HEAVY METAL CONTENT AND HEALTH RISK ASSESSMENT OF FISH IN 4 RESERVOIRS OF DALIAN

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Abstract. Reservoir is an important water source for residents, and heavy metal pollution as a common pollution factor has also attracted much attention. In the three seasons of spring (March), summer (August), and autumn (October) in 2018, 2019 and 2020, the fish resources in 4 reservoirs (Zhuanjiaolou Reservoir, Yingnahe Reservoir, Zhuweizi Reservoir, and Songshu Reservoir) were investigated, the species composition, distribution characteristics and growth of the catch were analyzed, and the inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the heavy metals (Cr, Cd, Pb, Hg, As) content. The results of the study showed that a total of 758 fishes were collected, belonging to 4 orders, 16 families and 24 genera. The fish importance index(IRI) analysis results showed that the main dominant species in Zhuanjiaolou Reservoir are *Carassius auratus*, *Cyprinus carpio*, *Zacco platypus*, *Rhodeinae*, *Pelteobagrus fulvidraco*. The main dominant species in Yingnahe Reservoir are *Cyprinus carpio*, *Carassius auratus*, *Pelteobagrus fulvidraco*, *Silurus asotus*, *Hemiculter leucisculus*,*Opsariichthys bidens*, *Rhodeinae*, *Culter alburnrs* and *Acheilognathus maCropterus*. The main dominant species in Zhuweizi Reservoir are *Cyprinus carpio*, *Carassius auratus*, *Rhodeinae*, *Zacco platypus*, *Hemiculter leucisculus*, *Acheilognathus maCropterus* and *Opsariichthys bidens*. The main dominant species of Songshu Reservoir are *Hypophthalmichthys molitrix*, *Opsariichthys bidens*, *Pelteobagrus fulvidraco*, *Acheilognathus maCropterus*, *Culter alburnrs* and *Carassius auratus*. The tissues of various dominant fish species have been contaminated by heavy metals. The pollution value of As in Zhuweizi Reservoir is the highest (1.836 mg/kg), but it does not exceed the standard value. The comprehensive pollution indexes of the 4 reservoirs were 1.266, 1.712, 1.536, 1.003 and 1.976, respectively. The exposure risk assessment results showed that *Pelteobagrus fulvidraco* had the highest Cr exposure coefficient, and other species were of lower risks.
Keywords: *Dalian, reservoir, fish, heavy metals, health risk assessment*

Introduction

Reservoir is an important water source for residents, and the artificial adjustment upon it makes it significantly different from natural water bodies in terms of hydraulic retention time and pollutant dilution and diffusion capacity. Heavy metal pollutants will be deposited in large quantities in the reservoir area as the water flow slows down, posing a threat to the safety of aquatic ecosystems. Fish as higher consumers in the reservoir ecosystem, has a close interaction relationship with the environment (Kominkova et al., 2007; Lü et al., 2011; Chang et al., 2021). After the water body is seriously polluted by heavy metals, the accumulation and enrichment of heavy metals exceeds the fish’s bearing capacity, thus bringing toxic hazards (Yu et al., 2013) to it reproducing (Wang et

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al., 2019), development (Shi et al., 2019), growth (Da Silva Cardoso et al., 2021) and physiological function (Niu et al., 2015), etc.

The rapid development of China's social economy has accelerated the progress of industrialization and urbanization. The discharge of pollutants accumulates every day, leading to a large amount of heavy metals in surface water bodies, such as reservoirs and rivers. The environmental problem of heavy metal pollution is becoming more and more serious (Xiao et al., 2019). With the improvement of living standards, people have higher requirements for food safety. However, when the living environment such as water bodies and bottom mud are polluted by heavy metals, fish exposed to the environment will accumulate heavy metals through feeding or breathing during the growth process, and those heavy metals cannot be discharged (Yao et al., 2014). When human consume contaminated fish, the heavy metals in it accumulate and are enriched in human body, causing corresponding damage to health (Ma et al., 2018), forming chronic poisoning (Monroy et al., 2014; Chen et al., 2019; Zeng et al., 2021), and it is not easy to be excreted (Lu et al., 1995; Tu et al., 2017).

Once heavy metals enter the human body through human breathing, daily diet and direct contact, the normal functions of the body will be greatly damaged. The heavy metals in the liver cannot be excreted from the body, and they are easily retained in the brain, kidneys and other organs. When their content exceeds the standard, they can easily cause gene mutations, endanger cell inheritance, and even lead to teratogenesis and cancer (Jian et al., 2015). With the development of urbanization and the extremely rapid improvement of living standards, water has been polluted by the increased human activities of mining, smelting, processing, etc. As the result, heavy metals such as Pb, Hg, and Cd enter the environment, causing serious pollution. And once that happens, they stay and further cause harm. For example, heavy metals can be concentrated in algae and bottom sludge even if there was little of them in discharged wastewater. Fish and other lives absorb and condense them in the food chain, which leads to risks (Ma al., 2014).

Chu et al. (2021) took *Carassius auratus* and *Pseudorasbora parva* as the research objects, which are common *Carassius auratusin* two lakes of Dajiu Lake, Shennongjia, Hubei Province. The contents of 7 heavy metals, Cu, Cd, Cr, Pb, As and Hg, were detected and analyzed. The results showed that the content of Zn, Cd, Cr, and Hg in the muscle of *Pseudorasbora parva* was significantly higher than that in the muscle of *Carassius auratus*. Liu et al. (2018) analyzed and concluded that the average content of heavy metals in the fish from Songhua River ranks as: Zn>Pb>Cr>Cu>Cd; Cd and Cr are enriched in carnivorous fish, and Pb pollution is the most serious; (Li et al., 2019) found that the Cd and Cr content of most fish samples in the collected areas exceeded the standard, and the heavy metal pollution of fish collected in some locations has caused a great health risk to human, thus it was recommended to reduce the consumption of fish from those areas; Lin et al. (2018) found through experimental testing that muscle tissue is the least affected part of a fish, and the safe concentration of fish contaminated by heavy metals for Cu, Zn, Cd and Cr are 0.009 mg/kg, 0.59 mg/kg, 24.41 mg/kg and 2.23 mg/kg, respectively. Zhang et al. (2017) discovered the phenomenon that heavy metals reach the fish body through the gills, the digestive tract, and the absorption through the body surface. In water bodies, heavy metal becomes harmful to fish once a certain amount is reached, and it also has an impact on fish respiration. Wu et al. (1999) conducted a difference test on *Branchiostoma* with different doses of heavy metals and found that low concentrations of heavy metals can accelerate the growth of *Branchiostoma*, while death will occur when the concentration is higher than a certain level.

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Alidadi et al. (2019) collected 140 water samples from the treated drinking water in Masad City, Iran, and conducted chemical analysis and tests on them with three methods including hazard quotient (HQ), hazard index (HI) and carcinogenic risk (Cr). The results showed that the value of heavy metals is below the safety level for adults, but for children, HI is relatively high, which may cause cancer through ingestion and skin routes. Okogwu et al. (2019) conducted heavy metal pollution investigation and risk exposure assessment on four important fishes and water bodies in Nigeria's trans-river ecosystem, and found that the heavy metal content in the water exceeded the allowable limit. Except Pb, the values of the other four heavy metals (Fe, Mn, Hg, Cr) were all lower than the allowable intake value. Although the risk factor is lower than 1, the total risk factor and carcinogenic risk of all fishes were higher than acceptable, which should be paid more attention to. Kaus et al. (2017) investigated the exposure of fish to heavy metals in the Hara River Basin in Mongolia. Ever since the beginning, gold mining in the Hara River Basin of Mongolia has been identified as the main cause of heavy metal pollution, where heavy metal pollutants such as Cr, Zn, As, Cd, Hg, Cu, Ni and Pb are found with enrichment potential. The results showed that the amount of As and Hg in the tributaries exceeded the national allowable limits for drinking water. The heavy metals Cr, As, Hg, and Pb were of high content in the muscles of fishes collected in the middle and lower reaches, while Zn was high in that of fishes from upstream tributaries. The accumulation of Cr, Cu, Hg and Pb will increase with the higher level in food chain. Among the heavy metals, the enrichment of Hg poses the greatest threat to human health. In the study, 10.7% of fish samples exceeded the internationally recommended Hg level for consumption, which may cause chronic heavy metal poisoning.

The health risk assessment was carried out by detecting the heavy metal content of fish in 4 reservoirs of Dalian. At the same time, the composition of the catch was investigated. So far, there has not been a comprehensive and systematic survey of fish resources in the 4 reservoirs. This study plays an important role in the protection of ecological environment and the effective preservation of fish resources. It provides scientific basis to better help the residents of Dalian to understand the pollution of heavy metals in the reservoir water.

Materials and Methods

Overview of the research locations

The 4 reservoirs in Dalian (Zhuanjiaolou Reservoir, Zhuweizi Reservoir, Yingnahe Reservoir and Songshu Reservoir) are rich in biological species, and fish resources there are particularly important. The following 23 locations (*Figure 1*) were chosen for fish sample collection in three seasons (spring in March, summer in August, autumn in October) between 2018-2020. See *Table 1* for latitude and longitude (*Table 1*).

The Yingnahe Reservoir is located on the main stream of the Yingna River, with a drainage area of 1004 km^2 and a total storage capacity of 287 million m^3. It is a big Type II reservoir mainly for Dalian's urban water supply, and flood control, agricultural irrigation, and freshwater aquaculture on the side (Shan et al., 2014).

The Zhuanjiaolou Reservoir is located on the west tributary of the Huli River in Zhuanghe City, with a total storage capacity of 140 million m^3. Its control basin covers an area of about 146 km^2 and integrates multiple functions such as irrigation, water supply, flood control, and fish farming (Zhao et al., 2009). The water area is about

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15.48 km^2, which can provide daily water supply for several thousand hectares of paddy fields in four nearby towns.

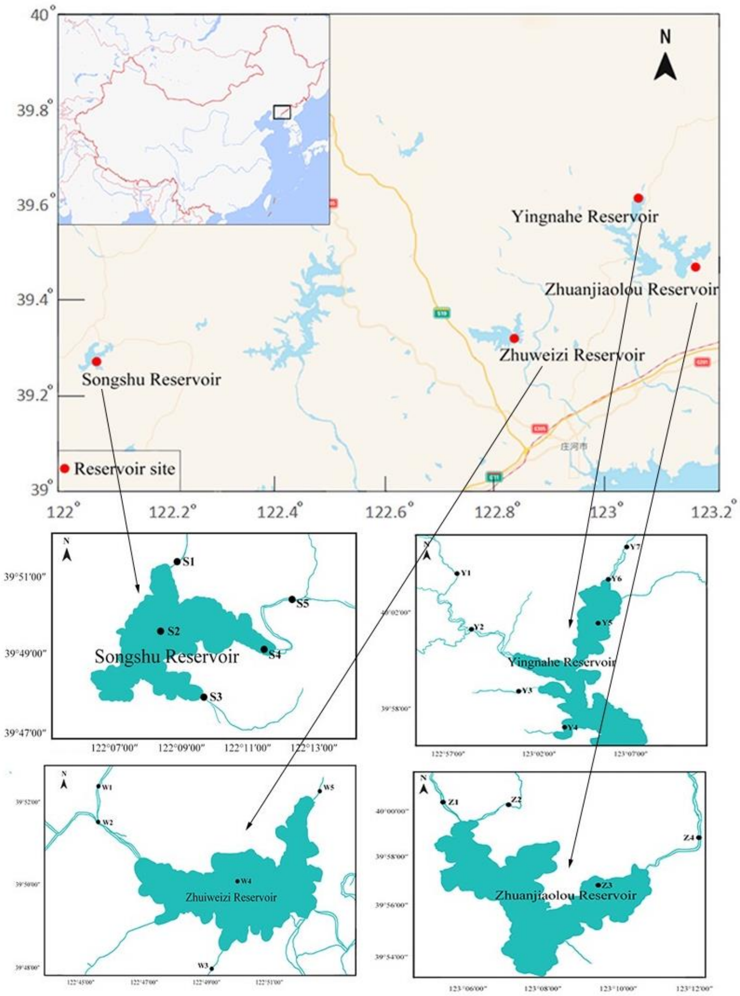

Figure 1. *Distribution map of sampling points in the study area*

Zhuweizi Reservoir is located on the west tributary of Taipingling Township, Zhuanghe City, with approximately 9,300 hectares of irrigated area and approximately 9,420 hectares of fish farming area. It is a large-scale reservoir that focuses on flood control and urban water supply (Liu et al., 2017), and takes into account the comprehensive utilization of irrigation, fish farming, and power generation. It is the only reservoir that's both the water source for the Zhuanghe Power Plant in Zhuanghe City and also a backup water source for Dalian City (Yang et al., 2018).

The Songshu Reservoir is located in the Fuzhou River Basin in Songshu Town, Wafangdian City. It is a big type II reservoir that's response of flood control, irrigation, and urban water supply, as well as fish farming and power generation. The water area is about 302.4 km^2, the total storage capacity is about 186 million m^3, the irrigation area is about 1.08 million hectares, and fish farming area is about 460 hectares. There are many ports in the reservoir area, and the flow is long and narrow, winding 5 km from east to west (Lin et al., 2018).

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Table 1. *The sampling stations and coordinates four reservoirs in Dalian area*

Sampling sites	Latitude (N)	Longitude (E)
Z1	40°0′1.2″	123°6′54.7″
Z2	40°0′7.9″	123°7′55.2″
Z3	39°56′19.9″	123°8′54.7″
Z4	39°58′50.6″	123°12′2.18″
Y1	40°2′20.9″	122°57′4.9″
Y2	40°0′28.9″	122°55′2.6″
Y3	39°58′48.6″	123°1′54.9″
Y4	39°57′14.2″	123°3′23.3″
Y5	40°0′52.9″	123°4′0.9″
Y6	40°3′2.9″	123°4′56.6″
Y7	40°4′36.4″	123°5′38.6″
W1	39°52′58.0″	122°45′33.8″
W2	39°52′43.4″	122°45′7.7″
W3	39°49′21.8″	122°49′31.2″
W4	39°50′47.9″	122°50′50.4″
W5	39°52′0.00″	122°52′9.9″
S1	39°50′47.4″	122°8′28.5″
S2	39°49′24.3″	122°7′47.2″
S3	39°48′1.5″	122°9′25.6″
S4	39°49′33.9″	122°10′16.8″
S5	39°50′29.7″	122°12′48.9″

Sampling and examination

Inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the heavy metal content in the dominant fish species. After the heavy metals were digested, a 0.45 um filter membrane was used. In order to eliminate the influence of sampling, transportation and other reasons on the water samples, quality control such as blanks, transportation blanks and parallel double sample collection were set up during the collection process. When the number of quality control was less than one, at least one quality control sample was set up to perform high-quality control on the collection, transportation and other processing steps. "National Food Safety Standard Determination of Total Arsenic and Inorganic Arsenic in Foods" (GB5009.11-2014), "National Food Safety Standard Determination of Total Mercury and Organic Mercury in Foods" (GB5009.17-2014), etc. were referred to.

The method of sampling fish in the reservoir was through net catching. In the tributary of the reservoir, the electrofishing method was used, which takes electric current as a tool to catch fish. By using a DC power supply and a wire, a strong electric field is formed around the electrode to coronate fishes in flowing water, which are then collected by a net. In local reservoirs, local fishermen or reservoir staff helped to obtain fish samples. It was done by a double-strap 32-tube ultrasonic electrofishing gear in water less than 1.5 m. The unit output is 16.7 ms, and 12.5% of the working area produces a voltage of 220-380V (depending on the water Conductivity). One person controlled the electric fishing device, while the other used an insulated net to catch fish from five points that evenly distributed about 100 m from the sampling point, covering habitats of different

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features, such as strong current, little current, various sediments, and rich with aquatic plants. The sampling time of each sampling point is about 30 minutes. in water deeper than 1.5 m, a net was used for fishing, which is about 200 m long with a diameter of 1.5-3 cm. The sampling time was 30 minutes (Liu et al., 2018), and all collected samples were checked regarding amount, weight, ovulation, abnormalities (deformities, lesions, tumors, fin tail erosion, etc.). Fish specimens were decided according to "Liaoning Zoology" (Liaoning Zoology, 1985) and "Chinese Economic Fishes" (Yang et al., 1963) etc., and all the fishes collected in the watershed with a body length greater than 20 mm were classified to the level of species (or subspecies).

Data analysis

The relative importance index(IRI) was used in the analysis of the dominance of the reservoir catch, expression (Chen et al., 2012) is as below:

$$IRI=(W+N)\times F \quad \text{(Eq.1)}$$

where W represents the ratio of the weight of a certain species to the total weight, N represents the ratio of the number of a certain species to the total number, and F represents the frequency of occurrence of a certain species.

The basis for the division of dominance is: rare species IRI<1; general species 1≤IRI<10; common species: 10≤IRI<100; main species 100≤IRI<1000; dominant species: IRI≥1000.

The comprehensive pollution index method (Liu et al., 2017) can show the pollution degree of heavy metals in a certain fish in an all-round way. The calculation formula is as follows:

$$P_{comp}= \sqrt{(p2_{imax} + p2_{iavg} / 2} \quad \text{(Eq.2)}$$

where Pimax represents the maximum value of the single-factor pollution index of all heavy metals in the same fish, and Piavg represents the average value of the single-factor pollution index of heavy metals in the same fish. P comp> 1.0 is regarded as light pollution, P comp <1.0 is regarded as no pollution.

The target hazard quotient method (Zhang et al., 2018; Wang et al., 2019; Xue et al., 2020) is a pollutant evaluation method proposed by the US Environmental Protection Agency USEPA. It is extremely suitable for evaluating the health risks of food that people can come into contact with in daily life. The formula is as follows:

$$THQ=C\times E_F\times E_D\times E_{IR}/R_{FD}\times T_A\times W_{AB}\times 10^{-3} \quad \text{(Eq.3)}$$

where C is the concentration of heavy metals in fish (mg/g), EF is the exposure frequency (365 day/year), ED is the exposure duration (year), EIR is the intake reference of fish (g/day), RFD Is the reference amount of heavy metals (mg/(kg·d)), TA is the average time of non-carcinogenic exposure (d), and WAB is the average weight of an adult (kg). Among them, EF is 365, ED is 30, EIR is 55, RFD is the reference amount of heavy metals (mg/(kg·d)); TA is 10950, WAB is 60 kg. When THQ<1, there is no health risk to the exposed population; When THQ>1, there is a health risk to the exposed population. The greater the value of THQ, the greater the health risk (*Table 2*).

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Table 2. *standard limit of heavy metals in fish*

	Cr (mg/kg)	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Hg (mg/kg)
CHINA	2.00	0.10	0.10	0.50	1.00
CAC	-	-	0.05	0.30	0.50

Results

List and distribution of catches in 4 reservoirs

A total of 758 fishes were collected in this survey, belonging to 4 orders, 7 families, 23 genera and 25 species (*Table 3*). *Cypriniformes* are the most numerous, with 19 species, 18 genera and 2 families, accounting for 76% of the total species. Salmoniformes are the least, with 1 family, 1 genus and 1 species, accounting for 4% of the total number of species. Among them, plankton feeding fishes accounted for 28%; herbivorous fishes accounted for 4%; omnivorous fishes accounted for 48%; carnivorous fishes accounted for 20%. The nine species that are found in all four reservoirs are *Hypophthalmichthys molitrix, Aristichthys nobilis, Cyprinus carpio, Carassius auratus, Pseudorasbora parva, Barbatula barbatula nuda, Phoxinus lagowskii, Opsariichthys bidens, Acheilognathus maCropterus.*

Fish dominance

Through the analysis of the dominance of the catch (*Table 4*), we can conclude that in the Zhuanjiaolou Reservoir, the IRI values of 9 fish species (*Carassius auratus*, *Phoxinus lagowskii*, *Pseudobagrus fulvidraco*, *Hypophthalmichthys molitrix*, *Rhodeinae*, *Abbottina rivularis*, *Hypomesus*, *Zacco platypus*, *Pseudorasbora parva*) are 896.4, 91.9, 147.7, 782.5, 184.6, 59.1, 76.4, 492.4 and 56.1. Among them, *Carassius auratus*, *Pseudobagrus fulvidraco*, *Hypophthalmichthys molitrix*, *Rhodeinae*, *Zacco platypus* are the main species, and *Phoxinus lagomesus*, *Abbottina rivularis*, *Hypomesus* and *Pseudorasbora parva* are common species. There is no rare species or dominant species.

In the Yingnahe Reservoir, the IRI values of 10 fish species (*Silurus asotus*, *Hemiculter leucisculus*, *Carassius auratus*, *Pseudobagrus fulvidraco*, *Opsariichthys bidens*, *Cyprinus carpio*, *Rhodeinae*, *Pseudorasbora parva*, *Culter alburnrs*, *Acheilognathus maCropterus*) are 130.7, 430, 787.6, 226, 330.2, 453, 161.2, 85.5, 129.9 and 312.4. Among them, *Silurus asotus*, *Hemiculter leucisculus*, *Carassius auratus*, *Pseudobagrus fulvidraco*, *Opsariichthys bidens*, *Cyprinus carpio, Rhodeinae*, *Culter alburnrs* and *Acheilognathus maCropterus* are main species, and *Pseudorasbora parva* is common species. There is no rare species or dominant species.

In the Zhuweizi Reservoir, the IRI values of 8 fish species (*Cyprinus carpio*, *Carassius auratus*, *Rhodeinae*, *Hemiculter leucisculus*, *Acheilognathus maCropterus*, *Zacco platypus*, *Opsariichthys bidens*, *Cultrichthys erythropterus*) are 384.5, 265.9, 535.2, 914.8334.4, 303.2, 224.4 and 81.4. Among them, *Cyprinus carpio*, *Carassius auratu*s, *Rhodeinae, Zacco platypus, Hemiculter leucisculus*, *Acheilognathus maCropterus* and *Opsariichthys bidens* are main species, *Cultrichthys erythropterus* is common species. There is no rare species or dominant species.

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Table 3. *Catalogue of catches from 4 reservoirs in Dalian*

Order	Family	Genus	Species	Zhuanjiaolou Reservoir	Yingnahe Reservoir	Zhuweizi Reservoir	Songshu Reservoir
Cypriniformes	Cyprinidae	*Hypophthalmichthys*	*Hypophthalmichthys molitrix*	+	+	+	+
		Aristichthys	*Aristichthys nobilis*	+	+	+	+
		Carassius	*Carassius auratus*	+	+	+	+
		Cyprinus	*Cyprinus carpio*	+	+	+	+
			Cyprinus carpio		+		
		Pseudorasbora	*Pseudorasbora parva*	+	+	+	+
		Rhodeus	*Rhodeinae*	+	+		+
		Phoxinus	*Phoxinus lagowskii*	+	+	+	+
		Opsariichthys	*Opsariichthys bidens*	+	+	+	+
		Zacco	*Zacco platypus*	+		+	+
		Hemiculter	*Hemiculter leucisculus*	+		+	+
		Acheilognathus	*Acheilognathus maCropterus*	+	+	+	+
		Culterichthys	*Cultrichthys erythropterus*	+		+	+
		Hemibarbus	*Hemibarbus labeo*	+		+	
		Culter	*Culter alburnrs*				+
		Megalobrama	*Megalobrama amblycephala*				+
	Cobitidae	*Misgurnus*	*Misgurnus anguillicaudatus*	+			+
		Barbatula	*Barbatula barbatula nuda*	+	+	+	+
		Paramisgurnus	*Paramisgurnus dabryanus*	+	+		
Perciformes	Gobiidae	*Rhinogobius*	*rhinogobius giurinus*	+		+	
	Eleotridae	*Hypseleotris*	*Hypseleotris swinhonis*		+	+	+
		Perccottus	*Perccottus glehni*	+	+		
Siluriformes	Siluridae	*Silur*us	*Silurus asotus*		+		
	Bagridae	*Pelteobagrus*	*Pseudobagrus fulvidraco*	+	+		+
Salmoniformes	Osmeridae	*Hypomesu*s	*Hypomesus olidus*	+			

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Table 4. *Dominance of catches in 4 reservoirs*

	Species name	W value	N value	F value	IRI value
Zhuanjiaolou Reservoir	*Carassius auratus*	15.73%	29.09%	20	896.4
	Phoxinus lagowskii	1.92%	7.27%	10	91.9
	Pseudobagrus fulvidraco	5.68%	9.09%	10	147.7
	Hypophthalmichthys molitrix	72.8%	5.45%	10	782.5
	Rhodeinae	0.17%	9.09%	20	184.6
	Abbottina rivularis	0.23%	5.45%	10	59.1
	Hypomesus	0.37%	7.27%	10	76.4
	Zacco platypus	2.8%	21.82%	20	492.4
	Pseudorasbora parva	0.16%	5.45%	10	56.1
Yingnahe Reservoir	*Silurus asotus*	8.72%	4.35%	10	130.7
	Hemiculter leucisculus	8.46%	13.04%	20	430
	Carassius auratus	21.99%	17.39%	20	787.6
	Pseudobagrus fulvidraco	2.26%	8.7%	20	226
	Opsariichthys bidens	4.92%	11.59%	20	330.2
	Cyprinus carpio	39.50%	5.80%	10	453
	Rhodeinae	1.63%	14.49%	10	161.2
	Pseudorasbora parva	1.30%	7.25%	10	85.5
	Culter alburnrs	8.64%	4.35%	10	129.9
Zhuweizi Reservoir	*Cyprinus carpio*	33.69%	4.76%	10	384.5
	Carassius auratus	17.07%	9.52%	10	265.9
	Rhodeinae	7.71%	19.05%	20	535.2
	Hemiculter leucisculus	20.34%	25.40%	20	914.8
	Acheilognathus maCropterus	4.02%	12.70%	20	334.4
	Zacco platypus	4.05%	11.11%	20	303.2
	Opsariichthys bidens	9.74%	12.70%	10	224.4
	Cultrichthys erythropterus	3.38%	4.76%	10	81.4
Songshu Reservoir	*Opsariichthys bidens*	8.69%	19.23%	20	558.4
	Pseudobagrus fulvidraco	5.00%	15.38%	10	203.8
	Acheilognathus maCropterus	1.51%	15.38%	10	168.9
	Culter alburnrs	6.66%	15.38%	10	202.4
	Hypophthalmichthys molitrix	64.62%	11.54%	10	761.6
	Carassius auratus	13.53%	23.08%	20	732.2

In Songshu Reservoir, the IRI values of 6 fish species (*Opsariichthys bidens*, *Pseudobagrus fulvidraco*, *Acheilognathus maCropterus*, *Culter alburnrs*, *Hypophthalmichthys molitrix*, *Carassius auratus*) are 558.4, 203.8, 168.9, 202.4, 761.6 and 732.2. Among them, *Opsariichthys bidens*, *Pseudobagrus fulvidraco*, *Acheilognathus maCropterus*, *Culter alburnrs*, *Hypophthalmichthys molitrix* and *Carassius auratus* are main species. There is no rare species, common species or dominant species.

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Heavy metal content of fish in 4 reservoirs in Dalian

The heavy metal content in the muscles of the four fishes *Carassius auratus*, *Hypophthalmichthys molitrix*, *Rhodeinae* and *Pseudobagrus fulvidraco* in Zhuanjiaolou Reservoir is shown in *Figure 2*. The Cr contents are all lower than the standard value of 2.0, ranking from high to low as: *Carassius auratus*> *Rhodeinae*> *Hypophthalmichthys molitrix*> *Pseudobagrus fulvidraco*. The Cd contents are all lower than the standard value of 0.01, ranking from high to low as: *Pseudobagrus fulvidraco*> *Rhodeinae*> *Hypophthalmichthys molitrix*> *Carassius auratus*. The Pb contents are all lower than the standard value of 0.5, ranking from high to low as: *Carassius auratus*> *Rhodeinae*> *Pseudobagrus fulvidraco*> *Hypophthalmichthys molitrix*. The Hg contents are all lower than the standard value of 1.0, ranking from high to low as: *Hypophthalmichthys molitrix*> *Pseudobagrus fulvidraco*> *Carassius auratus*> *Rhodeinae*. The As contents are all lower than the standard value of 0.10, ranking from high to low as: *Rhodeinae*> *Hypophthalmichthys molitrix*> *Carassius auratus*> *Pseudobagrus fulvidraco*. The highest content of the five heavy metals is the As in *Rhodeinae*, and the lowest is the Cd in *Carassius auratus*.

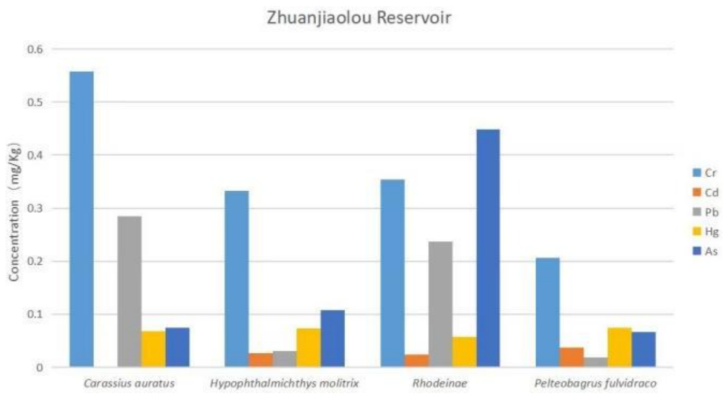

Figure 2. *Heavy metal content of fish in Zhuanjiaolou Reservoir*

The heavy metal content in the muscles of the four fishes *Carassius auratus*, *Opsariichthys bidens*, *Cyprinus carpio* and *Hemiculter leucisculus* in Yingnahe Reservoir are shown in *Figure 3*. According to the standard limit of heavy metal in fish, we can know that the Cr contents in the muscles of the four fishes are all lower than the standard value of 2.0, ranking from high to low as: *Cyprinus carpio*> *Carassius auratus*> *Hemiculter leucisculus*> *Opsariichthys bidens*, the Cd contents in the fish muscles are all lower than the standard value of 0.10, ranking from high to low as: *Hemiculter leucisculus*> *Cyprinus carpio*> *Opsariichthys bidens*> *Carassius auratus*, the Pb contents in the fish muscles are all lower than the standard value of 0.5, ranking from high to low as: *Cyprinus carpio*> *Hemiculter leucisculus*> *Opsariichthys bidens*> *Carassius auratus*, the Hg contents in the fish muscles are all lower than the standard value of 1.0, ranking from high to low as: *Carassius auratus*> *Cyprinus carpio*> *Opsariichthys bidens*> *Hemiculter leucisculus*, the As contents in the fish muscles are all lower than the standard value of 0.10, ranking from high to low as: *Hemiculter leucisculus*> *Opsariichthys bidens*> *Carassius auratus*> *Cyprinus carpio*. The highest content of the five heavy metals is the Cr in *Cyprinus carpio*, and the lowest is the Pb in *Carassius auratus*.

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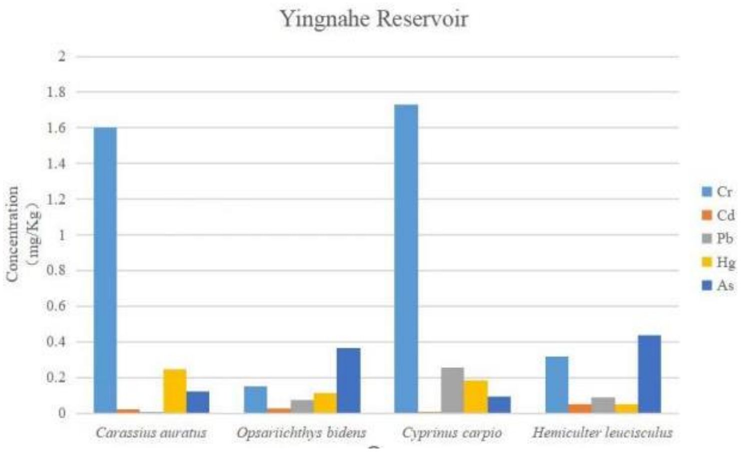

Figure 3. *Heavy metal content of fish in Yingnahe Reservoir*

The heavy metal content in the muscles of the four fishes *Rhodeinae*, *Carassius auratus*, *Cyprinus carpio* and *Hemiculter leucisculus* in Zhuweizi Reservoir are shown in *Figure 4*. According to the standard limit of heavy metal in fish, we can know that only the Cr content in the muscles of *Hemiculter leucisculus* is above the standard value of 2.0, while none of the others do, ranking from high to low as: *Hemiculter leucisculus*> *Rhodeinae*> *Carassius auratus*> *Cyprinus carpio*, the Cd contents in the fish muscles are all lower than the standard value of 0.10, ranking from high to low as: *Rhodeinae*> *Hemiculter leucisculus*> *Carassius auratus*> *Cyprinus carpio*, the Pb contents in the fish muscles are all lower than the standard value of 0.5, ranking from high to low as: *Rhodeinae*> *Carassius auratus*> *Hemiculter leucisculus*> *Cyprinus carpio*, the Hg contents in the fish muscles are all lower than the standard value of 1.0, ranking from high to low as: *Rhodeinae*> *Hemiculter leucisculus*> *Carassius auratus*> *Cyprinus carpio*, the As contents in the muscles of *Rhodeinae* and *Hemiculter leucisculus* are above the standard value of 0.5 while others don't, ranking from high to low as: *Hemiculter leucisculus*> *Rhodeinae*> *Carassius auratus*> *Cyprinus carpio*. The highest content of the five heavy metals is the Cr in *Hemiculter leucisculus*, and the lowest is the Cd in *Cyprinus carpio*.

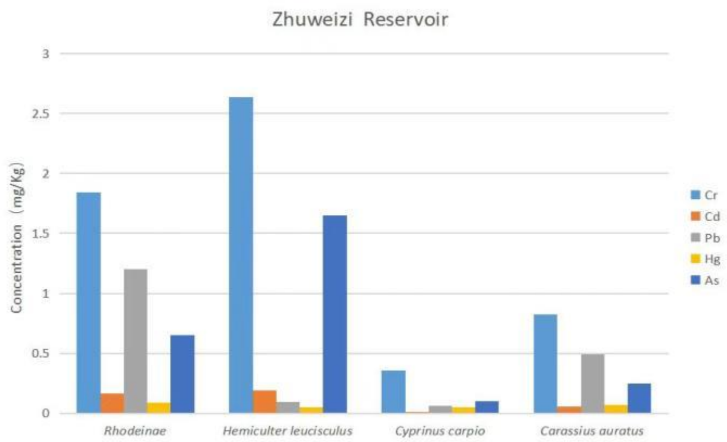

Figure 4. *Heavy metal content of fish in Zhuweizi Reservoir*

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The heavy metal content in the muscles of the four fishes *Carassius auratus*, *Opsariichthys bidens*, *Hypophthalmichthys molitrix* and *Pseudobagrus fulvidracoin* in Songshu Reservoir are shown in *Figure 5*. According to the standard limit of heavy metal in fish, we can know that only the Cr content in the muscles of *Pseudobagrus fulvidraco* is above the standard value of 2.0, while none of the others do, ranking from high to low as: *Pseudobagrus fulvidraco*> *Hypophthalmichthys molitrix*> *Opsariichthys bidens*> *Carassius auratus*, the Cd contents in the fish muscles are all lower than the standard value of 0.10, ranking from high to low as: *Pseudobagrus fulvidraco*> *Opsariichthys bidens*> *Hypophthalmichthys molitrix*> *Carassius auratus*, the Pb content in the muscles of *Hypophthalmichthys molitrix* is above the standard value of 0.5, while the rest don't, ranking from high to low as: *Hypophthalmichthys molitrix*> *Opsariichthys bidens*> *Pseudobagrus fulvidraco*> *Carassius auratus*, the Hg contents in the fish muscles are all lower than the standard value of 1.0, ranking from high tolow as: *Opsariichthys bidens*> *Pseudobagrus fulvidraco*> *Hypophthalmichthys molitrix*> *Carassius auratus*, the As contents in the muscles of *Pseudobagrus fulvidraco* and *Carassius auratus* are above the standard value of 0.10, while the rest don't, ranking from high to low as: *Carassius auratus*> *Pseudobagrus fulvidraco*> *Opsariichthys bidens*> *Hypophthalmichthys molitrix*. The highest content of the five heavy metals is the Cr in *Pseudobagrus fulvidraco*, and the lowest is the Pb in *Carassius auratus*.

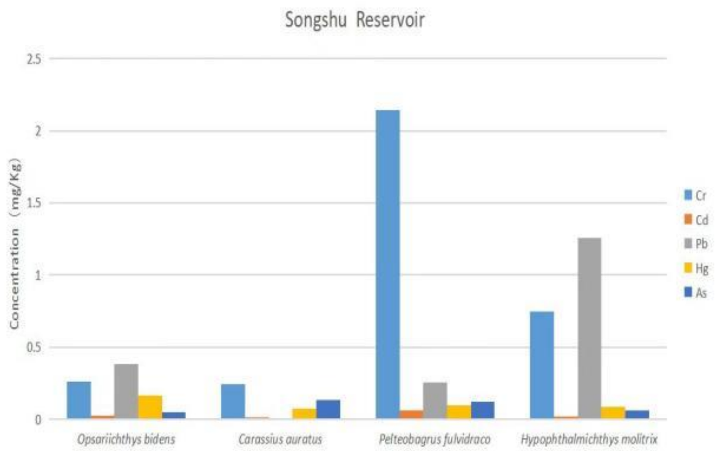

Figure 5. *Heavy metal content of fish in Songshu Reservoir*

Health risk assessment of heavy metals in fishes in 4 reservoirs of Dalian

The calculation results of the comprehensive pollution index (*Table 5*) showed that in Zhuanjiaolou Reservoir, the order of the comprehensive pollution index of the four fishes from high to low is: *Rhodeinae*> *Carassius auratus*> *Hypophthalmichthys molitrix*> *Pseudobagrus fulvidraco*. Among them, the index of *Pseudobagrus fulvidraco* is the lowest (P_{comp}=0.501), the index of *Rhodeinae* is the highest (P_{comp}=1.266), indicating light pollution. The indices of the other three fishes are below 1, indicating no pollution; In Yingnahe Reservoir, the order of the comprehensive pollution index of the four fishes from high to low is: *Opsariichthys bidens*> *Hemiculter leucisculus*> *Carassius auratus*> *Cyprinus carpio*. Among them, the index of *Cyprinus carpio* is the lowest (P_{comp}=0.774), the index of *Opsariichthys bidens* is the highest (P_{comp}=1.712), indicating light pollution. The index of *Hemiculter leucisculus* is above 1, indicating light pollution. While the

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indices of *Carassius auratus*, *Cyprinus carpio* are below 1, indicating no pollution; In Zhuweizi Reservoir, the order of the comprehensive pollution index of the four fishes from high to low is: *Rhodeinae*> *Hemiculter leucisculus*> *Cyprinus carpio*> *Carassius auratus*. Among them, the index of *Carassius auratus* is the lowest (P_{comp}=0.384), the index of *Rhodeinae* is the highest (P_{comp}=1.976), indicating light pollution. The index of *Hemiculter leucisculus* is above 1, indicating light pollution. And the indices of *Carassius auratus*, *Cyprinus carpio* are above 1, indicating no pollution; In Songshu Reservoir, the order of the comprehensive pollution index of the four fishes from high to low is: *Pseudobagrus fulvidraco*> *Hypophthalmichthys molitrix*> *Carassius auratus*> *Opsariichthys bidens*. Among them, the index of *Opsariichthys bidens* is the lowest (P_{comp}=0.597), the index of *Pseudobagrus fulvidraco* is the highest (P_{comp}=0.997), the indices of all are over 1, indicating no pollution; Among the 16 fish species in the four reservoirs, *Rhodeinae* of Zhuweizi Reservoir has the highest comprehensive pollution index (P_{comp} = 1.976) and *Carassius auratus* of Zhuweizi Reservoir has the lowest pollution index (P_{comp} = 0.384). Fish with a comprehensive pollution index of non-polluting accounted for 68.75% of the total.

Table 5. *Comprehensive pollution index of dominant fish species in 4 reservoirs in Dalian*

Location	Species name	P_{comp}
Zhuanjiaolou Reservoir	*Carassius auratus*	0.815
	Hypophthalmichthys molitrix	0.656
	Pseudobagrus fulvidraco	0.501
	Rhodeinae	1.266
Yingnahe Reservoir	*Carassius auratus*	0.943
	Opsariichthys bidens	1.712
	Cyprinus carpio	0.774
	Hemiculter leucisculus	1.536
Zhuweizi Reservoir	*Cyprinus carpio*	0.549
	Carassius auratus	0.384
	Hemiculter leucisculus	1.003
	Rhodeinae	1.976
Songshu Reservoir	*Opsariichthys bidens*	0.597
	Carassius auratus	0.625
	Pseudobagrus fulvidraco	0.997
	Hypophthalmichthys molitrix	0.643

The *THQ* values of Cr, Cd, Pb, Hg and As in the muscle tissues of dominant fish species from 4 reservoirs in Dalian are as shown in *Table 6*. In Zhuanjiaolou Reservoir, the health risk values of heavy metal Cr in the four fishes range from high to low as: *Carassius auratus*> *Hypophthalmichthys molitrix*> *Rhodeinae*> *Pseudobagrus fulvidraco*, the health risk values of heavy metal Cd in the four fishes range from high to low as: *Carassius auratus*> *Hypophthalmichthys molitrix*> *Pseudobagrus fulvidraco*> *Rhodeinae*, the health risk values of heavy metal Pb in the four fishes range from high to low as:*Rhodeinae*> *Carassius auratus*> *Hypophthalmichthys molitrix*> *Pseudobagrus fulvidraco*, the health risk values of heavy metal Hg in the four fishes range from high to low as: *Carassius auratus*> *Pseudobagrus fulvidraco*> *Rhodeinae*> *Hypophthalmichthys molitrix*, the health risk values of heavy metal As in the four fishes range from high to low as: *Rhodeinae*> *Carassius auratus*> *Pseudobagrus fulvidraco*> *Hypophthalmichthys*

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molitrix. The highest *THQ* value of the five heavy metals in the four fishes is Cr in *Carassius auratus*, and the lowest value is Hg in *Hypophthalmichthys molitrix*. All *THQ* values are less than 1, which means that the heavy metal content in the edible muscle tissue of the four fishes has no obvious effect on human health.

Table 6. *THQ values of different heavy metals in 16 fished from 4 reservoirs in Dalian*

Location	Species name	Cr	Cd	Pb	Hg	As
Zhuanjiaolou Reservoir	*Carassius auratus*	0.57136	0.01547	0.15431	0.00494	0.04161
	Hypophthalmichthys molitrix	0.41467	0.01262	0.09021	0.00342	0.00979
	Pseudobagrus fulvidraco	0.16302	0.00546	0.02928	0.00475	0.03941
	Rhodeinae	0.28014	0.00490	0.29042	0.00367	0.08837
Zhuweizi Reservoir	*Rhodeinae*	0.40676	0.00597	0.86890	0.00563	0.08113
	Hemiculter leucisculus	0.18834	0.04934	0.13216	0.00355	0.10897
	Cyprinus carpio	0.44316	0.00217	0.40913	0.00532	0.04178
	Carassius auratus	0.58086	0.00886	0.46136	0.00595	0.02202
Yingnahe Reservoir	*Carassius auratus*	1.26459	0.00783	0.00554	0.01545	0.01413
	Opsariichthys bidens	0.37194	0.01506	0.99157	0.00861	0.07864
	Cyprinus carpio	1.56056	0.00783	0.26985	0.00374	0.04718
	Hemiculter leucisculus	0.11237	0.01690	0.42417	0.01323	0.06677
Songshu Reservoir	*Opsariichthys bidens*	0.28172	0.01377	0.24770	0.01418	0.04523
	Carassius auratus	0.88790	0.03913	0.06885	0.00728	0.02659
	Pseudobagrus fulvidraco	1.69509	0.02394	0.40043	0.00627	0.06101
	Hypophthalmichthys molitrix	0.84200	0.00249	0.12345	0.00987	0.06048

In Zhuweizi Reservoir, the health risk values of heavy metal Cr in the four fishes range from high to low as: *Carassius auratus*> *Cyprinus carpio*> *Rhodeinae*> *Hemiculter leucisculus*. The health risk values of heavy metal Cd in the four fishes range from high to low as: *Hemiculter leucisculus*> *Carassius auratus*> *Rhodeinae*> *Cyprinus carpio*, the health risk values of heavy metal Pb in the four fishes range from high to low as: *Rhodeinae*> *Carassius auratus*> *Cyprinus carpio*> *Hemiculter leucisculus*, the health risk values of heavy metal Hg in the four fishes range from high to low as: *Carassius auratus*> *Rhodeinae*> *Cyprinus carpio*> *Hemiculter leucisculus*, the health risk values of heavy metal As in the four fishes range from high to low as: *Hemiculter leucisculus*> *Rhodeinae*> *Cyprinus carpio*> *Carassius auratus*. The highest *THQ* value of the five heavy metals in the four fishes is Pb in *Rhodeinae*, and the lowest value is As in *Carassius auratus*. All *THQ* values are less than 1, which means that the heavy metal content in the edible muscle tissue of the four fishes has no obvious effect on human health.

In Yingnahe Reservoir, the health risk values of heavy metal Cr in the four fishes range from high to low as: *Cyprinus carpio*> *Carassius auratus*> *Opsariichthys bidens*> *Hemiculter leucisculus*. The health risk values of heavy metal Cd in the four fishes range

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from high to low as: *Hemiculter leucisculus*> *Opsariichthys bidens*> *Cyprinus carpio* = *Carassius auratus*, the health risk values of heavy metal Pb in the four fishes range from high to low as: *Opsariichthys bidens*> *Hemiculter leucisculus*> *Cyprinus carpio*> *Carassius auratus*, the health risk values of heavy metal Hg in the four fishes range from high to low as: *Carassius auratus*> *Hemiculter leucisculus*> *Opsariichthys bidens*> *Cyprinus carpio*, the health risk values of heavy metal As in the four fishes range from high to low as: *Opsariichthys bidens*> *Hemiculter leucisculus*> *Cyprinus carpio*> *Carassius auratus*. The highest *THQ* value of the five heavy metals in the four fishes is Cr in *Cyprinus carpio*, and the lowest value is Pb in *Carassius auratus*. All *THQ* values are above 1, except for that of Cr in *Carassius auratus* and *Cyprinus carpio*, which are slightly higher than 1. That means that the heavy metal content in the edible muscle tissue of those two fishes has a slight impact on human health, and the rest have no obvious impact.

In Songshu Reservoir, the health risk values of heavy metal Cr in the four fishes range from high to low as: *Pseudobagrus fulvidraco*> *Carassius auratus*> *Hypophthalmichthys molitrix*> *Opsariichthys bidens*. The health risk values of heavy metal Cd in the four fishes range from high to low as: *Carassius auratus*> *Pseudobagrus fulvidraco*> *Opsariichthys bidens*> *Hypophthalmichthys molitrix*, the health risk values of heavy metal Pb in the four fishes range from high to low as: *Pseudobagrus fulvidraco*> *Opsariichthys bidens*> *Hypophthalmichthys molitrix*> *Carassius auratus*, the health risk values of heavy metal Hg in the four fishes range from high to low as: *Pseudobagrus fulvidraco*> *Opsariichthys bidens*> *Hypophthalmichthys molitrix*> *Carassius auratus*, the health risk values of heavy metal As in the four fishes range from high to low as: *Opsariichthys bidens*> *Hypophthalmichthys molitrix*> *Carassius auratus*> *Pseudobagrus fulvidraco*. The highest target hazard quotient value of the five heavy metals in the four fishes is Cr in *Pseudobagrus fulvidraco*, and the lowest value is Hg in *Pseudobagrus fulvidraco*. Only the *THQ* value of Cr in *Pseudobagrus fulvidraco* are above 1, means that the heavy metal content in the edible muscle tissue of that fish has a slight impact on human health, and the rest have no obvious impact.

Discussion

Characteristics of fish communities in 4 reservoirs of Dalian

As an important part of the aquatic ecosystem, fish promotes the energy flow and material conversion in the aquatic ecosystem. The stability of its community structure reflects the health of the aquatic ecosystem to a certain extent, and dominance level is one of the characteristics that affect the structure of fish communities (Wang et al., 2014). With the rapid development of social economy, in order to meet the needs of modern agricultural production development, irrigation, flood control, etc., reservoirs, as the water body connecting the upper and lower water surfaces, are important feeding grounds and habitats for fish (Yuan et al., 2015; Liu et al., 2016; Zheng et al., 2017; Yi et al., 2021). In the investigation, it was found that the fish community diversity index can reflect the stability of the community structure to a certain extent, and has a close relationship with the surrounding environment of the habitat. The complexity of habitat will affect the diversity of fish communities, and the diversity of fish communities can reflect the stability of the community structure. The richer the species in the community, the more even the distribution of individuals of various types. Similarly, the higher the richness index and uniformity index, the more stable the community structure (Bai et al.,

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2020). That may be related to the different fish dominance distribution at different points in the reservoir. The living environments of the upper and lower reaches of the reservoir are different, and the results of fish community diversity research are affected by the survey methods, which may be slightly biased, thus further research is needed (Liani et al., 2018).

Analysis of characteristics of heavy metal content in fish

Heavy metal pollution mainly refers to the harm to the environment caused by heavy metal compounds such as Hg, Cd, Zn, Cr, As, Zn and Cu that enter the environment through various channels. Heavy metal elements have a long residual poison time and are accumulative. They can be enriched in organisms and transmitted or amplified through the food chain, so that organisms that originally provide people with protein and other nutrients, such as fish, shrimp, crabs, shells, etc., become concentrates of toxic metals, which can affect or potentially affect human health (Xu et al., 2013).

Heavy metals are important pollutants in water bodies, and they can be enriched in fish through respiration, ingestion, and adsorption (Zhang et al., 2017; Li and Liu, 2019; Lin et al., 2018). It has been found from related studies that the level of heavy metals in fish tissues is mainly related to the environment. Fishes of different types have different heavy metal content, and fishes of the same type living in different environments also have different heavy metal content (Tchounwou et al., 2012). The four fishes with the highest IRI values in the four reservoirs and water bodies of Dalian were selected for heavy metal content testing. It was found that some fish have higher Cr values. That may be due to the discharge of wastewater from surrounding factories and enterprises, which caused heavy metal pollution in the water, and further lead to heavy metal enrichment in the fish through food chain.

The harm of heavy metal content in fish to human body

The risk exposure assessment of heavy metals refers to the qualitative or quantitative analysis of the heavy metal intake from food, that is, the estimation of the heavy metal intake according to people's dietary consumption pattern and dietary consumption amount of heavy metals (Duan et al., 2009). With the gradual acceleration of China's industrialization, there will be more and more pollutants of heavy metals in water bodies. For example, if the concentration of heavy metals in the well-loved Procambarus clarkii deepens, the total amount of heavy metals entering people's bodies will also increase, which can become harmful to health (Yang et al., 2020). There are many risk exposure assessment methods for heavy metals. For example, point assessment is a method of expressing population risk through a single value. This method is simple and clear. Zhou et al. (2018) used it to assess the risk of *Procambarus clarkii*. If the residents of Hubei Province consume one serving a day, the results indicate that they are at a safe level; The simple distribution assessment estimates based on the distribution of food intake. Considering the variability of consumption, heavy metal is a fixed reference value, which can also be seen as the highest level of heavy metal pollution.

The analysis of the comprehensive fish heavy metal pollution index can more comprehensively show the heavy metal pollution of 16 types of fishes in 4 reservoirs of Dalian. Among them, *Rhodeinae* in Zhuanjiaolou Reservoir, *Hemiculter leucisculus* in Yingnahe Reservoir and *Hemiculter leucisculus* and *Rhodeinae* in Zhuweizi Reservoir showed light pollution, with values above 1, and all others showed no pollution. *Rhodeinae* in Zhuweizi Reservoir had the highest value, which may be because that,

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compared with other fishes, *Rhodeinae* prefers to live in places with a lot of water and grass and close to the shore, making it easier for heavy metals to accumulate.

The method of health risk assessment adopted in this paper is the same as that used by Luo et al. (2021) and Xu et al. (2020) on the determination of heavy metal content in wild fish, the determination of heavy metal content in three cultured freshwater fish and the health risk assessment. Through the health risk assessment of the heavy metal elements of 16 fish species in 4 reservoirs of Dalian, the results showed that most of the fishes have no obvious health risks to human, except for *Pseudobagrus fulvidraco* in Songshu Reservoir, which has a slightly high value, indicating minor impact on human health.

Analysis of causes of changes in fish resources and protective measures

Biological invasion is already one of the global environmental problems today. The loss of global biodiversity and the destruction of global ecosystems are both extremely serious (Liu et al., 2019). The invasion of alien species will seriously harm the community structure, leading to the decline of indigenous fishes, and different fishes distributed in different locations will be different in size and quality (Andrzej et al., 2008; Liu et al., 2016).

Most of the exotic fishes such as *Pseudorasbora parva* have strong survival tolerance, and can adapt to the changes in the living environment quickly, change the structure of fish communities, and compete with indigenous fishes, which may pose threat to other fishes (Wang et al., 2016).

River water conservancy will also cause the reduction of fish species and changes in community composition, which will affect the structure, growth, reproduction and habitat environment of fish populations (Yang et al., 2013; Huang et al., 2015; Cao et al., 2017). The original hydrological environment was changed when 4 reservoirs were built and expanded, and the reservoir water being used for irrigation reduced the living space of fish (Wang et al., 2021).

Exotic fish should be strictly controlled and monitored regularly; fish habitats should be protected; fishery management should be strengthened and publicity should be strengthened; excessive fishing need to be strictly prohibited, proliferation and release should be actively carried out, and fish germplasm resources and gene banks should be established (Ma et al., 2014; Cheng et al., 2017; He et al., 2021; Wang et al., 2021; Liao et al., 2021).

Conclusion

Through the investigation of fish in 4 reservoirs of Dalian, a total of 758 fishes were collected in this survey, belonging to 4 orders, 7 families, 23 genera and 25 species. Among them, *Cypriniformes* are the most, with 2 families, 18 genera and 19 species, accounting for 76% of the total species. It was found from the comprehensive pollution index results that *Rhodeinae* in Zhuanjiaolou Reservoir, *Opsariichthys bidens* and *Hemiculter leucisculus* in Yingnahe Reservoir, *Hemiculter leucisculus* and *Rhodeinae* in Zhuweizi Reservoir have relatively high values. From the exposure risk assessment results of the four reservoirs, it can be found that the exposure coefficient of Cr in *Pseudobagrus fulvidraco* is the highest, indicating a certain exposure risk, while the risks of other types are low. We should fully implement the concept of ecological priority in the new era, strengthen the management and protection of the reservoir environment, rationally use the water suitable for fishing, explore a new model of high-quality

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development of green fisheries, and ensure the sustainable development of reservoir fishery resources.

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