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Distribution and bioaccumulation of heavy metals in aquatic organisms of different trophic levels and potential health risk assessment from Taihu lake, China

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ABSTRACT

Aquatic organisms of different trophic levels were taken from Taihu lake. Heavy metals (Cu, Zn, Cr, Ni, Cd, Pb) were measured in phytoplankton, zooplankton, in two species of zoobenthos, and in eight fish species, as well as in the water column and bottom sediments. Results showed that the concentration of Cu and Zn for all organisms was much higher than for other metals, and Cd was the lowest in all species. Generally, heavy metal concentrations in phytoplankton were higher than in zooplankton. In zoobenthos, the concentration in *Bellamya sp.*(human edible snail) was higher than that in *Corbiculidae* (bivalve). Metal concentrations had no significant difference between fish species but tended to be higher in predator fish such as *Coilia ectenes and Erythroculter ilishaeformis* than in herbivorous fish. The level of measured metals in Taihu fish was moderate-low compared with that of fresh water fishes from international results. Spatially, metal concentrations in organisms were higher in the north and west Taihu lake but lower in south and east lake and this appears to be related to river inputs that are heavily influenced by anthropogenic activities. The bio-concentration factor (*BCF*) for all aquatic organisms in the food chain indicated that it was generally highest in planktons, followed by zoobenthos, and lowest in fish. Health risk assessment and comparison with national and international standards showed that consumption of aquatic products from the lake was generally safe but fishermen were a higher risk group especially through dietary intake of *Bellamya sp*.

1. Introduction

Heavy metals from natural and anthropogenic sources pose serious threats to the environment and to human health (Borrego et al., 2002) due to their long persistence, toxicity, and bio-accumulation (Sainz et al., 2004; Olias et al., 2006). Heavy metals in the environment have become a wide concern owing to their ever increasing contamination of water, soil and food in many regions of the world, and particularly in some developing countries (including China), not only because of their threats to public water supplies, but also because they pose hazards through human consumption of aquatic products (Waqar, 2006). Therefore, heavy metals have been widely studied for their toxic effects (Borrego et al., 2002; Sainz et al., 2004; Olias et al., 2006), accumulation in organisms (Aucoin et al., 1999; Rasmussen and Anderson, 2000; Waqar, 2006), and bio-accumulation in food chains (Asuquo et al., 2004; David et al., 2011) in the past decades. In addition, bio-indicators for monitoring heavy metal pollution in aquatic environments are also widely studied; for example, bivalve mollusks have been found to accumulate heavy metals and therefore are widely used as an indicator (Lau et al., 1998; Liang et al., 2004). Studies have shown that urban and industrial development contributes substantially to heavy metal contamination in water environments and aquatic organisms, which has resulted in much research focused on industrialized areas (Xia et al., 2011).

Taihu area is one of the most economically developed regions in China. Lake Taihu, located in the delta region of the Yangtze River, is the third largest fresh water lake in China. The lake is dish-like and shallow, with average water depth of only 2 m and a lake area of some 2300 km^2. It is important for aquatic products in China, and is also an important drinking water source for surrounding cities such as the major metropolitan areas of Wuxi and Suzhou, two economically developed cities in Jiangsu province. With the intensive social and economic development in this densely populated area since the 1950s, untreated or inadequately treated wastewater from industrial, agricultural, and domestic sewage discharged into the lake has produced significant negative impacts on the water quality and ecology of the lake. Early investigation of environmental quality conducted by

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Shanghai Teachers University in 1980–1981 showed that heavy metal pollution was slight in Meiliang Bay, a north part of the lake (Yao and Xue, 2010). By 2005, the northern part of Taihu Lake was moderately polluted by heavy metals (Chi et al., 2007). More recently, Yu et al. (2011) investigated heavy metals in the water and sediment throughout the lake, and found that the heavy metal pollution was generally higher in the north and west part than in the east and south part; also, there existed a gradient from Caoqiao river to the lake for many metals; and metal concentrations were usually safe in water but more likely to pose ecological risks in sediments in terms of USEPA standards. Although fish consumption was considered to be relatively safe in terms of metal concentrations in the mid 2000s, it was recommended that consumption be limited (Chi et al., 2007). Overall, previous studies on heavy metals in Taihu lake mostly focused on sediments; metal studies in fish were few, and studies of metals in planktons and benthos have been scarcely reported. Monitoring of metal concentration in aquatic organisms of different trophic levels can be used as biomarker selection (David et al., 2011), which is significative to ecosystem health assessment and environment management. Also, considering that fish from Taihu is a staple of the regional diet, the potential human exposure risk (both acute and chronic) to metals through bio-magnification up the food chain is a cause for concern. With ecology and food safety becoming increasingly important concerns in China and worldwide, studies of heavy metals in the food chains and aquatic products of the lake are imperative.

In this work, we examined six heavy metals in organisms of different trophic levels in Taihu lake, including phytoplankton, zooplankton, two species of zoobenthos, and eight species of fish. We explored metal distribution and accumulation in aquatic organisms and assessed potential risks caused by consuming aquatic products from the lake. This study gives a comprehensive picture of metal status in organisms of different trophic levels in Taihu Lake, and provides a basis for the ongoing Chinese aquatic system-based water environment criteria strategy proposed by the China Ministry of Environment Protection (Wu et al., 2010). The comparison of our results with comparative international studies also provides basic knowledge for Chinese environment agencies in the development of their own water quality criteria.

2. Materials and methods

2.1. Sampling

Entire Taihu lake was investigated and six sites were sampled from the later August to early September in 2010, when planktons are abundant and fishing is allowed in the lake. Of the six sites, five (*T*2–*T*6) were located in major geographical areas of the lake; one (*T*1) was located in the Caoqiao River, upstream of its confluence with Taihu, to explore the linkage of river inputs to metal concentrations in lake organisms (Fig. 1). Aquatic organisms were collected at each site. A 200 mesh plankton net (74 μm) fitted to a 1 m handle was used to sample phytoplankton, and a 125 mesh net (113 μm) used to sample zooplankton, that is, to draw the net to and fro in the water for 5 min, then collect the sample in the net, and then repeat the step till enough samples were obtained. A sediment grab was used to sample zoobenthos (macro-invertebrate benthos-snail and bivalve). Phytoplankton and zooplankton samples were obtained at all sites, and zoobenthos were obtained at *T*1–*T*5, with *Bellamya sp.* (snail) obtained at *T*1, *T*2, *T*4 and *Corbiculidae* (bivalve) obtained at *T*3 and *T*5. The size of zoobenthos selected in this study was around 1 cm in length. Those obviously smaller and bigger (few in the lake) were not used. Each species had two parallel samples. Fish samples of different species (*Erythroculter ilishaefor*, *Hypophthalmichthys molitrix*, *Coilia ectenes*, *Protosalnax hyalocranius*, *Aristichthys nobilis*, *Carassius auratus*, *Pelteobagrus fulvidraco*, *Cyprinus carpio*) were bought immediately after they were caught by local fishers. The size of fish we selected was 17–20 cm for all species with the exception of *Protosalnax hyalocranius*, which was around 10 cm as it is a smaller fish. These fish are economically important to the local fisheries industry. We took the muscle of fish (edible part) to analyze and discuss in this work as the fish product is one of the most important functions of Taihu lake and food safety is a major concern presently in China. Fish samples of each species, which were

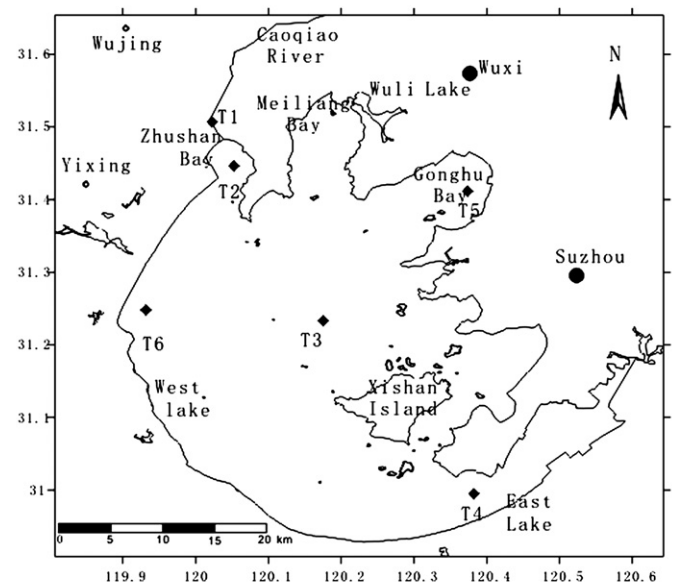

Fig. 1. Taihu Lake and sampling sites in this study.

randomly selected, represent the entire (average) lake situation because, unlike planktons living in a relatively fixed area and benthos sessile to sediment in their life, fish migrate throughout the lake and experience different pollution levels of the water. Therefore, the spatial variation of metal level in fishes from the lake is not a consideration in this study. Water and bottom sediment samples were also taken at each site to compare metal concentrations in organisms and their living environment. All samples were taken in duplicate (three replicates for organisms from the Caoqiao river) within approximate 300 m in each site (except for fish) and then preserved in polythene bottles (for planktons and water) and bags (for fishes, benthos and sediments) at the temperature of around 4 °C and then transported back to the lab for treatment and analysis.

2.2. Sample treatment and measurement

Phytoplankton and zooplankton samples were first rinsed with deionized water and enriched by centrifugation at 5000 rpm, at 4 °C for 5 min. This process concentrated plankton samples and removed solids from the sample. Then, the wet weight of samples was measured, then freeze-dried and ground after being dried. The dry samples were stored in airproof polyethylene bags for digestion. Zoobenthos and fishes samples (muscle) were cleaned with deionized water three times; their wet weight was measured and then freeze-dried and ground for digestion. Measurement of the wet weight of organisms was used to calculate their water content and convert between dry weight and wet weight. According to the measurement of all organisms in this study the average dry weight to wet weight ratio was 10:1 for planktons, 5.2:1 for benthos and 5.4:1 for fishes.

Dried samples of 0.3 g (for planktons) and 0.5 g (for zoobenthos and fishes) were weighed and put into 50 ml Bunsen beakers; 10 ml nitric acid and 1 ml perchloric acid were added. After 12 h of digestion, the beakers were moved to an electric hot plate at 150 °C until the digestion solution turn achromatic or pale yellow. After the solution cooled down to room temperature 5 ml hydrochloric acid was added. Then the digestion solution was transferred to 50 ml volumetric flasks for analysis. The total concentration of metals for each sample was tested using flame atomic absorbance spectrophotometry (AAS, Hitachi Z-2000) for Cu, Zn, Cr and using ICP-MS (Agilent, 7500 CX) for Ni, Pb, Cd.

Metals in water column samples were measured with ICP-MS after infiltration through a 0.45 μm membrane, and metals in sediments were measured using National Standard Method (GB/T17140). The results are listed in the Table 1.

All processed samples (organisms, water and sediment) were divided into two sub-samples for replicate testing before digestion, so each metal had four tested values with two replicate samples as the basis for calculations and statistical analysis

2.3. Analytical quality control

Parallel samples and replicate analysis were conducted to ensure the accuracy. Blank samples were used for each group of organism samples. National Certified Reference Material-Spirulina (GSB-16) and National Certified Reference Material-prawns (GSB-28) with known concentration of metals, were used as part of the quality control steps. The relative standard deviation (RSD) of each group of