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Mercury in lakes and lake fishes on a conservation-industry gradient in Brazil

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Abstract

Mercury contamination in freshwater food webs can be severe and persistent, and freshwater fish are a major source of mercury contamination in humans. Northern hemisphere studies suggest that the primary pathway by which freshwater fish accumulate mercury is the food web, and that atmospheric deposition is the primary route by which mercury enters freshwater systems. Levels of atmospheric deposition are closely linked to proximity to sources of mercury emissions. These propositions have not been tested in the southern hemisphere. In this study, we measured mercury levels at three lakes in southern Brazil and assessed relationships between mercury in precipitation, lake water, sediment and fish tissues at sites close to (industrial and suburban areas) and distant from (protected conservation area) sources of mercury emissions. We also assessed relationships between mercury in fish species and their trophic habits. Mercury concentrations in sediment and lake water did not vary among lakes. In contrast, mercury in precipitation at the study lakes increased with proximity to industrial sources. Mercury in fish tissue generally increased along the same gradient, but also varied with trophic level and preferred depth zone. Atmospheric mercury deposition to these closed lakes may be directly linked to concentrations in fish, with surface-feeding piscivorous species attaining the highest concentrations.

Keywords: Fish; Lake; Mercury contamination; Sediment; South America; Trophic level

1. Introduction

The human-health risk posed by mercury contamination in fish has been known for about 50 years (Harada, 1995). Despite this, biogeochemical pathways leading to contamination, and the geographic scale of the problem are still unclear. Mercury concentrations in lake fish have been shown to vary with sediment microflora, pH and organic carbon, among other factors (Bodaly et al., 1993; Gorski et al., 2003). These observations suggest that unique aspects of mercury cycling have strong effects on fish contamination. Variation in mercury concentration among fish species in single lakes (Jackson, 1991; Snodgrass et al., 2000) suggests that feeding behaviour and/or physiology are also critical factors.

The ultimate source of mercury to most lake basins is atmospheric deposition (Meili et al., 2003). Upon entering lakes, mercury undergoes complex transformations before being ingested by fish. Consequently, relationships between mercury concentrations in lake water and in fish are often weak (Sorensen et al., 1990). Most

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of the mercury assimilated in fish is monomethylmercury, and some lakes with large inorganic mercury stocks have low rates of mercury methylation (Gorski et al., 2003). Furthermore, direct mercury uptake from water by diffusion through gill epithelia accounts for only a small proportion of mercury in fish tissues (Hall et al., 1997). Relationships between mercury in sediments and fish are generally stronger, partly because mercury methylation is carried out by sediment-dwelling sulfate-reducing bacteria (Morel et al., 1998). Relationships between mercury in prey items and in fish are generally even stronger, because food is the dominant source of methylmercury, and consumption of food containing methylmercury leads to accumulation in fish tissues (Downs et al., 1998).

Within lakes, mercury concentrations in fish species that occupy high trophic levels (e.g., piscivores and zooplanktivores) are generally greater than in species at lower trophic levels (e.g., detritivores and herbivores) (Kidd et al., 1995; Snodgrass et al., 2000). These observations provide evidence of biomagnification, or incremental increases in concentration with successive trophic levels. Detailed relationships between trophic structure in lakes and mercury accumulation have not been developed, however. This is due in part to the confounding effects of variation in food availability and feeding habits (e.g., ontogenetic diet shifts).

Mercury contamination of lakes is a global phenomenon, not limited to areas of high-level local mercury emissions. Studies in the northern hemisphere indicate that many seemingly pristine lakes have been contaminated by atmospheric deposition (e.g., Bindler et al., 2001). Comparable data for South America are urgently needed, as mercury production and emissions in South America have increased sharply in the last decade, despite declines in global production (Hylander and Meili, 2003).

In this study, we examined mercury levels in lakes of the coastal savannah (pampas) of southern Brazil. Mercury contamination has been reported in estuaries of this region (Niencheski et al., 2001; Mirlean et al., 2003), but freshwater systems have not been examined. Lakes in the region support artisanal fisheries, and have diverse fish, invertebrate and bird faunas (e.g., Hartz et al., 2000). We assessed relationships between mercury in precipitation, lake water, sediment and fish tissues, and the intensity of human land use (from conservation to heavy industry), and between mercury in fish species and their trophic habits.

2. Methods

2.1. Study sites and species

The lakes used for the study are in the swamp-pampas of coastal southern Brazil. One of the lakes is natural and two are man-made (Table 1). Due to very flat topography, lakes in the region have few or no tributary streams; direct rainfall and groundwater are the major water and contaminant sources. One study lake was located in each of three regions representing a gradient in anthropogenic impact. The highest impact was expected in the lake (unnamed) located in an industrial zone of the city of Pelotas. There are numerous potential sources of mercury emissions within 5 km of the Pelotas lake, including chemical and pharmaceutical factories, railways and an urban dumpsite. Intermediate impact was expected in the lake (also unnamed) located in the suburbs of Rio Grande City. The suburb is primarily residential, but is within 10 km of a petroleum refinery and fertilizer factories. The lowest impact was expected in Lake Flores, located in the federally-protected Taim Ecological Station. This lake is 35 km from the nearest highway, 5 km from any residence, and >80 km from industrial sources of mercury emissions.

The suburban and natural lakes were both South of the industrial area (Fig. 1). The industrial area may have been a source of atmospheric mercury to the suburban and natural lakes in the summer and autumn, when prevailing winds are northeasterly, but rarely in the winter and spring, when prevailing winds are southerly.

The water columns of the study lakes are slightly acidic (pH ~ 6) and well-oxygenated (dissolved oxygen

Table 1
Study lake characteristics, dimensions, and average physical/chemical conditions during the study

Lake designation and location	Lake origin	Area (m^2)	D_m (m)	Volume (m^3)	pH	EC ($\mu S\ cm^{-1}$)	TSS ($mg\ l^{-1}$)	DO ($mg\ l^{-1}$)	SOC (%)
Natural, Lake Flores, Taim Ecological Station	Natural (pampas)	7050600	2.9	20445000	6.1	85	28.0	10.2	0.43
Suburban, unnamed Rio Grande City	Man-made (reservoir)	3750	3.5	6625	6.2	119	31.0	9.7	0.37
Industrial, unnamed Pelotas City	Man-made (sand quarry)	14250	3.2	13530	6.2	134	71.5	8.8	0.70

Abbreviations: D_m—maximum depth, EC—electrical conductivity, TSS—total suspended sediment, DO—dissolved oxygen, SOC—sediment organic carbon at lake bed surface.