Metals and aquaculture: Effects on sediment, benthos and fish

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Abstract

Concentration of metals in sediments and tissues of farmed and wild fish aggregating around farm cages and in benthos were investigated at fish farms in the Eastern Mediterranean Sea. In fish farms with anoxic substrata, metal concentrations were higher in sediment, in liver and gills of fish than in the respective samples from fish farms with oxic substrata. The behavior and bioavailability of metals were affected by changes in sediment grain size, organic content and redox regime. Seabass specimens were found to accumulate more metals than seabream. Wild fish accumulated more metals than farmed ones. Consumption of fish should be considered as safe for human health with the exception of some wild fish.

Keywords: farmed fish; wild fish aggregations; benthic macroinvertebrates; bioaccumulation; geochemistry

1. Introduction

Aquaculture currently provides a considerable proportion of edible fish which is expected to increase in future decades in order to meet the needs of the growing human population. However, fish farms affect the surrounding environment by increasing the amount of organic material, sulphides and fine particles in sediments and by reducing their redox potential of sediment (Karakassis et al., 1998). Metals can be bound by fine sediment particles, organic matter and sulphides and are made less bioavailable to aquatic animals (Kalantzi et al., 2013a; b). But resuspension and redistribution of sediments can re-oxidize sediment and release metals from the sediments to the water column, making them more bioavailable (Eggleton & Thomas, 2004).

Fish consumption is fundamental for human diet and the maintenance of good health due to important nutrients and micro- and macroelements. However, fish may also contain undesirable substances (Szlinder-Richert et al., 2011). Metal accumulation in different fish species may be affected by many factors such as size, sexual maturity, seasonal changes, feeding habits, trophic level, water quality and environmental contamination (Saha et al., 2006). Macroinvertebrates may accumulate metals from their environment through various pathways, including water, diet and/or sediment (Saha et al., 2006). However, the effectiveness of metal uptake from these sources may vary according to ecological needs and metabolism of animals and also environmental variables (Saha et al., 2006; Eggleton & Thomas, 2004). The main objective of this study was to determine the distribution of metals in different marine environmental matrices (sediment, fish, benthic macroinvertebrates) originating from fish farms with different background conditions. The overall aim of this study was to investigate whether sediment geochemistry plays an important role in elemental distributions in sediments and in the bioaccumulation and bioavailability of metals to organisms that inhabit the environment surrounding the fish cages.

2. Materials and methods

Samples were collected from seabass (Dicentrarchus labrax) and gilthead seabream (Sparus auratus) farms in two different sites in the Aegean Sea (AEG1 and AEG2) and two in the Ionian Sea (ION1 and ION2), Greece. Sediment samples were collected by scuba divers under the cages (0 m) as well as at 5, 10, 25 and 50 m from the edge of the cages downstream in the dominant current...
direction and from reference stations located at 400-1000 m from each farm. Farmed and wild fish tissues (muscle, liver, gills, bone, intestine, gonads, stomach, and stomach content) and macrofaunal taxa were also sampled. Sampling sites are described in detail in Kalantzi et al. (2013a; b). Physical and geochemical characteristics (percent of silt content, redox potential, sulphide content, refractory organic matter, labile organic matter, chlorophyll-a, total organic carbon, total organic nitrogen) of sampling sites have been included in Kalantzi et al. (2013a; b). Metal concentrations were determined using the protocols described in Kalantzi et al. (2013a; b; 2014). The estimation of human risk from consumption of farmed and wild fish from fish farms in Greece was assessed according to Kalantzi et al. (2013b).

3. Results

3.1. Metals in sediment

Based on elemental distribution, sediments from the farms were separated into coarse oxidized and silty reduced ones (Fig. 1) and sediments from impacted stations had higher concentrations of metals than from reference stations. In silty and anoxic sediments, element concentrations were higher than in coarse and oxic ones.

![CCA Plot](image-url)

**Fig. 1.** Canonical Correspondence Analysis (CCA) plot illustrating relations between fish farms and environmental variables based on element concentrations accumulated in sediment.

3.2. Metals in farmed and wild fish tissues

Seabass accumulates a greater number of metals in its tissues than seabream (Fig. 2a). Fish reared in sites with coarse, oxic substrata accumulate a greater number of metals with higher concentrations in muscle, bone and intestine and with lower concentrations in liver and gills than fish reared in sites with silty, anoxic substrata. The wild fish from sites with anoxic substrata accumulate...
metals from the ambient habitat in their gills whereas those from sites with oxic substrata concentrate these elements through their diet in their intestine (Fig. 2b). Tissues of wild fish aggregating around farm cages accumulate a greater number of metals than farmed fish (Fig. 3).

![Image 1](image1.png)

**Fig. 2.** nMDS ordination plots for all metals in liver for (a) farmed fish; (b) wild fish from oxic (Δ: AEG1; ◊: ION1) and anoxic (●: AEG2; ■: ION2) sites. Seabass (*D.l*) species (a) and wild fish species from oxic sites (b) are grouped in cycles.

![Image 2](image2.png)

**Fig. 3.** nMDS ordination plots for farmed and wild fish (▲: farmed fish; Δ: wild fish) for all metals in liver collected from (a) oxic and (b) anoxic sites. Farmed fish species are grouped in cycles.

4. Conclusions/Discussion

The behavior of elements and therefore their distribution in sediment is affected by changes in sediment grain size, organic content and redox regime. However, fish farms effects were negligible beyond 25 – 50 m from the edge of the cages. The differences found between farmed fish species
may be attributed to fish physiology (Kalantzi et al., 2015). Furthermore, the differences observed between fish reared in sites with oxic and anoxic substrata may be attributed to feed type, sediment properties (redox, grain size, organic matter, sulphides) and sediment re-suspension (Kalantzi et al., 2015). Habitat, diet, ecological needs, fat content of fish, and protein expression may play an important role in element differences between farmed and wild fish species as well as between the different wild fish species (Kalantzi et al., 2013b). Furthermore, elemental concentrations of benthic organisms were also influenced by sediment geochemistry. Hg and P were found to increase their concentrations from zoobenthos to wild fish aggregating around fish cages feeding on macrofauna (Kalantzi et al., 2014).

Assessment of potential sediment toxicity revealed that Cu, Zn and Fe can cause from threshold to extreme effects on aquatic life in anoxic, fine-grained sediments and As can cause threshold effects in all types of sediment around fish farms (Kalantzi et al., 2013a). Assessment of human health risk showed that consumption of farmed fish should be considered as safe for human health based on their metals concentrations. However, Fe, As and Hg in wild fish aggregating around fish cages may pose a risk for human health. Farmed and wild fish are good sources of P, K, Cr and Se while flathead grey mullet, picarel and comber are excellent sources of Ca and Se (Kalantzi et al., 2013b).

Our results showed that biological characteristics and sediment geochemistry play an important role in metal bioavailability to fish and benthic macroinvertebrates and in metal distribution in sediments. Uneaten fish feed and faeces are the main sources of elements in the sedimentary environment surrounding fish farms. Sediments around fish cages are an important scavenger of elements but also a possible delayed source of these contaminants into the water column due to the changes of environmental conditions induced by aquaculture industry.

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6. References


