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Mercury in environmental samples from a waterbody contaminated by gold mining in Colombia, South America

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Abstract

Environmental samples from a marsh, which receives mercury discharges from a gold mine in Colombia (South America), were evaluated for total mercury content. Mercury concentrations were analyzed in sediments, macrophytes and fish species from different trophic levels. The Mean mercury levels in sediments oscillated between 140 and 355 $\mu g/kg$ whereas in the macrophyte *Eichornia crassipes* levels were between 219 and 277 $\mu g/kg$ with practically no interseasonal variations. The mercury content in the muscle of fish varied depending on the position in the trophic chain and the feeding habits of each species, oscillating between non-detectable (< 7.4 $\mu g/kg$) and 1084 $\mu g/kg$. Seasonal variations were only observed in fish species whose habitats are mostly the bottom sediment. The presence of mercury in some fish appeared to be the result of bioaccumulation rather than a biomagnification processes. This was clearly evidenced in the detritivorous species *Triportheus magdalenae* which obtain their food within the sediments and whose mercury concentrations were significantly higher when compared to the other species including carnivorous. The relatively low mercury concentrations found in fish may be due to both the dispersion of the contaminant once it reaches the waterbody and the migrational characteristics of the fish species.

Keywords: Mercury; Gold mining; Fish; Macrophyte; Sediment

1. Introduction

The small gold mining industry is a source of income for many people in South America. However, there is a generalized environmental concern because most of the gold is extracted by mercury amalgamation, leading to the posterior introduction of this metal into the ecosystems. It has been established that populations exposed even to low levels of mercury can develop alterations in their nervous system functions with neurophysiological consequences (Lebel et al., 1996). Some symptoms of mercury intoxication have been detected among fishermen and miners living in marshes

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located near gold mines in Colombia (Olivero et al., 1995). Most of those people use fish as their primary source of protein and the incorporation of mercury in the food chain has not been investigated yet. In this work we report the content of mercury in some environmental samples collected from a marsh which receives direct incorporation of residues coming from gold extraction, mostly mercury and sand. This marsh, Mina Santa Cruz, belongs to the freshwater ecosystems that surrounds the Magdalena River, which carries the contamination downstream for more than 300 km, providing food sources to approx. 1 million people in north-western Colombia. This paper assesses the environmental impact of the gold mine in this marsh by measuring mercury concentrations in different abiotic and biotic samples.

2. Materials and methods

2.1. Study area and sampling periods

The Mina Santa Cruz marsh (Fig. 1) is a freshwater ecosystem which is located in north-western Colombia (8°42′–8°45′ N and 74°10′–74°14′ W). Next to this waterbody is one of the largest gold mines in Colombia, where approx. 5000 people live and consume fish from the surrounding marsh. From February to August 1996, different environmental samples were collected from this waterbody in three separated sampling periods including both the dry (February 1996) and the rainy season (June and August 1996).

2.2. Environmental samples

Sediments: Bottom sediment was collected manually and stored in polyethylene bags for transportation. In the laboratory the samples were dried at 40°C and the fraction < 63 μm was used for analysis (Gonzalez, 1991). Organic matter was measured in this fraction by using dichromate oxidation with diphenylamine as an indicator.

Macrophyte: Root samples of *Eichornia crassipes*, a floating representative species of the area, were collected from adult plants with green leaves and rinsed initially with marsh water and then with distilled water. Drying was done at room temperature for 24 h. Mercury concentrations for

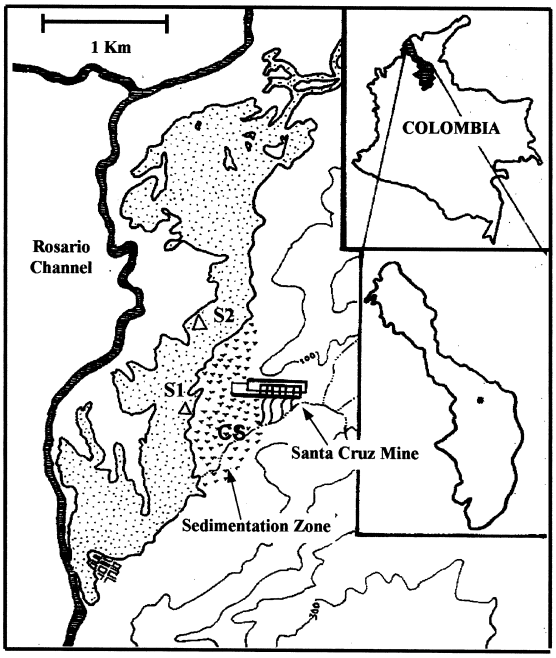

Fig. 1. Localization of the study area. S1 and S2, Stations 1 and 2, respectively; CS, site from where the core sediment was taken.

roots and sediments were corrected for humidity at 105°C for 6 h.

Fish: Collected fish belong to different trophic levels including the phytoplanktonic *Prochilodus reticulatus magdalenae* (Bocachico) and *Curimata mivartii* (Vizcaina), detritivorus with tendency to zooplanktonic *Triportheus magdalenae* (Arenca) and *Curimata magdalenae* (Pincho); and the carnivorous *Petenia krauusii* (Mojarra amarilla), *Aequidens pulcher* (Mojarra azul), *Plagioscion surinamensis* (Pacora) and *Hoplias malabaricus* (Moncholo).

2.3. Mercury analysis

After measuring length, fish were eviscerated and transported frozen to the laboratory. Dorsal muscle dissected using plastic knives was used for total mercury analysis by cold vapor atomic absorption spectroscopy after acid digestion. Fish and macrophytes were digested at temperature between 100 and 110°C (Sadiq et al., 1991) for 3 h and sediments at 90–95°C for 45 min (Coquery and Welbourn, 1995). All the determinations were made in duplicate and quality control was done by using both certified material and recovery of mercury in spiked samples, according to a previous paper (Olivero et al., 1997).

2.4. Statistics

Data were presented as mean ± S.E. of duplicate determinations. In samples below the detection limit (7.4 μg/kg), a mean value equal to half of the detection limit value was used for statistical analysis. The evaluations of the different mean mercury concentrations among species and sampling periods were performed by ANOVA. Where significant differences were observed means were compared using the *t*-test. Correlations between mercury content and fish length were obtained by linear regression. For all statistical analysis, the criterion for significance was $P < 0.05$.

Table 1
Total mercury concentrations (μg/kg wet wt.) in environmental samples collected in the Mina Santa Cruz marsh during the dry and rainy season

Species	*n*	Total mercury (μg/kg wet wt.)		
		Mean ± S.E.		Range
Dry season				
Fish				
Prochilodus reticulatus magdalenae	4	30 ± 4		20–38
Curimata mivartii	5	35 ± 11		15–62
Triportheus magdalenae	5	386 ± 69		188–1084[c]
Curimata magdalenae				
Station 1	17	104 ± 20		21–299
Station 2	10	44 ± 7		19–92
Macrophytes				
Eichornia crassipes	7	219 ± 30		126–315
Sediments				
Station 1	cs		355 (1.02 ± 0.035)[b]	
Station 2	cs		140 (3.04 ± 0.035)[b]	
Rainy season				
Fish				
Prochilodus reticulatus magdalenae	11	50 ± 13		11–129
Curimata mivartii	2[a]	35 ± 4		31–38
Triportheus magdalenae	3	94 ± 16		76–126
	4[a]	105 ± 32		37–180
Curimata magdalenae	17[a]	40 ± 12		DL–221
Aequidens pulcher	2[a]	40 ± 11		29–50
Petenia krauusii	5	127 ± 35		40–230
Hoplias malabaricus	1	322		—
Plagioscion surinamensis	1	195		—
Macrophytes				
Eichornia crassipes	9	225 ± 21		114–340
	7[a]	277 ± 27		206–432
Sediments				
Station 1	cs		393 (3.30 ± 0.052)[b]	
Station 2	cs		141 (3.05 ± 0.025)[b]	

[a]Sampled August 1996 (rainy season); DL, detection limit (7.4 μg/kg, wet wt.); cs, composite sample.
[b]Percentage of organic matter.
[c]Value excluded from the mean calculation.

3. Results

Table 1 shows the total mercury characterization in environmental samples from the Mina Santa Cruz marsh during the dry and rainy season, respectively.

The analysis of mercury in muscle sections of fish with low and high mercury concentrations, the phytoplanktonic *Prochilodus reticulatus magdalenae* and the carnivorous *Hoplias malabaricus*, respectively, appears in Fig. 2. The data reveal that mercury is almost homogeneously distributed among the muscle tissues.

Table 2 shows the results of the *t*-test for intra and interseason comparisons between some fish species.

Mercury and organic matter were analyzed in sediment samples taken from two different sites (S1 and S2 in Fig. 1). These stations were approx. 500 m distant from one another and sediment samples were collected for both the dry and the rainy season, in addition, specimens of *Curimata magdalenae* were captured in each station for the dry season. Significant statistical differences were observed for mercury concentrations in sediments between stations during each season but not between seasons. Samples of *Curimata magdalenae* collected during the dry season showed differences between stations, with the mercury concentrations in Station 1 double those of Station 2, which is in agreement with the mercury concentrations observed in the respective sediments.

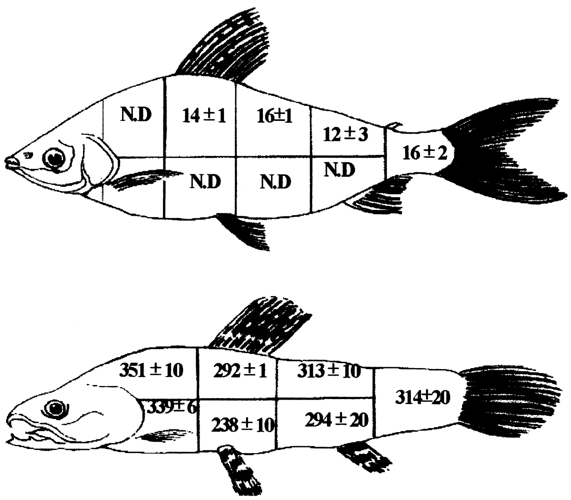

Fig. 2. Distribution of mercury in low- and high-contaminated fish from the Mina Santa Cruz marsh.

Table 2
Comparisons between mercury fish concentrations among species and seasons, according to the *t*-test

	Pr	Tm	Cm	Cmi
Pr	—	*	—	—
Tm	**	**	*	—
Cm	—	**	*	—
Cmi	—	**	—	—

*Statistically significant ($P < 0.05$); **($P < 0.01$); — no statistical differences at $P < 0.05$.
Abbreviations: Pr, *Prochilodus reticulatus magdalenae*; Tm, *Triportheus magdalenae*; Cm, *Curimata magdalenae*; Cmi, *Curimata mivartii*.
Notes: Comparisons between species in the dry season and rainy season appears on the right and the left side of the diagonal, respectively. Diagonal values represent the differences between seasons.

To determine the prevalence of mercury in the marsh sediment, we collected a sediment core sample of 60 cm in length, approx. 100 m from the waste water discharge (CS in Fig. 1) and at 1.5 m depth. Fig. 3 shows the results of the mercury analysis and organic matter performed from cross-sectional samples taken every 3 cm from the sediment core. It can be seen that the presence of high mercury concentrations was found only superficially as a result of recent mercury discharge which has not been dispersed.

4. Discussion

From Table 1 it is clear that there was a wide distribution of mercury at the different levels of the trophic chain, and most of the fish samples fell below the international accepted limit of 500 μg of mercury/kg, as a guideline for human consumption (WHO, 1991).

During the dry season the highest and lowest mercury values were found in the detritivorous *Triportheus magdalenae* and the phytoplancktonic *Prochilodus reticulatus magdalenae*, respectively.

The high concentration of mercury observed in *Triportheus magdalenae* (one sample was > 1 mg/kg) was consistent with the fact that those

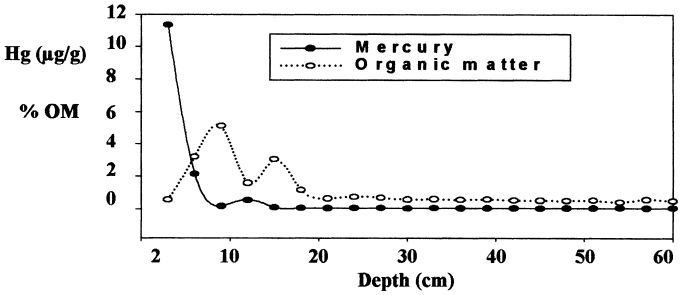

Fig. 3. Mercury and organic matter in a sediment core from the Mina Santa Cruz marsh.

fish search for their food within the bottom sediments where the mercury is present. This observation may imply a bioaccumulation of the metal in this species, considering that detected mercury concentrations in carnivorous species, such as *Petenia krauusii* and *Hoplias malabaricus* were lower than those observed in Arenca, which is a detritivorous species. Furthermore, although the rainy season is characterized by a more homogeneous distribution of mercury among species compared to the dry season, the bioaccumulation process is still evident in Arenca. During the rainy season mercury concentrations in Arenca were almost four times lower than those observed in the dry season. In general, mercury concentrations found for phytoplancktonic and carnivorous fish are in agreement with those found in a similar place in Brazil (Palheta and Taylor, 1995).

During the dry and rainy season significant differences were observed for mercury concentrations between *Triportheus magdalenae* and the rest of the species (Table 2), except in the rainy season where no statistical differences were observed when compared with *Curimata mivartii*, probably due to dilution processes. *Triportheus magdalenae* and *Curimata magdalenae*, species which search for food on the bottom sediment, showed interseasonal differences in mercury content with higher values during the dry season.

The fact that mercury concentrations for *Curimata magdalenae* were in agreement with the content of mercury in sediments, even when the stations are relatively close, can be partially explained considering that this species is a non-migratory detritivorous fish. Furthermore, this species obtains its food from sediment, similar to other tropical species which can directly and rapidly accumulate the inorganic mercury without biomagnification (Oliveira et al., 1996)

Because there seems to be a direct correlation between the mercury concentration in the muscle of *Curimata magdalenae* and the content in the sediments, we suggest this species as an indicator of mercury contamination.

The primary consumers *Prochilodus reticulatus magdalenae* (Bocachico) and *Curimata mivartii* (Vizcaina) were the species with the lowest levels of mercury in muscle. These results suggest that the consumption of Bocachico, the most important fish in the diet of fishermen in Colombia, when collected from the Mina Santa Cruz marsh may produce a low risk of mercury contamination, especially among those people who do not eat it daily. However, all kinds of fish consumption from this marsh should be avoided if food is available from uncontaminated sources.

No significant relationships were found between the mercury content and fish length for the studied species except for *Triportheus magdalenae* which during the dry season showed a significant inverse correlation ($r = -0.93$; $P = 0.02$). This was presumably due to the fact that some caught-fish could have come from low-contaminated sites where the environmental conditions were better than in Mina Santa Cruz, showing less mercury content and a larger length similar to that observed for the carnivorous species Barbudo (Olivero et al., 1997).

Interseasonal statistical differences were not observed between mercury concentrations for the macrophyte *Eichornia crassipes*. Although it has been recognized that plants with floating leaves can bioaccumulate high concentrations of mercury (Samecka and Kempers, 1996), it was not detected (< 7.4 μg/kg) in *Eichornia crassipes* collected from a control marsh located in a different area (8°46′–8°48′ N and 75°6′–75°8′ W) even though mercury concentrations in sediments (112 ± 24 μg/kg) were similar to those found in Station 2, Mina Santa Cruz. The observed differences between the two marshes may be explained considering factors, such as microbiological activity, depth and nature of sediments.

Mercury in sediments varied significantly between stations which were not considerably distant one from another (see Fig. 1 and Table 1). In addition, their concentrations did not change drastically among seasons.

The release of material contaminated with mercury into the marsh produces a local accumulation of this metal near the discharge site. It is clear in Fig. 3 that during the first 20 cm of sediments, mercury and organic matter varied inversely indicating fluctuating periods of high discharge followed by organic matter deposition between them. After 20 cm, both mercury and organic matter are constant, which may be an indicator of high depuration rates in the marsh due to water interchange with the river. This fact could partially explain the relatively low mercury concentrations found in fish, compared to those reported for other gold mining contamination of freshwater ecosystems (Boischio and Henshel, 1996; Bidone et al., 1997).

Although the Mina Santa Cruz marsh directly receives water contaminated with mercury, this ecosystem is highly dynamic which diminishes the grade of mercury accumulation. Additionally, constant displacement of floating macrophytes and the migratory nature of most of the analyzed fish can result in a diffusion of the contamination everywhere.

It is possible to conclude that the environmental samples taken from the Mina Santa Cruz marsh have a mercury distribution dependent on the position in the trophic chain but with relatively low values in most of the species. An exception is *Triportheus magdalenae*, whose consumption is relatively high among fishermen, increasing the risk of mercury contamination. However, additional data related to the dynamics of the mercury in this waterbody is of great importance for determining the extent of contamination along the waterbodies around this marsh.

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