Metal Biological Enrichment Capacities, Distribution Patterns and Health Risk Implications in a Major Aquacultured Fish Species Worldwide

Yang-Guang Gu (hydrobio@163.com)
South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences https://orcid.org/0000-0003-2314-0463
Xu-Nuo Wang
South China Sea Fisheries Research Institute
Zeng-Huan Wang
South China Sea Fisheries Research Institute
Hong-Hui Huang
South China Sea Fisheries Research Institute
Xiu-Yu Gong
South China Sea Fisheries Research Institute

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Abstract

Seabass (*Lateolabrax japonicas*) is a major aquacultured fish species worldwide. The bioconcentration, bioaccumulation and biomagnification of metals present in water, sediments and commercial feed were investigated in *L. japonicas* from an aquaculture pond in the Pearl River Delta (south China). Aluminum (Al), chromium (Cr), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), and lead (Pb) were determined in the dorsal muscle, viscera, backbone, gill and stomach contents of *L. japonicas*. The gill and stomach contents were found to have higher levels of bioconcentration of most metals than other parts. Based on the bioaccumulation factor, the gill and backbone exhibited the highest accumulation of Zn, while the viscera had the highest capacity to accumulate Cu. The mean biomagnification factor values exceeded for As in dorsal muscle, for Cu in the viscera, for Cr and Pb in the gill, and for Al, Cr, Fe, Cu and Pb in the stomach contents, indicating efficient bioaccumulation from commercial feed and their habitat. Non-metric multidimensional scaling analysis revealed two groups that primarily resulted from the accumulation of metals in various parts of *L. japonicas*. Moreover, health risk assessment indicated that no notable adverse health effects are likely to occur from the ingestion of *L. japonicas* as an aquacultured food source.

1. Introduction

The Pearl River Delta (PRD), located in the southern part of China, is one of China's most important economically developed regions due to large-scale agricultural, commercial, and industrial development in the region over the last three decades (Cheng et al. 2013; Tong et al. 2018; Chen et al. 2019). However, the rapid rate of development in the PRD region has resulted in increasing levels of environmental pollution (Gu et al. 2014; Tong et al. 2018; Wang et al. 2019). In particular, widespread environmental contamination with heavy metals and petroleum hydrocarbons has occurred because of high levels of anthropogenic emissions (Cheng et al. 2013; Hu and Cheng 2013; Gu et al. 2014). In the PRD region, previous investigations by our institute have shown that the traditional method of filling fish ponds using river water is still adopted by most fish farmers. Metals may enter fishponds through various pathways, including atmospheric deposition, sewage discharge, agricultural, and industrial runoff (Cheng et al. 2013). In addition, commercial fish feed is a major source of some metals in aquaculture. When metals enter aquatic ecosystems, sediments serve as both a major heavy metal reservoir and a pollution source, releasing heavy metals back into the waterbody due to changes in environmental conditions, such as redox potential or pH (Gu et al. 2012; Cheng et al. 2013; Gu et al. 2020). If toxic metal accumulation in fish tissues exceeds the maximum permitted concentrations, the consumption of fish poses a human health risk.

In recent years, due to industrial and agricultural activities, the occurrence of metals has been reported in the aquatic environment in many countries worldwide, which has attracted particular concern due to their toxicity and potential for accumulation in aquatic organisms (Signa et al. 2017; Nasyitah Sobihah et al. 2018; Shilla et al. 2019). Biomagnification refers to an increased concentration of chemicals or pollutants in the tissues of organisms at successively higher levels in the food chain (Barwick and Maher 2003; Zhang and Wang 2012). Metal biomagnification in organs of living organisms may threaten their circulatory and central or peripheral nervous systems (Afonso et al. 2013; Rajeshkumar et al. 2018).

Fish serve as good bioindicators because they are typically able to bio-magnify metals in higher trophic levels (Signa et al. 2017; Łuczyńska et al. 2018; Rajeshkumar et al. 2018). Furthermore, fish are an important source of high-quality protein in the human diet worldwide (Kalantzi et al. 2013; Tlusty et al. 2019), resulting in the quality and safety of fish products being an important human health risk factor.

With increasing economic development and population growth worldwide, fish consumption has increased steadily, providing many essential nutrients to the human diet such as high-value proteins, vitamins and minerals and polyunsaturated omega-3 fatty acids (Bosch et al. 2016, Gu et al. 2018a). Aquaculture is considered as an important source for sustainable seafood supply (Cao et al. 2015; Gui et al. 2018). In order to meet the increasing demand for fish, the aquaculture industry has grown rapidly particularly over the last 20 years, with aquaculture production now exceeding that of wild capture (FAO 2018; Hannah and Max 2017).

China is the largest aquaculture producer and consumer globally (Cao et al. 2015) with pond aquaculture being the predominant practice, accounting for 71.7% of total freshwater aquaculture production in 2015 (Gui et al. 2018). At present, *L. japonicas* is one of the major aquaculture bred species worldwide (Wu et al. 2016; FAO, 2017; Gui et al. 2018). Aquacultured fish accumulate metals from both their diet and their habitat (Martins et al. 2011; Nasyitah Sobihah et al. 2018). However, no studies are conducted to study/explore the relationships between metal distribution patterns of an aquatic organism and their living environment; and few studies have focused on the biomagnification, enrichment capacities and distribution of metals in *L. japonicas* from aquaculture.

Thus, the major aims of this study were to: (1) investigate metal concentrations in various parts of *L. japonicas*; (2) explore the metal bioconcentration, bioaccumulation and biomagnification in pond-cultured *L. japonicas* from the PRD; (3) study the relationships between metal distribution patterns of *L. japonicas* and their living environment; (4) assess the potential health risks to Guangdong province residents, due to dietary intake of these products.

2. Materials And Methods

2.1 Sampling and analytical methods

The Doumen district of Zhuhai city in the PRD, is the largest *L. japonicas* aquaculture region in China (Fig. S1; Lin and Yang 2020). The study pond was located in the aquacultural regional cluster of the Doumen district, which is occupied by quaternary sedimentary rocks (Lin et al. 2019), indicating that this pond environment is representative of the aquacultural regional cluster. The water depth and pond area were 1.6m and 5,336 m^2, respectively. In March, 2018, sixty thousand fish (*L. japonicas*) were added to the pond, with an average total length of 3 cm and weight of 0.8 g. In September 2018, water and sediment samples were sampled from five points across the aquaculture pond during a research cruise, following a ‘zigzag’ route (Fig.S1) and commercial feed samples were also synchronously collected. The distances between the five sampling sites are indicated in Fig. S1. Furthermore, five water samples were mixed thoroughly to form a representative water sample; and five sediment samples were also well homogenized to form a representative sediment sample. Thirty-five *L. japonicas* individuals were collected from the five sampling locations in the pond using a cast net (Fig. S2 and Fig. 1). The collected fish were weighed and measured, with the total length and weight of fish ranging from 21.1 – 27.5 cm and 139 – 315 g, respectively. The seven fish collected at each site were dissected to obtain the dorsal muscles, viscera, backbones, gills, and stomach contents (Fig. 1).

Water chemical parameters such as temperature, salinity, dissolved oxygen (DO) and pH were determined *in-situ* using a portable YSI Professional Plus Multiparameter Instrument (YSI Inc./Xylem Inc., USA). The method used for metal analyses in water samples was in accordance with the method reported by Li et al. (2017). Briefly, water samples were immediately filtered through Whatman GF/F fiber filters 0.45 μm, then acidified with 10% nitric acid and kept on ice during transportation to the laboratory for storage at 4 °C prior instrumental analysis. Sediment, commercial feed and fish samples were lyophilized, ground and then passed through 150 μm nylon sieves for further extraction. The detailed procedures used for metal extraction from sediment, commercial feed (using sediment method) and fish samples have been described previously (Gu et al. 2015). The metal contents were measured by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7700 series) for Al, Cr, Mn, Fe, Ni, Cu, Zn, Cd, and Pb, whereas the concentrations of As were analyzed using an atomic fluorescence spectrometer (AFS, Bejing Titan 9230 series).

2.2 Quality assurance (QA) and quality control (QC)

QA and QC approaches were utilized rigorously in all analytical procedures involving the use of standard operating procedures, calibration by standards and analysis of reagent blanks (Chinese National Standard Offshore Marine Sediment material (GBW 07314) and Chinese National Standard scallop material (GBW10024)). The recovery of metals varied from 91–106% and the relative standard deviation (RSD) of all replicate samples was less than 10%, indicating that no contamination occurred during the analysis process.

2.3 Calculation models

2.3.1 Bioconcentration and bioaccumulation factors

The bioconcentration factor (BCF) and bioaccumulation factor (BAF) refer to the ratios of metal concentrations in aquatic organisms to their surrounding environment (water and sediments) (Jahan and Strezov 2019), which were calculated using Equations (1) and (2) as follows:

$$\mathrm{BCF} = \frac{C_{tissue}}{C_{water}} \quad (1)$$

$$\mathrm{BAF} = \frac{C_{tissue}}{C_{sediment}} \quad (2)$$

Where, C_{tissue} is the metal concentration in the specific part of the organism (mg/kg, dry weight); C_{water} is the metal concentration in water (mg/L); and $C_{sediment}$ is the metal concentration in sediments (mg/kg, dry weight).

2.3.2 Biomagnification factor

The biomagnification factor (BMF) was established to measure the efficiency of biomagnification of metals transferred from the diet to predators, which was calculated using Eq. (3) according to Arnot and Gobas (2006), as follow:

$$\mathrm{BMF} = \frac{C_{predator}}{C_{diet}} \quad (3)$$

Where $C_{predator}$ is metal concentration in predator and C_{diet} is metal concentration in commercial feed.

2.3.3 Health risk assessment

The human health risk via ingestion of fish is quantitatively evaluated in terms of non-carcinogenic effects based on the hazard ratio (HR) (Cheng et al. 2013). Higher HR values indicate a higher probability of experiencing long-term non-carcinogenic risks (Gu et al. 2017). An HR value exceeding 1 indicates that there is a potential risk to human health, while an HR value less than 1 suggests no risk of adverse health effects. Accordingly, the HR was calculated using Eq. (4) as follows:

$$HR = \frac{EF \times ED \times FIR \times C}{RfD \times BW \times AT} \qquad (4)$$

Where, EF is the exposure frequency (365 days/year); ED is the exposure duration (70 years); FIR is the food ingestion rate (5.17 g/day) of individuals in Guangdong province; C is the metal concentration (mg/kg wet weight); RfD is the oral reference dose (mg/kg/day); BW is the average body weight in China (58.1 kg); AT is the average exposure time (25,550 days) (Gu et al. 2017). According to USEPA (2018) and Gu et al. (2017), the RfD values (mg/kg/day) were 1000 for Al, 3 for Cr, 140 for Mn, 700 for Fe, 11 for Ni, 40 for Cu, 300 for Zn, 0.3 for As, 1 for Cd, and 20 for Pb.

Furthermore, exposure to two or more metals may cause additive and/or interactive effects. In order to assess the risk of mixtures of co-occurring metals, the total HR was established as the sum of individual metal HR values, as shown in Eq. (5) according to the method of Chen et al (2013):

$$\text{Total HR (THR)} = \text{HR (metal 1)} + \text{HR (metal 2)} + \ldots + \text{HR (metal } n\text{)} \qquad (5)$$

2.4 Data pretreatment and statistical analysis

For any metal with a content below the detection limit (DL), a content of 1/2 DL was applied as the actual concentration. Metal distribution patterns in various parts of *L. japonicas* were established using non-metric multidimensional scaling (NMS). NMS is a cogent to visualize the levels and patterns of metal distribution between different aquatic organisms (Gu et al. 2018b; Shilla et al. 2019). NMS analysis was undertaken using the vegan package in v R 3.5.0 software. All other statistics performed in this study were performed using IBM SPSS v 19.0 for Windows.

3. Results And Discussion

3.1 Water chemical parameters and metal concentrations in water, sediments and commercial feed

The water temperature, salinity, dissolved oxygen (DO) and pH and were 31.1°C, 1.78‰, 6.1 mg/L, and 7.81, respectively. The metal concentrations (mg/L) in water samples were 1.37E-01 Al, 1.75E-03 Cr, 1.95E-02 Mn, 5.55E-02 Fe, 1.97E-03 Ni, 6.47E-02 Cu, 3.46E-01 Zn, 9.57E-01 As, 5.48E-02 Cd, and 4.73E-04 Pb. The metal concentrations (mg/kg) in sediments were 35320.22 Al, 56.04 Cr, 913.32 Mn, 39612.72 Fe, 34.85 Ni, 62.82 Cu, 128.88 Zn, 13.21 As, 0.54 Cd, and 40.25 Pb. The metal concentrations (mg/kg) in commercial feed were 239.71 Al, 1.77 Cr, 43.12 Mn, 547.51 Fe, 2.32 Ni, 16.62 Cu, 139.82 Zn, 1.49 As, 0.28 Cd, and 0.40 Pb, respectively.

Based on Chinese national water quality standard for fisheries (GB11607-89), the maximum allowable concentrations (mg/L) of metals in water are 0.05 Cd, 0.05 Pb, 0.1 Cr, 0.01 Cu, 0.1 Zn, and 0.05 Ni, respectively. According to the Chinese agricultural soil environmental quality criteria (GB 15618 – 1995), the maximum permitted concentrations (mg/kg) of metals in soils (sediments) are 1.5 Cd, 30 As, 400 Cu, 500 Pb, 400 Cr, 500 Zn, and 200 Ni.

3.2 Metal concentrations in L. japonicas

The basic descriptive statistics of ten metals in different parts of *L. japonicas* are presented in Table 1. The metal concentrations (mg/kg) exhibited wide variations: 8.24–395.29 Al, < 0.09–8.04 Cr, < 0.007–31.47 Mn, 11.49–909.26 Fe, < 0.127–4.18 Ni, 0.74–111.53 Cu, 10.38–315.14 Zn, 0.66–4.46 As, 0.010–0.170 Cd, 0.06–1.54 Pb. The mean concentration patterns in different parts of *L. japonicas* were as follows: in dorsal muscles, Fe > Zn > Al > As > Cu > Mn > Cr > Ni > Pb > Cd; in viscera, Fe > Al > Zn > Cu > Mn > As > Cr > Ni > Pb > Cd ; in backbones, Zn > Fe > Al > Cu > Mn > As > Cr > Ni > Pb > Cd; in gills, Zn > Fe > Al > Cu > Mn > Cr > Ni > As > Pb > Cd ; and in stomach contents, Fe > Al > Zn > Mn > Cu > Cr > Ni > As > Pb > Cd. The maximum allowable concentrations of Pb, Cd and As in fish according to Chinese national standards (GB 2762 – 2012) are 0.5 mg/kg, 0.1 mg/kg, and 0.1 mg/kg, respectively. The Food and agriculture organization (FAO) allows maximum concentrations of 0.5 mg/kg Cd, 0.5 mg/kg Pb, 30 mg/kg Cu, and 30 mg/kg Zn (FAO, 1983). Accordingly, Fe, Zn and Al were the predominant metals found in all parts of *L. japonicas*, whereas Cd was found in negligible concentrations. This suggests that *L. japonicas* could be utilized as a potential bio-indicator species to monitor Fe, Zn and Al pollution in aquaculture areas, which is supported by previous studies which have shown that marine fish can accumulate high concentrations of Fe, Zn and Al in their tissues (Yılmaz et al. 2010; Subotić et al. 2013; Chua et al. 2018; Nasyitah Sobihah et al. 2018).

A comparison of ten metals in different parts of *L. japonicas* is illustrated in Fig. 2. Although heavy metal concentrations varied in different parts of *L. japonicas*, significantly higher Al, Mn, Fe, Ni and concentration were found in the stomach contents, Cu and As were significantly increased in the viscera and dorsal muscles, respectively, while Zn and Pb concentrations were significantly higher in the gills. In different wild marine fish species, previous studies have suggested that concentrations of Cd, Pb, Cr, Ni, and Cu were higher in the stomach contents than in the muscles, the backbones and the gills, while Zn concentrations were higher in the gills than in the stomach contents, muscles and backbones (Gu et al. 2017).

Table 1
Metal concentrations in various parts of *Lateolabrax japonicas* (mg/kg, dry weight).

Tissue	Value	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb
Dorsal muscle	Mean	23.67	0.55	1.43	49.09	0.34	1.66	32.21	2.74	0.016	0.33
	SD	11.52	0.65	0.86	37.87	0.28	0.57	8.69	0.85	0.010	0.28
	Min.	8.24	< 0.09	< 0.007	11.49	< 0.127	1.07	22.59	1.70	0.010	0.14
	Max.	44.39	1.52	2.48	119.52	0.69	2.51	48.97	4.46	0.030	0.95
Viscera	Mean	70.44	0.17	5.29	73.44	0.15	27.02	31.93	1.22	0.043	0.13
	SD	67.61	0.31	11.57	93.75	0.23	38.01	43.37	0.61	0.052	0.05
	Min.	17.93	< 0.09	< 0.007	16.52	< 0.127	4.58	10.38	0.66	0.010	0.06
	Max.	212.23	0.87	31.47	282.93	0.67	111.53	129.90	2.10	0.160	0.22
Backbone	Mean	15.08	1.19	2.04	33.47	0.55	2.09	133.94	1.33	0.017	0.21
	SD	4.32	1.61	0.48	13.98	0.66	0.95	33.46	0.56	0.005	0.08
	Min.	11.58	< 0.09	1.47	19.00	< 0.127	0.74	98.20	0.98	0.010	0.10
	Max.	21.79	4.13	3.03	57.00	1.60	3.18	194.16	2.59	0.020	0.32
Gill	Mean	53.62	2.30	4.62	156.56	1.32	6.67	178.07	1.05	0.036	0.71
	SD	31.24	3.51	1.48	67.88	1.80	3.57	62.77	0.45	0.011	0.47
	Min.	29.26	< 0.09	2.66	81.30	< 0.127	3.73	127.78	0.76	0.030	0.20
	Max.	118.79	7.41	7.13	280.46	4.18	12.47	315.14	2.05	0.060	1.54
Stomach content	Mean	330.17	3.56	19.05	850.89	1.90	17.72	91.39	0.99	0.132	0.60
	SD	49.44	2.55	4.54	43.93	0.97	1.67	14.44	0.22	0.036	0.25
	Min.	277.05	1.95	11.71	806.45	1.08	15.73	68.77	0.85	0.080	0.39
	Max.	395.29	8.04	22.58	909.26	3.50	19.42	106.03	1.39	0.170	0.95

3.3 Biological enrichment capacities

3.3.1 Bioconcentration and bioaccumulation factors

Metal concentrations in the water and sediment samples were established to estimate the bioconcentration and bioaccumulation of metals, respectively, in *L. japonicas*. The metal bioconcentration factor (BCF) and bioaccumulation factor (BAF) in the parts of *L. japonicas* are shown in Figs.S3 and S4 and Tables S1 and S2.

Based on the BCF results, the gill and stomach content had the highest capacity for metal bioconcentration among all parts investigated (Table S1 and Fig.S3). The stomach contents, gills, viscera and dorsal muscles had the highest capacity to accumulate Fe, while the backbones had the highest Cr enrichment capacity. The highest BCF values of Fe (15343.88 ± 792.12), Al (2410.03 ± 360.85), Cr (2034.06 ± 1457.60) and Mn (978.77 ± 233.08) were found in the stomach contents, which also exhibited the highest capacity to bioaccumulate Ni (961.48 ± 493.23) and Cd (2.39 ± 0.66). The highest BCF values of Pb (1502.81 ± 1001.52) and Zn (514.63 ± 181.43) were detected in gills, while those of As (2.86 ± 0.89) and Cu (417.51 ± 587.33) were found in the dorsal muscles and viscera, respectively.

A considerable level of transfer of these metals from sediments to fish, is likely to contribute to an increase in fish stress (Cheng et al. 2013; Voigt et al. 2015). BAF is an important index to assess the accumulation characteristics of environmental pollutants (Arnot and Gobas 2006; Cheng et al. 2013). The trend in metal BAF values in the dorsal muscles was Zn > As > Cu > Cr > Ni > Pb > Mn > Fe > Al > Cd, in the viscera was Cu > Zn > As > Mn > Ni > Pb > Cr > Al > Fe > Cd, in the backbones was Zn > As > Cu > Cr > Ni > Pb > Mn > Fe > Al > Cd, in the gills was Zn > Cu > As > Cr > Ni > Pb > Mn > Fe > Al > Cd, and in the stomach contents was Zn > Cu > As > Cr > Ni > Fe > Mn > Pb > Al > Cd (Table S2). The gills and backbones exhibited the highest BAF capacity for Zn, while for the viscera the highest BAF was for Cu (Fig.S4).

Studies based on estimated BCF and BAF values in *L. japonicas*, have shown that different tissue types exposed to metals exhibit different BCF and BAF responses. It has been proven that environmental parameters can influence the accumulation and concentration of metals in different tissues and parts of aquatic organisms, with the concentration of metal exposure through water and sediments thought to be the most important (Cheng et al. 2013; ; Łuczyńska et al. 2018; Jahan and Strezov 2019). Meanwhile, other factor can also influence the accumulation of metals including the mobility, activity and degree of bioavailability of metals, as well as seasonal variations, competition with other metals, and anion bonds, and biotic parameters (Martins et al. 2011; Wei et al. 2014; Voigt et al. 2015; Łuczyńska et al. 2018; Nasyitah Sobihah et al. 2018).

3.3.2 Biomagnification factor

The BMF values in various parts of *L. japonicas* are presented in Fig. 3 and Table S3. The mean BMF values for As in dorsal muscles, Cu in viscera, Cr, Pb and Pb in the gills, and Al, Cr, Fe, Cu and Pb in the stomach contents varied from 1.07 (stomach contents) to 2.01 (stomach contents), exhibiting a clear tendency for efficient bioaccumulation from commercial feed (BMF > 1), while no biomagnification was detected in the remaining metals in the dorsal muscles, viscera, backbones, gills, or the stomach contents.

It has been established, that the gill and stomach are the two main two pathways for metals to enter fish bodies (Liang et al. 1999; Kalantzi et al. 2013Fonseca et al. 2017;). Interestingly, it was observed that different the metals were biomagnified by dorsal muscles, compared to the stomach and gills. Fish muscle tissues are closely associated with human consumption and health. Therefore, biomagnification in the muscles of fish in aquatic systems, particularly in aquaculture, are of critical importance.

3.4 Metal distribution patterns and potential sources

Nonmetric multidimensional scaling (NMS) was used to identify groups of metal accumulation for *L. japonicas* tissues and parts, with two groups found to represent 95.83% of the total variance (Fig. 4A). In addition, stress was implemented to examine the validity of the NMS before interpreting the results, with a stress value of 0.02, established, indicating an excellent dimensionality reduction (Lattin et al. 2003). Based on Table 2, the first axis (NMS1) was associated with Al, Mn, Fe, Cu, and Cd accumulation in the stomach contents, viscera and dorsal muscles. NMS2 was associated with Cd, Ni, Pb, Zn and As accumulation in the gill, backbone, and dorsal muscles. Furthermore, Zn was found to be more easily accumulated by the backbone, Cr and Ni by the gill, while Al was more readily enriched by the viscera. NMS1 was also associated with sediments and commercial feed indicating this is the source of accumulation, while NMS2 was associated with water as the source (Fig. 4B).

Gills are the main pathway of metal ion exchange from water as they have large surface areas that facilitate the rapid diffusion of metals (El-Moselhy et al. 2014). These results imply that the content of Cd, Ni, Pb, Zn and As in dorsal muscles, the backbone and gills of *L. japonicas* were based on the gill pathway of metal ion exchange from water. In contrast, the Al, Mn, Fe, Cu, and Cd content in dorsal muscles, viscera and stomach contents depended on uptake from commercial feed and sediments.

3.5 Human health risk from consuming fish muscle tissues

The evaluated HR values and THR values are shown in Fig. 5, with the average HR values established as 5.63E-04 ± 2.69E-04 for Al, 4.08E-03 ± 4.79E-03 for Cr, 2.38E-04 ± 1.32E-04 for Mn, 1.55E-03 ± 1.10E-03 for Fe, 6.87E-04 ± 5.44E-04 for Ni, 9.74E-04 ± 3.08E-04 for Cu, 2.53E-03 ± 6.67E-04 for Zn, 2.21E-01 ± 8.40E-02 for As, 3.65E-04 ± 2.01E-04 for Cd, and 3.86E-04 ± 3.07E-04 for Pb. The average THR values were 2.32E-01 ± 8.62E-02. Both the values of HR and THR were significantly less than 1, indicating that metal concentrations in the muscles of *L. japonicas* present no notable risk to health for consumers of fish in Guangdong province.

4. Conclusions

To establish the biological enrichment capacities and distribution patterns of metals in sea bass (*Lateolabrax japonicas*), metal concentrations were investigated in water, sediments, commercial feed and different parts of *L. japonicas* collected from an aquaculture pond in the Pearl River Delta. Results showed that Fe, Zn and Al were the predominant metals found in various parts of *L. japonicas*. The highest BCF values were for Fe, Al, Cr and Mn, which were all detected in the stomach contents, while the gill and backbone exhibited the highest BAF for Zn and the viscera presented the highest BAF for Cu. NMS analysis established two accumulation groups for the metals in various parts of *L. japonicas*. THR values of dorsal muscles were lower than 1, indicating that the ingestion of *L. japonicas* tissues presents no health risk for the inhabitants in Guangdong province.

Declarations

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Ethical Approval

The manuscript was established, according to guidelines of the Committee on Publication Ethics (COPE) and the experimental protocol was approved by the Human Ethics Committee of South China Sea Fisheries Research Institute.

Consent to Participate

Written informed consent was obtained from individual or guardian participants.

Consent to Publish

Not applicable.

Authors Contributions

The corresponding author contributed to the study conception and design. Material preparation, data collection and analysis were performed by Yang-Guang Gu, Xu-Nuo Wang, Zeng-Huan Wang, Hong-Hui Huang and Xiu-Yu Gong. The first draft of the manuscript was written by Yang-Guang Gu and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Competing Interests

The authors declare that they have no competing interests.

Data availability

All data generated or analyzed during this study are included in this published article.

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Figures

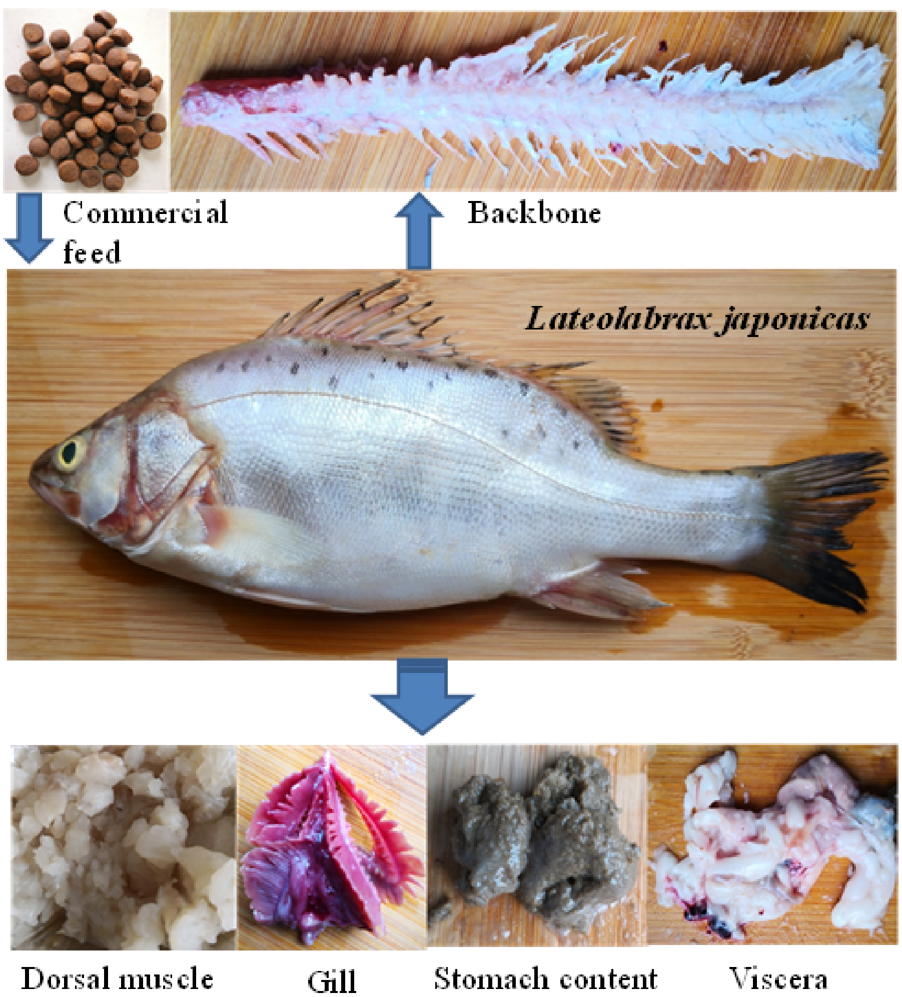

Figure 1

The model species, sea bass Lateolabrax japonicas and the various parts assessed for metal content, as well as the commercial feed utilized in this study.

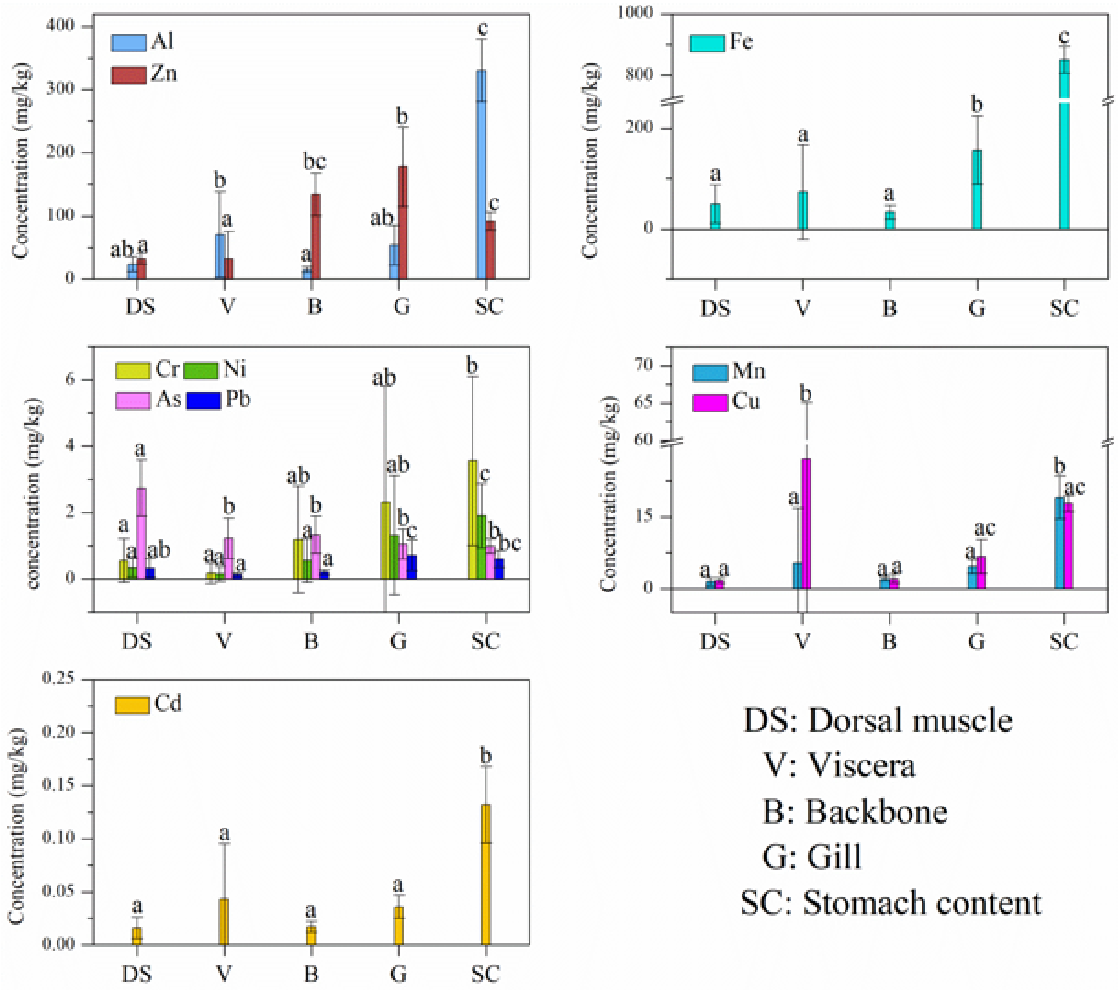

Figure 2

Distribution of metals in various parts of Lateolabrax japonicas. Within each graph, means with the same letter in the same location are not significantly different based on Duncan’s Multiple Range Test ($p < 0.05$).

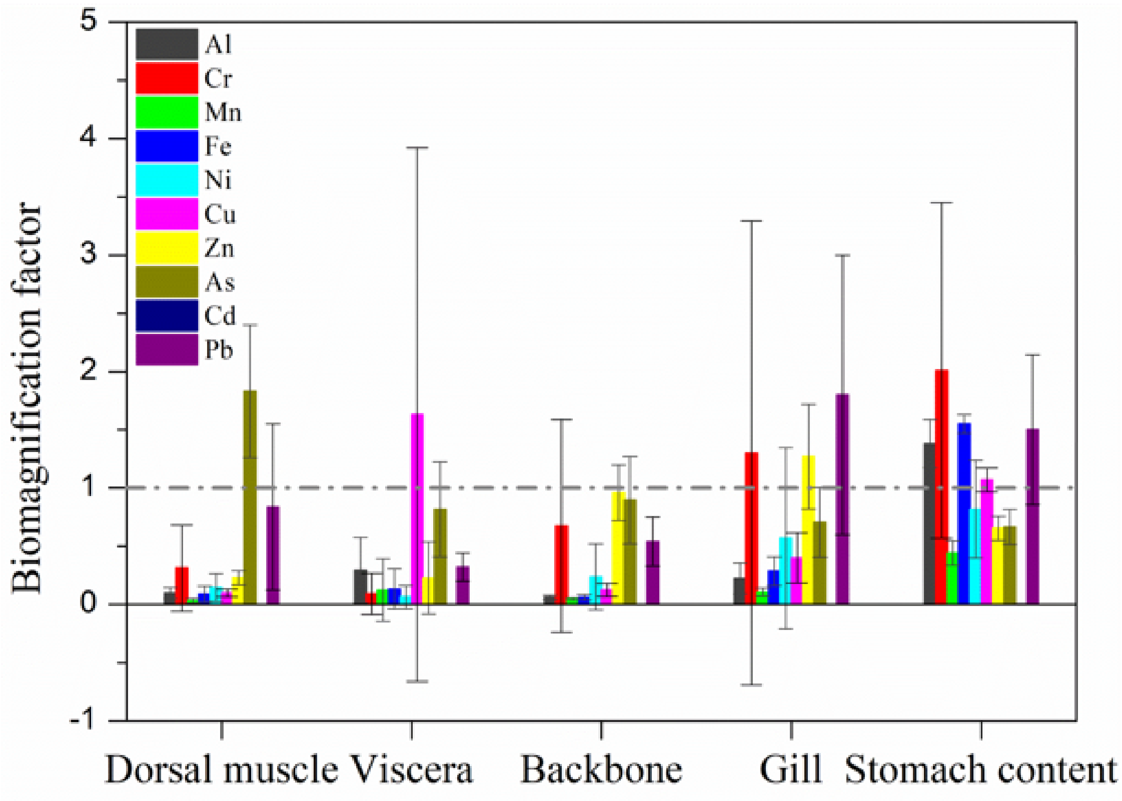

Figure 3

Distribution of metal biomagnification factor (BMF) values in different parts of Lateolabrax japonicas.

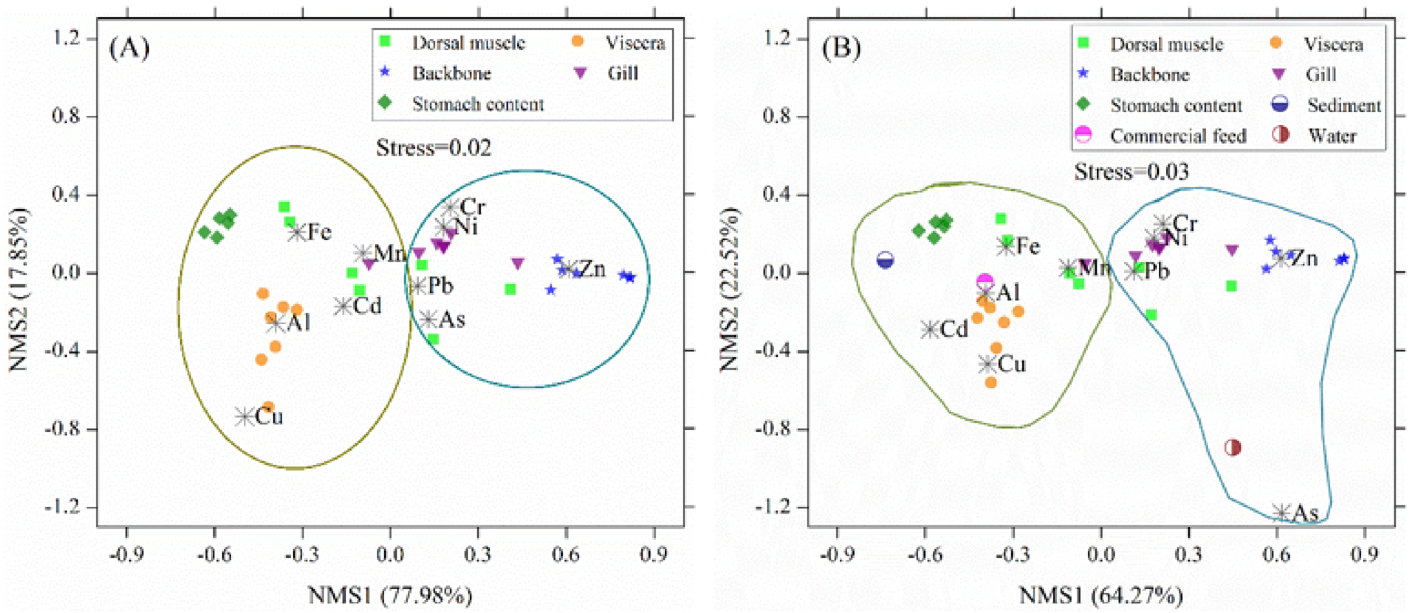

Figure 4

Nonmetric multidimensional scaling ordinance of (A) metals in various parts of Lateolabrax japonicas and (B) metals among various parts of Lateolabrax japonicas, sediments, water and commercial feed.

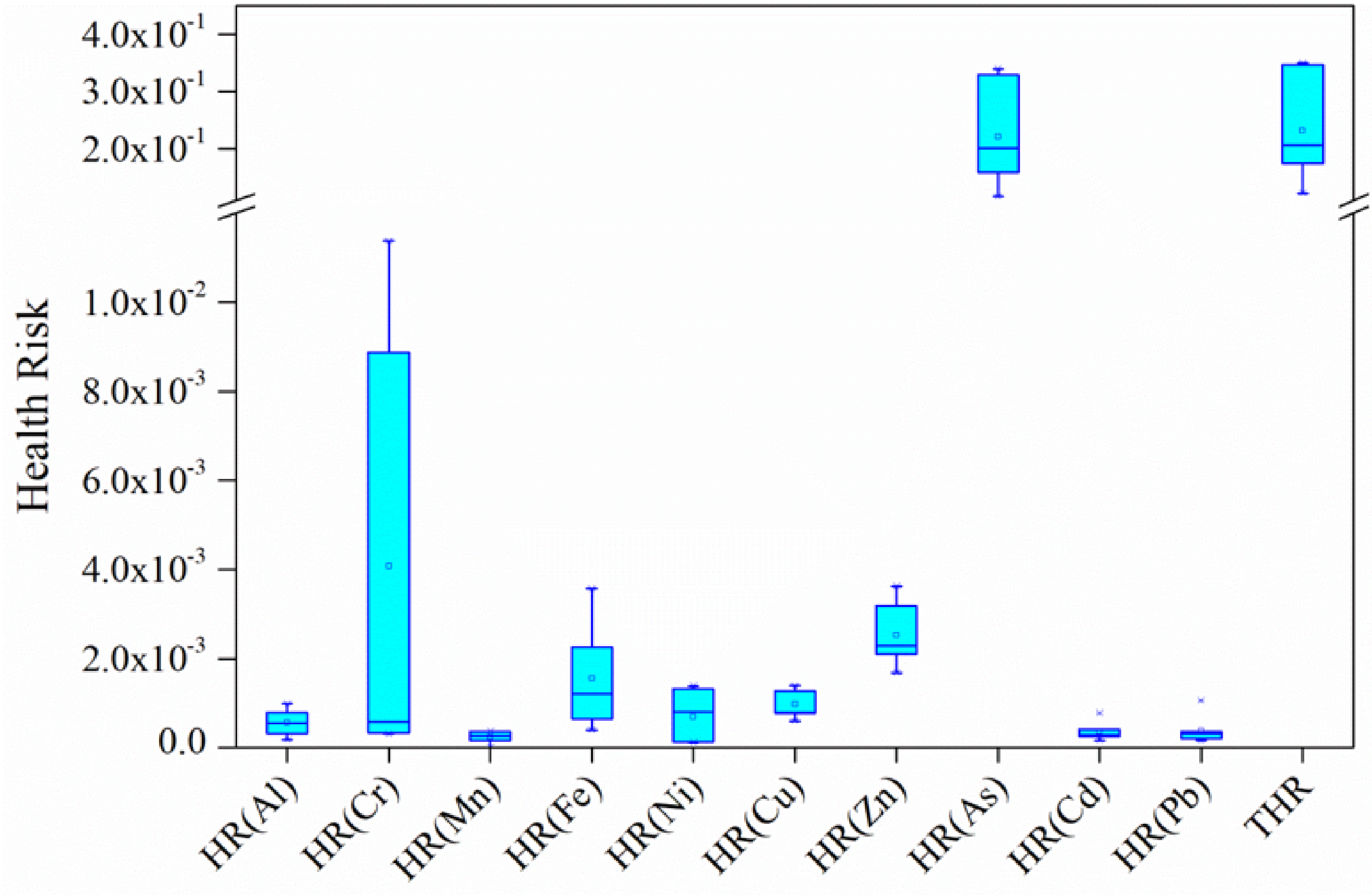

Figure 5

The hazard ratio (HR) and total HR (THR) established for the consumption of Lateolabrax japonicas.

Supplementary Files

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