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FISH INTAKE FROM DIFFERENT ECOSYSTEMS AND EXPOSURE IN FAMILY FISHERIES IN THE BRAZILIAN AMAZON

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ABSTRACT

Evidence of human exposure to mercury through fish consumption is restricted to the riparian areas of Madeira and Tapajós. Little is known about exposure to populations that regularly consume fish from other Amazonian ecosystems. Mercury exposure levels were compared in fishermen and relatives living in different geographic regions, in the State of Pará, considering the weekly frequency of fish intake and fish ecosystem (river or estuarine). The study included 407 residents of fishermen villages in three different regions (Tapajós, Tocantins and Caeté) and different species of fish from each region. High weekly frequency of fish intake was observed in all studied communities. The median concentrations Total mercury were 4,6µg/g (0,0-30,1µg/g), 8,9µg/g (1,2-50,6µg/g), 0,7µg/g (0,0-6,2µg/g) e 1,8µg/g (0,1-20,7µg/g), respectively in the villages A and B (Tapajós), village C (Tocantins) and D (Caeté), with differences in the observed concentrations between the studied communities. Fish with higher Total mercury concentrations were found in the Tapajós region, 0.160±0.000µg/g in the Leporinus friderici species and the lowest in the Tocantins species 0.004±0.003µg/g in Mugil curema. Riparians from Tocantins are less exposed and consume fish with lower concentrations of mercury. The herbivorous and detritus species of the estuarine area are safe species for human consumption.

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INTRODUÇÃO

In the Amazon, fishing is a traditional activity that contributes to the regional economy and responsible for the main source of animal protein for coastal communities. In general, this activity reaches 30 to 40% of the family income in the region of the lower Amazonas, in the State of Pará (1). Production varies with the time of year and seasonal season (2). The diversity of ecosystems is one of the characteristics of the Amazon region that presents a variety of water bodies, including lakes and rivers, estuarine areas and coastal region, each with aquatic life pertinent to the respective ecosystem. Any of these water bodies may suffer human actions threatening the fish fauna. Heavy metals, including mercury in organic form, bioaccumulate in the food chain reaching man through food. Different species of fish are affected, particularly predators (3). Fish intake is considered to be the main route of exposure of man to methyl mercury, and the frequency and duration of consumption, species, food habit and fish size are implicated in the intensity and form of exposure, which can cause harm health to varying degrees(4).

Contamination by mercury in the aquatic environment has been confirmed in the Brazilian Amazon, in regions with and without intense anthropogenic activities, mainly those related to gold mining. A number of species of fish consumed by the riverine population have presented mercury levels unfit for human consumption (5–8). According to the Brazilian standards, the limits established for safe fish consumption are 0.5 mgHg/kg for non-predator (herbivore) fish and 1.0 mgHg/kg for predatory or piscivorous fish (4). On the other hand, human exposure through fish intake has been confirmed in the Tapajós River and in Madeira River, where concentrations of total mercury in sample hair exceeded the safety limit established by Brazilian legislation and; despite the evidence of prolonged exposure and the suspicion of mild cases, no clinically specific case of Minamata disease was confirmed. Exposure to methylmercury is mainly a risk factor for pregnant women, fetuses and children resulting in irreversible neurological damage as a consequence of the affinity of mercury for immature nervous tissue. More severe cases with cerebral palsy, delayed cognitive development, blindness, and deafness are examples of damage this type of environmental exposure observed in tragedies in Japan and Iraq (9). Studies on mercury

exposure through fish diet have been concentrated in river regions, little knowledge has been produced in estuarine areas of the Amazon. Particularly in the State of Pará there are extensive fishing estuaries that contribute to domestic trade, whose safety related to concentrations of mercury in fish is unknown, as well as there is a shortage of records on the frequency of weekly fish consumption and the impact of this consumption on the exposure of riparian from these regions not studied. The current study investigated the mercury exposure in association with frequency of fish intake, species consumed and the ecosystem of fish consumed (river and estuarine).

MATERIALS AND METHODS

This study was carried out from August 2014 to November 2015 involving members of fisher families living in communities located in three fishing regions in the State of Pará, two located on the banks of the Tapajós river in the municipality of Itaituba (village A and B), one on the banks of the Samaúma river, in the estuarine region, in Limoeiro do Ajuru (village C) and the other in the region of the Caeté river with coastal and maritime influence in the municipality of Bragança (village D). Villages A and B had respectively 960 and 450 inhabitants, village C had 350 inhabitants and village D 520 inhabitants, according to the records of the local Health Strategy. All villages were characterized by subsistence fishing activity and habitual consumption of fish in the diet. Young, adult, male and female residents of the community who agreed to provide information and hair samples to Total mercury (TotalHg) analysis were included. Residents who were bedridden and fishermen and family members in transit through the community were excluded.

Demographic data and fish consumption: Socio-demographic information including age, sex, place of residence, occupation, schooling, income, besides the weekly frequency of fish intake were obtained through a questionnaire. The frequency of fish consumption was based on the classification of Nordberg et al (1992), which establishes the following categories: no consumption; less than two meals a week, two to four meals and more than four meals a week and consumption unknown (10).

Hair samples and quantification of Total Mercury (TotalHg)): A sample of hair with approximately 50 to 100 threads was obtained from the scalp of the occipital region with stainless steel scissors from each participant. The samples were duly identified and stored until the analysis was performed to determine TotalHg. In the Laboratory of Human and Environmental Toxicology of the Nucleus of Tropical Medicine (NMT) of Federal University of Pará (UFPA), Brazil, these samples were processed and analyzed. Initially, they were submitted to the washing process in distilled water and acetone, placed to dry in an exhaust hood, and then subjected to micro fragment cuts with stainless steel scissors. These micro fragments were weighed to an approximate amount of 10mg and submitted to TotalHg analysis by atomic absorption spectrophotometry with gold-plate amalgamation using an automatic mercury meter known as Mercury Analyzer (MA), model SP-3D of Nippon Corporation-Japan. The entire analytical process followed the manufacturer's instructions strictly. Precision determination was obtained by quantification in duplicate. The accuracy established through the international reference standard termed IAEA 085. The reproducibility demonstrated by linearity r = 1, by means of a calibration curve, consisting of five points (0, 10, 20, 50, 100). Results were expressed as µg / g (ppm).

Fish specimens and TotalHg quantification: In the period from 2014 to 2015, 189 specimens of fish of different species and different ecosystems (river and estuary) available in the diet of the communities during the dry season (June to November) were obtained. One hundred and thirteen (113) specimens of the Tapajós fluvial region, 38 of *Semaprochilodus spp* (jaraqui), 25 of *Mylossoma spp* (pacú), 30 of *Leporinus spp* (aracú piau), 11 of *Leporinus affinis* (aracú pinima) and 9 of *Leporinus friderici (*aracú cabeça gorda). From the Tocantins estuary, 50 specimens were obtained: 23 of the detrivorous species *Hypophthalmidae spp* (mapará), 15 of the herbivorous species *Macrodon ancylodon* (pratiqueira) and 12 of white hake *Plagioscion squamosissimus* (piscivora). From the region of the Caeté river, 26 specimens were obtained, among which 14 of a herbivorous species, *Genyatremus luteus* (peixe pedra) and 03 piscivorous species, among which 05 specimens of *Brachyplatystoma flavicans* (dourada), 03 specimens of *Cynoscion acoupa* (pescada amarela) and 04 of *Arius couma* (bagre). The number of specimens, the food habit and the origin ecosystem of the specimens and the biometry of the fish are shown in Picture 1.

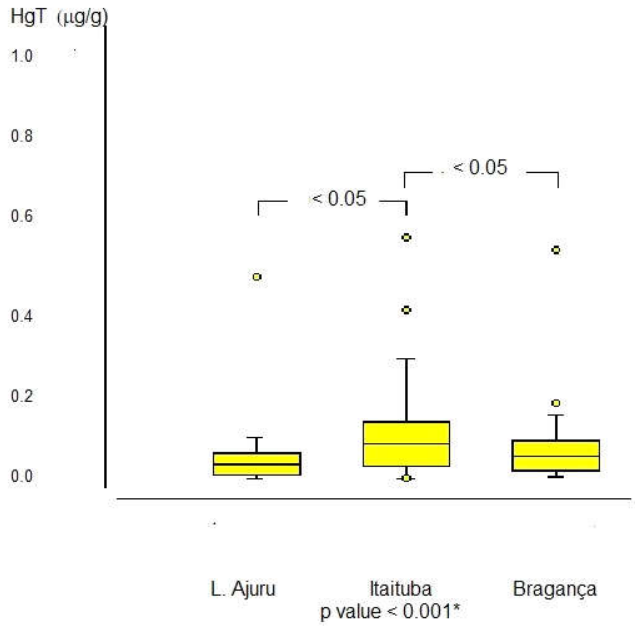

Figure 1. TotalHg concentrations in muscular tissue of fish of the different regions in the State of Pará

After identification of the species, morphometric measurements were recorded, such as weight in grams (g), total length in centimeters (cm) with tape measure, and a sample of tissue Muscle without skin and without spine, obtained from the dorsal region of the fish (11,12). Then, all specimens packed in individually identified plastic bags were kept at -20°C for about 30 days when subjected to TotalHg analysis in the NMT/UFPA Laboratory of Human and Environmental Toxicology. The quantification of the TotalHg was performed in fish muscle tissue through atomic absorption spectrophotometry using the Japanese-made Mercury Analyzer Hg 201. Analytical quality control and validation of the methodology for precision and accuracy for the determination TotalHg was guaranteed using the international standard DORM 3. All samples were analyzed in duplicates and the results transformed in µg/g (ppm).

Presentation and analysis of results: The results were analyzed through descriptive statistics using median, minimum and maximum values and relative frequency. The Kuskal-Wallis test was used to compare the concentrations of mercury in hair samples and muscle tissue of fish. Statistical analyzes were performed using the statistical program Biostat 5.0 (13), differences were considered significant when p value <0.05.

RESULTS

Table 1 shows the distribution of the participants of the different fishing villages, considering the age, the TotalHg concentrations and the weekly frequency of fish meals. A total of 407 residents of fishermen's villages located in different watersheds of the State of Pará, including 99 from Vila A, whose median age was 38 years (18 to 80 years) and 76 from Vila B, with a median age of 35 years (13-85years), both in the Tapajós region, 152 in Vila C (Tocantins region), aged 39 years, ranging from 16 to 80 years, and 80 participants from village D (Caeté region) with a median age of 36.5

years ranging from 16 to 69 years. There was no significant difference in the age of participants among the four villages (p>0.05). The mean TotalHg concentration in sample hair was 4.6 µg/g (0.0-30.1 µg/g) in village A, 8.9 (1.2-50.6µg/g) in village B, 0.7 (0.1-20.7µg/g) in village C and 1.8 (0.1-20.7µg/g) in village D. There was a significant difference (p<0.05) in concentrations of the residents of the studied villages. The estuarine villages (C and D) had the lowest TotalHg concentrations. More than 70% of all participants consumed two and more weekly fish meals in the diet. Consumption greater than four meals per week was observed in more than 50% in villages B and C.

species analyzed, including the piscivorous species (*Plagioscion squamosissimus*). The lowest concentrations were observed in herbivorous species (*Macrodon ancylodon*) whose median value was 0.0030µg/g, ranging from 0.0010-0.0100 µg/g and the highest were in *Hypophthalmidae spp* with a median value of 0.0470 µg/g (0.0170-0.0960 µg/g). In the Caeté River region, the herbivorous species (*Geniatremus luteus*) presented a median TotalHg concentration of 0.0550 (0.0050-0.5420µg/g), while predatory species bagre, dourada and pescada amarela respectively presented the following median concentrations 0.0540µg/g, 0.0520µg/g and 0.0320µg/g (Picture 2).

Table 1. Species, weight and length of fish caught in Tapajós river waters, 2014-2015

Fish species	N	Food habit	Ecossystem	Weight (g)	Length (cm)
Semaprochilodus spp (Jaraqui)	39	Herbivore	Tapajós / fluvial	163.58 ± 34.23 155 (120-240)	27.25 ± 2.33 27 (23-32.5)
Mylossoma spp. (Pacu)	29	Herbivore	Tapajós / fluvial	88.75 ± 67.12 77.5 (20-170)	21.12 ± 4.54 20.5 (15-28.5)
Leporinus spp (Aracú piau)	30	Herbivore	Tapajós / fluvial	203.33 ± 53.19 190 (110-340)	28.9 ± 1.55 29 (25.5-32)
Leporinus friderici (Aracú head fat)	09	Herbivore	Tapajós / fluvial	145.61 ± 21.18 150 (110-170)	25.61 ± 1.55 26 (23-27.5)
Leporinus affinis (Aracú pinima)	11	Herbivore	Tapajós / fluvial	160.90 ± 45.48 180 (100-240)	27.72 ± 3.06 29 (21-32)
Hypophthalm us spp (Mapará)	23	D etrívoro	Tocantins / estuary	169.13 ± 110.69 120 (35-415)	34.19 ± 5.62 31 (26.5-46.0)
Plagioscion squamosissimus (Hake)	12	Predator	Tocantins / Estuary	125.41 ± 58.67 105 (30-230)	24.12 ± 2.00 24 (21-29)
Macrodon ancylodon (Pratiqueira)	15	Herbivore	Tocantins / Estuary	53.73 ± 17.53 50 (30-85)	19.06 ± 1.36 19.5 (15-20)
Brachyplatystoma flavicans (Gold)	0 5	Predator	Caeté / Estuary	1.306 ± 953 980 (650-2,990)	53.80 ± 8.7 50 (47-69)
Cynoscion covers (Yellow hake)	03	Predator	Caeté / Estuary	483.30 ± 119.3 430 (400-620)	43.66 ± 4.04 43 (40-48)
Catfish (Arius couma)	04	Predator	Caeté / Estuary	220 ± 50.3 230 (150-270)	32.6 ± 4.6 34.2 (26-36)
Geniatremus luteus (Fish-stone)	14	Predator	Caeté / Estuary	94.2 ± 23.4 90 (70-150)	17.42 ± 1.28 17 (16-20)

Source: Author (2019).

Table 2. Characterization regarding age, concentrations of HgT and frequency of fish consumption in communities of different geographic regions in the State of Pará, 2013-2015

Variables	Itaituba Vila A	Itaituba Vila B	L. Ajuru Villa C	Bragança Vila D
Age (years)*				
N	99	76	152	80
Md	38	35	39	36.5
(Min-max)	(18-80)	(13-85)	(16-80)	(16-69)
25%	31	27	28	27
75%	55	50	49	48
HgT (µg/g) **				
N	99	76	152	80
Md	4.6	8.9	0.7	1.8
Min-max	(0.0-30.1)	(1.2-50,6)	(0.0-6.2)	(20.1- .7)
25%	2.8	4.5	0.3	1.1
75%	8.4	16.7	1.2	3.1
Meals fish / week (%)				
<2 meals	15 (23.1)	13 (17.6)	11 (15.3)	19 (24.0)
2-4food	30 (46.1)	22 (29.7)	23 (31.9)	24 (30.4)
> 4 meals	20 (30.8)	39 (52.7)	38 (52.8)	36 (45.6)

* Kruskal Wallis p> 0.05.
** Kruskal Wallis p <0.05 Vila D versus Vila C, Vila A e Vila B versus Vila D, Vila A e Vila B versus Vila C. P> 0.05 Vila B versus Vila A.
Source: Author (2019).

TotalHg concentrations were associated with frequency of fish consumption in villages A and B (p<0.05), where the highest TotalHg concentrations were observed in participants with more than four weekly meals, 17.4 ± 10.4 µg/g and 8,3±7.0 µg/g respectively, whereas in the C and D villages the different fish intake frequency categories showed no significant difference (p>0.05). Higher TotalHg concentrations were observed in the fish consumed in the Tapajós region. The species *Leporinus friderici* showed a median concentration of 0.0890 µg/g ranging from 0.0440 to 3,180µg/g, and the lowest were found in the *Leporinus spp* with median of 0.0515, maximum value 0.0920 µg/g and minimum 0.0170µg/g. In the Tocantins (estuarine) region, TotalHg concentrations were low in all

DISCUSSION

The exposure to mercury through the ingestion of fish contaminated by methylmercury has been admitted to the Brazilian Amazon for more than two decades, several studies were carried out in fluvial regions impacted by gold mining activity such as the Madeira and Tapajós rivers but few is known about exposure from other aquatic systems not impacted by mineraries activities (14–18). This study compared the levels of mercury exposure in families of fishermen living in two villages in the Tapajós river basin (A and B) and two estuaries, one in Tocantins (village C) and another in Caeté (village D).

Table 3. TotalHg concentrations in samples hair, according to the frequency of weekly consumption of fish by fish populations in the different regions in the State of Pará, 2013-2014

County / Village ecosystem	<2 meals HgT X ± DP	2-4 meals HgT X ± DP	> 4 meals HgT X ± DP	p value*
Itaituba / Vila A River area (n: 74)	(13) 2.8 ± 2.5	(22) 8.2 ± 5.8	(39) 17.4 ± 10.4	p <0.05
Itaituba / Vila B Area riverside (n: 65)	(15) 3.1 ± 2.9	(30) 5.9 ± 4.0	(20) 8.3 ± 7.5	p <0.05
L.Ajurú / Villa C Estuarine area (n: 54)	(10) 0.7 ± 0.5	(16) 0.4 ± 0.3	(28) 1.0 ± 1.2	p> 0.05
Bragança / Vila D Coastal Region (n: 79)	(19) 2.0 ± 2.8	(24) 1.9 ± 1.0	(36) 3.8 ± 4.2	p> 0.05

*Kruskal Wallis.
Source: Author (2019).

Table 4. TotalHg concentrations in fish muscle tissue according to origin and dietary habits

Species	N	Habit to feed	Ecosystem	HgT (µg/g wet weight)
Semaprochilodus spp (Jaraqui)	38	Herbivore	Tapajós / fluvial	0.1218± 0.1021 0.0920 (0.0400-0.0574)
Mylossoma spp (Pacu)	25	Herbivore	Tapajós / fluvial	0.0539±0.0044 0.0350(0.0000-0.2770)
Leporinus spp (Aracú piau)	30	Herbivore	Tapajós / fluvial	0.0524±0.0195 0.0515(0.0170-0.0920)
Leporinus affinis (Aracu pinima)	11	Herbivore	Tapajós / fluvial	0.0866±0.0321 0.0910(0.0410-0.1400)
Leporinus friderici (Aracu cabeça gorda).	07	Herbivorous	Tapajós / fluvial	0.5319 ±1.1680 0.0890(0.0440-3.180)
Hypophthalmidae spp (Mapará)	23	Detrívoro/ planctivorous	Tocantins / estuary	0.0449±0.0193 0.0470(0.0170-0.0960)
Plagioscion squamosissimus (Pescada branca)	12	Piscivora	Tocantins / estuary	0.0486±0.0163 0.0430(0.0250-0.0770)
Macrodon ancylodon (Pratiqueira)	15	Herbivoro	Tocantins / estuary	0.0043±0.0033 0.0030(0.0010-0.0100)
Brachyplatystoma flavicans (Dourada)	05	Predator	Coastal	0.0614±0.0320 0.0520(0.0400-0.11170)
Cynoscion acoupa (Pescada amarela).	03	Predator	Coastal	0.0397±0.0187 0.0320(0.0260-0.0610)
Arius couma (Bagre)	04	Predator	Coastal	0.0518±0.0082 0.0540(0.0400-0.0590)
Geniatremus luteus (Peixe pedra)	14	Herbivorous	Coastal	0.0981±0.1383 0.0550(0.0050-0.5420)

Source: NMT / UFPA Laboratory of Human and Environmental Toxicology.

All participants had similar age ranges, with 75% presenting age under 55 years, thus a population of young adults and mature adults, in fully productive of life, and whose food base is the regular consumption of fish caught locally, with a frequency of weekly consumption higher than two meals by more than 70% of the population studied, with villages B and C consuming more than four meals per week. The highest TotalHg concentrations were recorded in residents of villages A and B, in the Tapajós region, where 34,1% and 67,1% respectively had TotalHg concentrations higher than 6 µg/g. This is reference limit for exposed populations (WHO, 1990). Although there is a high frequency of individuals exposed to mercury, especially in village B, the concentrations found in the present study are lower than those observed in previous studies in the same communities (15,16,19). Recent studies in the Madeira River region and Tapajós have demonstrated that exposure continues, with possible health risks, especially for pregnant women (6,7). Based on the Iraq accident, mercury concentrations in samples hair greater than 10µg/g represent health risks for pregnant women and fetuses (9). In this study, more than 50% of the population evaluated was represented by women of reproductive age, a group that should be a priority in the evaluation of mercury exposure, considering the effects on human reproduction. Previous studies in the same region involving women of childbearing age had already shown dangerous concentrations for maternal-fetal health, if pregnancy occurred (15,16).

The current study confirms the findings of others who admit the occurrence of mercury exposure associated with the frequency of fish consumption in areas impacted by mining activity, where it was observed that the higher the frequency of fish intake was associated the greater TotalHg concentration in samples hair ($p<0.05$). However, in non-impacted (estuarine) areas there was no association between these two variables ($p>0.05$), indicating that the high frequency of fish consumption in these areas does not represent a risk for damages associated with methylmercury. In this way, fish from Tocantins estuarine is a healthy food, considering of the benefits that fish offers as a source of energy, protein and a variety of important nutrients, including minerals and long-chain polyunsaturated fatty acids, according to (4,20). A study carried out with women who consumed fish from Mexico's coastal region showed that high intake increased the risk of exposure to mercury, although the majority presented levels below 0.5µg/g, an acceptable value for consumption established by the Mexican norms (21). It should be noted that in the present study the fish studied were from two different estuarine regions, but the fish consumed had TotalHg concentrations well below the reference value for the species and values found in the coastal region from Mexico. Mercury in hair samples is used to assess the prolonged exposure arising from the ingestion of foods contaminated with methylmercury. The concentrations of mercury found in relatives of fishermen in the estuarine area were the lowest in relation to the other villages studied. Concentrations ranged from a

value below the detection limit to 6.2µg/g, with a median concentration of 0.7µg/g, where 75% of participants had values below 2µg/g, a reference value for non-fish population (22). These results may be related to the low levels of fish contamination, because they are not explained by the frequency of fish consumption, which was relatively higher than that observed in the other studied communities. The importance of fruit consumption in the Tapajós region on the prevention of mercury exposure was suggested by Passos et al (23). On the other hand, the region of Tocantins is recognized by the frequent production and consumption of açaí in the diet of the local riverine. Frequent consumption of this fruit with antioxidant properties, due to its high content of anthocyanins, may be a further protective factor against the toxic effects of mercury. In fishermen and families of estuarine and coastal areas the consumption frequency was as high as that of the Tapajós region, however, the concentrations of mercury in hair did not exceed the safety limit, averaging 3.8± 4.2µg/g for those who had the highest consumption of fish in the diet.

Village D located on the banks of the Caeté river, in the municipality of Bragança, has a diet influenced by fish from coastal waters. In this village, 84.7% of the population consumed more than two meals a week in fish in the region. The median TotalHg concentration in sample hair from Caeté was lower than Tapajós' riparians, but higher than the ones in the estuarine village where 75% of the studied population had concentrations below 6µg/g, a limit accepted for daily fish consumers (4). Concentrations high in about 25% of the population of village D can be attributed to frequent ingestion of predatory fish species containing concentrations unfit for consumption. All species of fish obtained were available in the diet of the riverside and had been captured on the same day of the meal and sample collection. The highest TotalHg concentrations were observed in fish from the Tapajós region (impacted by gold mining activity), particularly in the herbivorous *Leporinus friderici*, with a median concentration of 0.0890µg/g (0.0440-3,180µg/g), with 1.9% of the samples presenting values between 0.5µg/g and 1µg/g. The other specimens of the other herbivorous species analyzed, S*emaprochilodus spp* (jaraqui) and *Mylossoma spp* (pacu) showed TotalHg concentrations that were within the limits acceptable for human consumption. A study to evaluate concentrations of mercury in sediments and river fish where mining activity occurred upstream showed that the fish did not present high concentrations when compared to the concentrations of those of two unaccented rivers (24). In the estuarine region of Tocantins, the lowest concentrations were found in the herbivorous species *Macrodon ancylodon* with 0.0030µg/g (0.0010-0.0100µg/g), and the highest in *Hypophthalmidae spp* 0.0470µg/g (0.0170-0.0960µg/g). Similar values were found in a study carried out in the Tocantins medium by Milhomen Filho *et al*; these results suggest that, in general, these species from Tocantins estuarine do not present risks of damages caused by mercury in a diet with high frequency of ingestion. In the estuarine region, the most consumed species were *Hypophthalmidae spp* (mapará), *Plagioscion squamosissismus* (pescada branca) and *Macrodon ancylodon* (pratiqueira) (25).

Hypophthalmidae spp is one of the most consumed species in the diet of the riverside from Tocantins region, where the lowest TotalHg concentrations were found. These results can be explained by the reduced agricultural development process that would require deforestation and absence of mining activity in this region, actions that make mercury available to negatively impact the environment.

Macrodon ancylodon, another species widely consumed in the estuarine region, presented the smallest dimensions of weight and length, and were those that presented the lowest TotalHg concentrations conferring with the observations of Colino *et al*. that estuarine fish are still young, small, and have not reached sexual maturity, feeding mainly on debris and fruits, which decreases their ability to accumulate mercury. In the hotter months (spring and summer) in the shallower estuaries, a larger number of fish in the juvenile stage and few adults, data that are consistent with those observed in this study (26). The *Macrodon ancylodon* (pratiqueira) and *Hypophthalmidae spp* (mapará) species were found in young stages and presented the lowest TotalHg concentrations in relation to other species of similar habit (herbivores and detrívoras), in other regions. Particularly in the Caeté estuarine region, the most consumed species were piscivorous, including *Brachyplatystoma flavicans* (dourada), *Plagioscion squamosissimus* (pescada amarela) and *Arius couma* (bagre). Among the non-piscivorous species, *Geniatremus luteus* (peixe pedra) was included. The predatory species consumed by riparians from this region had lower concentrations than the herbivorous species (peixe pedra) and below the reference level for human consumption (0.5µg/g), according to the (22). These species with carnivorous and detrivorous habits accumulate mercury in the tissues more easily. According to Kasper *et al* (2012) several other factors contribute to bioaccumulation, such as temperature, availability of organic matter, planktonic species, local microbiota, pH and salinity. These factors, the small number of specimens and the seasonal (not rainy) period in which the specimens were obtained may explain the low concentrations found in these predatory species (27). In Brazil, there are few records of fish intake in estuarine and coastal fishery populations, especially those not impacted by anthropogenic actions. Fish species at the top of the marine trophic chain, captured on the south and southeast coast of Brazil, showed 16% of samples above the limit of 1.0µg/g and 62% of samples above 0.5 µg/g. Regular consumption (100g.dia^{-1}) of the species surveyed would result in a daily intake that would exceed by more than twice that recommended by international standards (28). The predatory species obtained from the Caeté river are commonly found in the coastal region of northern Brazil. None of these species had HgT concentrations greater than 0.5µg/g. Most of the fish specimens analyzed had concentrations well below the recommended limit for consumption, contrary to the findings of ancient and recent studies that piscivorous fish tend to have higher levels of mercury bioaccumulation (6,29). In general, the species of fish consumed in the Tapajós region presented higher concentrations than those found in the Tocantins and Caeté estuaries suggesting that the fish frequently consumed in the diet of riparian populations, impacted areas should be monitored and the health of these communities periodically evaluated.

Conclusion

The frequency of fish intake in the riverine diet is high. In the Tapajós region, herbivorous species presented levels commonly found in piscivorous species of areas impacted by mercury. In the Caeté estuarine region, piscivorous species presented low TotalHg concentrations. Higher concentrations of mercury were found in riparian Tapajós' riparian and smaller ones in the estuarine area of Tocantins that presented the lowest TotalHg concentrations in the diet fish. These results suggest that the frequency of ingestion of fish, the species consumed and the fish ecosystem contributed to the exposure to mercury. That the species of herbivorous and detrivorous fish of the Tocantins estuary are safe for human consumption. New studies are recommended considering the Tocantins region as a control area for exposure to mercury.

Contributing Authors

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Pinheiro, MCN: execution of the project, responsible for collecting samples of hair, fish and preparing and conclusion the article.

Souza GS: assisted in the collection of information by applying questionnaires to research participants.

Silva MCF: responsible for toxicological analysis of total mercury in hair and fish samples.

Costa Junior JMF: responsible for formatting the article according to the magazine's rules and for translating it into English.

Silva, SA: assisted in toxicological analysis of total mercury in hair samples and fishes.

Corbett, CEP: collaborated in the execution of the project and in the elaboration of the article, making criticisms and corrections.

Corvelo TCO: collaborated in the execution of the project and in the elaboration of the article, making criticisms and corrections.

Carneiro SR: collaborated in the normalization reviews and corrections.

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