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Bioaccumulation of heavy metals both in wild and mariculture food chains in Daya Bay, South China

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ABSTRACT

Bioaccumulation and trophic transfer of heavy metals both in the natural marine ecosystem (seawater, sediment, coral reef, phytoplankton, macrophyte, shrimp, crab, shellfish, planktivorous and carnivorous fish) and in the mariculture ecosystem (compound feed, trash fish, farmed pompano and snapper) were studied at Daya Bay, a typical subtropical bay in Southern China. The levels of Cu, Zn, Pb and Cd in sediment were 11.7, 10.2, 53.8 and 2.8 times than those in coral reef, respectively. Pb and Zn levels were markedly higher in phytoplankton than in macrophyte, probably caused by the larger specific surface area in phytoplankton. The highest levels of Zn (98.1), Pb (1.87) and Cd (5.11 $\mu g\ g^{-1}$ dw) in wild organisms were all found in clam (*Veremolpa scabra*), indicating that these metals were apt to bioaccumulate in shellfish. The average concentrations of Cu, Zn, Pb and Cd in wild fish were 3.7, 2.1, 0.4 and 22.2 times than those in farmed fish, confirming the "growth dilution" hypothesis in farmed fish. Heavy metal bioconcentration factors (BCFs) in algae, bioaccumulation factors (BAFs) in wild species and transfer factors (TFs) in organism were calculated and discussed. The results suggested that biologically essential Cu and Zn were easier to accumulate in fish than non-essential Cd. Concentrations of Cu, Zn and Cd were several times higher in wild fish than in farmed fish whereas the opposite was observed for Pb. This metal also showed the highest transfer factor from food, which means that special attention must be given to fish feed production in relation to metal contamination.

1. Introduction

Heavy metals, such as copper, zinc, lead and cadmium, are persistent contaminants that bioaccumulate throughout the food chain, causing serious ecological and human health hazards. Metals differ from other toxic substances in that they are neither created nor destroyed, but transformed. Marine plankton is at the bottom of many food chains, and their metals accumulation could greatly affect its trophic transfer and thus the metals accumulation at higher trophic levels, including in fish. There is evidence showing bioaccumulation and biomagnification of trace metals in aquatic food chains, with higher concentrations detected in carnivorous fish (Nfon et al., 2009). Understanding the mechanisms of bioaccumulation in food webs is critical to predicting which food webs are at risk for higher rates of bioaccumulation (McIntyre and Beauchamp, 2007).

Trace metal concentration in an organism is controlled by the balance between uptake and elimination (Luoma and Rainbow, 2008; Wang and Rainbow, 2008). Accumulation of trace metal in the tissues of organism depends primarily on ambient water concentrations, levels in prey or commercial feed, and chemical uptake and elimination kinetics. Other factors such as chemical speciation/bioavailability as well as fish growth cycle, age and trophic position, also can influence the extent of trace metal accumulation in organism (Kelly et al., 2008). Food quality and quantity may significantly affect the dietary assimilation and ingestion rate of fish. For marine fish, dietary uptake (highly associated with trophic transfer) is the predominant pathway by which metals are accumulated, primarily because of the very low dissolved uptake rate of metals (Wang and Rainbow, 2008). Both laboratory and field investigations have confirmed that food can be a major source of trace metals bioaccumulated in fish (Spry et al., 1988; Mount et al., 1994; Wang et al., 2012). With the rapid economic growth over the last few decades, environmental pollution is the serious problem throughout the world. Many studies have been carried out to study persistent organic pollutants (POPs) and heavy metals bioaccumulation in marine food chains/webs, primarily concentrating

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in lakes and the Arctic regions (e.g., Hoekstra et al., 2003; Nfon et al., 2009; Kehrig et al., 2009). Comparatively, little information is available for heavy metals in marine food chains and webs from the subtropical bay. Previous investigations in the coast of south China mainly focused on the metals levels in seawater, sediment and organism (e.g., Li et al., 2000; Cheung et al., 2003; Ip et al., 2005, 2007; Qiu et al., 2011; Zhang and Wang, 2012).

To better understand heavy metals pollution levels and bioaccumulation along the marine food chain in the typical subtropical bay of the South China, the aims of the present study were (1) to analyze Cu, Zn, Pb and Cd concentrations both in the natural marine ecosystem, including sediment, phytoplankton, macrophyte, benthos (shrimp, crab, and shellfish), planktivorous and carnivorous fish, and in the mariculture ecosystem, including compound feed, trash fish, and farmed fish (pompano and snapper) in Daya Bay, South China (Fig. 1); (2) to examine the factors influencing bioaccumulation of metals in food webs at Daya Bay; and finally (3) to compare the metals levels between marine wild fish and marine farmed fish. Comparison of metal concentrations between wild and farmed fish is an issue of great concern regarding regulations and monitoring cultured fish food contamination.

2. Materials and methods

2.1. Study area

Daya Bay, adjacent to Hong Kong, is one of the most important economic development districts and mariculture areas in Guangdong Province, with a coastal line of 92 km and an area of 600 km^2. There are a few small seasonal streams flowing into the bay, and the Daya Bay nuclear power station is located on the bank. Non-reef coral communities are patchily and sporadically distributed in the bay, with 34 species of hermatypic corals (Chen et al., 2010). The annual average values of water color, transparency, turbidity, temperature, salinity, pH and dissolved oxygen in the past two decades were 8.0, 3.0 m, 2.53, 23.81 °C, 31.52‰, 8.23 and 7.06 mg l^{-1}, respectively, based on a long-term monitoring program (Qiu et al., 2005a). Impaired water quality as characterized by frequent occurrence of red tides has resulted in a drastic decline of zooplankton biomass, severely depressing the fish population (Qiu et al., 2005b; Song et al., 2009).

2.2. Sample collection and processing

Seawater, sediment, phytoplankton, macroalgae and wild benthos (shrimp, crab and shellfish), planktivorous and carnivorous fish, fish feed, trash fish and two species of farmed fish (pompano and snapper) samples in Daya Bay were collected in July 2007. The fish farm was located in sites S1, S2 and S3, and site Sc was the control location (Fig. 1). The wild organism samples were collected in site S1, S2 and S3, and seawater and sediment samples were collected from the four sites. Briefly, 2 L surface water (0.5 m under the sea level) and bottom water (0.5 m above the sea floor) samples were collected. Three sediment samples at each site (triangle sampling method) were collected from the upper 2 cm layer using a box sediment grab sampler and placed in acid-rinsed polypropylene bag. Phytoplankton were collected by the phytoplankton trawl (using 0.077 mm mesh size) while macrophyte (*Ulva fasciata*, also known as sea lettuce) samples were collected by hand. The seawater samples were stored at ~4 °C until laboratory analysis. For taxonomic group identification, sub-samples of microplankton were preserved in 4% buffered formalin. The dominant phytoplankton species were *Nitzschia* sp., *Skeletonema costatum* and *Scrippsiclla trochoidea*. Meanwhile, the wild organisms, including shrimp (*Penaeus*), crab (*Portunus pubescens*), shellfish (*Veremolpa scabra*), planktivorous fish (*Stromateoides argenteus*) and carnivorous fish (*Saurida undosquamis*), with the body length ranging between 5 and 8 cm, 4–6 cm, 5–8 cm, 8–15 cm and 8–15 cm, respectively, were collected from the above mentioned waters by the benthos trawl. One wild species which concurrently appeared in all three sites was picked in each of three sites.

A total of 32 pompano (*Trachinotus blochii*) and 29 snapper (*Lutjanus malabaricus*) individuals of different sizes (~10 pompano and ~10 snapper in each of three sites), with a median body weight of 506 g (ranging between 185 and 1334 g) for farmed pompano and a median body weight of 616 g (ranging between 160 and 3500 g) for farmed snapper, were collected. Fish feed samples included compound fish feed (16 commercial brands) and trash fish feed (4 batches) were simultaneously collected. Approximately 70% of compound feed and 30% of trash fish were used to feed the farmed fishes in Daya Bay. All organism and sediment samples were stored in polyethylene bag with ice immediately after collection and frozen at −20 °C prior to treatment.

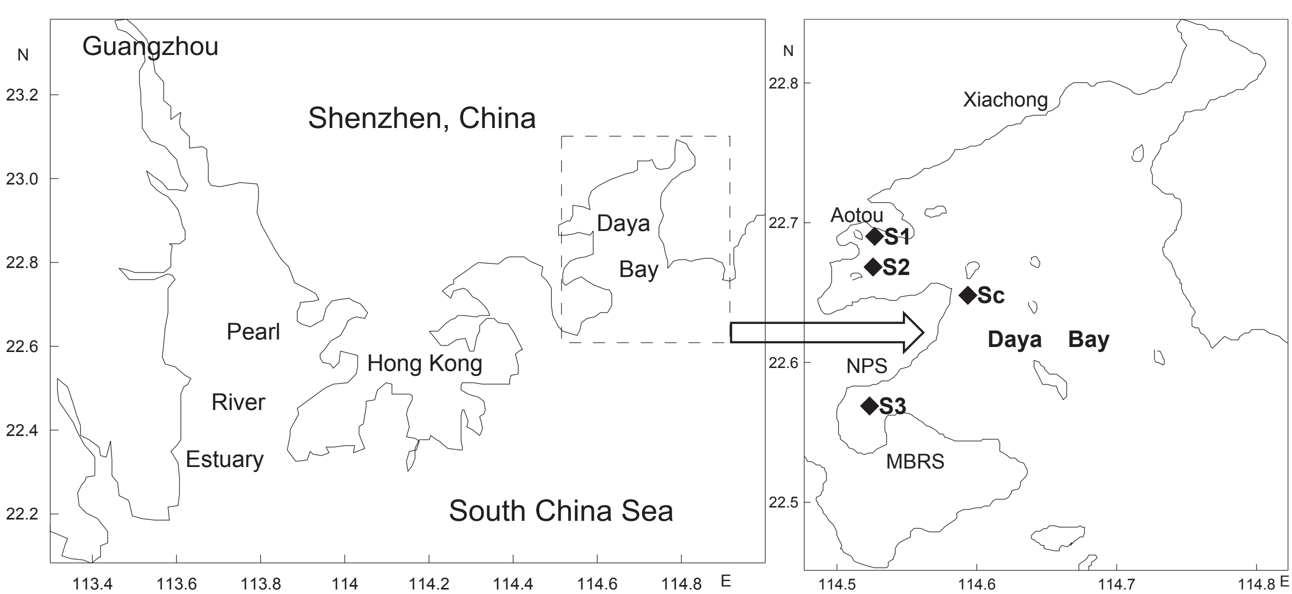

Fig. 1. Sampling locations in Daya Bay, South China.