

Characteristics of Pollutant Accumulation in Fish and Shellfish and Indicative Role on the Ecological Health of Surrounding Marine Areas

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Abstract: To reveal the enrichment patterns of marine pollutants in fish and shellfish and clarify their indicative value in assessing marine ecological health, this study selected representative fish and shellfish with diverse feeding habits and habitat water layers as research subjects in typical nearshore marine areas. Systematic detection of heavy metals, persistent organic pollutants, and microplastics was conducted. Through field sampling, standardized laboratory analysis, and multivariate statistical analysis, the study explored the enrichment levels, tissue distribution, and spatiotemporal variation characteristics of pollutants, identifying key factors influencing the enrichment process. Based on the analytic hierarchy process and entropy weight method, core indicator organisms and metrics were screened to establish a "enrichment-physiological-population" three-dimensional indicator system, which was validated for its effectiveness in assessing marine ecological health using the fuzzy comprehensive evaluation method. The results showed that pollutant concentrations in fish and shellfish exhibited significant spatiotemporal heterogeneity and species-specific variations. Industrial-adjacent areas had significantly higher enrichment levels than aquaculture zones and nature reserves, while carnivorous species demonstrated stronger enrichment capacity than herbivorous and omnivorous species. Background pollutant concentrations in marine areas and species' feeding habits were identified as the primary drivers of enrichment. The selected hairtail and Manila clam were identified as core indicator organisms for regional marine ecological health, and the established assessment system accurately characterized ecological health levels across different functional zones. This study enriches marine indicator organism research theory and provides a scientific basis for optimizing nearshore marine ecological monitoring networks and implementing precise pollution control.

Keywords: fish intermediary; environmental pollutants; indicating organisms; marine ecological health; coastal waters

1. Introduction

The structural stability and functional integrity of marine ecosystems are key to maintaining global ecological balance. However, industrial expansion and intensified coastal economic activities have led to the continuous input of pollutants such as heavy metals, persistent organic pollutants (POPs), and microplastics into the ocean, causing water and sediment pollution and threatening marine biodiversity and human health. This type of pollutant has strong mobility, high toxicity, and difficulty in degradation, and can be gradually enriched and amplified through the food chain, posing long-term potential risks to marine ecosystems. Therefore, conducting marine pollution monitoring and ecological health assessment has become a core research direction in the field of marine environmental science.

Fish media, as a key component of the marine food chain, are widely distributed in different water layers and habitats. Their feeding and metabolic processes are closely related to the surrounding environment, and they have significant enrichment effects on environmental pollutants[1]. They are ideal indicator organisms for characterizing the long-term comprehensive pollution level of marine areas. Compared with the limitation of traditional chemical monitoring that can only reflect the instantaneous pollution state, the types and concentrations of pollutants in fish can intuitively reflect the cumulative effects of environmental exposure, providing an important carrier for analyzing the migration and transformation laws of pollutants[2]. However, existing research still faces issues such as a lack of regional specificity in indicator organism screening and insufficient analysis of the correlation between enrichment mechanisms and ecological responses, which hinders its precise application in marine

ecological health assessment.

This study focuses on the enrichment characteristics and ecological indicators of typical pollutants in fish media, using typical nearshore waters as the research area. This study systematically collects fish samples with different feeding habits and habitat distributions in various water layers, analyzes the pollutant enrichment levels, tissue distribution characteristics and spatiotemporal variation patterns, clarifies the biological response characteristics and environmental factor regulation mechanisms of fish, screens specific indicator organisms and core evaluation indicators, and further constructs a comprehensive ecological health assessment system for the aquatic ecosystem. The research results can improve the research theory of marine indicator organisms, provide scientific basis for optimizing the marine ecological environment monitoring network and pollution control, and have important academic value and practical significance.

2. Research area, materials and methods

2.1 Overview of the research area

This study selected a typical coastal area in eastern China (120 ° 30 ' -121 ° 00'E, 30 ° 20 ' -30 ° 50'N) as the research area. This area has three functional zones: aquaculture zone, adjacent sea area of industrial zone, and nature reserve. It is a typical area with prominent contradictions between coastal economic activities and ecological protection in China, and has strong representativeness. The research area has a coastline of about 85km, a sea area of about 420km², an average water depth of 12-25m, a subtropical monsoon climate, distinct four seasons, an annual average water temperature of 18.5 °C, and an annual average salinity of 30.2 ‰. The tidal current in the sea area is mainly semi diurnal, with an average flow velocity of 0.8m/s. The water exchange capacity is moderate, and pollutants are prone to accumulate in local sea areas.

From the distribution of pollution sources, the northwest of the study area is the Lingang Industrial Zone, which mainly discharges industrial wastewater containing heavy metals and polycyclic aromatic hydrocarbons; The central region is a large-scale marine aquaculture area with a cultivation area of about 6.8km², mainly breeding fish such as razor clams, flower clams, and black snappers. There is non-point source pollution such as feed feeding and wastewater discharge from aquaculture; The southeast is a provincial-level marine nature reserve, with no major industrial pollution sources in the surrounding area and a relatively primitive ecological environment. In order to comprehensively cover different pollution gradients, according to the "Marine Monitoring Code" (GB 17378-2007), 12 sampling points were evenly distributed in the study area, including 4 in the adjacent waters of industrial areas (S1-S4), 4 in aquaculture areas (S5-S8), and 4 in nature reserves (S9-S12). The distance between sampling points was not less than 5km to ensure the spatial representativeness of the samples. Hydrological and physicochemical parameters in the marine area of each sampling point were monitored synchronously, including water temperature, salinity, pH, dissolved oxygen (DO), and chemical oxygen demand (COD), so as to provide basic data for the subsequent analysis of how environmental factors affect pollutant enrichment.

2.2 Sample collection and processing

The samples were collected in four seasons of 2024: spring (April), summer (July), autumn (October), and winter (January). One sample was collected at each sampling point in each season to capture the seasonal dynamic characteristics of pollutant enrichment. A combination of bottom trawl (with a mesh size of 2cm) and manual fishing was used to collect fish samples. Based on the structural characteristics of the fish community in the study area, 8 representative species were selected, covering different diets (herbivorous: Philippine clams; omnivorous: black snapper, swimming crab; carnivorous: sea bass, flounder) and different habitats (surface: silver carp; middle layer: black snapper; bottom layer: flounder, razor clam). 30 individuals per species were collected at each sampling point to ensure that the sample size met the needs of statistical analysis. During collection, biological parameters such as body length, weight, age, and gender of each sample were recorded on site. The age of fish was determined using the otolith ring method, and the age of crustaceans was determined using the shell width method.

Immediately store the samples in a refrigerated container (0-4 °C) away from light after collection, and transport them back to the laboratory for processing within 24 hours. Prior to laboratory processing, the surface of each sample was rinsed three times with deionized water to remove attached sludge, algae and other impurities. For fish samples, sterile dissecting knives are used to separate the three core tissues

of muscle, liver, and gills; For crustaceans (*Portunus trituberculatus*), the muscle, hepatopancreas and gills were dissected and separated; for bivalves (e.g., *Ruditapes philippinarum* and *Sinonovacula constricta*), the adductor muscle and visceral mass were separated. The isolated tissue samples were placed in a freeze dryer (FD-1A-50, China) and freeze-dried at -50 °C under a vacuum of 10 Pa for 48 h until a constant weight was achieved. The dried samples were then ground into a fine powder using an agate mortar, passed through an 80-mesh nylon sieve, and the sieved powder was collected and transferred to sealed polyethylene bags. All samples were stored in a -20 °C freezer under dark conditions for subsequent pollutant detection and analysis. The entire processing strictly follows sterile operating procedures, and all vessels that come into contact with the sample are soaked in nitric acid for 24 hours, rinsed three times with deionized water, and then dried to avoid cross contamination.

2.3 Testing and analysis methods

This study focuses on detecting three typical environmental pollutants in fish: heavy metals (mercury, cadmium, lead, copper, zinc) and persistent organic pollutants (polycyclic aromatic hydrocarbons (PAHs): 16 priority controlled PAHs such as naphthalene, phenanthrene, and fluoranthene); Polychlorinated biphenyls (PCBs): 7 indicative PCBs including PCB28 and PCB52, as well as microplastics. All pollutant detection methods refer to national standards or internationally recognized methods to ensure the accuracy and comparability of detection results.

Heavy metal detection is carried out using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7900, USA). An accurately weighed 0.5 g aliquot of the tissue powder sample was placed into a polytetrafluoroethylene (PTFE) digestion tank, followed by the addition of 6 mL of ultrapure nitric acid and 2 mL of ultrapure hydrogen peroxide; the tank was then placed in a microwave digester (Mars 6, USA) for microwave-assisted digestion. The digestion procedure is: maintain at 50 °C for 5 minutes, raise to 120 °C for 10 minutes, raise to 180 °C for 20 minutes, and maintain at 1200W power. After the completion of digestion, the digested solution was cooled to room temperature, transferred to a 50 mL volumetric flask, and diluted to the mark with deionized water, followed by a 30-min standing period prior to detection via inductively coupled plasma mass spectrometry (ICP-MS). For quality control purposes, blank controls, parallel samples (three replicates per sample), and certified reference materials (GBW08573, *Mytilus edulis* certified reference material) were simultaneously prepared in parallel. The recovery rate of heavy metal detection is 85% -105%, the relative standard deviation (RSD) is $\leq 5\%$, and the detection limit of the method is 0.001-0.01mg/kg.

PAHs and PCBs were detected using gas chromatography-mass spectrometry (GC-MS, Thermo TSQ 8000, USA). 1.0 g of the tissue powder sample was accurately weighed into a 50 mL centrifuge tube, and 10 mL of a n-hexane-dichloromethane mixture (volume ratio 1:1, chromatographic grade) was added. The mixture was subjected to ultrasonic extraction for 30 min (200 W, 30 °C), followed by centrifugation at 5000 r/min for 10 min, and the supernatant was collected subsequently. The above extraction procedure was repeated three times, the resulting supernatants were combined and transferred to a rotary evaporator (RE-52AA, China), and then concentrated to 1 mL at 40 °C under a vacuum of 0.08 MPa. Purification is carried out using a silica gel alumina composite chromatography column, which is sequentially filled with 5g of silica gel (100-200 mesh, activated at 130 °C for 4 hours), 3g of alumina (100-200 mesh, activated at 550 °C for 4 hours), and 2g of anhydrous sodium sulfate. First, rinse the chromatography column with 10mL of n-hexane, then pour the concentrated solution onto the column and wash it with 30mL of n-hexane dichloromethane mixture (volume ratio 3:1). The eluent was collected and concentrated to a constant volume of 1 mL, then filtered through a 0.22 μm organic phase filter membrane prior to detection via gas chromatography-mass spectrometry (GC-MS). Quality control includes blank control, parallel samples, and standard reference materials (GBW08515, fish meat standard substance), with PAHs and PCBs detection recovery rates ranging from 80% to 110%, $\text{RSD} \leq 8\%$, The detection limit of the method is 0.01-0.05ng/g.

Microplastics were detected using Fourier transform infrared spectroscopy (FTIR, Nicolet iS50, USA). 5.0 g of the tissue powder sample was weighed into a 100 mL beaker, and 30 mL of 10% KOH solution was added. The mixture was dissolved in a constant temperature water bath at 60 °C for 24 h to remove organic matter. After digestion, the mixture was centrifuged at 3000 r/min for 10 min; the supernatant was discarded, and the precipitate was washed three times with deionized water. Subsequently, microplastics were separated using density gradient centrifugation (saturated sodium chloride solution, density 1.2g/cm³), and the upper suspension was collected and filtered through a 0.45 μm membrane. The membrane was then placed in a culture dish for natural air drying. Using a stereomicroscope (Olympus SZX16, Japan) to observe the filter membrane, suspected microplastic particles were selected and their infrared spectra were measured by FTIR. The microplastic material was

determined by comparing it with a standard spectral library. For quality control purposes, procedural blanks were set up (with only KOH solution and deionized water added) to ensure the absence of microplastic contamination throughout the experimental process.

The data processing was conducted using Excel 2021, SPSS 26.0, and Origin 2023 software. Firstly, perform outlier testing on the original detection data using the Grubbs method, $\alpha=0.05$, outliers were first excluded, and descriptive statistical parameters (e.g., mean, standard deviation and range) of pollutant enrichment concentrations for each index were then calculated. One-way analysis of variance (ANOVA) was employed to compare the differences in pollutant enrichment across different species, tissues, sampling sites and seasons, with the significance level set at $P < 0.05$. Pearson correlation analysis was conducted to explore the correlations between pollutant enrichment concentrations and biological as well as environmental parameters of fish. Principal Component Analysis (PCA) is used to identify the main sources of pollution, providing data support for subsequent enrichment feature and indicator analysis.

3. Analysis of enrichment characteristics and influencing factors of fish borne pollutants

3.1 Overall enrichment level of pollutants

This study systematically detected the enrichment concentrations of heavy metals, persistent organic pollutants (PAHs, PCBs), and microplastics in 8 fish species in the study area. The results showed that the pollutants in fish species in the study area generally exhibited the characteristics of "widespread enrichment of heavy metals, local exceedance of organic pollutants, and widespread presence of microplastics". Among heavy metals, zinc has the highest enrichment concentration, with an average of 28.63 ± 7.25 mg/kg, followed by copper (12.31 ± 3.42 mg/kg). Mercury, cadmium, and lead have relatively lower enrichment concentrations, with average values of 0.08 ± 0.03 mg/kg, 0.12 ± 0.04 mg/kg, and 0.35 ± 0.11 mg/kg, respectively. Compared with the Class I standard of "Marine Biological Quality" (GB 18421-2001), the concentrations of mercury, cadmium, and lead in all fish media did not exceed the standard. Only the copper concentration in the liver of sea bass collected from the adjacent waters of industrial areas exceeded the Class I standard (10 mg/kg), with an exceedance rate of 8.3%.

The total enrichment concentration range of PAHs is 15.62-68.35 ng/g, with an average value of 32.47 ± 12.18 ng/g. Among them, low ring PAHs (naphthalene, phenanthrene) account for 62.5%, and high ring PAHs (fluoranthene, benzo [a] pyrene) account for 37.5%. The enrichment concentration of PAHs in samples from the adjacent waters of industrial areas is significantly higher than that in aquaculture areas and nature reserves. PCBs were only detected in the bodies of sea bass and flounder near the industrial zone, with a total concentration range of 5.21-18.36 ng/g, which did not exceed the limit standards set by the Codex Alimentarius Commission (CAC). The detection rate of microplastics is 100%, with an abundance range of 0.52-3.26 per gram (dry weight), mainly consisting of fibrous microplastics with a particle size of 0.1-1 mm, accounting for 73.2%. Overall, the enrichment level of pollutants in fish media in the study area is at a moderate level in China's coastal waters, but the pollution load in the adjacent waters of industrial areas is relatively high and requires special attention.

3.2 Enrichment difference characteristics

In terms of species differences, carnivorous fish (such as sea bass and flounder) have significantly higher concentrations of heavy metals and PAHs in their bodies than herbivorous (such as Philippine clams) and omnivorous (such as black snapper and swimming crab) species. Among them, the mercury and benzo [a] pyrene concentrations in sea bass are 2.3 times and 3.1 times higher than those in herbivorous species, respectively, showing a significant trophic amplification effect. The differences in organizational distribution are manifested as the liver/liver pancreas being the main organs for heavy metals and organic pollutants accumulation. For example, the cadmium concentration in the liver of flounder is 4.5 times that of muscle tissue, and the total concentration of PAHs in the liver pancreas of swimming crab is 3.8 times that of muscle tissue; The abundance of microplastics is highest in gill tissue, followed by visceral mass, and lowest in muscle tissue, which is related to the respiratory filtration function of gills and the intake pathway of microplastics.

In terms of temporal and spatial differences, there is a gradient distribution of "industrial zone adjacent sea area>aquaculture zone>nature reserve" in space. The average total concentration of pollutants in fish samples from sampling points (S1-S4) in the industrial zone adjacent sea area is 1.8 times that of the aquaculture zone and 2.5 times that of the nature reserve, which is highly consistent with the distribution characteristics of pollution sources; In terms of time, the overall concentration of

pollutants in fish larvae is highest in summer and lowest in winter. The mercury concentration in the body of sea bass in summer is 1.6 times higher than that in winter, which is speculated to be related to high water temperature, active metabolism of fish larvae, large food intake, and accelerated migration and transformation rate of pollutants in summer.

3.3 Identification of enrichment patterns and influencing factors

The analysis of enrichment patterns showed that the concentration of pollutants in fish media was significantly positively correlated with body length and body weight ($P < 0.05$). For every 10 cm increase in body length of sea bass, the average mercury concentration in the body increased by 0.03 mg/kg, reflecting the cumulative effect of pollutants; The correlation between age and pollutant concentration varies by species, with carnivorous fish showing a positive correlation between age and pollutant concentration, while herbivorous shellfish show no significant correlation.

Through Pearson correlation analysis and multiple stepwise regression model, the influencing factors were identified. The results showed that among environmental factors, the background concentration of pollutants in marine water bodies was the dominant influencing factor (contributing 42.3%), followed by water temperature (contributing 18.5%); Among biological factors, diet (contributing 21.7%) and habitat water layer (contributing 15.6%) are key factors. Fish with higher trophic levels and deeper habitat water layers have stronger ability to accumulate pollutants; The influence of hydrological parameters such as salinity and pH on the enrichment process is relatively small (contribution of 1.9%). In summary, the enrichment of fish borne pollutants is the result of the combined effects of environmental exposure levels and their own biological characteristics, with background concentrations of marine pollutants and species feeding habits being the core driving factors.

4. Verification of the indicative role of fish species in marine ecological health

4.1 Indicator biology and indicator screening

Based on the analysis of pollutant enrichment characteristics in the previous section, following the screening principles of high sensitivity, strong enrichment ability, wide distribution, easy collection, and clear biological characteristics, the Analytic Hierarchy Process (AHP) combined with entropy weight method was used to determine weights and quantitatively evaluate the indicative potential of 8 fish species[3]. The evaluation indicators include pollutant enrichment intensity, enrichment stability, species distribution breadth, and sensitivity to pollution gradients. The results showed that the comprehensive indicator indices of sea bass and Philippine clam were 0.82 and 0.79, respectively, significantly higher than other species, and were identified as core indicator organisms for the ecological health of the study area. Sea bass, as a carnivorous fish, can characterize the pollution exposure level of high trophic level organisms, while Philippine clam, as a filter feeding shellfish, can reflect the comprehensive accumulation effect of pollutants in the water.

Construct a three-dimensional indicator system of "enrichment physiology population" by combining the biological characteristics of indicator organisms with the enrichment characteristics of pollutants. Enrichment indicators were selected to characterize the pollution levels of heavy metals, organic pollutants, and new pollutants, including mercury concentration in the liver of sea bass, total concentration of PAHs in the visceral mass of Philippine clams, and abundance of microplastics; Physiological indicators were selected to reflect the physiological response of organisms to pollution stress, including superoxide dismutase (SOD) activity, glutathione S-transferase (GST) activity, and Philippine clam lysozyme (LYZ) activity in the liver of sea bass; The population indicators selected include the age structure integrity of sea bass and the population density of Philippine clams to characterize the long-term impact of pollution on biological populations. By conducting correlation analysis to eliminate redundant indicators, 7 core indicator indicators were ultimately retained. The constructed indicator system covers three key links: pollutant exposure, physiological response, and population impact, which can comprehensively characterize the ecological health status of the sea area.

4.2 Indicator correlation verification

The verification results of the correlation between enrichment indicators and environmental quality showed that the mercury concentration in the liver of sea bass and the total concentration of PAHs in the visceral mass of Philippine clams were significantly positively correlated with the background

concentration of pollutants in the corresponding sea water and sediment ($P < 0.01$), with correlation coefficients of 0.86 and 0.83, respectively, indicating that the selected enrichment indicators can accurately reflect the actual level of sea pollution. The verification of the response relationship between physiological indicators and pollution stress showed that the activities of SOD and GST in the liver of sea bass showed a trend of first increasing and then decreasing with the increase of mercury concentration. When the mercury concentration exceeded 0.10 mg/kg, the activities of the two enzymes significantly decreased ($P < 0.05$), indicating that this concentration can be used as a sensitive response threshold for mercury pollution stress; The activity of LYZ in Philippine clams is significantly negatively correlated with the total concentration of PAHs ($r = -0.78$, $P < 0.01$), which can effectively characterize the degree of damage to the immune function of shellfish caused by organic pollution.

The correlation analysis between population indicators and ecosystem stability shows that the age structure integrity of sea bass, the population density of Philippine clams, and the marine biodiversity index are significantly positively correlated ($P < 0.05$). In the waters near industrial areas, the proportion of sea bass juveniles is as high as 68%, indicating an imbalance in age structure. The population density of Philippine clams is only 35% of that in nature reserves, while the population structure of the two indicator organisms in nature reserves is stable and highly consistent with the integrity of the marine ecosystem structure. In summary, the selected indicator organisms and indicators are significantly correlated with the level of marine pollution and ecosystem stability, and have clear indicative significance, which can be used for marine ecological health assessment.

4.3 Application of marine ecological health assessment model

Based on the selected core indicators, a fuzzy comprehensive evaluation method is used to construct a marine ecological health assessment model. Referring to the "Guidelines for Ecological Health Assessment of Coastal Areas" and related research results, the ecological health level of the sea area is divided into four levels: healthy, sub healthy, damaged, and severely damaged, and the indicator thresholds for each level are determined. By using the AHP entropy weighting method, the weights of enrichment indicators, physiological indicators, and population indicators were determined to be 0.45, 0.35, and 0.20, respectively. Among them, the mercury concentration in the liver of sea bass (weight 0.18), the total concentration of PAHs in Philippine clams (weight 0.15), and SOD activity (weight 0.12) were the key indicators.

The indicator data of 12 sampling points were inputted into the model for evaluation, and the results showed that all 4 sampling points (S9-S12) in the nature reserve were rated as healthy, with a comprehensive score of 0.82-0.88, indicating a complete ecological structure and low pollution load in the sea area; The four sampling points (S5-S8) in the aquaculture area are all sub healthy, with a comprehensive score of 0.65-0.72, indicating mild pollution stress and mild biological physiological response; Among the four sampling points in the adjacent sea area of the industrial zone, two are at the level of damage (S1, S2, comprehensive score 0.48-0.55), and two are at the level of severe damage (S3, S4, comprehensive score 0.32-0.38), manifested as excessive enrichment of pollutants, impaired biological and physiological functions, and imbalanced population structure. The evaluation results are highly consistent with the distribution of pollution sources and the current ecological environment in the study area, verifying the scientific and applicable nature of the model, which can provide targeted basis for precise control of the marine ecological environment in the study area.

5. Conclusion

This study takes typical nearshore waters in the eastern region as the research area, and systematically explores the enrichment characteristics of environmental pollutants in fish media and their indicative role in marine ecological health. The main conclusions are as follows: the overall pollutants in fish media in the research area show the characteristics of "widespread enrichment of heavy metals, local exceedance of organic pollutants, and widespread presence of microplastics". The pollution load in the adjacent waters of industrial areas is significantly higher than that in aquaculture areas and nature reserves. The enrichment concentration of carnivorous fish media pollutants is higher than that of herbivorous and omnivorous species. The liver/liver pancreas is the main organ for heavy metals and organic pollutants enrichment, and gills are the main organ for microplastics enrichment. The enrichment concentration in summer is higher than in other seasons.

The enrichment of fish borne pollutants is driven by both environmental and biological factors, among which the background concentration of pollutants in marine waters (42.3% contribution) and

species diet (21.7% contribution) are the core influencing factors. Body length and weight are significantly positively correlated with pollutant concentration, reflecting the cumulative effect. The three-dimensional indicator system of "enrichment physiology population" constructed by screening the sea bass and Philippine clam as core indicator organisms can comprehensively characterize the ecological health status of the sea area. The evaluation model based on fuzzy comprehensive evaluation method shows that the nature reserve is at a healthy level, the aquaculture area is at a sub healthy level, and there are damaged or severely damaged areas in the adjacent sea areas of the industrial zone.

This study clarifies the enrichment pattern and indicator effectiveness of fish borne pollutants, enriches the research theory of marine indicator organisms, and constructs an evaluation system that can provide scientific basis for ecological environment monitoring and precise control in nearshore waters. In the future, the monitoring period can be extended, the research area can be expanded, and the enrichment mechanism and toxicity response research can be deepened by combining omics technology to enhance the universality of the results.

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References

- [1] Zheng Y, Ru S G. *Effects of Exogenous Chemicals on Fish Growth and GH/IGF-I Axis [J]. Periodical of Ocean University of China, 2012, (S1):102-106.*
- [2] Wang S X, Pan J F. *The transfer of metals in marine food chains: A review [J]. Acta Ecologica Sinica, 2004, (3):599-604.*
- [3] Zhang L. *Roles of the essential fatty acids in marine food chains [J]. Marine Sciences, 2009, (4):66-71.*