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Original Article

Mercury in Fish from the Xingu River in Environments Influenced by the Belo Monte Hydroelectric Plant, Amazon, Brazil

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Abstract

Hydropower plants are widely recognized for their environmental impacts. These projects can lead to increased mercury (Hg) levels in Amazonian rivers by altering the functioning of these aquatic systems. Our study examined Hg concentrations in water, sediments, and tissues of two fish species in the Xingu River, sampled at eight points (P1 to P8) affected by the Belo Monte Hydroelectric Plant (Pará, Brazil). The highest sediment Hg concentrations were found within the reservoir, while the lowest concentrations were recorded downstream of the reservoir. The peacock bass (*Cichla melaniae*, a piscivorous species) exhibited higher tissue Hg concentrations than the Golden Nugget Pleco (*Baryancistrus xanthellus*, a detritivorous species). Both species showed the same tissue Hg concentration pattern: liver > muscle > gill. In *C. melaniae*, Hg concentrations in all three tissues increased proportionally with body size. In *B. xanthellus,* there was a tendency for gill Hg concentrations to decrease with increasing total length. *B. xanthellus* presented higher Hg concentrations in the reservoir than in other sampling sites. In *C. melaniae*, gill Hg concentrations differed between P1 (upstream of the reservoir and outside the hydroelectric plant's influence) and P3 (in the reduced flow section of the dam). The muscle tissue Hg concentrations of both species remained within the safety limits established by Brazilian legislation for human consumption. This study enabled us to evaluate Hg levels in fish, water, and sediments of the Xingu River after the construction of the Belo Monte Hydroelectric Plant and to compare them with levels observed in other areas influenced by hydropower plants.

Keywords: Anthropogenic impacts, contamination, fish, Potentially Toxic Elements (PTEs), reservoirs; run-of-river.

INTRODUCTION

Mercury (Hg) is a trace metal known for its toxicity and high capacity to cause harmful effects on human and environmental health. This metal can exist in various chemical forms, which can be organic or inorganic (Gustin *et al.,* 2020). Among the different forms of Hg, methylmercury (MeHg) is the most concerning due to its high toxicity (Lee *et al*., 2020). Human exposure to Hg can occur both occupationally (Wang *et al.,* 2021) and through the consumption of contaminated fish (Djermanovic *et al.,* 2020; Faial *et al.,* 2015), with the latter considered the main route of human exposure to Hg. However, depending on the degree of contamination, Hg can cause various adverse health effects in humans, including neurological, immunological, endocrine, reproductive, and embryonic effects (Eagles-Smith *et al.,* 2018).

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In aquatic environments, inorganic Hg can be biologically converted to MeHg by anaerobic microorganisms. This bioconversion is mainly attributed to sulfate-reducing bacteria and methanogenic bacteria (Thomas *et al.*, 2020). This process occurs notably in anaerobic sediments (Zeng *et al.,* 2016). MeHg can bio-magnify in the food chain (Crespo-Lopez *et al.,* 2021), and consequently, higher concentrations of Hg can be found in higher trophic levels (Lee and Fisher, 2017).

The bioaccumulation of Hg in fish, for example, can be influenced by various factors, such as the feeding habits (de Castro Paiva *et al.,* 2022), age and body size (Sinkus *et al.,* 2017), physiological characteristics (Baskaran *et al.,* 2019), and abiotic factors such as pH and dissolved organic carbon in the water at the fish habitat (Ma *et al.,* 2019). Additionally, the degree of Hg contamination in the environment is another important factor that can influence the concentrations of this toxic element in fish.

Fish are widely used organisms in studies assessing environmental damage because they are considered good bioindicators of aquatic pollution (Authman *et al.,* 2015). Consequently, several studies have used fish as bioindicators of heavy metal pollution (Wang and Wang, 2019; Luczynska *et al.,* 2018) since the metal concentrations in the tissues of these organisms can reflect both environmental conditions and indicate the risks associated with human consumption.

Studies have shown that anthropogenic disturbances to aquatic systems, such as the construction of hydroelectric reservoirs, can lead to increased Hg levels in fish (Willacker *et al.,* 2016; Hsu-Kim *et al.,* 2018). This increase is mainly due to the flooding of substantial amounts of organic matter (Bilodeau *et al.,* 2017) during reservoir formation. The inorganic Hg present in the flooded organic matter can be converted to MeHg through microbial methylation (Graham *et al.,* 2013; Bilodeau *et al.,* 2017) and incorporated into the aquatic biota (Clayden *et al.,* 2013).

The Belo Monte Hydroelectric Plant (UHE Belo Monte), located on the Xingu River (3°7'44.41"S, 51°46'43.59"W), is one of the largest hydroelectric developments in the Amazon region and has been operating since 2016. Hydroelectric reservoirs can influence the mobility and bioavailability of Hg in aquatic ecosystems. This influence is mainly associated with the decomposition of flooded organic matter and the consequent increase in methylmercury production (Pestana *et al.,* 2019). Elevated Hg concentrations in fish have been reported in hydroelectric reservoirs. For example, Hylander *et al.* (2006) found higher Hg concentrations in fish from the Manso Hydroelectric Reservoir in Mato Grosso. These findings indicate the importance of monitoring Hg concentrations in recently established reservoirs. However, studies evaluating Hg concentrations in areas affected by the operation of the UHE Belo Monte are still limited. In addition, studies simultaneously assessing Hg levels in water, sediment, and fish from different trophic levels remain scarce. Unlike most Amazonian reservoirs, UHE Belo Monte operates as a run-of-river system, and its operation depends on the natural flow regime of the Xingu River (Fearnside, 2019). Therefore, Hg dynamics in this region may differ from those observed in conventional reservoirs, highlighting the importance of studies that improve our understanding of Hg behavior in areas affected by the operation of the UHE Belo Monte.

This study aimed to investigate the total Hg concentrations in water, sediment, and tissues of two fish species (*Cichla melaniae* and *Baryancistrus xanthellus*) at different locations affected by the Belo Monte hydroelectric complex in the Xingu River. Our hypotheses were as follows: (I) fish from the reservoir exhibit higher Hg concentrations than those caught outside this environment, as the reservoir may have become a suitable site for Hg methylation; (II) due to the trophic position of the two species, it is expected that *Cichla melaniae* (a piscivorous species) would have higher Hg concentrations than *Baryancistrus xanthellus* (a detritivorous species).

MATERIALS AND METHODS

Study Areas

The Belo Monte Hydroelectric Plant (3° 7'44.41"S, 51°46'43.59"W) is located on the Xingu River, one of the main tributaries of the Amazon River. The project covers areas in the municipalities of Altamira and Vitória do Xingu, in the state of Pará, Brazil. The region experiences two well-defined seasonal periods, with April and May being the rainiest months and September and October being the driest, or least rainy, months.

Sampling

Sampling of the fish was done in May 2019 (at the end of the rainy season) at eight collection points influenced by the Belo Monte Hydroelectric Plant (Figure 1), which ensured that all sites were sampled under similar hydrological conditions.

Point 1 (P1) is located upstream of the hydroelectric plant and serves as a reference site not directly influenced by the dam. Point 2 (P2) is in the reservoir area, upstream of the city of Altamira. Points 3 (P3) and 4 (P4) are in the Xingu Reservoir. Points 5 (P5) and 6 (P6) are in the Volta Grande do Xingu, an area impacted by the hydroelectric plant due to a drastic reduction in water flow after the implementation of the Belo Monte hydroelectric plant. This region also has a history of manual gold extraction. P5 is located upstream of the Bacajá River, and P6 is downstream of that river. Point 7 (P7) is located near the main dam's slope, and point 8 (P8) is near the city of Vitória do Xingu, both downstream of Belo Monte. The geographic coordinates of each sampling location are provided in Table S1 (Supplementary Material).

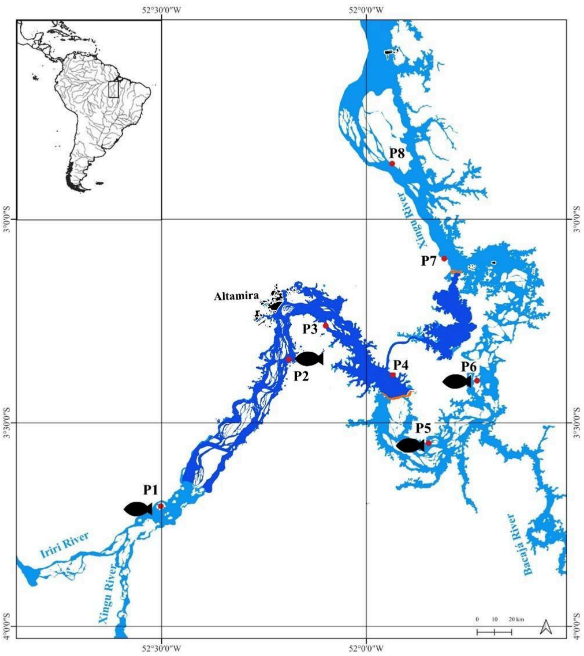

Figure 1. Map of the study area indicating the sampling sites in the Xingu River. Red points represent water and sediment sampling sites; fish icons indicate fish sampling points; orange areas mark dams; and the darker-colored region indicates the reservoir zone.

Fish capture and tissue

Samples of two fish species (*Baryancistrus xanthellus* and *Cichla melaniae*) were collected under authorization SISBIO no. 71763-1. These species have different feeding habits. The Golden Nugget Pleco *Baryancistrus xanthellus* (*Siluriformes: Loricariidae*) is an endemic species of the Xingu River with a detritivorous feeding habit, while the peacock bass *Cichla melaniae* (*Cichliformes: Cichlidae*) is predominantly piscivorous in the adult stage. Due to the distribution of the two species along the study area, fish were only collected at points P1, P2, P5, and P6. Both species do not occur downstream of the hydroelectric plant. *Baryancistrus xanthellus* occurs in the Middle Xingu, from Belo Monte to São Félix do Xingu, and throughout the Iriri River.

The captured fish were anesthetized with eugenol and euthanized according to the procedures approved by the Animal Ethics Committee (CEUA/UFPA) of the Federal University of Pará (UFPA) (No. 8166251119). Subsequently, fish were measured for Total Length (TL) and dissected to obtain liver, muscle, and gill samples. The samples were stored in Falcon tubes and kept refrigerated until analysis.

Surface water and sediment

Samples of surface water and sediment were collected at all sampling locations (P1–P8). In the field, water samples for total and dissolved Hg analyses were collected in 50 mL Falcon tubes and preserved with nitric acid (HNO_3). Sediment samples were preferably collected in backwater areas (locations with low flow velocity) using a Van Veen sediment sampler. The samples collected were stored in plastic bags and kept refrigerated until laboratory procedures were performed. Limnological variables (surface water temperature, dissolved oxygen, electrical conductivity, and pH) were measured *in situ* using a HANNA® multiparameter meter (model HI9828), and water turbidity was measured with a portable turbidimeter from QUIMIS®.

Total mercury analysis in fish tissues

In the laboratory, muscle, liver, and gill samples were homogenized. The samples were carefully minced and mixed until a homogeneous matrix was obtained prior to total mercury analysis. Then, 0.5 mg of tissue was taken in 50 mL volumetric flasks for subsequent acid digestion. Then, 1 mL of deionized water, 1 mL of HNO_3, 1 mL of $HClO_4$, and 5 mL of H2SO$_4$ were added to the samples. The sample solutions were heated on an electric hot plate at a temperature of 200 to 230 °C for 30 minutes, and after cooling, the concentrations of total Hg were quantified by Cold Vapor Atomic Absorption Spectrometry (CVAAS) using an Hg analyzer (model Hg 201, SANSIO). For total Hg analyses in tissues, the limit of quantification (LQ) of the method was 0,556 µg/g. To evaluate the method's precision, analyses of certified reference material (DORM-3, n = 22) were used, showing a recovery efficiency of 101.9%. The analysis procedures were conducted according to the method described by Akagi (2004).

Total mercury analysis in surface water and sediment

For the analysis of dissolved Hg in water, samples were filtered using a vacuum pump through cellulose acetate filter membranes with a pore size of 0.45 µm (Millipore, Merck). From the filtered samples, aliquots of 4.975 mL were transferred to 15 mL Falcon tubes, and 25 µL of internal standard was added to improve the accuracy of Hg determination. They were then analyzed using an Inductively Coupled Plasma Mass Spectrometer (Bruker 820®). For the analysis of total Hg, 9 mL of water was transferred to 75 mL flasks, and 25 µL of internal standard and 975 µL of deionized HNO_3 were added. Subsequently, the samples were subjected to microwave digestion for 40 minutes. After these procedures, the analysis was conducted. For total Hg analysis in water and sediment, the limits of detection (LD) and LQ of the method were 0,037 and 0,123 µg/L for water and 0,000556 and 0,1226 µg/kg for sediment, respectively. Quality control was performed through analyses of certified reference material NIST 1641, with an average recovery rate of 91.7%.

The sediment samples were air-dried. After drying, the sediment particles were disaggregated and sieved using a granulometric sieve with a mesh size of 2.0 mm. For the analysis of total Hg content in the sediment, 200 to 250 mg aliquots of sediment were weighed into 50 mL volumetric flasks and subjected to acid digestion by the addition of 1 mL of deionized water, 5 mL of H_2SO_4, and 2 mL of HNO_3 (1:1). The samples were then heated on a hot plate at 200–230 ºC for 30 min. After cooling, the resulting solutions were diluted to 50 mL with deionized water. The analysis procedures were conducted according to the method developed by Akagi (2004). The method's quality control was evaluated through analyses of a certified reference sample (WQB-3, n = 2), with a recovery percentage of 99.63%.

Statistical analysis

Before conducting the analyses, data normality was checked using the Shapiro-Wilk test and variance homogeneity was assessed using the Levene test. When necessary, data were transformed (log10) to meet the assumptions of parametric tests. To test the differences in total Hg concentrations in fish tissues among the collection sites, an analysis of covariance (ANCOVA) was performed separately for each species and tissue type (muscle, liver, and gills), followed by the Bonferroni *post hoc* test. A two-way analysis of variance (ANOVA) was conducted to test differences in Hg concentrations between the two fish species and among the three types of biological tissues. To assess the effect of body size on total Hg concentrations in fish, a simple linear regression was performed. All analyses were conducted in the R Studio statistical environment (version 3.6.1), with a significance level of $p < 0.05$ is considered for all tests.

RESULTS

Limnological characteristics and total mercury in water and sediment

The limnological variables and mercury concentrations in surface water and sediment evaluated in the study area are presented in Table 1.

Mercury bioaccumulation in fish tissues

Our results show that Hg accumulation in the tissues of *C. melaniae* and *B. xanthellus* followed the concentration order: liver > muscle > gills. The average total Hg concentrations in the tissues of both species per sampling site are presented in Table 2.

The total Hg concentrations recorded in the tissues of *C. melaniae* were significantly higher than those in *B. xanthellus* (GL = 2; F = 40.43; p = 0.001) (Figure 2).

Table 1. Limnological variables and total mercury concentrations in water and sediment from sampling points at the Xingu River

Sample Points	Hg	Hg in water		Abiotic parameters				
	Sed. (µg/g)	Total (µg/L)	Dissolved (µg/L)	Cond. (µs/cm)	Temp. (ºC)	OD (mg/L)	pH	Turb. (NTU.)
P1	0.14	<LD	<LD	23	27.5	7.9	6.8	8.14
P2	0.09	<LD	<LD	21	27.9	8.1	6.9	16.0
P3	0.16	<LD	<LD	23	27.6	7.4	6.4	8.94
P4	0.09	0.013	<LD	23	27.7	7.7	6.7	15.8
P5	0.08	<LD	0.015	28	28.0	*	6.7	10.1
P6	0.10	<LD	<LD	26	28.8	*	6.7	11.2
P7	0.06	<LD	<LD	23	28.3	6.8	6.3	10.9
P8	0.06	<LD	<LD	25	28.2	9.4	6.9	10.1

Note: Sed=sediment, Cond=electrical conductivity, Temp=temperature, DO=dissolved oxygen, pH=hydrogen potential, Turb=turbidity, <LD=less than detection limit, *not measured.

Table 2. Mean mercury concentrations in tissues of *C. melaniae* and *B. xanthellus* per sampling site in the Xingu River.

	Points	N	Muscle	Liver	Gills
C. melaniae	P1	12	0.349 ± 0.15	1.202 ± 0.80	0.050 ± 0.02
	P2	8	0.433 ± 0.19	1.776 ± 0.95	0.091 ± 0.03
	P5	15	0.427 ± 0.20	0.996 ± 0.73	0.081 ± 0.04
	P6	15	0.265 ± 0.12	0.941 ± 0.69	0.062 ± 0.02
B. xanthellus	P1	14	0.043 ± 0.01	0.333 ± 0.20	0.005 ± 0.00
	P2	15	0.068 ± 0.02	0.338 ± 0.12	0.010 ± 0.00
	P5	16	0.041 ± 0.01	0.238 ± 0.15	0.008 ± 0.00
	P6	15	0.038 ± 0.01	0.272 ± 0.10	0.007 ± 0.00

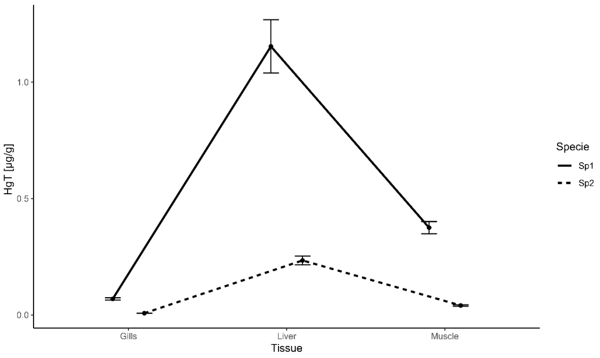

Figure 2. Variation in total Hg concentrations among fish species and biological tissues (Sp1 = *B. xanthellus*; Sp2 = *C. melaniae*).

Correlation between total mercury and fish length

We evaluated the effect of size on Hg levels in the tissues of both species, including all captured fish. The results show that *C. melaniae* exhibited a positive linear relationship between total Hg levels in the tissues and TL, suggesting that larger individuals tended to accumulate higher Hg levels in the liver ($r^2 = 0.30$; $p = 0.001$), muscle ($r^2 = 0.71$; $p = 0.001$), and gills ($r^2 = 0.40$; $p = 0.001$), as shown in Figure 3. In our study, TL was used as a proxy for body size and cumulative exposure time, since larger individuals are generally older and may experience longer periods of dietary mercury exposure.

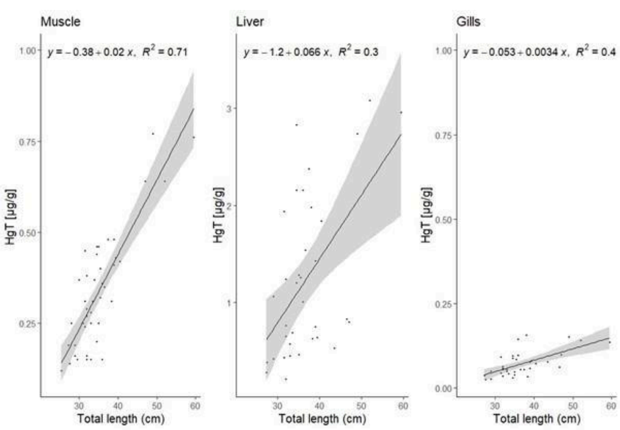

Figure 3. Relationship between total Hg concentrations in *C. melaniae* tissues and total length (TL).

In contrast, *B. xanthellus* showed a weak negative relationship between total Hg concentrations in the gills ($r^2 = 0.11$; $p = 0.023$) and TL, indicating a tendency for Hg levels in this tissue to decline with increasing body size (Figure 4). On the other hand, Hg concentrations in the liver ($r^2 = 0.01$; $p = 0.40$) and muscle ($r^2 = 0.05$; $p = 0.07$) showed no relationship with TL.

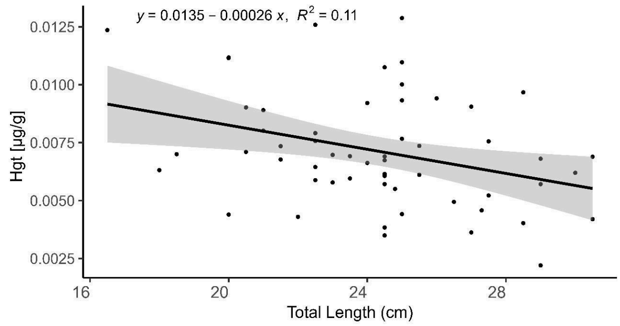

Figure 4. Negative relationship between total Hg concentrations in *B. xanthellus* gills and total length (TL).

Influence of sampling sites on mercury levels

We investigated the variation in total Hg concentrations in the tissues of the two fish species among sampling sites. Regarding *C. melaniae*, our results indicate differences between the sampled sites $F (3,42) = 5.02$, $p = 0.004$. According to the Bonferroni test, the total Hg concentrations in the muscles of fish captured at points P5 and P6 differed from each other ($p = 0.03$). As for the gills, there were also differences in Hg concentrations among the collection points $F (3,42) = 5.49$, $p = 0.002$. These differences were observed between points P1 and P2 ($p = 0.01$) and between points P1 and P5 ($p = 0.01$) (Table S2 of the Supplementary Material). In contrast, the total Hg concentrations in the liver of *C. melaniae* showed no difference among the sampling points $F (3,42) = 2.20$, $p = 0.101$. Figure 5 shows the variation in total Hg concentrations in the muscles and gills of *C. melaniae* at different sampling points.

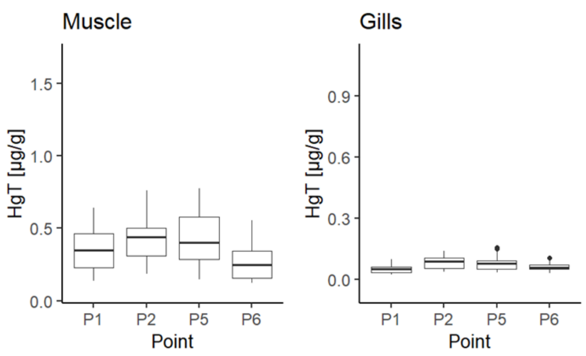

Figure 5. Box plot showing the variation of Total Hg concentrations in muscles (left) and gills (right), at the different collection sites.

For *B. xanthellus,* our results indicate that the average Hg concentrations in the muscles of fish captured at point P2, located in the reservoir, were higher compared to those at the other collection points. We observed differences in Hg concentrations between points P1 and P2 (p = 0.01), P2 and P5 (p = 0.01), and between points P2 and P6 (p = 0.01) for this biological tissue. Regarding the total Hg concentrations recorded in the liver, differences were observed between points P1 and P5 (p = 0.03) and between points P2 and P5 (p = 0.01). As for the gills, point P1, located outside the reservoir, had the lowest Hg concentrations compared to the other sampling points, with significant differences between points P1 and P6 (p = 0.01), and between points P2 and P6 (p = 0.01) (Table S3). Figure 6 shows the variation in total Hg concentrations in the three biological tissues of *B. xanthellus* among the collection sites.

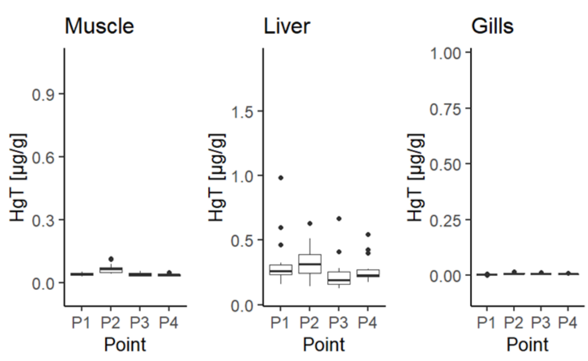

Figure 6. Box plot showing the variation of Total Hg concentrations in livers (Figure A), muscles (Figure B) and gills (Figure C), at the different collection sites.

DISCUSSION

In this study, we evaluated the limnological conditions and total Hg concentrations in water and sediments in areas influenced by the Belo Monte hydroelectric power plant. Overall, our results show that water temperature, dissolved oxygen, and pH remained within the range observed in pre-construction studies by Rodrigues-Filho *et al.* (2015) in the Xingu River, with most sites exhibiting near-neutral pH. Regarding turbidity, points P2 and P4 had the highest particle concentrations, likely due to a greater number of suspended solids.

Organic matter plays an important role in the distribution and accumulation of Hg in sediments (Hsu-Kim *et al.,* 2018). In our study, point P3 located in the reservoir area had the highest total Hg concentration in sediment (0.16 µg/g), possibly due to a higher load of organic material resulting from reservoir formation. Conversely, we observed lower Hg concentrations in sediments downstream of the hydroelectric plant (P7 and P8) compared to other sites. This decline is likely due to Hg sedimentation in the reservoir, as Eagles-Smith *et al.* (2018) found a relationship between Hg concentration and water flow, suggesting that Hg associated with particulate matter can be retained in the reservoir when flow decreases following damming.

Regarding total and dissolved Hg in water, most sampling sites showed concentrations below detectable levels. The volatilization of dissolved gaseous mercury is an important mechanism that reduces the Hg load in aquatic systems (Lyman *et al.,* 2020), which could explain the low concentrations observed.

Hg concentrations can vary according to the feeding habits of different fish species (Crespo-Lopez *et al.,* 2021), and our analyses reflect this. The variation in total Hg concentrations in the tissues of the two evaluated species mirrored their feeding habits and trophic positions. The piscivorous species, *Cichla melaniae,* exhibited higher total Hg concentrations in its tissues compared to the detritivorous *Baryancistrus xanthellus*. This suggests that the feeding habit of *C. melaniae* leads to greater Hg exposure through the diet, resulting in higher tissue concentrations. Similarly, Soares *et al.* (2018) observed a trend in Hg concentrations dependent on feeding habits in a study conducted in the Madeira River (Amazon, Brazil), suggesting that feeding habits may influence Hg bioaccumulation.

Both species showed a similar pattern in tissue Hg distribution, with the liver having the highest concentrations, followed by muscle and gills. The elevated Hg levels in the liver can be attributed to its role in heavy metal detoxification (Silva and Lima, 2020) and the presence of metallothioneins proteins that bind metals and facilitate detoxification (Vieira *et al*., 2023).

In contrast, the lower Hg concentrations in the gills, which are in direct contact with the water, may reflect the low Hg levels observed in the aquatic environment, consistent with previous observations (Hosseini *et al.,* 2013; Mehmood *et al.,* 2017). Analyses of *C. melaniae* revealed a positive relationship between total Hg in tissues and TL, indicating that larger fish tend to accumulate more Hg (Silva *et al*., 2019; Dang *and* Wang, 2012). This finding has important implications for human health, as the consumption of larger fish may result in higher Hg exposure. *C. melaniae* is highly valued by local riverine communities and the wider Amazonian population due to its size and taste. However, our results suggest that larger individuals tend to accumulate higher Hg concentrations, which may increase Hg exposure through fish consumption.

In contrast, Hg concentrations in *B. xanthellus* tissues were generally unrelated to body size. The only exception was the gills, which showed a negative correlation with TL. Similarly, Silva *et al.* (2019) observed a negative relationship between Hg concentrations and body size in other detritivorous species from the upper Solimões River region.

Although the Belo Monte dam is a relatively new hydroelectric facility, its impacts on Hg levels in local biota are already evident, particularly in *C. melaniae and B. xanthellus*. In general, fish captured in the reservoir area exhibited higher average Hg concentrations in their tissues. For *C. melaniae,* significant differences in muscle Hg concentrations were observed between sampling points P1 and P2, and between P1 and P5. The difference between P1 and P2 may reflect the dam's impact, as P2 is located in an area influenced by the damming process where flooding of surrounding vegetation introduces large amounts of allochthonous organic material that favor Hg methylation (Bravo and Cosio, 2020). The higher Hg concentrations observed at P5 suggest the influence of local anthropogenic sources. Previous studies have reported elevated Hg levels in residents from this area (Carvalho *et al.,* 2009), which have been associated with historical gold mining activities (WWF, 2018).

For *B. xanthellus*, Hg concentrations in all three tissues were highest in individuals collected at P2, located within the reservoir area. This suggests that reservoir formation may enhance Hg availability and uptake by aquatic organisms. The accumulation of organic matter in flooded areas can stimulate Hg methylation processes (Meng *et al.* 2016; Campos *et al.* 2018), which may explain the higher concentrations observed at this site. Similar increases in Hg levels associated with reservoir formation have also been reported by Ni (2021) and Cebalho *et al.* (2017).

Belo Monte operates as a run-of-river system and stores less water than conventional reservoirs (Fearnside, 2019). However, fish collected within the reservoir area showed higher Hg concentrations. These findings suggest that even reservoirs with smaller flooded areas may provide conditions that increase Hg availability to aquatic biota. In the same region, Macedo *et al.* (2025) also observed spatial variation in trace element concentrations in *Cichla melaniae*, reinforcing the influence of local environmental conditions on contaminant dynamics.

The Hg concentrations observed in *C. melaniae* and *B. xanthellus* were lower than those reported by Souza-Araújo *et al.* (2016) for fish from the Bacajá River, a tributary of the Xingu River located between sampling sites P5 and P6. This difference may reflect differences in Hg exposure between the two environments. Higher Hg concentrations in the Bacajá River have been associated with historical gold mining activities in the region. These activities may increase Hg availability and accumulation in aquatic biota (Lino *et al.,* 2019).

The construction of dams in the Amazon has generally contributed to increased Hg levels in aquatic ecosystems (Pestana *et al.,* 2019). For example, Porvari (1995) reported high Hg concentrations (1.3 ± 0.89 mg/kg) in two fish species (*Cichla temensis* and *Plagioscion squamosissimus*) from the Tucuruí hydroelectric reservoir. These values exceed the limits established by Brazilian legislation for human consumption, defined as 0.5 m g/kg for non-predatory fish and 1.0 mg/kg for predatory fish (BRASIL, 2013). Such concentrations may represent a potential health risk to riverside communities that frequently consume these organisms. The high Hg concentrations may be related to the flooding of large forested areas, which can favor Hg methylation and its incorporation into the food chain (Fearnside, 2019). These concentrations exceeded those observed in *C. melaniae* in our study. Moreover, *C. melaniae* exhibited lower total Hg levels than those reported in other Amazonian rivers, such as the Negro (Dorea *et al.,* 2003), Madeira (Bastos *et al.,* 2007), and Tapajós (Faial *et al.,* 2015), the latter in areas previously impacted by gold mining.

The total Hg concentrations observed in the muscle tissues of *C. melaniae* and *B. xanthellus* were below the maximum limits established by Brazilian legislation for human consumption, which are 1.0 mg/kg for predatory fish and 0.5 mg/kg for non-predatory fish (BRASIL, 2013). These results indicate that the Hg concentrations observed in the present study do not exceed the recommended limits for human consumption.

This study evaluated total Hg concentrations in water, sediment, and fish from different environments of the Xingu River influenced by the operation of the Belo Monte Hydroelectric Plant. As one of the first studies to investigate Hg levels in areas impacted by the largest installed capacity hydroelectric plant in the Amazon. Our results showed that P2, located within the reservoir area, exhibited the highest total Hg concentrations in *B. xanthellus.* This finding is consistent with observations from other hydroelectric reservoirs, where reservoir formation has been associated with increased Hg accumulation in fish.

We recommend that future studies also assess other fish species downstream of Belo Monte, given reports of high Hg contamination in such areas (Kasper *et al.,* 2012, 2014). However, these results are still preliminary for drawing definitive conclusions about Hg behavior under the influence of Belo Monte, as the plant is recent and a definitive hydrograph has not yet been established for the different sections of the Xingu River analyzed. Therefore, additional long-term studies are needed to evaluate Hg concentrations and Hg dynamics in areas influenced by the operation of the reservoir.

CONCLUSION

This study shows that total Hg concentrations in sediments were lower downstream of the Belo Monte hydroelectric plant, suggesting Hg retention in the reservoir sediment. The evaluated fish species exhibited different patterns regarding Hg levels in their tissues; notably, *B. xanthellus* appears to be more sensitive to the impacts of the hydroelectric plant compared to *C. melaniae*. Although the Belo Monte plant has been operational for only a short period, its impact on mercury levels is already evident. However, to better understand the damming effects on Hg levels, further medium-term studies on the Xingu River and its fauna are needed.

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AUTHOR CONTRIBUTIONS

HS: Writing, Investigation, Conceptualization, Methodology, Field Collection, Analysis; **TN:** Field Collection, Data Curation, Review, Editing; **ML:** Data Curation, Supervision, Project Administration; **TP:** Data Collection, Data Curation, Review, Funding, Acquisition, Supervision, Project. Administration.

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