Environmental Research 151 (2016) 286–296

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Mercury biomagnification and the trophic structure of the ichthyofauna from a remote lake in the Brazilian Amazon

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ARTICLE INFO

Article history:
Received 5 April 2016
Received in revised form
20 July 2016
Accepted 23 July 2016

Keywords:
Trophic magnification factor
Fish
Migration
River-floodplain system
Mercury

ABSTRACT

The present study assesses mercury biomagnification and the trophic structure of the ichthyofauna from the Puruzinho Lake, Brazilian Amazon. In addition to mercury determination, the investigation comprised the calculation of Trophic Magnification Factor (TMF) and Trophic Magnification Slope (TMS), through the measurements of stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in fish samples. These assessments were executed in two different scenarios, i.e., considering (1) all fish species or (2) only the resident fish (excluding the migratory species). Bottom litter, superficial sediment and seston were the sources used for generating the trophic position (TP) data used in the calculation of the TMF. Samples from 84 fish were analysed, comprising 13 species, which were categorized into four trophic guilds: iliophagous, planktivorous, omnivorous and piscivorous fish. The $\delta^{13}C$ values pointed to the separation of the ichthyofauna into two groups. One group comprised iliophagous and planktivorous species, which are linked to the food chains of phytoplankton and detritus. The other group was composed by omnivorous and piscivorous fish, which are associated to the trophic webs of phytoplankton, bottom litter, detritus, periphyton, as well as to food chains of igapó (blackwater-flooded Amazonian forests). The TP values suggest that the ichthyofauna from the Puruzinho Lake is part of a short food web, with three well-characterized trophic levels. Mercury concentrations and $\delta^{13}C$ values point to multiple sources for Hg input and transfer. The similarity in Hg levels and TP values between piscivorous and planktivorous fish suggests a comparable efficiency for the transfer of this metal through pelagic and littoral food chains. Regarding the two abovementioned scenarios, i.e., considering (1) the entire ichthyofauna and (2) only the resident species, the TMF values were 5.25 and 4.49, as well as the TMS values were 0.21 and 0.19, respectively. These findings confirm that Hg biomagnifies through the food web of Puruzinho Lake ichthyofauna. The migratory species did not significantly change mercury biomagnification rate in Puruzinho Lake; however, they may play a relevant role in Hg transport. The biomagnification rate (TMS value) in Puruzinho Lake was higher than the average values for its latitude, being comparable to TMS values of temperate and polar systems (marine and freshwater environments).

1. Introduction

Mercury (Hg) is a toxic metal whose effects comprise neurotoxicity, nephrotoxicity and genotoxicity, among others (JPHA, 2001; WHO, 2003). This metal presents a complex biogeochemical cycle, which includes biomagnification (Fitzgerald and Mason, 1997; Morel et al., 1998; Barbosa et al., 2003). Newman and Unger (2002) define biomagnification as an increase in concentration of a contaminant from a trophic level to the superior one through feeding, i.e., between prey and predator. Nevertheless, biomagnification is generally associated to the trophic transfer of a contaminant, with a concentration increase through successively

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http://dx.doi.org/10.1016/j.envres.2016.07.035
0013-9351/

higher trophic levels (Kidd et al., 1995; Meili, 1997; Watras et al., 1998). As a result, the highest concentrations are found in the species occupying the highest trophic positions, including human beings (Beek et al., 2000). Mercury biomagnification has been verified by a number of studies comprising different aquatic environments (Lavoie et al., 2013). However, much need to be understood about the subject in Amazon, due to the complexity of its aquatic environments. The generation of more knowledge on pollutant biomagnification in Amazonian environments would be important from the human health point of view as well, given the high importance of fish for the nutrition of Amazonian riparians (Dorea, 2003).

The Amazon basin presents a wide diversity of freshwater ecosystems, with different geomorphological, physicochemical and biological features, including river-floodplain systems (Furch & Junk, 1997; Junk et al., 1989). The floodplain constitutes a mosaic of open waters (lakes and rivers), flooded forests and floating meadows that have their areas and proportions modified according to the water level seasonal variation (Junk et al., 1989, Junk, 1997b). Methylmercury formation and accumulation have been verified in tropical river-floodplain systems (Guimarães et al., 2000a, 2000b; Roulet et al., 2001). These aspects favour Hg biomagnification and the contamination of riparian Amazonian populations, for whom fish constitute the main protein source (Malm et al., 1995; Boischio and Hensel, 2000; Bastos et al., 2006).

Regarding anthropogenic input of Hg, the Amazon region has been the main gold producer in Brazil since the 1970–1980s (Porto et al., 2002). The gold mining activities in Amazon resulted in the release of 87 t of mercury (Hg) to the environment between 1979 and 1990 (Lacerda et al., 1989). Investigations performed in the region during 1980–1990 s attributed the high environmental levels of Hg to these activities (*e.g.* Martinelli et al., 1988; Lacerda et al., 1989; Pfeiffer et al., 1991). At the end of the 1990s however, investigations carried out in the Amazon region demonstrated the high soil Hg concentrations to be of natural origin (Roulet et al., 1998; Lechler et al., 2000; Fadini and Jardim, 2001). A number of studies on mercury have been performed in the region in order to understand both the biogeochemical processes and the toxic effects on riparian populations (*e.g.* Pfeiffer and Lacerda, 1988; Malm et al., 1990; Malm, 1998; Malm et al., 1995; Guimarães et al., 2000a, 2000b; Maurice-bourgoin et al., 2000; Dorea et al., 2006; Bastos et al., 2007; Almeida et al., 2014). Despite being a part of Hg biogeochemical cycle that contributes to the human exposure to this toxic metal, little is known on the trophic flow of Hg through the aquatic Amazonian food webs (Barbosa et al., 2003).

Considering the demonstrated importance of searching for a better understanding of Hg biogeochemical cycle in the region, we propose the following hypothesis (H_1): Hg biomagnifies through the food web of Puruzinho Lake ichthyofauna. In addition, we have tested the importance of migratory species to the calculation of biomagnification rates. The latter testing is based on the fact that Borgå et al. (2012) highlighted that the presence of migratory species may influence the calculation of biomagnification rates. In addition, the fish assemblage of the Amazon region presents a high diversity (Junk, 1997a) with migratory species playing an significant role in energy flow and matter cycling (Hoeinghaus et al., 2006) and hence being important for trace element cycling as well.

2. Study area

This study was performed in Puruzinho Lake, which is part of the Puruzinho River drainage basin (Fig. 1). The Puruzinho River is located at the Lower Plateau of the Western Amazon, covering an area of "cerrado" vegetation downstream to the middle section of

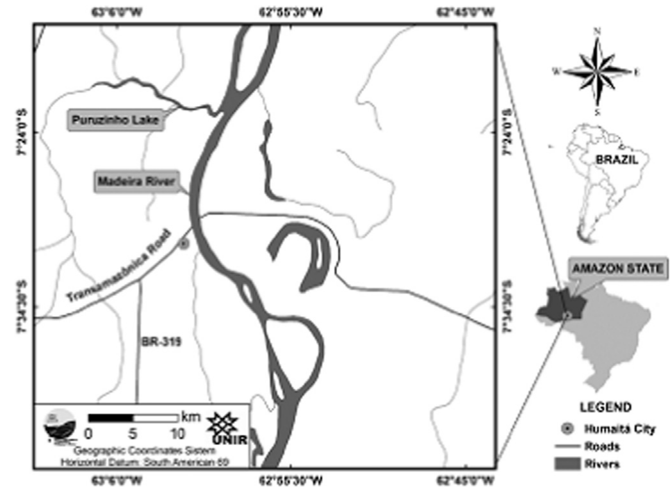

Fig. 1. South American map, highlighting Brazil and the Amazonas state, amplifying the Madeira river basin, as well as stressing Puruzinho Lake (Almeida et al., 2014).

its course. Subsequently, the rivers cover an area of dense ombrophylous forest and rain forest within its area of seasonal flooding (IBGE, 2003; Almeida, 2006). The study area is part of a region characterized by Junk et al. (1989) as a river-floodplain system and presents a monomodal flooding. Puruzinho Lake has an area of 4.84 Km^2 during the dry season and is located between the latitudes 07° 20' 53"S and 07° 22' 38"S and between the longitudes 63° 05' 05" W and 63° 00' 57"W. The lake has been classified as a blackwater system, with anoxic and hypoxic periods in water column (Almeida, 2006; Nascimento et al., 2006; Azevedo-silva, 2011).

3. Material and methods

3.1. Sampling

Sampling was performed in two phases of the Puruzinho Lake hydrological cycle. The first sampling procedure was carried out at the end of the dry season, in September 2006. The second sampling period was in February 2007, during the high water period.

3.1.1. Sampling for the calculation of the baseline

Seston, bottom litter and superficial sediment were used as energy sources (baseline) for the calculation of the trophic position (TP). Seston and bottom litter integrate the isotopic signatures of pelagic and littoral food chains, respectively, corresponding to the input of allocthonous matter to the lake (Post, 2002). Additionally, in tropical river-floodplain systems, bottom litter also integrates the pelagic food chain associated to the igapó (blackwater-flooded Amazonian forests). According to Layman et al. (2005a), the allocthonous production may play an important role for tropical river-floodplain systems. The choice for the superficial sediment was a consequence of the fact that detritivorous/iliophagous fish are key species in tropical riverine environments, being able to predominate the ichthyobiomass of these systems (Bowen, 1983). This turns the superficial sediment into an important source for the benthic food chain (Jepsen and Winemiller, 2002).

Seston sampling was performed through horizontal surface hauls using a 20 μm mesh-size net. In order to reduce the interference from zooplankton, samples were subsequently filtered with a 68 μm mesh-size net. Six seston samples were collected, comprising three samples from each hydrological phase. Bottom