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Heavy Metal Concentrations in the Common Benthic Fishes Caught from the Coastal Waters of Eastern Taiwan

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ABSTRACT

People in Taiwan consume a large amount of marine fish, most of which are captured from the costal waters around Taiwan. Heavy metals are recognized as one of the most important pollutants, and their accumulations in the organisms have been studied and monitored for the safety of seafood consumption in the coastal waters of Taiwan; however, its regulation has been overlooked in the eastern region. This study evaluates the seafood consumption safety of the coastal fisheries in eastern Taiwan and establishes a baseline reference of the heavy metal levels in the fish of this region for the future monitoring of heavy metal pollution. Zinc, copper, cadmium and lead concentrations were determined in muscles, gills, intestines and livers of twenty benthic species of the most common commercial fish caught from the coastal waters of eastern Taiwan using a flame atomic absorption spectrometer. The results showed that zinc concentrations were the highest in the tissues, followed by copper and cadmium, and lead being the lowest except in the gills. Among the tissues, liver showed the highest metal concentrations, followed by intestine and gill, and was found to be the lowest in the muscle. The concentrations of zinc, copper, cadmium and lead in muscle ranged 2.0~6.2, 0.15~0.81, 0.02~0.12 and < 0.02~0.15 μg/g wet weight, respectively. The concentrations of the four elements in liver were in the range of 16.9~59.1, 1.4~12.4, 0.11~1.16 and < 0.02~1.09 μg/g wet weight, respectively. The concentrations of the heavy metals in the tissues varied significantly among species. Spottyback searobin *Pterygotrigla hemistica* and soldierfish *Myripristis berndti* contained in general higher concentrations of the metals in muscle and liver than other species of fish, respectively. The metal concentrations of fish found in this study are similar to the metal levels of the fish caught from slightly polluted waters in other parts of Taiwan, while the metal concentrations in our fish muscle are far below the consumption safety tolerance set by most countries in the world. Therefore, no public health problem would be raised from the consumption of fish from the coastal waters of eastern Taiwan.

Key words: heavy metals, benthic fish, muscle, liver, eastern Taiwan

INTRODUCTION

The people in Taiwan consume a large amount of marine fishes. Most of these fishes sold in the market were captured from the costal waters around Taiwan. Heavy metals have long been recognized as one of the most important pollutants in the coastal waters of western Taiwan, due to heavy industrialization, which discharges anthropogenic metal pollutants from the land. Some of these elements are toxic to living organisms even at considerably low concentrations, whereas others are biologically essential and natural constituents of the aquatic ecosystems and only become toxic at very high concentrations[(1)]. The metals entering the aquatic ecosystem may not directly cause damage to organisms; however, they can be deposited in aquatic organisms through the effects of bio-concentration, bioaccumulation and the food chain process, and eventually threaten the health of humans via seafood consumption[(2)]. Therefore, both the metal toxicity and the capacity of metal accumulation in the organisms have attracted considerable concern over the safety of seafood consumption in Taiwan.

The coastal waters of eastern Taiwan have long been considered as one of the few uncontaminated marine areas in Taiwan. This is due to the small number of factories and the relatively small population in this region. In addition, Kuroshio, a current of equatorial origin, sweeps the coastal waters of eastern Taiwan and carries in the meantime a considerable portion of pollutants away to distant waters. However, medium-high and medium-low levels of lead and cadmium contaminations, respectively, in certain areas of the land soil of eastern Taiwan were documented[(3)]. Therefore, the potential for seawater contamination is a legitimate concern. The studies concerning heavy metal levels in seafood originating from eastern Taiwan are extremely small in number. This contrasts strikingly with the large number of similar studies conducted in western Taiwan[(2, 4-8)]. The lack of public concern for the health of eastern coastal marine ecosystems has long been overlooked. Thus, it is very important and urgent to study the levels of heavy metals in the common edible fishes of the coastal waters of eastern Taiwan in order to clarify the current status of seafood consumption safety and the influence of onshore heavy metal pollution on seafood contamination levels in the region.

The purpose of this work was to determine zinc, copper, cadmium and lead concentrations in edible dorsal muscles, as well as non-edible gills, intestines and livers, of twenty species of the benthic fishes from the coastal waters of eastern Taiwan. The fishes chosen in this study are com-

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mercial and considered one of the most important sources of animal protein in the studied area. The results could be used to evaluate the seafood consumption safety of the coastal fisheries in eastern Taiwan. It could also be used as the baseline reference of the heavy metal levels in the fishes of this region for the future monitory of heavy metal pollution.

MATERIALS AND METHODS

Eighty-one fishes of twenty species were collected on the decks of local fishing vessels from March to November 2002 in the coastal waters of eastern Taiwan (Figure 1). After collection, specimens were placed immediately in plastic bags and, then, put into an icebox. They were transported to the laboratory and kept in a freezer at -20˚C prior to the chemical analysis. Identification of species and measurements of standard length and body weight of the fish were made after defrosting in the laboratory. The detailed information of the fish samples is shown in Table 1.

The dorsal muscles, gills, intestines and livers of each fish were dissected with the aid of a stainless steel knife which had been cleaned with acetone and rinsed with hot distilled water prior to use. Gut contents were cleaned from intestines as much as possible. Each sample of the dissected tissue (3~5 g) was accurately weighed and placed in a 100 mL Pyrex vessel that had been soaked in 65% nitric acid and distilled water (1:1 v/v) solution for at least 24 hours and rinsed with distilled and deionized water for reduction of the potential lead contamination in the vessels. 6 mL of 65% nitric acid and 1.5 mL of 30% hydrogen peroxide (GR grade, Merck Company) were then added to each sample. Each vessel was then put into an oven and gently heated to a temperature varying between 75~80˚C for 24 hours until the digestion was complete. The digested solution was cooled at room temperature and diluted with 7.5 mL of distilled water. The solutions were then filtrated into polypropylene tubes for the examination of heavy metal concentrations under an exhaust fume hood. The

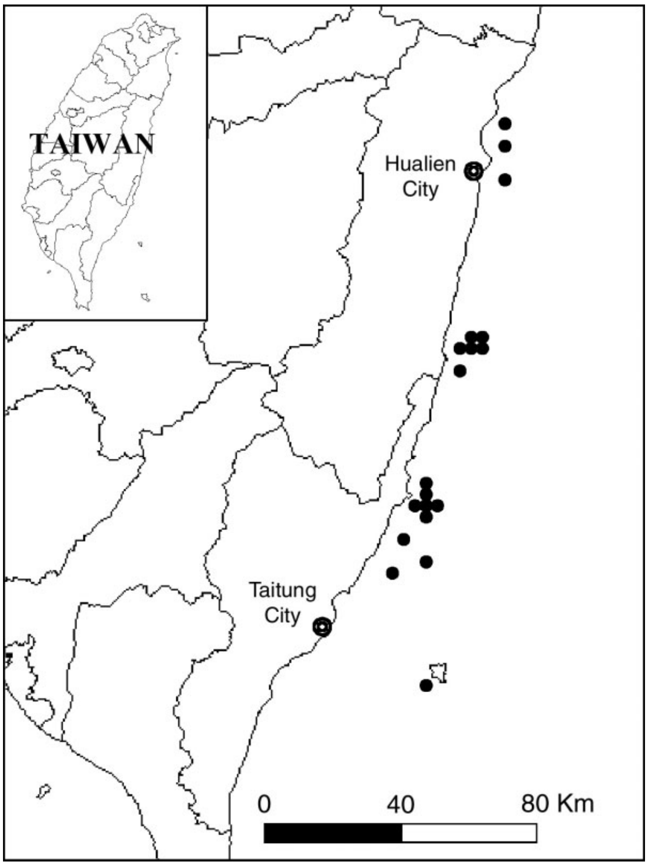

Figure 1. Locations of the sampling area (•) in the coastal waters of eastern Taiwan.

Table 1. Species, number, standard length (SL) and body weight (BW) of the fishes caught from the coastal water of eastern Taiwan, 2002

Species	Chinese Name	No.	SL (cm)	BW (g)	Month of Catch				
			mean ± s.e.	mean ± s.e.	Mar.	May	July	Sep.	Nov.
Argyrops bleekeri	小長棘鯛	3	14.0 ± 0.9	136.4 ± 29.4				•	
Branchiostegus japonica	日本馬頭魚	6	20.9 ± 1.1	200.9 ± 28.2				•	•
Calotomus calolinus	卡羅鸚鯉	2	25.6 ± 0.3	523.0 ± 21.3			•		
Dentex tumifrons	赤鯮	12	14.9 ± 0.4	128.1 ± 11.0	•			•	•
Girella melanichthy	黑瓜子鱲	2	26.9 ± 1.2	551.9 ± 34.3	•				
Gymnocranius griseus	白鱲	3	20.3 ± 1.6	282.8 ± 59.5					•
Lethrinus mahsena	白點龍占	3	18.3 ± 0.8	194.1 ± 23.2			•		
Lutjanus lutjanus	正笛鯛	5	15.4 ± 0.5	100.8 ± 8.9		•		•	
Myripristis berndti	凸頷松毬	3	16.7 ± 2.2	181.1 ± 54.3	•				
Nemipterus bathybius	底金線魚	15	16.6 ± 0.4	111.2 ± 6.7		•	•	•	•
Neobythites sivicola	新鼬鳚	3	16.6 ± 1.5	40.0 ± 13.6		•			
Paracaesio xanthururs	黃擬烏尾冬	2	27.6 ± 1.3	519.9 ± 51.7	•				
Parapristipoma trilineatum	三線雞魚	2	25.5 ± 2.2	342.0 ± 72.0			•		
Physiculus japonicus	日本鬚稚鱈	2	32.5 ± 1.3	430.3 ± 58.3		•			
Plectorhinchus diagrammus	雙帶石鱸	2	20.2 ± 0.1	190.1 ± 6.3				•	
Priacanthus hamrur	寶石大眼鯛	3	26.0 ± 0.4	440.8 ± 14.5			•		
Priacanthus macracanthus	大眼鯛	3	19.5 ± 0.3	158.2 ± 9.7		•			
Pristipomoides filamentosus	絲鰭姬鯛	3	22.3 ± 1.9	256.7 ± 65.1				•	
Pterygotrigla hemistica	尖棘角魚	5	18.7 ± 0.6	152.2 ± 13.6	•	•			
Scarus rubroviolaceus	紅紫鸚哥魚	2	32.9 ± 1.7	969.4 ± 174.0		•			

digestion method used in this study followed that reported in Chen[9].

Concentrations of zinc, copper, cadmium and lead in the digested samples were determined with a flame atomic absorption spectrometer (Perkin Elmer-AA100). The detection limits were 0.5 μg/g for zinc, 0.1 μg/g for copper and 0.01 μg/g for cadmium and lead. All samples were analyzed at least twice. For each series of 10 samples, an analytical blank was prepared in a similar manner without samples to check for possible contamination. In addition, standard reference materials of bovine liver from National Institute of Standards and Technology (NIST) were adopted in the digestion procedure to check the analysis accuracy and precision. The results showed that the recovery percentages of all metals were above 94%.

Two-factor analysis of variance (ANOVA) was used to determine the significant level in difference of the heavy metal concentrations in different fish tissues and different fish species. Since the month of catch may affect the heavy metal concentrations in fishes, we used the month of catch as blocks. The sum of squares for the two factors (tissues and species) are adjusted by partitioning the sum of squares for blocks (month of catch) to separate the factorial and the block effects[10]. The software of the statistics calculation and model was SAS, and all statistics tests were considered significant when $p \leq 0.05$.

RESULTS AND DISCUSSION

I. *Metal Concentrations in Fishes*

Table 2 gives the mean values of zinc, copper, cadmium and lead concentrations in liver, intestine, gill and muscle tissues of 20 benthic fish species in this study. The order of the metal concentrations is generally zinc > copper > cadmium and lead. The largest means (± standard error) of the essential elements, zinc and copper, were 33.83 (± 1.86) and 5.58 (± 0.45) μg/g found in livers, respectively, and the smallest means were 3.79 (± 0.57) and 0.34 (± 0.03) μg/g found in muscles, respectively. The largest means of the non-essential elements, cadmium and lead, were 0.52 (± 0.04) and 0.32 (± 0.03) μg/g found in livers and gills, respectively, and the smallest means were 0.05 (± 0.01) and 0.05 (± 0.01) μg/g found in muscles, respectively.

In general, accumulation of zinc and copper are higher than lead and cadmium in fish tissues[11]. The essential elements, such as zinc, are regulated to maintain a certain homeostatic status in fish[12]. On the contrary, the non-essential elements, such as lead, have no biological function or requirement and their concentrations in marine fish tissues are generally low[13]. The results in our study were in accord with those reported in the said documents.

II. *Metal Concentrations in Tissues*

The results presented in Table 2 show that in general the heavy metals are more concentrated in livers than in intestines or gills. Gills contain lower levels of the heavy metals than livers and intestines except in the case of lead. The concentrations of the heavy metals are the lowest in muscles (Table 2).

Liver is the tissue that can accumulate the highest level of metal concentrations, followed by gill or intestine[1, 12, 14-19]. Our results are in accord with these report except in the case of lead (Table 2). That liver can contains the highest metal concentration because it is an organ for storage and detoxification of metals[20] as well as an organ where the specific metabolism processes and enzyme-catalyzed reactions related to these metals take place[21]. Liver has also an important role in storage, redistribution, detoxification or transformation of contaminants, and also acts as an active site of pathological effects induced by contaminants[22]. The liver tissues are more often recommended as an indicator of water pollution than any other organs in fishes[15].

Fish may accumulate heavy metals by absorption through gills or by consumption of contaminated food and sediments[11]. The different degrees of the metals accumulated in various tissues depend on the biochemical characteristics of the metal[14]. With the exception of zinc, which significantly showed both gastrointestinal absorption and gill uptake, cadmium and copper demonstrate more significant uptake through gill rather than digestive tract absorption[12]. Generally in fishes, the gill is the tissue that is more often found to have high heavy metal concentrations[1, 14, 17-19]. However, the feeding habits and the metal content in food are also related to the metals accumulated in various tissues in fishes[14]. In our study the metal concentrations in the intestines were mostly higher than those in the gills (Table2), indicating that the metal uptake was mainly through gastrointestinal absorption, originating from the food or sediments consumed by the benthic fishes, rather than gill. Besides, the concentrations of metals in gills reflect the concentrations of metals in the water, where the fish species lives[17]. The high concentration of lead

Table 2. The mean and standard error of zinc, copper, cadmium and lead concentrations in liver, intestine, gill and muscle tissues of fishes from the coastal waters of eastern Taiwan, 2002

Tissues	Heavy metal concentration (μg/g wet weight)			
	Zinc	Copper	Cadmium	Lead
Liver (n = 81)	33.83 ± 1.86	5.58 ± 0.45	0.52 ± 0.04	0.21 ± 0.04
Intestine (n = 81)	26.37 ± 1.67	3.33 ± 0.29	0.33 ± 0.02	0.14 ± 0.02
Gill (n = 81)	18.12 ± 0.52	1.45 ± 0.09	0.27 ± 0.02	0.32 ± 0.03
Muscle (n = 81)	3.79 ± 0.57	0.34 ± 0.03	0.05 ± 0.01	0.05 ± 0.01

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found in the gills of the fishes might indicate that the lead concentration level could be high in the water of the fish habitat and it could originate from the medium-high level of lead contamination in the onshore areas of eastern Taiwan[(3)]. However, further work should be undertaken to verify the said two inferences. Muscle generally has the lowest metal concentration in fishes[(1, 15-17)], coinciding with our results.

III. *Metal Concentrations in Species*

The observed metal concentrations showed significant species differences in our study. The significant effects of the tissues and species interactions showed that the levels of the metal concentrations distributed in the four tissues were varied among the twenty species (Table 3). In muscle, the metal concentrations were markedly high in spottyback searobin *Pterygotrigla hemistica* (Table 4; Zn: 6.14 μg/g, Cu: 0.76 μg/g, Cd: 0.12 μg/g, Pb: 0.12 μg/g, wet weight). Concentrations of zinc, copper, cadmium and lead were also higher in small scale blackfish *Girella melanichthy* (Zn: 5.74 μg/g), Japanese hakeling *Physiculus japonicus* (Cu: 0.81 μg/g), crimson snapper *Pristipomoides filamentosus* (Cd: 0.11 μg/g, Pb: 0.14 μg/g). Whereas, silver-banded sweetlip *Plectorhinchus diagrammus* generally showed the lowest metal concentrations (Zn: 2.27 μg/g, Cu: 0.21 μg/g, Cd: 0.04 μg/g, Pb: 0.02 μg/g). In livers, the metal concentrations were markedly higher in soldierfish *Myripristis berndti* (Table 4; Zn: 68.93 μg/g, Cu: 12.36 μg/g, Cd: 1.16 μg/g, Pb: 1.09 μg/g). Concentrations of zinc, copper, cadmium and lead were also higher in whitespotted brotula *Neobythites sivicola* (Zn: 59.07 μg/g), bull-eye perch *Priacanthus macracanthus* (Cu: 9.60 μg/g), blanquillo *Branchiostegus japonica* (Cd: 1.11 μg/g), crimson snapper *P. filamentosus* (Pb: 0.74 μg/g). Whereas, Japanese hakeling *P. japonicus* generally showed the lowest metal concentrations (Zn: 21.67 μg/g, Cu: 3.78 μg/g, Cd: 0.11 μg/g, Pb: below the detection limit).

Metal accumulations in tissues are generally found to be species specific. The observed differences between the metal concentrations in fishes may be related to their feeding habits and the bio-concentration capacity of each species[(14)]. Maximum concentrations of the metals are found in bottom feeders as compared to plankton feeders and pelagic carnivores[(16)]. In the livers of the benthic fishes, higher levels of the metals, especially cadmium, are encountered as compared to that of the pelagic fish, though both their muscles show low levels of the metals[(17)].

Table 3. ANOVA table of zinc, copper, cadmium and lead concentrations at different fish tissues and different fish species

Source	D.F.	Zinc		Copper		Cadmium		Lead	
		MS	F	MS	F	MS	F	MS	F
Block (month of catch)	4	33.86	0.38	12.76	2.57[a]	0.649	4.94[c]	0.575	5.92[c]
Tissue (adjusted)	3	8594.56	95.68[c]	277.98	55.96[c]	7.334	55.85[c]	2.713	27.90[c]
Species (adjusted)	19	361.28	04.02[c]	7.92	1.60	0.438	3.34[c]	0.798	8.21[c]
Interaction (adjusted)	57	216.70	02.41[c]	8.90	1.79[b]	0.481	3.66[c]	0.243	2.49[c]

[a]Significant at $p \leq 0.05$; [b]significant at $p \leq 0.01$; [c]significant at $p \leq 0.001$; MS, means squares; D.F., degrees of freedom.

Table 4. Mean and standard error of zinc, copper, cadmium and lead concentrations in the muscles and livers of 20 common benthic fish species from the coastal waters of eastern Taiwan, 2002

Species	n	Heavy metal concentration in Muscle(μg/g wet wt)				Heavy metal concentration in Liver (μg/g wet wt)			
		Zinc	Copper	Cadmium	Lead	Zinc	Copper	Cadmium	Lead
Argyrops bleekeri	3	2.66 ± 0.08	0.23 ± 0.01	0.03 ± 0.00	0.03 ± 0.00	30.64 ± 1.04	2.84 ± 0.20	0.30 ± 0.03	0.05 ± 0.00
Branchiostegus japonica	6	2.95 ± 0.55	0.47 ± 0.19	0.07 ± 0.01	0.03 ± 0.01	21.65 ± 4.44	3.79 ± 1.51	1.11 ± 0.26	0.36 ± 0.11
Calotomus calolinus	2	2.54 ± 0.08	0.46 ± 0.04	0.05 ± 0.01	0.04 ± 0.02	16.93 ± 0.29	2.64 ± 0.18	0.13 ± 0.03	0.04 ± 0.00
Dentex tumifrons	12	2.97 ± 0.14	0.26 ± 0.17	0.06 ± 0.01	0.06 ± 0.02	40.07 ± 1.66	7.05 ± 0.86	0.68 ± 0.09	0.28 ± 0.07
Girella melanichthy	2	5.74 ± 1.46	0.50 ± 0.00	0.06 ± 0.00	0.02 ± 0.01	33.60 ± 13.48	1.40 ± 0.20	0.44 ± 0.11	0.03 ± 0.01
Gymnocranius griseus	3	2.38 ± 0.09	0.28 ± 0.04	0.05 ± 0.02	0.03 ± 0.01	22.13 ± 1.73	3.37 ± 0.08	0.53 ± 0.04	0.21 ± 0.08
Lethrinus mahsena	3	2.03 ± 0.06	0.24 ± 0.02	0.04 ± 0.00	0.08 ± 0.02	30.27 ± 3.74	6.20 ± 1.53	0.35 ± 0.06	0.39 ± 0.14
Lutjanus lutjanus	5	2.80 ± 0.10	0.30 ± 0.05	0.02 ± 0.01	D.L.	28.92 ± 1.81	4.81 ± 0.68	0.27 ± 0.10	0.05 ± 0.02
Myripristis berndti	3	2.23 ± 0.24	0.31 ± 0.03	0.08 ± 0.01	0.10 ± 0.02	68.93 ± 20.38	12.36 ± 5.55	1.16 ± 0.25	1.09 ± 0.26
Nemipterus bathybius	15	3.16 ± 0.15	0.25 ± 0.04	0.03 ± 0.01	0.03 ± 0.01	33.02 ± 2.55	6.07 ± 1.50	0.46 ± 0.07	0.14 ± 0.05
Neobythites sivicola	3	4.37 ± 0.11	0.44 ± 0.08	0.04 ± 0.02	D.L.	59.07 ± 13.54	4.64 ± 1.13	0.56 ± 0.13	D.L.
Paracaesio xanthururs	2	2.28 ± 0.09	0.31 ± 0.02	0.05 ± 0.00	0.02 ± 0.00	20.12 ± 5.31	4.36 ± 0.33	0.95 ± 0.05	0.08 ± 0.04
Parapristipoma trilineatum	2	2.36 ± 0.08	0.25 ± 0.01	0.06 ± 0.01	0.04 ± 0.01	27.76 ± 2.19	8.32 ± 1.93	0.40 ± 0.03	0.04 ± 0.00
Physiculus japonicus	2	2.51 ± 0.18	0.81 ± 0.35	0.06 ± 0.02	D.L.	21.67 ± 0.41	3.78 ± 0.31	0.11 ± 0.04	D.L.
Plectorhinchus diagrammus	2	2.27 ± 0.10	0.21 ± 0.02	0.04 ± 0.00	0.02 ± 0.01	36.76 ± 8.63	8.19 ± 0.78	0.66 ± 0.27	0.07 ± 0.05
Priacanthus hamrur	3	2.46 ± 0.09	0.15 ± 0.01	0.04 ± 0.01	D.L.	50.25 ± 16.88	4.22 ± 2.13	0.47 ± 0.00	0.03 ± 0.01
Priacanthus macracanthus	3	2.79 ± 0.57	0.33 ± 0.04	0.03 ± 0.01	0.02 ± 0.00	27.54 ± 2.17	9.60 ± 0.26	0.51 ± 0.06	0.04 ± 0.00
Pristipomoides filamentosus	3	2.40 ± 0.22	0.47 ± 0.02	0.11 ± 0.01	0.14 ± 0.01	30.04 ± 4.96	3.72 ± 0.27	0.24 ± 0.03	0.74 ± 0.21
Pterygotrigla hemistica	5	6.14 ± 1.73	0.76 ± 0.25	0.12 ± 0.02	0.15 ± 0.02	33.06 ± 3.25	4.35 ± 0.98	0.26 ± 0.08	0.23 ± 0.05
Scarus rubroviolaceus	2	2.45 ± 0.08	0.34 ± 0.02	0.05 ± 0.00	D.L.[a]	26.88 ± 3.18	4.99 ± 0.56	0.20 ± 0.04	D.L

[a]D.L., concentration below the detection limit.

IV. *Comparison of the Metal Levels in Fishes form Other Coastal Waters in Taiwan*

For evaluating the contamination and the heavy metals bio-accumulated in the fishes of the coastal waters of eastern Taiwan, the results in this study were compared with the heavy metal concentrations of the fishes from slightly polluted and polluted waters elsewhere in Taiwan. Table 5 indicates that the zinc and copper concentrations in muscles and livers of the fishes found in the coastal waters of eastern Taiwan were the same as or slightly lower than those of mildly polluted waters. Cadmium and lead concentrations in muscle were higher than and similar to those of the slightly polluted waters, respectively, but they were still lower than those of the polluted waters. However, cadmium and lead concentrations in livers were higher than and similar to those of the polluted waters, respectively. Cadmium concentrations in livers were higher in soldierfish *Myripristis berndti* and blanquillo *Branchiostegus japonica*, in which the levels could reach as high as 1.16 and 1.11 μg/g wet wt, respectively (Table 4); while in other species they were always below 0.95 μg/g wet wt. Lead concentrations in livers were higher in soldierfish *M. berndti* and crimson snapper *Pristipomoides filamentosus*, and could reach as high as 1.09 and 0.74 μg/g wet wt, respectively; whereas in other species they were all below 0.39 μg/g wet wt.

Generally speaking, the concentrations of zinc and copper in the edible muscle and livers of the 20 species in the coastal waters of eastern Taiwan were the same as or slightly lower than those of the mildly polluted waters, and they were far below the seafood safety standards (Table 6) set up for fisheries products in various countries. The concentrations of cadmium and lead in muscles were higher than those of the slightly polluted waters in Taiwan but they were still lower than those of the polluted regions in Taiwan. In livers they were similar to those of the polluted regions, while most of them were below the seafood safety standards recognized by most countries (Table 6).

V. *The Influence of the Metal Containments in Land Soil*

Some fishes were found to be high in concentrations of cadmium and lead in their livers in this study (Table 4). The medium levels of cadmium and lead containments were documented in the land soil of eastern Taiwan[(3)]. However, the relationship of the toxic elements between the fish and land soil is still unclear, and the high metal concentrations in some fish species could be due to species-specific capacity in metal accumulations, pending further investigation and verification in the future.

Table 5. Heavy metal concentrations (μg/g) in muscles and livers of the fishes from various coastal waters around Taiwan

Tissue	Area of Taiwan	Location	No. of fish species	PS	Zinc	Copper	Cadmium	Lead	Reference
Muscle	South-West	Chi-Ku Lagoon	23	S	2.3 ~ 13.7	0.11 ~ 0.81	< 0.004	–	(2)
		Ann-Ping coastal waters	9	S	4.6 ~ 7.3	0.20 ~ 0.45	< 0.0005	–	(2)
		Bu-Dai coastal waters	1	S	2.5 ~ 8.0	0.26 ~ 0.34	0.02	0.08 ~ 0.16	(23)
		Jiang-Jiun Estuary	33	S	0.26 ~ 11.8	0.05 ~ 4.90	< 0.05 ~ 1.23	< 0.1 ~ 2.69	(6)
		Kaohisung harbor	7	P	6.7 ~ 28.1	0.1 ~ 15.7	0.01 ~ 0.02	< 0.1 ~ 1.3	(7)
	North	Keeling harbor	5	P	8.0 ~ 14.9	< 0.01 ~ 0.98	< 0.004 ~ 0.08	< 0.02 ~ 0.12	(8)
	Central-West	Chang-Hua coastal waters	–	S	3.5 ~ 5.0	< 1.60	< 0.02	0.01 ~ 0.17	(24)
	East	Hualien and Taitung coastal waters	20	–	2.0 ~ 6.1	0.15 ~ 0.81	0.02 ~ 0.12	< 0.02 ~ 0.15	This study
Liver	South-West	Chi-Ku Lagoon	23	S	23.3 ~ 59.9	1.7 ~ 31.9	< 0.01 ~ 0.12	–	(2)
		Ann-Ping coastal waters	9	S	23.0 ~ 66.6	3.33 ~ 48.2	0.07 ~ 0.70	–	(2)
		Bu-Dai coastal waters	1	S	20.4 ~ 45.3	1.15 ~ 6.4	0.03 ~ 0.87	0.12 ~ 1.27	(23)
		Kaohisung harbor(Viscera)	7	P	14.2 ~ 124.1	< 0.2 ~ 7.3	0.02 ~ 0.09	< 0.1 ~ 4.2	(7)
	North	Keeling harbor(Viscera)	5	P	31.5 ~ 52.6	< 0.65 ~ 1.97	< 0.01 ~ 0.81	0.2 ~ 0.96	(8)
	East	Hualien and Taitung coastal waters	20	–	16.9 ~ 59.1	1.4 ~ 12.4	0.11 ~ 1.16	< 0.02 ~ 1.09	This study

Table 6. Seafood standards of heavy metal concentrations (μg/g wet weight) in various countries (modified from Chen[(2)])

Country	Standard[a]	Zinc	Copper	Cadmium	Lead
America	FDA	—	—	2.0[b]	—
America	NAS	—	—	0.5[b]	—
Australia	NHMRC	1000	30	2.0	5.5
Australia	TPHR	40	30	5.5	
Canada	—	—	100	—	2.0
Japan	—	—	—	1.0	
United Kingdom	MAFF	50	20	—	1.0
United Kingdom	FSC	50	—	—	—

[a]FDA = Food and Drug Administration, NAS = National Academy of Science, NHMRC = National Health Research Council, TPHR = Tasmania Public Health Regulation, MAFF = Ministry of Agriculture Fisheries and Food, FSC = Food Standards Committee.
[b]μg/g, dry weight.

VI. *Consumption Safety*

From a study of nutrition survey on residents in Taiwan, the average daily protein consumption is about 79 g, composed of roughly 50% plant protein and 50% animal protein, in 1993-1996[25]. Based on this study the estimated maximum amounts of the daily intake of zinc and copper from consumption of the fish from eastern Taiwan were 0.079~0.241 mg and 0.006~0.032 mg, respectively, assuming the fish muscle is consumed and it's the most dominant animal protein. The amounts of the essential metal zinc and copper were far below the acceptable daily intake (ADI) set by the USA[26] (ADI: Zn = 15 mg, Cu = 2~3 mg). Therefore, under normal consuming habits, the intake of zinc and copper from the 20 species of the coastal waters of eastern Taiwan are not harmful to human health. Cadmium and lead are elements toxic to human, but their concentrations in fish muscle in this study are far lower than the consumption safety tolerance set for seafood by most countries in the world (Table 6). The estimated daily intake (Cd: 1.6~9.6 μg, Pb: 1.6~11.9 μg) is also far lower than the acceptable daily intake set by WHO/FAO[27-28] (Provisional Tolerable Daily Intake, PTDI: Cd = 70 μg; Pb = 250 μg, for body weight of 70 kg). The cadmium and lead concentrations in livers of some fish species were close to the safety standard set by some countries and should be cautioned in the future. However, since muscle was the major consuming portion in fish, while livers were rarely consumed, there should not be any health threat to the public because of consumption of fish meat.

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