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Large-scale projects in the amazon and human exposure to mercury: The case-study of the Tucuruí Dam

Gabriela P.F. Arrifano[a], Rosa C. Rodríguez Martín-Doimeadios[b], María Jiménez-Moreno[b], Vanesa Ramírez-Mateos[b], Núbia F.S. da Silva[a], José Rogério Souza-Monteiro[a], Marcus Augusto-Oliveira[c], Ricardo S.O. Paraense[a], Barbarella M. Macchi[d], José Luiz M. do Nascimento[d], Maria Elena Crespo-Lopez[a,*]

[a] Laboratório de Farmacologia Molecular, Instituto de Ciências Biológicas, Universidade Federal do Pará, Belém, Brazil

[b] Department of Analytical Chemistry and Food Technology, Faculty of Environmental Sciences and Biochemistry, University of Castilla-La Mancha, 45.071 Toledo, Spain

[c] Laboratório de Investigações em Neurodegeneração e Infecção no Hospital Universitário João de Barros Barreto, Instituto de Ciências Biológicas, Universidade Federal do Pará, Belém, Brazil

[d] Laboratório de Neuroquímica e Biologia Celular, Instituto de Ciências Biológicas, Universidade Federal do Pará, Belém, Brazil

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ABSTRACT

The Tucuruí Dam is one of the largest dams ever built in the Amazon. The area is not highly influenced by gold mining as a source of mercury contamination. Still, we recently noted that one of the most consumed fishes (*Cichla* sp.) is possibly contaminated with methylmercury. Therefore, this work evaluated the mercury content in the human population living near the Tucuruí Dam. Strict exclusion/inclusion criteria were applied for the selection of participants avoiding those with altered hepatic and/or renal functions. Methylmercury and total mercury contents were analyzed in hair samples. The median level of total mercury in hair was above the safe limit (10 µg/g) recommended by the World Health Organization, with values up to 75 µg/g (about 90% as methylmercury). A large percentage of the participants (57% and 30%) showed high concentrations of total mercury (≥ 10 µg/g and ≥ 20 µg/g, respectively), with a median value of 12.0 µg/g. These are among the highest concentrations ever detected in populations living near Amazonian dams. Interestingly, the concentrations are relatively higher than those currently shown for human populations highly influenced by gold mining areas. Although additional studies are needed to confirm the possible biomagnification and bioaccumulation of mercury by the dams in the Amazon, our data already support the importance of adequate impact studies and continuous monitoring. More than 400 hydropower dams are operational or under construction in the Amazon, and an additional 334 dams are presently planned/proposed. Continuous monitoring of the populations will assist in the development of prevention strategies and government actions to face the problem of the impacts caused by the dams.

1. Introduction

Mercury exposure is a serious public health problem in the Amazon. Since 2013, Brazil, along with 128 countries, became a signatory of the Minamata Convention on Mercury (www.mercuryconvention.org), with the aim of adding international efforts to reduce and combat environmental and human exposure to this metal. The World Health Organization (WHO) endorsed this action in January 2014 (available at: http://apps.who.int/gb/ebwha/pdf_files/EB134/B134_R5-en.pdf).

Traditional gold mining is one of the main economic resources for the human population in the Amazon, using mercury to extract the gold particles found in the rivers. In the 1990s, the activity of traditional small-scale gold mining sites (named *garimpos* in Brazil) was responsible for the emission of up to 120 t of mercury per year into the environment (Veiga, 1997). Thus, in recent decades, *garimpos* and the contaminated areas downstream have been routinely monitored for human exposure to this metal (Berzas Nevado et al., 2010).

Other factors, such as river damming, may show the potential to facilitate mercury accumulation in the Amazonian environment. Both mercury methylation and bioaccumulation may be increased by submerging terrestrial areas (peatlands, upland soils, and vegetation) (Bodaly et al., 1997). Some hypotheses account for this general, if not

* Correspondence to: Laboratorio de Farmacologia Molecular, Instituto de Ciências Biológicas, Universidade Federal do Pará, Av. Augusto Correa, 01. Campus do Guamá, 66075-110 Belém, PA, Brazil.
E-mail address: maria.elena.crespo.lopez@gmail.com (M.E. Crespo-Lopez).

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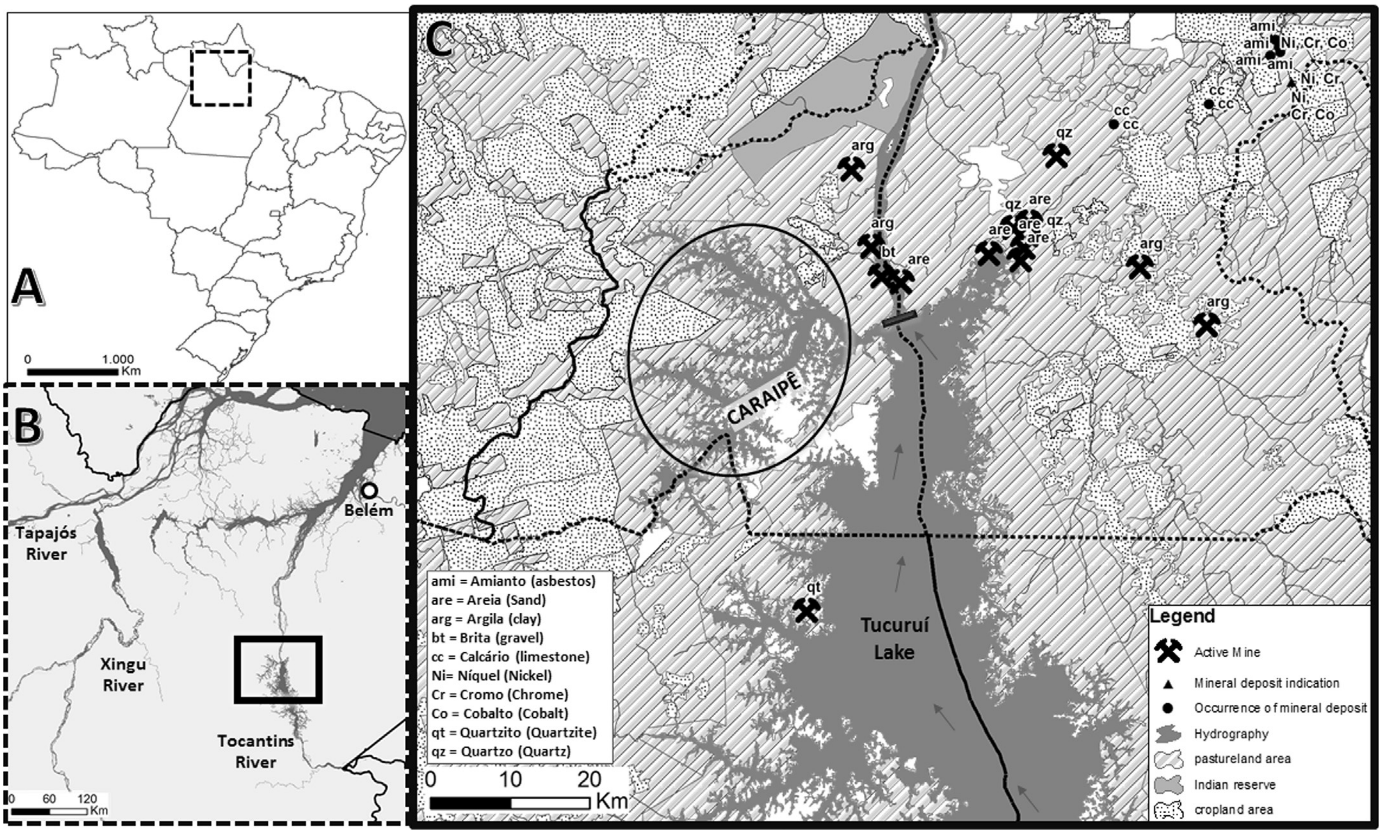

Fig. 1. Maps of Brazil (A), State of Pará (B) and Tucuruí (C). In C, the two communicated compartments (Caraipé and Lake) of the reservoir are shown in addition to the water flow, the dam (black bar), the land use and the present active mine points (note that none of these points are for gold extraction). Participants of the study were from Caraipé (area included in the circle). Maps were obtained from the Instituto Brasileiro de Geologia e Estatística (IBGE, Brazil), Departamento Nacional de Produção Mineral (DNPM, Brazil) and Ministério da Agricultura, Pecuária e Abastecimento (MAPA, Brazil).

universal, effect of impoundment: the degradation of organic carbon by microbiota and oscillations of temperature, and redox status of reservoirs, among others (Kelly et al., 1997). This occurrence has been repeatedly registered in reservoirs of different regions of the globe with no known sources (anthropogenic) of mercury (Bodaly et al., 2007; Berzas Nevado et al., 2009; Gray and Hines, 2009; Li et al., 2013; Johnson et al., 2015).

An increased number of dams are in different development or operational stages, occupying about 100,000 km^2 (or 3% of Brazil's Amazon forest) (Fearnside, 1995). Recently, the Brazilian government has approved the construction of several dams on the rivers of the Amazon rainforest, in order to provide electricity for some large cities in the country and to attend the growing industrial necessity (especially that of the Aluminum Industry) (Fearnside, 2016). The impacts of these dams will profoundly affect the environment and human health of the riverside populations of the Amazon. Yet, studies of human exposure to mercury in dam areas in the Amazon are scarce.

One of the largest dams ever built in the Amazon is the Tucuruí Dam in Tocantins River basin, East Amazon (Fig. 1 and Table 1). After its completion in 1984, this dam caused the inundation of 2430 km^2, generating the displacement of the local population, and exacerbating insect proliferation and the incidences of endemic diseases such as malaria (Fearnside, 2001). It generates electricity for a major part of the country; still, it remains controversial because of the absence of adequate studies about the environmental impact and sustainable development (Fearnside et al., 2001).

Different from other regions in the Amazon (such as Tapajós River basin), the Tucuruí area is not highly influenced by *garimpos* using mercury. About 50 years ago, mining activity was drastically reduced because it was not enough lucrative economically. Still, works in the past indicated mercury contamination in this environment (Aula et al., 1995; Porvari, 1995; Palermo et al., 2004; Kehrig et al., 2008, 2009; Rodríguez et al., 2014). Mercury was detected in water and sediments with values of 12.7 ± 8.4 ng/l and 0.012–0.037 μg/g, respectively (Aula et al., 1995; Kehrig et al., 2009). Also, floating plants such as *Eichhornia crassipes* or *Scirpus cubensis* showed levels of mercury as high as 0.075 ± 0.038 μg/g, especially concentrated in the roots of the plants (Aula et al., 1995). The highest contents of mercury were found in fish of this region, according to their positions in the food chain. Herbivorous fish such as *Anostomidae* sp. and *Prochilodus nigricans*

Table 1
Geological and limnological characteristic of Tucuruí reservoir.

Geographic localization	03°43´ – 05°15´S 49°12´ – 50°00´W
Main tributary[a]	Tocantins River
Drainage area (km^2)[a]	803,250
Inundated area (km^2)[a]	2875
Maximum depth (m)[a]	75
Total volume (km^2)[a]	45.5
Average flow (m^3/s)[a]	11,000
Water color[a]	Clear water
Trophic stage[a]	Mesotrophic
pH[a]	6.5 – 7.4
Conductivity (μS/cm)[a]	47 – 62
Vegetation[a]	Humid forest
Water Hg levels (ng/L)[b]	4.7 – 28.2
Sediments Hg levels (μg/g)[c]	0.012 – 0.037
Predatory fish Hg levels (μg/g)[d]	0.66 – 4.00

Note: Data from
[a] Espindola et al. (2000).
[b] Kehrig et al. (2009).
[c] Aula et al. (1995).
[d] Rodríguez et al. (2014).

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