02	31.90 ± 0.43	4.06 ± 0.07	4.78 ± 0.38	3.00 ± 0.04
Xiamen	10	0.79 ± 0.02	35.93 ± 0.78	4.02 ± 0.04	4.17 ± 0.10	2.86 ± 0.11
Tongan	10	0.72 ± 0.04	35.26 ± 2.22	4.32 ± 0.09	4.04 ± 0.09	2.68 ± 0.11
Meizhou	10	0.65 ± 0.02	32.63 ± 0.56	3.16 ± 0.13	3.34 ± 0.11	2.62 ± 0.16
Fuqing	10	0.93 ± 0.05	29.14 ± 1.08	3.91 ± 0.08	3.79 ± 0.13	2.92 ± 0.09
Luoyuan	10	0.93 ± 0.05	38.79 ± 0.78	3.69 ± 0.11	4.10 ± 0.06	2.60 ± 0.08
Sandu-ao	10	0.43 ± 0.02	39.24 ± 0.78	3.62 ± 0.08	4.17 ± 0.09	2.85 ± 0.08

amounts of these feeds varied for the two fish species and seasons. The metal levels in the artificial feed were generally higher than those in the fresh feed samples (Table 3). The level in the artificial feed was about 4.4 times higher for Cu, 5.3 times higher for Zn, 9.5 times higher for Cd, and 14 times higher for Fe and Mn than those in the trash feed from the Luoyuan cage site, where both feeds were collected. For Dongshan, where only fish viscera were available, the As, Cd, Se, and Zn concentrations were also much higher than those measured in the trash feed sampled elsewhere. Indeed, the concentrations of As, Cd, Se, and Zn in the fish viscera from Dongshan were significantly higher than those in artificial feed ($p < 0.01$). However, it was difficult to quantitatively assess the contribution of different fish feeds, since the farmers generally feed the fish whatever is available on that day (so a mixture of artificial feed, ground fish viscera and trash fish was used over a period of time).

The mean trace element concentrations in the three tissues (muscle, stomach and livers) of the two species are shown in Tables 4 and 5. In general, there was very little difference in trace element concentrations in the muscles among the different sampling stations. The largest differences were 5-fold for Se in seabass muscle and 9-fold for Ag in red seabream. In the stomach tissue, the largest difference was 12 times for As in seabass and 13 times for Ag in red seabream. In the livers, the largest difference was 7 times for Cd in seabass and 14 times for Ag in red seabream. The accumulation pattern of trace elements in the tissues followed the expected pattern of muscle < stomach < liver in both species, except for arsenic where the pattern in the seabass was stomachs < livers < muscles. The ratios of trace element concentrations in liver and in muscle in the seabass were 3 for Ag, 7 for Cd and Zn, 12 for Mn, 13 for Co and Se, 78 for Fe, and 510 for Cu. In the red seabream, these ratios were 2 for Ag and As, 3 for Co and Se, 8 for Zn, 14 for Cd, 21 for Cu, 23 for Mn, and 56 for Fe. Fe was the highest in the livers of both fish. The much higher concentrations of Cu, Fe and Zn in the livers have also been recorded in earlier measurements in marine fishes (Dugo et al., 2006; Fernandes et al., 2007, 2008; Agusa et al., 2007; Kojadinovic et al., 2007; Tepe et al., 2008; Türkmen et al., 2009). Two conspicuous observations were that Cu concentrations in seabass were as high as 28–80 μg/g, and Fe concentration in their livers was 95–295 μg/g.

Table 2
Comparison of trace element concentrations in the oyster tissue standard reference material (SRM) (μg/g dry weight) with our own measurements. Data are mean ± SD ($n = 11$).

Metal	Oyster tissue-1566a (NIST-SRM)	Observed	Recovery (%)	Detection limit (μg/ml)
Silver	0.67 ± 0.01	0.73 ± 0.54	109	0.03
Arsenic	7.65 ± 0.65	7.18 ± 2.96	93.8	0.10
Cadmium	2.48 ± 0.08	2.24 ± 0.15	90.2	0.01
Cobalt	0.37 ± 0.01	0.36 ± 0.17	97.2	0.01
Copper	71.6 ± 1.60	67.9 ± 1.26	94.8	0.05
Iron	206 ± 6.80	194 ± 7.70	94.1	0.08
Manganese	18.5 ± 0.20	16.9 ± 0.57	91.6	0.008
Selenium	2.06 ± 0.15	2.05 ± 1.15	99.5	0.10
Zinc	1424 ± 46	1254 ± 67.6	88.1	0.004

There was no significant correlation between trace elements in the three fish feeds and trace elements in the fish tissues. One of the possible reasons was that a mixture of artificial feed, ground fish viscera and trash fish was used over time. The only exception was for the Luoyuan cage site where two types of fish feeds were provided. There was a linear correlation between Cd and Mn in the feeds and in the stomachs of seabass ($p < 0.05$). Trace elements in the feeds showed no significant correlation with those in the red seabream tissues. In addition, there was no significant correlation between trace element concentration in fish and fish size since similar sizes of fish were collected from different cages.

Comparing the mean trace element concentrations in muscle between the two species from the same location, As and Cd in seabass were significantly higher ($p < 0.01$, 1.5 times), whereas Co and Cu were significantly lower ($p < 0.01$, 2 times) than those in the red seabream. In the stomach, only Ag in the seabass was significantly higher ($p < 0.01$, 5 times) and As, Cd, Cu, Fe, Mn, Se and Zn were significantly lower ($p < 0.01$, 1.3–6 times) than those in the red seabream. In the livers, Co, Cu, Fe and Se in seabass were significantly higher ($p < 0.01$, 2–14.5 times), but As, Cd and Mn concentrations were significantly ($p < 0.05$, 1.3–1.8 times) lower than those in the red seabream. Such inter-species difference in trace element accumulation may result from a difference in fish feeds or species-specific metal metabolism in fish.

3.2. Individual metals

The concentrations of each trace element in the two fish are described below and compared with earlier studies in marine fishes (Table 6). Earlier studies have reported trace element concentrations in fish based on dry weight, so in this study a wet/dry weight conversion factor of 4 was used to convert to the wet weight for easy comparison (Table 1).

Table 3
Trace element concentrations in fish feeds from Fujian marine fish cages (μg g^{-1} dry weight). Data are mean ± SE ($n = 4$). For each trace element, different letters indicate significant difference between the two sampling cages ($p < 0.05$).

Trace element	Sampling sites								
	Dongshan (FF-viscera)	Xiamen (AF)	Tongan (AF)	Xinghua (FF)	Meizhou (FF)	Fuqing (FF)	Luoyuan (AF)	Luoyuan (FF)	Sandu-ao (FF)
Ag	0.20 ± 0.07^{a}	0.16 ± 0.04^{a}	0.11 ± 0.02^{a}	0.32 ± 0.14^{a}	0.17 ± 0.04^{a}	0.34 ± 0.08^{a}	0.09 ± 0.06^{a}	0.20 ± 0.13^{a}	<0.03
As	19.2 ± 0.55^{d}	1.80 ± 0.28^{a}	3.10 ± 0.26^{abc}	6.01 ± 0.83^{bc}	5.09 ± 0.41^{abc}	6.20 ± 0.99^{bc}	2.64 ± 0.76^{ab}	4.14 ± 1.05^{abc}	6.47 ± 1.06^{c}
Cd	3.47 ± 0.58^{b}	0.98 ± 0.02^{a}	1.15 ± 0.21^{a}	<0.01	0.07 ± 0.06^{a}	0.13 ± 0.03^{a}	1.33 ± 0.30^{a}	0.14 ± 0.03^{a}	0.07 ± 0.07^{a}
Co	0.12 ± 0.04^{ab}	0.32 ± 0.02^{cd}	0.26 ± 0.01^{bcd}	0.06 ± 0.02^{a}	0.15 ± 0.03^{ab}	0.18 ± 0.03^{abc}	0.37 ± 0.04^{d}	<0.01	0.11 ± 0.03^{ab}
Cu	17.2 ± 7.29^{cd}	22.0 ± 0.02^{d}	18.8 ± 0.22^{d}	3.57 ± 0.19^{ab}	3.37 ± 0.11^{a}	18.5 ± 0.69^{d}	15.1 ± 0.11^{bcd}	3.43 ± 0.24^{a}	6.03 ± 0.23^{abc}
Fe	362 ± 42.9^{d}	406 ± 9.05^{de}	362 ± 18.7^{d}	269 ± 25.0^{c}	176 ± 17.3^{b}	445 ± 6.09^{de}	487 ± 10.2^{e}	34.8 ± 1.77^{a}	390 ± 4.31^{d}
Mn	4.13 ± 0.25^{a}	54.5 ± 0.32^{d}	53.6 ± 0.17^{d}	7.92 ± 0.36^{a}	19.8 ± 0.53^{b}	35.3 ± 5.35^{c}	55.3 ± 0.60^{d}	3.97 ± 0.16^{a}	6.68 ± 0.16^{a}
Se	9.51 ± 0.70^{c}	1.46 ± 0.35^{ab}	2.34 ± 0.22^{ab}	1.98 ± 0.21^{ab}	3.49 ± 0.54^{b}	2.57 ± 0.50^{ab}	1.09 ± 0.26^{a}	2.39 ± 0.60^{ab}	2.17 ± 0.50^{ab}
Zn	562 ± 5.17^{f}	106 ± 2.90^{d}	105 ± 2.81^{d}	45.7 ± 2.21^{b}	48.7 ± 2.03^{b}	57.2 ± 0.78^{b}	141 ± 4.22^{e}	26.5 ± 0.59^{a}	82.8 ± 1.22^{c}

FF, fresh feed (trash fish or fish viscera); AF, artificial feed (pelleted).

In the present study, Ag concentrations were <0.03–0.07 μg/g in muscle and stomach tissue, and 0.06–0.18 μg/g in liver for the seabass, compared with <0.03–0.09 μg/g in muscle, <0.03–0.13 μg/g in stomach and <0.03–0.14 μg/g in liver for the red seabream. Its concentrations in the livers was significantly higher ($p \leq 0.01$) than in muscle. In a few cages, Ag was only detectable in one sample, so there calculating a standard deviation of the measurements was impossible. Generally, Ag did not show strong inter-cage differences in any of the tissues. Ag levels in muscle in captured coastal fish in Southeast Asia were <0.003 μg/g (Agusa et al., 2007), and 0.001–0.05 μg/g in marine fish from the East China Sea (Asante et al., 2008). Ag concentrations in the livers of wild fish from Southeast Asia range from 0.002 to 0.12 μg/g (Agusa et al., 2007), which is higher than in their muscles. A permissible concentration of Ag in fish has not yet been established.

Total As levels in *L. japonicus* were 1.54–4.48 μg/g in muscles (with the highest concentration in Meizhou), 0.18–2.09 μg/g in stomach and 1.39–4.19 μg/g in livers. In *P. major*, As concentrations were 0.88–2.94 μg/g in muscles, 1.11–2.96 μg/g in stomachs, and 1.75–6.47 μg/g in livers, with the highest level founded in Xiamen. These As levels in the fish muscle were higher than the 1.0 μg/g wet weight of China's national standards (China National Standards Management Department, 2001), except for *P. major* at the Fuqing site. Total As in livers was significantly higher ($p < 0.01$) than in muscles and stomachs, consistent with previous observations of marine fish (0.045–15.39 μg/g) (Han et al., 1998; Kohlmeyer et al., 2003; Burger and Gochfeld, 2005; Fabris et al., 2006; Falco et al., 2006; Cheung et al., 2008; Martí-Cid et al., 2008).Thiboldeaux (2006) found that most (80–99%) of As in fish was in the form of arsenobetaine, arsenocholine and organoarsenicals, all of which have low toxicity and can be rapidly excreted in urine. Many studies only measured the total As, without further differentiating the various As species (inorganic and organic). The As concentrations observed in muscle in this study were also generally higher than

Table 4
Trace element concentrations in the tissues of the Japanese seabass, *L. japonicus*, from the Fujian marine fish cages (μg g^{-1} wet weight). Data are mean ± SE ($n = 10$). For each metal, different letters indicate significant difference between the two sampling cages ($p < 0.05$).

Trace elements	Tissue	Sampling sites						
		Xiamen	Tongan	Xinghua	Meizhou	Fuqing	Luoyuan	Sandu-ao
Ag	Muscle	<0.03	0.05 ± 0.01^{a}	0.05 ± 0.02^{a}	<0.03	0.04 ± 0.02^{a}	0.07 ± 0.02^{a}	<0.03
	Stomach	<0.03	0.05 ± 0.01^{a}	<0.03	<0.03	0.07 ± 0.02^{a}	0.06 ± 0.02^{a}	<0.03
	Liver	0.11 ± 0.02^{a}	0.13 ± 0.04^{a}	0.06	0.09 ± 0.02^{a}	0.10 ± 0.02^{a}	0.13 ± 0.02^{a}	0.18 ± 0.02^{a}
As	Muscle	3.24 ± 0.21^{c}	2.37 ± 0.27^{abc}	1.94 ± 0.26^{ab}	4.48 ± 0.42^{d}	2.42 ± 0.23^{abc}	2.70 ± 0.24^{bc}	1.54 ± 0.08^{a}
	Stomach	0.86 ± 0.08^{bc}	1.23 ± 0.17^{cd}	0.18 ± 0.03^{a}	1.52 ± 0.06^{d}	1.53 ± 0.08^{d}	2.09 ± 0.10^{e}	0.63 ± 0.06^{ab}
	Liver	1.39 ± 0.12^{a}	2.39 ± 0.23^{c}	2.28 ± 0.21^{bc}	2.41 ± 0.19^{c}	3.22 ± 0.12^{d}	4.19 ± 0.27^{e}	1.52 ± 0.07^{ab}
Cd	Muscle	0.03 ± 0.00^{bc}	0.04 ± 0.00^{c}	0.01 ± 0.00^{a}	0.03 ± 0.00^{c}	0.03 ± 0.00^{bc}	0.04 ± 0.01^{c}	0.02 ± 0.00^{ab}
	Stomach	0.04 ± 0.00^{bcd}	0.06 ± 0.01^{d}	0.02 ± 0.00^{ab}	0.02 ± 0.00^{a}	0.03 ± 0.00^{abc}	0.04 ± 0.00^{cd}	0.03 ± 0.00^{abc}
	Liver	0.13 ± 0.01^{ab}	0.46 ± 0.07^{c}	0.19 ± 0.02^{ab}	0.07 ± 0.01^{a}	0.10 ± 0.01^{a}	0.18 ± 0.02^{ab}	0.23 ± 0.02^{b}
Co	Muscle	0.01 ± 0.00^{a}	0.02 ± 0.01^{b}	0.01	0.01 ± 0.00^{ab}	0.02	0.01	0.01 ± 0.00^{ab}
	Stomach	0.01 ± 0.00^{a}	0.01	0.02 ± 0.01^{a}	0.01 ± 0.01^{a}	0.03	0.01 ± 0.00^{a}	0.02 ± 0.00^{a}
	Liver	0.11 ± 0.01^{ab}	0.29 ± 0.03^{e}	0.07 ± 0.01^{ab}	0.05 ± 0.01^{a}	0.13 ± 0.01^{bc}	0.19 ± 0.02^{d}	0.18 ± 0.01^{cd}
Cu	Muscle	0.12 ± 0.01^{b}	0.09 ± 0.02^{ab}	0.16 ± 0.01^{c}	0.11 ± 0.01^{b}	0.09 ± 0.01^{ab}	0.06 ± 0.01^{a}	0.12 ± 0.01^{bc}
	Stomach	0.82 ± 0.07^{bc}	0.66 ± 0.03^{ab}	0.56 ± 0.02^{a}	0.70 ± 0.03^{abc}	0.87 ± 0.07^{c}	0.75 ± 0.02^{abc}	0.75 ± 0.03^{abc}
	Liver	80.0 ± 9.49^{b}	29.2 ± 3.52^{a}	61.4 ± 7.72^{b}	28.5 ± 4.14^{a}	54.0 ± 5.82^{ab}	54.8 ± 7.59^{ab}	70.1 ± 8.24^{b}
Fe	Muscle	1.64 ± 0.20^{a}	1.85 ± 0.23^{a}	1.62 ± 0.17^{a}	1.52 ± 0.15^{a}	2.23 ± 0.65^{a}	2.23 ± 0.36^{a}	3.02 ± 0.71^{a}
	Stomach	10.2 ± 0.59^{c}	8.29 ± 0.63^{bc}	5.51 ± 0.33^{a}	7.86 ± 0.49^{b}	7.71 ± 0.65^{ab}	9.31 ± 0.48^{bc}	9.24 ± 0.37^{bc}
	Liver	142 ± 14.1^{a}	295 ± 19.5^{c}	126 ± 7.56^{a}	101 ± 10.9^{a}	94.9 ± 5.53^{a}	222 ± 17.9^{b}	126 ± 9.32^{a}
Mn	Muscle	0.08 ± 0.00^{bc}	0.11 ± 0.01^{d}	0.04 ± 0.01^{a}	0.07 ± 0.00^{abc}	0.06 ± 0.01^{ab}	0.09 ± 0.01^{bcd}	0.09 ± 0.01^{cd}
	Stomach	0.35 ± 0.04^{b}	0.28 ± 0.03^{ab}	0.26 ± 0.02^{ab}	0.22 ± 0.02^{a}	0.23 ± 0.02^{a}	0.18 ± 0.12^{a}	0.25 ± 0.03^{ab}
	Liver	0.84 ± 0.06^{ab}	1.09 ± 0.15^{b}	1.08 ± 0.06^{b}	0.68 ± 0.08^{a}	0.96 ± 0.04^{ab}	1.14 ± 0.10^{b}	0.97 ± 0.04^{ab}
Se	Muscle	0.41 ± 0.05^{bc}	0.55 ± 0.14^{bc}	0.18 ± 0.03^{a}	0.84 ± 0.05^{d}	0.53 ± 0.09^{bcd}	0.87 ± 0.14^{cd}	0.44 ± 0.03^{bcd}
	Stomach	0.60 ± 0.05^{ab}	0.69 ± 0.11^{abc}	0.48 ± 0.09^{a}	1.13 ± 0.03^{d}	0.82 ± 0.08^{bcd}	0.92 ± 0.07^{cd}	0.86 ± 0.04^{bcd}
	Liver	4.79 ± 0.49^{ab}	3.99 ± 0.54^{a}	7.98 ± 0.87^{b}	6.17 ± 0.75^{ab}	8.22 ± 0.75^{b}	8.21 ± 0.93^{b}	14.7 ± 1.47^{c}
Zn	Muscle	3.61 ± 0.12^{b}	3.75 ± 0.46^{b}	2.39 ± 0.22^{a}	4.29 ± 0.20^{b}	3.66 ± 0.16^{b}	4.29 ± 0.24^{b}	4.49 ± 0.24^{b}
	Stomach	13.5 ± 0.53^{a}	16.5 ± 0.49^{b}	16.6 ± 0.64^{b}	16.9 ± 0.53^{b}	16.1 ± 0.44^{b}	15.0 ± 0.72^{ab}	14.7 ± 0.46^{ab}
	Liver	18.5 ± 2.23^{a}	48.0 ± 3.72^{d}	32.2 ± 1.44^{c}	15.9 ± 1.16^{a}	24.2 ± 1.33^{abc}	27.9 ± 2.07^{bc}	22.8 ± 1.55^{ab}

Table 5
Trace element concentrations in the tissues of the red seabream, *P. major*, from the Fujian marine fish cages (μg g^{-1} wet weight). Data are mean ± SE ($n = 10$). For each trace element, different letters indicate significant difference between the two sampling cages ($p < 0.05$).

Trace elements	Tissue	Sampling sites						
		Dongshan	Xiamen	Tongan	Meizhou	Fuqing	Luoyuan	Sandu-ao
Ag	Muscle	0.04 ± 0.02^{a}	<0.03	0.06 ± 0.02^{a}	<0.03	0.06 ± 0.02^{a}	0.09 ± 0.02^{a}	<0.03
	Stomach	0.13 ± 0.02^{a}	0.10 ± 0.02^{a}	<0.03	<0.03	0.04	<0.03	<0.03
	Liver	0.08	0.07	0.14 ± 0.02^{a}	<0.03	0.11 ± 0.01^{a}	0.11 ± 0.02^{a}	<0.03
As	Muscle	2.47 ± 0.13^{c}	2.94 ± 0.18^{c}	1.42 ± 0.14^{ab}	1.78 ± 0.13^{b}	0.88 ± 0.13^{a}	1.06 ± 0.11^{a}	1.14 ± 0.07^{a}
	Stomach	1.94 ± 0.17^{b}	2.96 ± 0.17^{c}	1.50 ± 0.17^{ab}	1.59 ± 0.08^{ab}	1.26 ± 0.11^{a}	1.28 ± 0.12^{a}	1.11 ± 0.05^{a}
	Liver	3.13 ± 0.27^{bc}	6.47 ± 0.37^{d}	3.09 ± 0.33^{bc}	3.68 ± 0.24^{c}	1.75 ± 0.07^{a}	2.41 ± 0.12^{ab}	2.79 ± 0.14^{abc}
Cd	Muscle	0.03 ± 0.00^{bc}	0.03 ± 0.01^{c}	0.01 ± 0.00^{a}	0.01 ± 0.00^{a}	0.02 ± 0.00^{abc}	0.02 ± 0.00^{abc}	0.01 ± 0.00^{ab}
	Stomach	0.17 ± 0.02^{c}	0.03 ± 0.01^{ab}	0.07 ± 0.01^{ab}	0.03 ± 0.00^{a}	0.04 ± 0.01^{ab}	0.03 ± 0.00^{a}	0.07 ± 0.01^{b}
	Liver	0.45 ± 0.02^{d}	0.24 ± 0.01^{bc}	0.33 ± 0.04^{cd}	0.10 ± 0.01^{ab}	0.08 ± 0.01^{a}	0.08 ± 0.01^{ab}	0.79 ± 0.08^{e}
Co	Muscle	0.03 ± 0.01^{b}	0.03 ± 0.01^{b}	0.02 ± 0.00^{ab}	0.02 ± 0.00^{a}	0.01 ± 0.00^{ab}	0.02 ± 0.00^{ab}	0.01 ± 0.00^{ab}
	Stomach	0.02 ± 0.01^{ab}	0.03 ± 0.01^{ab}	0.03 ± 0.01^{b}	0.02 ± 0.00^{ab}	0.02 ± 0.00^{ab}	0.01 ± 0.00^{ab}	0.01 ± 0.00^{a}
	Liver	0.08 ± 0.02^{a}	0.07 ± 0.01^{a}	0.08 ± 0.01^{a}	0.07 ± 0.01^{a}	0.04 ± 0.01^{a}	0.05 ± 0.02^{a}	0.08 ± 0.01^{a}
Cu	Muscle	0.18 ± 0.02^{b}	0.18 ± 0.02^{b}	0.18 ± 0.02^{b}	0.18 ± 0.01^{b}	0.22 ± 0.01^{b}	0.22 ± 0.01^{b}	0.11 ± 0.01^{a}
	Stomach	1.75 ± 0.25^{b}	1.06 ± 0.03^{a}	1.69 ± 0.26^{b}	1.68 ± 0.08^{ab}	1.37 ± 0.06^{ab}	1.30 ± 0.08^{ab}	1.46 ± 0.09^{ab}
	Liver	5.21 ± 0.68^{b}	5.51 ± 0.44^{b}	3.73 ± 0.38^{a}	3.05 ± 0.21^{a}	2.36 ± 0.09^{a}	3.29 ± 0.28^{a}	3.69 ± 0.12^{a}
Fe	Muscle	0.83 ± 0.12^{a}	2.37 ± 0.49^{b}	1.04 ± 0.22^{ab}	2.27 ± 0.24^{ab}	4.57 ± 0.67^{c}	1.47 ± 0.24^{ab}	2.05 ± 0.26^{ab}
	Stomach	14.6 ± 1.08^{bc}	11.3 ± 0.78^{ab}	16.7 ± 1.03^{c}	12.1 ± 0.47^{ab}	14.1 ± 0.79^{bc}	13.6 ± 0.90^{bc}	9.12 ± 0.48^{a}
	Liver	150 ± 13.2^{de}	105 ± 7.32^{bcd}	167 ± 16.5^{e}	90.6 ± 10.3^{ab}	56.7 ± 5.85^{a}	138 ± 9.40^{cde}	101 ± 10.6^{abc}
Mn	Muscle	0.02 ± 0.00^{a}	$0.07 \pm 0.01b^{c}$	0.05 ± 0.01^{ab}	0.10 ± 0.00^{d}	0.10 ± 0.01^{cd}	0.07 ± 0.01^{bcd}	0.10 ± 0.00^{d}
	Stomach	0.43 ± 0.04^{a}	1.27 ± 0.07^{b}	1.70 ± 0.11^{b}	1.41 ± 0.08^{b}	2.24 ± 0.13^{c}	1.46 ± 0.17^{b}	1.65 ± 0.15^{b}
	Liver	0.72 ± 0.04^{a}	2.17 ± 0.25^{c}	1.81 ± 0.18^{bc}	1.40 ± 0.05^{b}	1.77 ± 0.06^{bc}	1.48 ± 0.09^{b}	2.35 ± 0.14^{c}
Se	Muscle	1.28 ± 0.18^{b}	0.72 ± 0.11^{a}	0.44 ± 0.09^{a}	0.81 ± 0.06^{a}	0.50 ± 0.13^{a}	0.62 ± 0.09^{a}	0.46 ± 0.03^{a}
	Stomach	2.77 ± 0.32^{c}	1.71 ± 0.13^{b}	0.73 ± 0.14^{a}	1.85 ± 0.13^{b}	0.94 ± 0.11^{a}	1.39 ± 0.10^{ab}	1.01 ± 0.10^{a}
	Liver	3.98 ± 0.08^{d}	2.65 ± 0.14^{c}	1.24 ± 0.12^{a}	2.40 ± 0.20^{c}	1.56 ± 0.10^{a}	2.17 ± 0.13^{bc}	1.75 ± 0.05^{ab}
Zn	Muscle	3.21 ± 0.17^{ab}	3.13 ± 0.16^{ab}	2.88 ± 0.17^{a}	4.57 ± 0.23^{c}	3.90 ± 0.21^{bc}	3.46 ± 0.21^{ab}	3.39 ± 0.15^{ab}
	Stomach	49.1 ± 4.15^{b}	18.8 ± 0.62^{a}	17.3 ± 0.45^{a}	20.4 ± 0.76^{a}	16.0 ± 0.34^{a}	17.8 ± 0.55^{a}	17.7 ± 0.54^{a}
	Liver	27.9 ± 1.48^{ab}	30.4 ± 1.05^{b}	24.8 ± 0.88^{a}	24.6 ± 1.21^{a}	23.4 ± 0.94^{a}	26.3 ± 1.14^{ab}	30.4 ± 0.77^{b}

those in the fish feeds. The source inputs of As in the Fujian coastal waters are not exactly known. Suburban soil in Fujian province appears to be high in As (1.29–25.3 μg/g, Huang et al., 2006), and approximately 30 tons of As runs off annually in the Jiulong River, which is in the coastal Fujian (Cao and Wong, 2007). Such input may be the main source of As in Fujian's fish cages.

Cadmium levels in *L. japonicus* were 0.01–0.04 μg/g in muscle, 0.02–0.06 μg/g in stomachs and 0.07–0.46 μg/g in livers. The highest Cd concentration was found at Tongan. Cd concentrations also differed significantly among the three different tissues ($p < 0.01$). Cd concentrations in the red seabream were 0.01–0.03 μg/g in muscle, 0.03–0.17 μg/g in stomachs and 0.08–0.79 μg/g in livers, with the highest concentrations in Sandu-ao. The Cd in fish muscle was lower than the safe level of 0.1 μg/g established by China's national standard (China National Standards Management Department, 2001) and the European Union (2001). The Cd concentrations in the caged fish were rather similar to those measured earlier in cultured fish (Dugo et al., 2006; Fernandes et al., 2007, 2008). On the other hand, the Cd concentrations in *L. japonicus* from supermarkets in Taiwan have been measured as 0.005–0.180 μg/g (Han et al., 1998), 4.5 times higher than the measurements in this study. In captured marine fish, Cd concentrations range from 0.001 to 0.4 μg/g (Burger and Gochfeld, 2005; Fabris et al., 2006; Zheng et al., 2007; Martí-Cid et al., 2008; Cheung et al., 2008; Tepe et al., 2008; Storelli, 2008; Türkmen et al., 2009).

Cobalt concentrations in the seabass were 0.01–0.02 μg/g in muscle, 0.01–0.03 μg/g in stomachs, and 0.05–0.29 μg/g in livers. For the red seabream, Co concentrations were 0.01–0.03 μg/g in muscle and stomachs, and 0.04–0.08 μg/g in livers. The Co concentrations in the livers were significantly higher than those in other tissues. In the East China Sea, Co concentrations in captured marine fish range from 0.01 to 0.06 μg/g (Asante et al., 2008), and in Southeast Asia they range from <0.001 to 0.07 μg/g in muscle (Agusa et al., 2007). In the liver, Co concentrations in marine fish have previously been reported as 0.007–0.73 μg/g (Agusa et al., 2007) and 0.11–1.45 μg/g (Tepe et al., 2008). Our results were thus 2–5 times lower than those previous measurements. Tepe et al. (2008) reported Co concentrations of 0.03–0.44 μg/g in two species of marine fish from Turkey.

The Cu levels in the seabass were 0.06–0.16 μg/g in muscle, 0.56–0.87 μg/g in stomachs and 28.5–80.0 μg/g in livers. Cu concentrations in the red seabreams were 0.11–0.22 μg/g in muscle, 1.06–1.75 μg/g in stomachs, and 2.36–5.51 μg/g in livers. Cu levels in the livers of the two species were significantly ($p \leq 0.01$) higher than in other tissues. In addition, Cu concentrations in the seabass livers were 9–23 times higher than in the red seabream. The Cu in fish muscle was lower than the safety level of 50 μg/g established as China's national standard (China National Standards Management Department, 2001) and the 10–100 μg/g limit established by the FAO (Tepe et al., 2008). By comparison, Cu concentrations of 0.22–0.70 μg/g (Dugo et al., 2006) and 0.25–1.0 μg/g have been observed in the muscle of caged seabass (*Dicentrarchus labrax*) from Southern Portugal, Northeast Spain and Italy (Fernandes et al., 2008). Cu levels in the livers of caged seabass from Italy have been found to be 0.63–1.56 μg/g (Dugo et al., 2006), and as high as 25–225 μg/g in samples from Portugal and Spain (Fernandes et al., 2008).

Fe concentrations in the seabass were 1.52–3.02 μg/g in muscle, 5.51–10.2 μg/g in stomachs and 94.9–295 μg/g in livers, and in the red seabream they were 0.83–4.57 μg/g in muscle, 9.12–16.7 μg/g in stomachs and 56.7–167 μg/g in livers. In Tongan, the Fe levels in the livers of both fish were the highest among all the cages. For comparison, Fe levels in muscle from Turkish marine fish have been measured as 8.93–160 μg/g (Tepe et al., 2008; Türkmen et al., 2009),

Table 6
Trace element concentrations (μg/g wet weight) in cultured marine fish and captured marine fish measured in different studies. Data reported based on dry weights are converted to wet weight basis for comparison using a wet weight/dry weight ratio of 4.

Species	Tissue	Ag	As	Cd	Co	Cu	Fe	Mn	Se	Zn	References
Farmed marine fish											
L. japonicus	Muscle	<0.03–0.07	1.54–4.48	0.01–0.04	0.01–0.02	0.06–0.16	1.52–3.02	0.04–0.11	0.18–0.87	2.39–4.49	This study
(Japanese seabass)	Liver	0.06–0.18	1.39–4.19	0.07–0.46	0.05–0.29	28.5–80.0	94.9–295	0.68–1.14	3.99–14.7	15.9–48.0	
P. major	Muscle	<0.03–0.09	0.88–2.94	0.01–0.03	0.01–0.03	0.11–0.22	0.83–4.57	0.02–0.10	0.44–1.28	2.88–4.57	This study
(Red seabream)	Liver	<0.03–0.14	1.75–6.47	0.08–0.79	0.04–0.08	2.36–5.51	56.7–167	0.72–2.35	1.24–3.98	23.4–30.4	
Dicentrarchus labrax (seabass)	Muscle			0.02–0.03		0.22–0.70			0.05–0.14	0.66–1.02	Dugo et al. (2006)
(Tyrrhenian and Sicilian, Italy)	Liver			0.01–0.07		0.63–1.56			0.13–0.38	1.08–1.73	
D. labrax (seabass) (South Portugal)	Liver			0.03–0.30		26.0–249				37.5–55.0	Fernandes et al. (2007)
D. labrax (seabass)	Muscle			0.003–0.008		0.25–1.0				5.3–7.0	Fernandes et al. (2008)
(South Portugal and Northeast of Spain)	Liver			0.1–0.3		25–225				8.25–27.8	
Captured marine fish											
Coastal fishes (Southeast Asia)	Muscle	<0.003		<0.05	<0.07	0.21–1.10		0.05–0.81	0.10–0.95	3.08–15.0	Agusa et al. (2007)
	Liver	0.002–0.12		0.009–8.45	0.007–0.73	0.66–7.43		0.17–10.5	0.28–5.0	6.78–238	
Tonguefish (Huludao, China)	Muscle			0.12		1.95–2.17				14.0–14.2	Zheng et al. (2007)
Sleeve-fish (Huludao, China)	Muscle			0.16–0.24		38.6–44.2				30.3–34.5	
Goby (Huludao, China)	Muscle			0.07–0.09		0.99–1.26				8.96–10.5	
Market fishes (Pearl River Estuary, China)	Muscle		0.16–2.03	<0.01–0.05		0.04–0.07				0.86–1.87	Cheung et al. (2008)
Pelagic fishes (Western Indian Ocean)	Muscle			0.03–0.26		0.16–0.50	3.15–17.6	0.05–0.09	0.40–3.95	10.4–40	Kojadinovic et al. (2007)
	Liver			4.68–42.3		10–60	52.8–324	0.88–1.80	3.38–22.7	33.8–129	
Pagrus auratus(Snapper) (Victoria, Australia)	Muscle		2.5–12.1	0.02		0.2–0.4			0.43–0.80	3.1–7.5	Fabris et al. (2006)
Market fishes (Catalonia, Spain)	Muscle		0.99–15.4	<0.1							Falco et al. (2006)
Market fishes (Catalonia, Spain)	Muscle		1.13–6.08	<0.025–0.05							Martí-Cid et al. (2008)
Mullus barbatus (red mullet)	Muscle			0.01–0.40	0.03–0.44	0.15–1.56	8.93–49.3	0.08–0.88		3.15–10.5	Tepe et al. (2008)
(Turkish Seas)	Liver			0.04–1.13	0.11–1.45	1.62–46.2	83.9–889	0.61–7.33		9.83–195	
Merlangius merlangus	Muscle			0.01–0.24	0.04–0.27	0.57–5.06	21.9–160	0.40–1.12		5.73–12.9	
(Whiting) (Turkish Seas)	Liver			0.04–0.35	0.12–1.08	1.11–26.7	49.9–328	0.92–4.19		17.4–34.9	
Marine fishes (Aegean Sea and Mediterranean Sea)	Muscle			<0.01–0.39	<0.01–0.45	0.34–7.05	9.18–136	0.08–2.78		3.51–53.5	Türkmen et al. (2009)
	Liver			0.03–0.86	0.10–0.96	1.56–51.1	54.2–318	0.47–9.90		13.2–93.8	
Commercial fishes (New Jersey, USA)	Muscle		0.23–3.3	<0.01				0.15–0.70	0.31–1.02		Burger and Gochfeld (2005)

and 3.15–17.6 μg/g level have been recorded in pelagic fishes from the western Indian Ocean (Kojadinovic et al., 2007). Fe at 54.2–889 μg/g ww has been found in the livers of fish in Turkey (Tepe et al., 2008; Türkmen et al., 2009), and 52.8–324 μg/g in pelagic fish from the western Indian Ocean (Kojadinovic et al., 2007).

Mn levels in the seabass were 0.04–0.11 μg/g in muscle, 0.18–0.35 μg/g in stomachs and 0.68–1.14 μg/g in the livers. The highest levels were founded in the livers of Luoyuan fish. In the red seabream, Mn was 0.02–0.10 μg/g in muscle, 0.43–2.24 μg/g in stomachs, and 0.72–2.35 μg/g in livers, with the highest concentrations observed in livers from the Sandu-ao cage site. The Mn levels in the stomachs and livers of red seabream were twice those in seabass. By comparison, the Mn concentrations in the muscle of marine fish from New Jersey, USA, were 0.15–0.70 μg/g (Burger and Gochfeld, 2005), and 0.08–2.78 μg/g for Turkish mullet, whiting, and other fish (Tepe et al., 2008; Türkmen et al., 2009). In the East China Sea, Mn levels in marine fish have previously been measured as 0.26–43.0 μg/g (Asante et al., 2008), and in Southeast Asia as 0.05–0.81 μg/g (Agusa et al., 2007). In the western Indian Ocean, Mn levels in pelagic marine fish were measured at 0.05–0.09 μg/g (Kojadinovic et al., 2007). As with the iron, the Mn concentrations in the muscle of both fish were 2–390 times lower than have been reported earlier. The Mn levels in the livers of marine fish in these earlier reports were 0.47–9.90 μg/g (Tepe et al., 2008; Türkmen et al., 2009), or 0.17–10.5 μg/g in coastal and pelagic fish (Agusa et al., 2007; Kojadinovic et al., 2007).

Se concentrations in the seabass were 0.18–0.87 μg/g in muscle, 0.48–1.13 μg/g in stomachs and 3.99–14.7 μg/g in livers. The highest Se levels were found in the Luoyuan (muscle), Meizhou (stomachs) and Fuqing (livers) fish cages. The Se concentrations in the red seabream were 0.44–1.28 μg/g in muscle, 0.73–2.77 μg/g in stomachs and 1.24–3.98 μg/g in livers. The highest Se concentrations for all tissues were found at the Dongshan cage site. Hepatic Se in both fish showed significant differences ($p \leq 0.01$) from the Se levels in their muscles and stomachs. By comparison, Se levels in the muscle of cultured marine fish from the Tyrrhenian Sea and Sicily were measured at 0.13–0.38 μg/g for cultured seabass, *D. labrax* (Dugo et al., 2006). Other studies have reported Se concentrations in captured marine fish of 0.31–1.02 μg/g for commercial fish from New Jersey markets (Burger and Gochfeld, 2005), and 0.43–0.80 μg/g for snappers *Pagrus auratus* from the coastal waters of Victoria, Australia (Fabris et al., 2006). Captured marine fish from Southeast Asia had Se concentrations of 0.10–0.95 μg/g (Agusa et al., 2007). The measurements here gave results rather comparable to these earlier measurements. Se concentrations in the livers of seabass (*D. labrax*) cultured in Italy were 0.13–0.38 μg/g (Dugo et al., 2006), and in captured marine fish from South East Asia waters they were 0.28–5.0 μg/g dw (Agusa et al., 2007).

Zn was found in the seabass at 2.39–4.49 μg/g in muscle, 13.5–16.9 μg/g in stomachs, and 15.9–48.0 μg/g in livers. The highest zinc levels were in fish from Sandu-ao (muscle), Meizhou (stomachs) and Tongan (livers). Zinc in the red seabream was determined to be 2.88–4.57 μg/g in muscle, 16.0–49.1 μg/g in stomachs, and 23.4–30.4 μg/g in livers. The highest Zn concentrations were found in red seabream from Meizhou (muscle), Dongshan (stomachs) and Xiamem and Sandu-ao (livers). The Zn in fish muscle was lower than the safety level of 40–100 μg/g of various international standards (Tepe et al., 2008). For comparisons, Zn levels in *L. japonicus* from supermarkets in Taiwan were measured as 17.4–52.0 μg/g (Han et al., 1998), 7–11 times higher than these measurements. Zn concentrations in muscle from seabass (*D. labrax*) cultured in Italy were determined to be 0.66–1.02 μg/g (Dugo et al., 2006), 5.3–7.0 μg/g from Southern Portugal and Northeast Spain (Fernandes et al., 2008). Zn in muscle from captured marine fish has been measured at 0.86–53.5 μg/g (Fabris et al., 2006; Zheng et al., 2007; Cheung et al., 2008; Tepe et al., 2008; Türkmen et al., 2009).

3.3. Risk to humans

The mean muscle concentrations were used to conduct health risk assessments for human fish consumption. The mean trace element concentrations in fish muscles were used for this assessment. Based on statistics on 158,666 Chinese from all provinces compiled by Gu et al. (2006), an average weight of 58.1 kg was assumed for a Chinese person. On average, the daily consumption rate of marine fish is 3 g/person/day in China (FAO, 2008). On this basis, the estimated daily intake (EDI) of trace elements is shown in Table 7.

As in seafood exists both as inorganic As and organic As (arsenobetaine, arsenocholine and organoarsenicals). Although seafood

Table 7
Daily intake of trace elements through marine fish consumption by people in China. EDI, estimated daily intake; ADI, allowed daily intake, calculated from the provisional tolerance weekly intake set by the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives (2003); RfD, reference doses of trace elements as established by the United States Environmental Protection Agency (2005); Hazard quotient = EDI/RfD. If the ratio is <1, there is no obvious risk. [a]Average concentration of inorganic As was estimated as 10% of total As (United States Food and Drug Administration, 1993).

Fish species and trace elements	Average concentration (μg/g ww)	EDI (μg/kg bw/day)	ADI (μg/kg bw/day)	Rfd (μg/kg bw/day)	Hazard quotient
Seabass (*L. japonicus*)					
Ag	0.04	0.002	5	5	<0.01
As[a]	0.27	0.014	2.14	0.3	0.05
Cd	0.03	0.002	1	1	<0.01
Co	0.01	0.001	20	0.3	<0.01
Cu	0.11	0.006	500	40	<0.01
Fe	2.02	0.101	800	700	<0.01
Mn	0.08	0.004	140	140	<0.01
Se	0.58	0.029	5	5	<0.01
Zn	3.78	0.190	300	300	<0.01
Red seabream (*P. major*)					
Ag	0.06	0.003	5	5	<0.01
As[a]	0.17	0.009	2.14	0.3	0.03
Cd	0.02	0.001	1	1	<0.01
Co	0.02	0.001	20	0.3	<0.01
Cu	0.18	0.009	500	40	<0.01
Fe	2.04	0.105	800	700	<0.01
Mn	0.07	0.004	140	140	<0.01
Se	0.68	0.035	5	5	<0.01
Zn	3.52	0.182	300	300	<0.01

contains a high concentration of organic arsenic, it is much less toxic than inorganic arsenic (Han et al., 1998). In mammals, the organic forms can be efficiently and rapidly excreted in urine without transformation (Buchet et al., 1996). In contrast, inorganic arsenic from seafood consumption is a suspected carcinogen. About 10% of total As in fish muscle is in inorganic forms (Buchet et al., 1996; United States Food and Drug Administration, 1993), and thus only inorganic As was considered in the hazard calculations.

The calculations showed that for an average Chinese person, the EDI of seabass and red seabream lead to trace element consumption 22–34,900 times lower than the RfD guidelines for all of the metals studied, thus strongly indicating no health risk due to trace elements in cage-reared marine fish. The average fish and seafood consumption of Chinese people (71 g/person/day according to the FAO) includes freshwater fish (29 g/person/day), shellfish (29 g/person/day), and marine fish (3 g/person/day). Of course, Chinese people living along the coast can be assumed to consume much more seafood than people living inland. In Hong Kong, for example, the estimated daily consumption of marine fish is 25 g/day (or 8 times higher than the average Chinese consumption). Even with such a high fish consumption, the EDI was much lower than the established ADI.

To conclude, trace element concentrations in fish farmed in cages in Fujian generally do not exceed the safety levels for trace element content except in the case of arsenic levels in the muscle of *L. japonicus*. Even then, the As levels exceed China's national standard, but it is probably still safe to consume the fish because most of the accumulated As is in the less toxic organic form. Cage-reared marine fish generally have a very short food chain structure, since they are generally fed artificial fish pellets and small trash fish or fish viscera. It has been shown recently that trace elements in the food contribute predominantly to metal accumulation in marine fish due to a very low uptake from the dissolved phase (Xu and Wang, 2002; Wang and Rainbow, 2008). Dietary accumulation of trace elements is determined by the dietary assimilation efficiency, the ingestion rate, as well as the trace element concentrations in the food ingested. The dietary assimilation is inversely related to the ingestion rate in fish. Since the fish farmers generally feed caged fish large volumes of food, it is possible that the dietary assimilation is low, leading to relatively low accumulation of these trace elements in the fish. However, this needs to be further examined in future studies.

Acknowledgments

S.O. thanks the China Scholarship Council and Thailand's International Development Cooperation Agency for financial support. This study was supported by the Changjiang Scholar Program awarded to W.-X. Wang.

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