Original article DOI: 10.2478/aiht-2022-73-3611

Fish consumption habits of pregnant women in Itaituba, Tapajós River basin, Brazil: risks of mercury contamination as assessed by measuring total mercury in highly consumed piscivore fish species and in hair of pregnant women

Ricardo Bezerra de Oliveira[1], Domingas Machado da Silva[1], Thamilles Santa Bárbara Sousa Franco[1], Cláudio Ramon Sena Vasconcelos[1], Deise Juliane dos Anjos de Sousa[1], Sandra Layse Ferreira Sarrazin[1], Mineshi Sakamoto[2], and Jean-Paul Bourdineaud[3]

[1] Federal University of Western Pará, Santarém, Brazil
[2] National Institute for Minamata Disease, Minamata, Japan
[3] University of Bordeaux, CNRS, UMR 5234, European Institute of Chemistry and Biology, Pessac, France

[Received in November 2021; Similarity Check in November 2021; Accepted in May 2022]

The Tapajós River basin in the Amazon region, Brazil is one of the most active gold mining areas in the world. In this study, we evaluated fish consumption habits and mercury exposure in 110 pregnant women in the city of Itaituba by measuring their total hair mercury concentrations. In addition, we investigated seasonal differences in mercury concentrations in two highly consumed piscivorous fish species, tucunaré (*Cichla* spp.) and pescada (*Plagioscion squamosissimus*). Total fish mercury concentrations (THg) during the dry season were 0.62±0.07 mg/kg for *Cichla* spp. and 0.73±0.08 mg/kg for *P. squamosissimus*. During the rainy season they were 0.39±0.04 and 0.84±0.08 mg/kg, respectively. Of our participants 44 % declared that they ate *Cichla* spp. and 67 % *P. squamosissimus*. Mean mercury concentration in their hair was 1.6±0.2 mg/kg and was above the US Environmental Protection Agency (US EPA) reference dose of 1 mg/kg in 48 % of them. Mean fish THg concentrations were also above the joint Food and Drug Administration and US EPA safety limit of 0.5 mg/kg for *P. squamosissimus* during both seasons and for *Cichla* spp. during the dry season only. These results show that pregnant women should avoid consumption of these piscivorous fish species during pregnancy and call for a regular programme to monitor Hg levels in that area.

KEY WORDS: *Cichla* spp.; hair; methylmercury; *Plagioscion squamosissimus*

Since its beginning in 1970, artisanal gold mining in the Amazon region has been releasing 200 t of mercury (Hg) a year into the environment (1) and has been responsible for deforestation, forest degradation, and limited biomass recovery (2–3). When released into rivers elemental mercury (Hg^0) used in the gold extraction process can be methylated to generate a highly toxic chemical form of Hg known as methylmercury (MeHg) (4), which then undergoes biomagnification along the trophic chain. The main sources for the transfer of MeHg to humans are aquatic biota and fish (1, 5–7) with more than 85 % and 95 % of total mercury concentration (THg) found in herbivorous and piscivorous fish tissue, respectively (8). The percentage of MeHg in muscle samples, in fact can be as high or even higher than 98 %, as reported in French Guiana carnivorous species (9) and the Madeira River in Brazil (10). Large-scale gold mining activity in this region has decreased since 1990, but artisanal gold mining has not stopped and is even increasing.

As fish is the primary protein source for local people, its consumption may reach as many as nine meals a week (11). This calls for monitoring fish Hg concentrations, but the vastness of the region makes it rather difficult. Since 1995, the number of research studies of Hg in the area has increased (8–15), as there are other prominent sources of aquatic environment pollution with Hg besides gold mining (16), including its natural presence in soil, which is then released through erosion and land use for agriculture (17–19). During the rainy season, river levels rise and large areas are flooded. Previous studies have shown that flooded land increases MeHg levels in the aquatic environment (20–22). Another source of pollution with MeHg from inorganic Hg are the dams (23–27).

Methylmercury is neurotoxic and easily crosses biological barriers such as the placenta and blood brain barrier (28–30). In the Amazonian basin there have been reports of impaired cognitive function in children (31), motor performance, visual function,

Corresponding author: Jean-Paul Bourdineaud, University of Bordeaux, CNRS, UMR 5234, European Institute of Chemistry and Biology, 2 rue Robert Escarpit, 33607 Pessac, France, E-mail: *jean-paul.bourdineaud@u-bordeaux.fr*, ORCID: 0000-0002-1619-7050

immune system, genotoxicity, and changes in blood pressure (32). Pregnant women and their foetuses are at particular risk of adverse health effects (33–35).

Even though the vastness of the area, intensified land use, burning of forests, and artisanal gold mining make it difficult to estimate possible health risks for the local population in direct contact with Hg, fish can be very useful to biomonitor its presence in the environment (36–40). Establishing total Hg concentrations can provide a reasonable insight or proxy into exposure to MeHg, as it accounts for more than 95 % of THg in piscivorous fish from the region (8–10).

Among the several local fish species, some are more consumed than others because they are highly palatable and abundant, including the tucunaré (*Cichla* spp.) and pescada (*Plagioscion squamosissimus*) species chosen for this study. Both are piscivorous and available throughout the year. In addition, these species are among the most consumed by citizens. Our aim was to establish their THg concentrations over 12 months and compare them with THg concentrations in the hair of mothers who had just given birth at the municipal hospital in Itaituba, Brazil to see if mercury exposure increased the health risk for pregnant women and their future newborns.

PARTICIPANTS AND METHODS

Study area

The municipality of Itaituba (04°16'34.0" S, 55°59'01.0" W) is situated in the Tapajós River basin in the southwestern region of the state of Pará, Brazil, with a population of over 98 thousand and territory of over 62 million km^2 (41) (Figure 1). It is the reference centre in public health care for patients referred from other municipalities (Aveiro, Jacareacanga, Novo Progresso, Rurópolis and Trairão) and receives patients from riverbank communities, countryside, forest, and gold mining areas such as those marked in Figure 1.

Study participants

This study included 110 pregnant women (aged 18–40; mean age 24.6±4.8 years), admitted to the obstetric clinic at the Municipal Hospital of Itaituba (state of Pará, Brazil) to give childbirth. For the purpose of this study, we designed a specific questionnaire to collect their socio-demographic data (including residence, age, education, marital status, race, and occupation), health status, weight, height, blood pressure, smoking habit, diet, alcohol use, and fruit

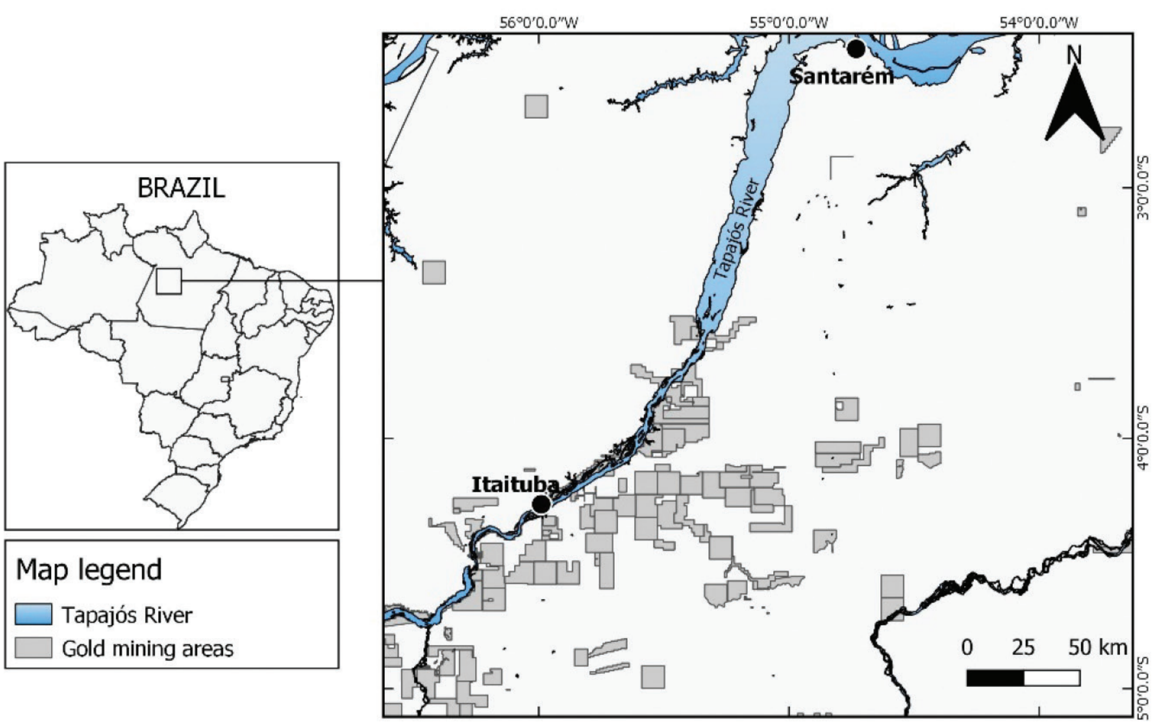

Figure 1 Geographical position of Itaituba

consumption. We also collected information about their fish consumption, including the species and weekly estimates of meals (g). To help them estimate consumption per meal, we showed them a silicon (50 and 100 g) fish filet very similar to the natural fish filet.

All participants were informed about all study details (duration, objectives, method, risks, and benefits) and signed the informed consent form before they entered the study. The study followed the principles described in the Declaration of Helsinki and was approved by the Research Ethics Committee of the University of the State of Pará (UEPA), Santarém, Brazil (approval No.: CAAE 94880318.9.0000.5168 on 11/21/2018).

Hair sampling

The participants also gave hair samples (n=110), which were taken with sterile scissors as close as possible to the scalp in the occipital region to minimise aesthetic changes. Each sample was placed in a paper envelope until analysis. Considering that hair grows 1 cm a month on average, we took only four centimetres off the tip of the hair for THg analysis to obtain an average Hg concentration in the last four months of pregnancy.

To remove impurities, hair samples were first washed with the 0.1 %, (v/v) Triton™ X-100 solution (Sigma-Aldrich, St. Louis, MO, USA) and then with ultra-pure water. Excess water was rinsed with acetone (Sigma-Aldrich) and samples dried at room temperature. Each sample was then cut into very thin pieces with sterile scissors for better homogenisation.

Fish sampling and river level information

Cichla spp. and *P. squamosissimus* are mostly piscivores, yet occasionally they also feed on crustaceans and other invertebrates (42–46). In general, they are sedentary, although they have a short lateral range of movement (47, 48). These two species are not protected by spawning regulations and are sold at markets throughout the year.

All samples used in this study were purchased from the same artisanal fishermen in Itaituba, by whose account the fish had been caught in the small lakes around the village of São Luiz do Tapajós in the municipality of Itaituba (Figure 1). This upper Tapajós river area receives water from small tributaries with artisanal gold mines. Purchases were always made between the 15th and 17th of each month from July 2018 to June 2019 to cover the dry (July–December) and the rainy (January–June) season corresponding to low and high river water levels, respectively, measured in Itaituba with a pole placed about 10 m from the bank (Figure 2). Fish were weighed and their size measured. The samples consisted of dorsolateral muscle cuts, divided by season into groups of 60 and frozen at -20 °C until analysis. The dry season group contained 30 samples of *Cichla* spp. and *P. squamosissimus* each and so did the rainy season group.

THg analyses

Aliquots (duplicates) weighing 0.005–0.007 g of finely cut hair or 0.05–0.06 g of fresh fish were placed on quartz boats and inserted into a direct mercury analyser, DMA-80 (Milestone Srl, Sorisole, Italy), as this method does not require sample pretreatment because it involves thermal degradation of the sample, catalytic conversion, amalgamation, and spectrophotometry (a mercury lamp with a wavelength equal to 253.55 nm). Oxygen (99.99 % purity) was used as the carrier gas, and the detection limit was 0.0015 ng. To ensure analytical quality we used certified reference materials NIES 13 (human hair; National Institute for Environmental Studies, Tsukuba, Japan) and BCR-463 (tuna fish flesh; European Commission Directorate - Joint Research Centre, Geel, Belgium). Respective recoveries of 94 and 97 % were routinely observed for either.

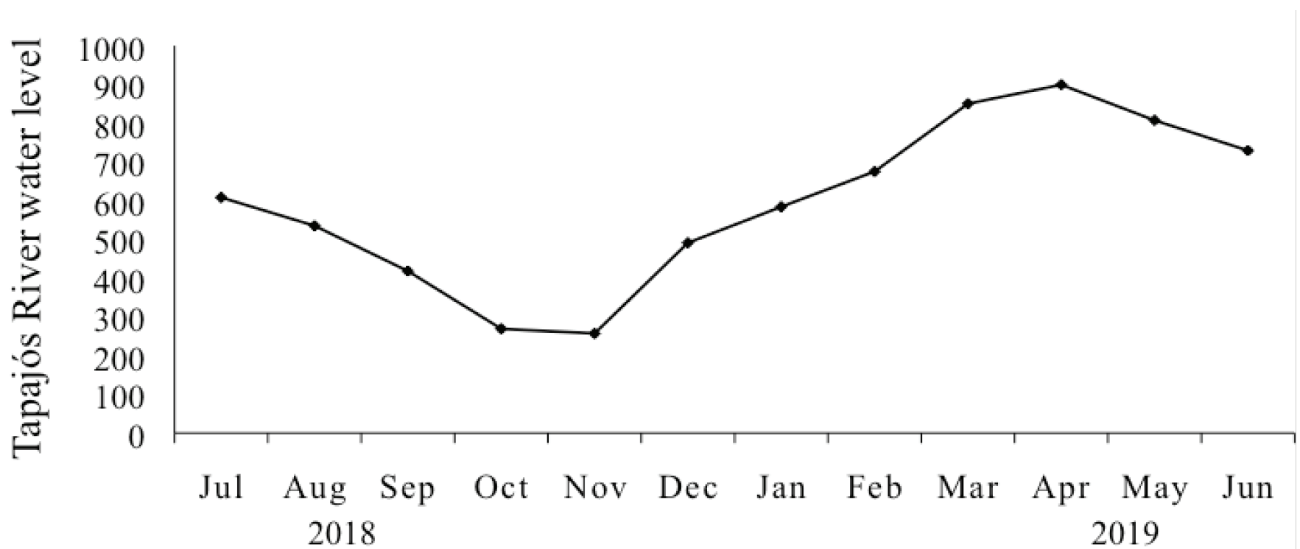

Figure 2 Variations of the Tapajós River water levels (cm) in Itaituba from July 2018 to June 2019

Risk assessment calculation

The risk was calculated for each woman by dividing hair THg concentration by either the hair reference dose (RfD) proposed by the United States Environmental Protection Agency (US EPA) of 1.0 mg/kg (49) or by the lowest observable adverse effect hair concentration (LOAEHC) of 0.3 mg/kg associated with an adverse neurodevelopmental effect (50). The US EPA hair RfD corresponds to the provisional tolerable weekly Hg intake of 0.7 μg/kg body weight (PTWI) adopted in 2001 based on neurologic developmental effects in children associated with exposure to MeHg from maternal diet *in utero* (51). It is more protective than other relevant RfDs (52, 53), which is why we selected it to assess the risk for the newborns of our study participants.

Statistical analyses

The normality of data distribution was tested with the Kolmogorov-Smirnov and Shapiro-Wilk test significant differences ($p<0.05$) confirmed with one-way analysis of variance (ANOVA). The software used was Prism GraphPad 8 (GraphPad Software, San Diego, CA, USA).

RESULTS AND DISCUSSION

Fish consumption habits

Our participants declared consuming 21 fish species during pregnancy (Table 1), 13 of which are non-piscivorous. Piscivorous *Cichla* spp. and *P. squamosissimus* were at the top of consumed fish in that group, as reported by 44 and 67 % of participants, respectively.

Fish THg

The fish did not significantly differ in weight and length between the seasons (Table 2). It has been claimed that larger and heavier carnivorous fish tend to concentrate more Hg (54), but we found no significant correlation between THg concentration and fish weight or size (Figure 3), which is in line with an earlier report for *Cichla* spp. in Jacareacanga, which is 300 km upstream the Tapajós River from Itaituba (36), whereas contrasting correlations were reported for carnivorous species *Pseudoplatystoma* sp. (surubim) and *Brachyplatystoma flavicans* (dourada), also consumed in Itaituba (39)

Table 1 Fish species consumed by pregnant women (n=110) from Itaituba, Brazil

Fish local name (species)	Participants reporting eating listed fish (N)	%	Fish description by diet
Tambaqui (*Colossoma macropomum*)	90	82	Frugivore
Pescada branca (*Plagioscion squamosissimus*)	74	67	Piscivore
Pacú (*Serrassalmidae* spp.)	60	54	Frugivore
Tucunaré (*Cichla* spp.)	49	44	Piscivore
Aracú (*Leporinus* spp.)	41	37	Omnivore
Caratinga (*Geophagus* spp.)	40	36	Omnivore
Surubim (*Pseudoplatystoma* spp.)	37	33	Piscivore
Charutinho (*Hemiodus* spp.)	33	30	Omnivore
Dourada (*Brachyplatystoma rousseauxii*)	33	30	Carnivore
Filhote (*Brachyplatystoma filamentosum*)	33	30	Carnivore
Pirarucu (*Arapaima gigas*)	30	27	Piscivore
Curimatá (*Prochilodus nigricans*)	28	25	Detritivore
Acari (*Pterygoplichthys* spp.)	22	20	Detritivore
Matrinxã (*Brycon* spp.)	22	20	Omnivore
Aruanã (*Osteoglossum bicirrhosum*)	21	19	Carnivore
Pirarara (*Phractocephalus hemioliopterus*)	21	19	Omnivore
Apapá (*Pellona* spp.)	18	16	Carnivore
Piau (*Anostomidae* spp.)	16	14	Detritivore
Pirapitinga (*Piaractus brachypomus*)	16	14	Frugivore
Jaraqui (*Semaprochilodus* spp.)	2	2	Detritivore
Mapará (*Hypophthalmus* spp.)	2	2	Planktivore

Table 2 Biometric parameters in two predator fish species from the Tapajós River basin, Amazon, Brazil

	Biometric parameters	Dry season		Rainy season	
		Mean ± SD	**Min–Max**	**Mean ± SD**	**Min–Max**
Plagioscion squamosissimus	Weight (g)	224±40	150–315	207±32	149–261
	Total length (cm)	27.2±0.5	25.0–30.5	27.1±1.2	25.4–29.7
	Standard length (cm)	22.4±1.4	20.1–24.8	22.4±1.2	20.7–25.4
Cichla spp.	Weight (g)	344±129	195–792	271±69	194–406
	Total length (cm)	29.4±3.1	25.0–38.5	27.8±2.0	25.5–32.1
	Standard length (cm)	24.5±2.8	20.7–32	23.2±1.7	21.0–27.3

SD – standard deviation

Table 3 Total mercury concentrations (mg/kg) in *Cichla spp.* (tucunaré) and *P. squamosissimus* (pescada) fish caught in the Tapajós River basin, Brazil

	Dry season (July – December 2018)		Rainy season (January – June 2019)	
	***Cichla* spp. (n=26)**	***P. squamosissimus* (n=24)**	***Cichla* spp. (n=24)**	***P. squamosissimus* (n=24)**
Mean ± SD	0.62±0.35	0.73±0.37	**0.39±0.21***	0.54±0.37
Min–max	0.17–1.68	0.05–1.37	0.12–0.94	0.25–1.65
Median	0.59	0.83	0.29	0.89
25th quartile	0.39	0.55	0.24	0.55
75th quartile	0.75	0.92	0.54	1.12

* Significantly different from dry season ($p<0.05$). SD – standard deviation

or herbivorous species caratinga (*Geophagus* spp.) and carnivorous traíra (*Hoplias malabaricus*) caught in Jacareacanga (36).

Table 3 shows fish THg concentrations for both species by season. Dry season concentrations did not significantly differ between the two species, but *Cichla* spp. showed a 37 % lower THg ($p<0.05$) in the dry season, whereas THg concentrations in *P. squamosissimus* did not significantly differ between seasons.

The maximum Hg concentration in fresh fish flesh recommended by the joint Food and Drug Administration (FDA) and the US EPA for consumption by pregnant or breastfeeding women and children below 12 years of age is 0.5 mg/kg (55). The following fish species should be avoided by this vulnerable population group: king mackerel, marlin, orange roughy, shark, swordfish, tilefish, and tuna bigeye (55), as they contain mean THg (recorded between 1990 and 2012) of 0.73, 0.49, 0.57, 0.98, 1.00, 1.12, 0.69 mg/kg fresh weight, respectively (56). In the dry season, 71 % of *Cichla* spp. and 80 % of *P. squamosissimus* specimens had THg above this recommended limit of 0.5 mg/kg. In the rainy season, this percentage dropped to 37 % for *Cichla* spp. and to 71 % for *P. squamosissimus* specimens.

Total mercury concentrations found in the present study are in the range of those previously reported for carnivorous fish from the Tapajós River basin (40), ranging from 0.4 to 1.51 mg/kg, and Itaituba in particular (8), ranging from 0.9 to 3.2 mg/kg. Previous studies showed that near Itaituba, THg concentrations in *Cichla* spp. ranged from 0.19 to 1.00 mg/kg (10, 57, 58) and in *P. squamosissimus* from 0.09 to 1.35 mg/kg (11, 58). Nowadays, after more than twenty years of studies at the Tapajós River basin, the THg levels in carnivorous fish are still above the safe limit of 0.5 mg/kg, and the same is true for THg concentrations in *P. squamosissimus* of the upper Amazon (59).

Hair THg and associated risks

Most of our study participants lived in the urban (n=75) area of Itaituba, followed by rural residents (n=17) and other (n=10) cities close to Itaituba (Figure 4). We found no difference in hair THg levels between these three groups of residents.

Table 4 shows hair THg levels by age, education level, marital status, race, and occupation groups. It does not include smoking as none reported to have smoked. None of these parameters significantly influenced hair THg concentration, nor did alcohol and fruit consumption (data not shown). The same is true for body mass index (mean ± SD: 27.4±4.4, median: 26.7, interquartile range: 24.4–30.2, n=110) (Table 5), and systolic/diastolic blood pressure (Table 6).

Mean (±SD) hair THg concentration of all participants (n=110) was 1.6±1.5 mg/kg, ranging from 0.09 to 17.97 mg/kg (median: 0.95 mg/kg, interquartile range: 0.6–2.2 mg/kg, n=108), which is below previously reported means in small villages along the Tapajós River (10, 12, 14, 39, 54, 58, 60–73). However, it exceeds the US EPA RfD (49) of 1 mg/kg for hair. In 30 participants (27 %) it was 2–6 mg/kg, in four (3.6 %) >6 μg/g, and in one as high as 17.9 mg/kg.

Table 7 shows hair THg concentrations by fish consumption. Only the group consuming >400 g/week had significantly higher THg than the group consuming the lowest amounts (0–100 g/week) ($p<0.05$). Considering the US EPA RfD, health risk was increased

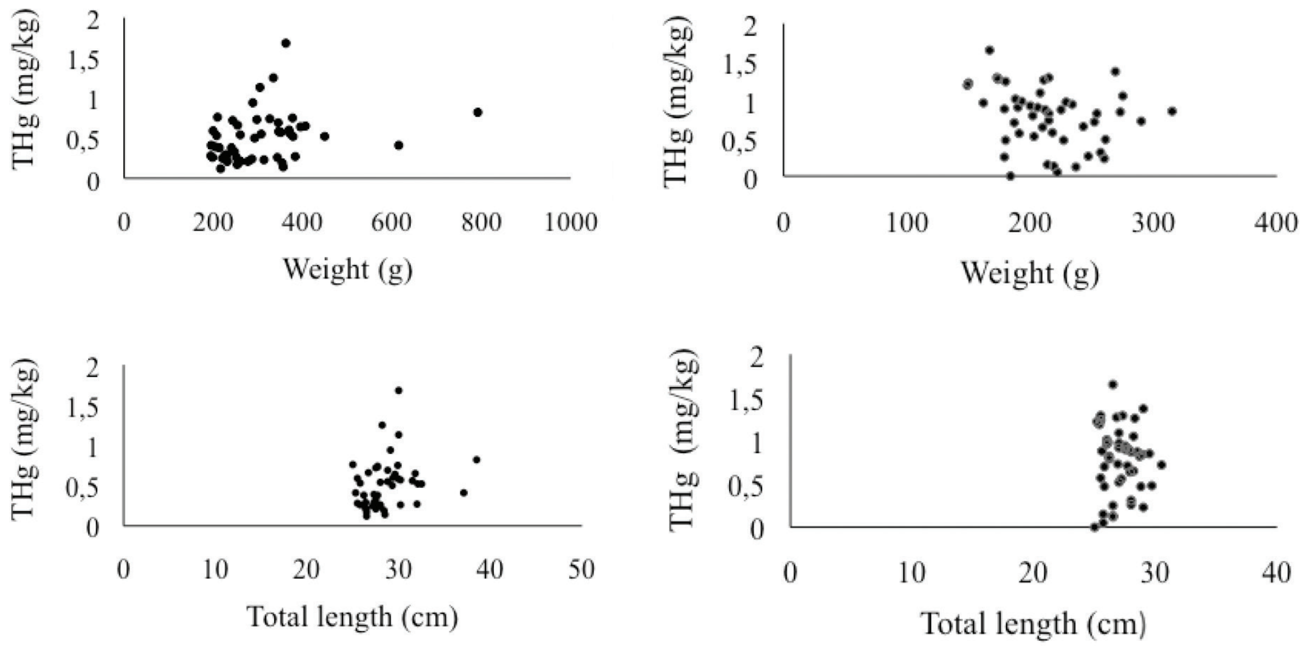

Figure 3 Relationship between mercury concentration and weight and total length of fish caught and consumed in Itaituba. Left columns: *Cichla* spp. (tucunaré; n=48); right columns: *P. squamosissimus* (pescada; n=48)

in 33 % of the women consuming up to 100 g of study fish a week and in 56 % of those consuming more than that (Table 7). Considering the LOAEHC, neurodevelopmental risks of MeHg to the unborn child from maternal fish consumption (49) were increased in 85 % of women consuming up to 200 g/week and in all women consuming more than that (Table 7).

Our hair THg findings are comparable with those reported for women of childbearing age from the island of Vieques offshore from Puerto Rico (median: 0.66 mg/kg, in 26.8 % of these women above the US EPA RfD) (74), Sweden (median: 0.7 mg/kg, in 20 % above the US EPA RfD) (75), and Moroccan coastal communities (median: 1.18 mg/kg, in 50 % above the US EPA RfD) (76).

Exposure in newborns has already been evidenced by a Spanish study (77) which established hair THg concentrations of 1.4 and 2.0 mg/kg in Madrid and Sabadell, exceeding the US EPA RfD in 39 and 60 % of newborns, respectively. Adverse effects have been

Table 4 Relationship between socio-demographic characteristics of participating pregnant women from Itaituba and hair THg concentrations (mg/kg)

		n	%	**Hair THg** (mean ± SD)
Age	18–20	40	36.4	2.3±3.5
	21–30	57	51.8	1.6±1.4
	31–40	13	11.8	1.5±2.3
Schooling	Elementary school	54	49.2	2.1±2.3
	High school	38	34.5	1.7±2.1
	Academic education	18	16.3	1.5±2.3
Marital status	Married or living as married	85	77.2	1.5±1.7
	Single	25	22.8	2.5±4.3
Race	White	2	1.8	0.6±0.01
	Black	7	6.3	3.9±6.3
	Mixed race	101	91.9	1.7±1.9
Occupation	Housewife	90	81.9	1.8±2.0
	Student	7	6.3	3.6±6.4
	Other occupation	13	11.8	1.3±1.5

Table 5 Relationship between body mass index (BMI) of participating pregnant women from Itaituba and hair THg concentration (mg/kg)

BMI	Weight status	n	Hair THg (mean ± SD)
18.5–24.9	normal	33	1.9±2.8
25.0–29.9	overweight	49	1.8±2.7
30.0–39.9	obese	24	1.8±1.4
≥40.0	severe obesity	4	1.4±0.6

BMI was calculated as weight (kg) divided by height squared (m^2)

Table 6 Relationship between blood pressure in participating pregnant women from Itaituba and hair THg concentration (μg/g)

Blood pressure (mmHg, mean ± SD)[a]		n	Fish intake (g/week)	Hair THg (mg/kg, mean ± SD)
Systolic	Diastolic			
101±7	65±6	40	0–100	1.1±0.9
103±8	68±8	26	101–200	1.7±1.3
101±10	67±5	23	201–400	1.6±1.3
103±12	69±10	21	401–800	2.43±2.2

[a] Blood pressure data are the mean of the last five months of pregnancy

highlighted worldwide for maternal hair THg concentrations in the range and even below those measured in our study: lower cognitive scores in six month-old US children associated with maternal hair THg concentration of 0.55 mg/kg (78, 79), impairment in behavioural ability in Chinese newborns associated with maternal hair THg concentration of 1.25 mg/kg (80), and lower psychomotor development index in 30-month-old Seychelles children associated with maternal hair THg concentration of 5.7 mg/kg (81). In indigenous Suriname communities, preterm birth (<37 weeks) was associated with maternal hair THg concentration of 3.5 mg/kg (82), and Michigan women who delivered too early (<35 weeks) had hair THg concentrations between 0.55 and 2.5 mg/kg (83).

Although mean hair THg concentration found in this study (1.6±0.2 mg/kg) is below that of the Barreiras community close to Itaituba (10.38 mg/kg) (13), it is nevertheless quite higher than those recorded in women of childbearing age from Barreiras and São Luis do Tapajós (villages close to Itaituba) between 1999 and 2012 (1.07±0.03 and 0.74±0.05 mg/kg, respectively) (84) and between hair THg concentrations found in women of childbearing age living in Santarém (300,000 inhabitants, a city located at the confluence of the Tapajós and Amazon Rivers) and Oriximiná (63,000

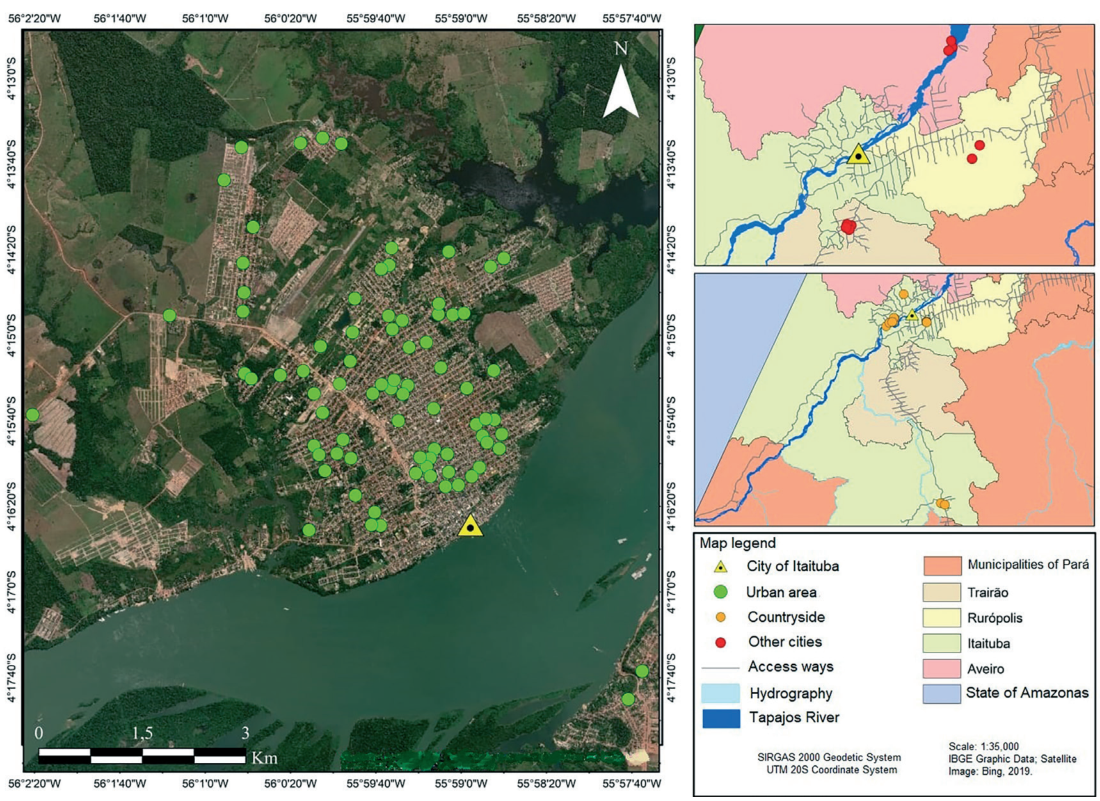

Figure 4 Distribution of participants by residence in and around Itaituba along the Tapajós River (Amazon, Brazil). The left panel shows residences as green dots. The lower part of the right panel shows the legend, translated as follows: Itaituba (Cidade de Itaituba); Urban area (Área urbana); Rural zone (Zona rural); Other cities (Outras cidades); Access roads (Vias de acesso); Water (Hidrographia); the Tapajós River (Rio Tapajós); Pará Municipalities (Municipios do Pará); State of Amazonas (Estado do Amazonas)

Table 7 Hair THg levels in participating pregnant women from Itaituba and distribution of increased health risks from Hg exposure by fish consumption

Fish consumption (g/week)	Hair THg (mg/kg, mean ± SD)	Risk rate based on US EPA RfD [a]	Risk rate based on LOAEHC [b]
0–100 (n=37)	1.1±0.9	0.7 (33 %)	2.3 (83 %)
101–200 (n=25)	1.7±1.3	1.7 (58 %)	5.7 (87 %)
201–400 (n=24)	1.6±1.3	1.1 (54 %)	3.8 (100 %)
> 400 (n=22)	**2.4±2.2***	1.2 (57 %)	3.9 (100 %)

* Significant difference ($p<0.05$) from the group of women consuming 0–100 g of fish a week. [a] reference dose of 1.0 mg/kg (49). [b] lowest observable adverse effect hair concentration of 0.3 mg/kg, (50). Both risk rates are given as medians of distribution. Percentage in parentheses refers to women above these safety limits (raw data and calculations are available from the authors upon request)

inhabitants, a city located on the Trombetas River, 40 km upstream from its confluence with the Amazon River) of 1.1±0.2 mg/kg and 2.5±1.0 mg/kg, respectively (85).

Previous studies conducted in women from villages located in the Tapajós River basin showed higher consumption of fish than our study participants: the mean amounts of fish ingested by women during one meal varied from 80±25 g in Açaituba to 147±72 g in São Luis do Tapajós (58). Mean fish portions (fish per meal per capita) of 243±135 g (median: 200 g) have been reported for the riverside general population (including adult men and women) of the Madeira River basin (86), and an average fish consumption of 110 g/day for fishermen of the Alta Floresta region (87) and for villagers of the Balbina reservoir (88). One should also take into account socioeconomic implications. The two piscivorous fish species evaluated in this study are more expensive than other species and most of our participants are of modest means, judging by self-reported elementary school level in nearly 50 % and unemployment in nearly 82 %, (Table 4), who therefore eat other, cheaper fish. This suggests that women with higher income may be at higher risk of Hg exposure than those with low income.

Previous studies have shown that non-piscivorous fish from the Tapajós River basin have considerably lower THg concentrations than piscivorous fish: 0.18 vs 1.66 mg/kg (8), 0.03–0.30 mg/kg vs 0.40–1.51 mg/kg (40), 0.095 vs 0.297 mg/kg (36), 0.05–0.08 vs 0.37–0.84 mg/kg (39), and 0.01–0.04 vs 0.12–0.66 mg/kg (89), respectively.

Considering that fish is beneficial for humans, non-piscivorous fish should be the best choice for consumption, especially during pregnancy. The supply of non-piscivorous fish bred in aquacultures has increased around Itaituba in recent times, such as that of the species *Colossoma macropomum* (the local name is tambaqui), which most of our participants (n=90) have reported eating. With its THg content of 0.08±0.03 mg/kg (39), 0.03±0.01 mg/kg (89), and 0.04±0.01 mg/kg (40), it may provide a healthier alternative at lower price. In addition, Itaituba is nowadays connected with the rest of the country by roads, which makes diet choices more diversified. This, however, is still not true for small villages along the Tapajós River banks. Furthermore, the expansion of local cattle and farms has increased the supply of beef and chicken at prices lower than those of fish.

This study has some limitations. The number of participants (n=110) is low, although it allows statistical analysis. Only two fish species have been sampled (although they are the two most favoured piscivorous species by our participants), and the ideal experimental protocol would have been to sample all of the species consumed and then collect consumption data for each participant (weight consumed on a weekly or monthly basis for each species) in order to calculate dietary exposure. However, its implementation was not feasible, as people are reluctant to measure the weight of each fish in their meal, and we could only get a rough estimation of weekly servings.

CONCLUSION

The consumption of *Cichla* spp. and *P. squamosissimus* should be completely avoided by pregnant women, since these species contain THg levels higher than 0.5 mg/kg and put their and newborns' health at risk. However, fish is important for healthy diet, especially during pregnancy, and eating non-piscivorous fish seems to be a better alternative, since it contains much lower levels of Hg.

Our findings call for a continuous environmental biomonitoring programme for Hg in the Tapajós River basin.

Acknowledgments

We wish to thank our participants for helping us carry out this study and professor Göran Klobučar from the University of Zagreb for having translated the title and abstract into Croatian.

This work was supported by the Comissão de aperfeiçoamento de pessoal de nível superior (CAPES), the Programa pesquisador visitante sênior (PVE) (grant Nos. 88881.030.467/243-01 and 88881.030472/20), the Conselho nacional de desenvolvimento científico (CNPQ), the Programa institucional de bolsas de iniciação científica (PIBIC), and the Federal University of Western Pará, Brazil.

Conflicts of interest

None to declare.

REFERENCES

1. Crespo-Lopez ME, Augusto-Oliveira M, Lopes-Araújo A, Santos-Sacramento L, Yuki Takeda P, Macchi BM, do Nascimento JLM, Maia CSF, Lima RR, Arrifano GP. Mercury: What can we learn from the Amazon? Environ Int 2021;146:106223. doi: 10.1016/j.envint.2020.106223
2. Espejo CJ, Messinger M, Román-Dañobeytia F, Ascorra C, Fernandez LE, Silman M. Deforestation and forest degradation due to gold mining in the Peruvian Amazon: A 34-year perspective. Remote Sens 2018;10(12):1903. doi: 10.3390/rs10121903
3. Kalamandeen M, Gloor E, Johnson I, Agard S, Katow M, Vanbrooke A, Ashley D, Batterman SA, Ziv G, Holder-Collins K, Phillips OL, Brondizio ES, Vieira I, Galbraith D. Limited biomass recovery from gold mining in Amazonian forests. J Appl Ecol 2020;57:1730–40. doi: 10.1111/1365-2664.13669
4. Beckers F, Rinklebe J. Cycling of mercury in the environment: Sources, fate, and human health implications: A review. Crit Rev Environ Sci Technol 2017;47:693–794. doi: 10.1080/10643389.2017.1326277
5. Albuquerque FEA, Minervino AHH, Miranda M, Herrero-Latorre C, Júnior RAB, Oliveira FLC, Sucupira MCA, Ortolani EL, López-Alonso M. Toxic and essential trace element concentrations in fish species in the Lower Amazon, Brazil. Sci Total Environ 2020;732:138983. doi: 10.1016/j.scitotenv.2020.138983
6. Berzas Nevado JJ, Rodriguez Martin-Doimeadios RC, Guzman Bernardo FJ, Jimenez Moreno M, Herculano AM, do Nascimento JL, Crespo-Lopez ME. Mercury in the Tapajós River basin, Brazilian Amazon: a review. Environ Int 2010;36:593–608. doi: 10.1016/j.envint.2010.03.011
7. Hacon SS, Oliveira-da-Costa M, Gama CS, Ferreira R, Basta PC, Schramm A, Yokota D. Mercury exposure through fish consumption in traditional communities in the Brazilian Northern Amazon. Int J Environ Res Public Health 2020;17(15):5269. doi: 10.3390/ijerph17155269
8. Lino AS, Kasper D, Guida YS, Thomaz JR, Malm O. Total and methyl mercury distribution in water, sediment, plankton and fish along the Tapajós River basin in the Brazilian Amazon. Chemosphere 2019;235:690–700. doi: 10.1016/j.chemosphere.2019.06.212
9. Fréry N, Maury-Brachet R, Maillot E, Deheeger M, de Mérona B, Boudou A. Gold-mining activities and mercury contamination of native amerindian communities in French Guiana: key role of fish in dietary uptake. Environ Health Perspect 2001;109:449–56. doi: 10.1289/ehp.109-1240303.
10. Akagi H, Malm O, Branches FJP, Kinjo Y, Kashima Y, Guimaraes JRD, Oliveira RB, Haraguchi K, Pfeiffer WC, Takizawa Y, Kato H. Human exposure to mercury due to goldmining in the Tapajos River basin, Amazon, Brazil: Speciation of mercury in human hair, blood and urine. Water Air Soil Pollut 1995;80:85–94. doi: 10.1007/BF01189656
11. Lebel J, Roulet M, Mergler D, Lucotte M, Larribe F. Fish diet and mercury exposure in a riparian Amazonian population. Water Air Soil Pollut 1997;97:31–44. doi: 10.1023/A:1018378207932
12. Dolbec J, Mergler D, Sousa Passos CJ, Sousa de Morais S, Lebel J. Methylmercury exposure affects motor performance of a riverine population of the Tapajos river, Brazilian Amazon. Int Arch Occup Environ Health 2000;73:195–203. doi: 10.1007/s004200050027
13. Faial K, Deus R, Deus S, Neves R, Jesus I, Santos E, Alves CN, Brasil D. Mercury levels assessment in hair of riverside inhabitants of the Tapajós River, Pará State, Amazon, Brazil: fish consumption as a possible route of exposure. J Trace Elem Med Biol 2015;30:66–76. doi: 10.1016/j.jtemb.2014.10.009
14. Harada M, Nakanishi J, Yasoda E, Pinheiro MDCN, Oikawa T, de Assis Guimarâes G, da Silva Cardoso B, Kizaki T, Ohno H. Mercury pollution in the Tapajos River basin, Amazon: Mercury level of head hair and health effects. Environ Int 2001;27:285–90. doi: 10.1016/S0160-4120(01)00059-9
15. Kehrig H do A, Howard BM, Malm O. Methylmercury in a predatory fish (*Cichla* spp.) inhabiting the Brazilian Amazon. Environ Pollut 2008;154:68–76. doi: 10.1016/j.envpol.2007.12.038
16. Siqueira GW, Aprile F, Irion G, Braga ES. Mercury in the Amazon basin: Human influence or natural geological pattern? J South Am Earth Sci 2018;86:193–9. doi: 10.1016/j.jsames.2018.06.017
17. Roulet M, Lucotte M, Saint-Aubin A, Tran S, Rhéault I, Farella N, de Jesus da Silva E, Dezencourt J, Sousa Passos CJ, Santos Soares G, Guimarães JRD, Mergler D, Amorim M. The geochemistry of mercury in central Amazonian soils developed on the Alter-do-Chao formation of the lower Tapajos River Valley, Para state, Brazil. Sci Total Environ 1998;223:1–24. doi: 10.1016/S0048-9697(98)00265-4
18. Roulet M, Lucotte M, Canuel R, Farella N, Courcelles M, Guimarães JRD, Mergler D, Amorim M. Increase in mercury contamination recorded in lacustrine sediments following deforestation in the central Amazon. Chem Geol 2000;165:243–66. doi: 10.1016/S0009-2541(99)00172-2
19. Roulet M, Guimarães JRD, Lucotte M. Methylmercury production and accumulation in sediments and soils of an Amazonian floodplain-effect of seasonal inundation. Water Air Soil Pollut 2001;128:41–60. doi: 10.1023/A:1010379103335
20. Heyes A, Moore TR, Rudd JWM. Mercury and methylmercury in decomposing vegetation of a pristine and impounded wetland. J Environ Qual 1998;27:591–9. doi: 10.2134/jeq1998.00472425002700030017x
21. Kelly CA, Rudd JWM, Bodaly RA, Roulet NP, St.Louis VL, Heyes A, Moore TR, Schiff S, Aravena R, Scott KJ, Dyck B, Harris R, Warner B, Edwards G. Increases in fluxes of greenhouse gases and methyl mercury following flooding of an experimental reservoir. Environ Sci Technol 1997;31:1334–44. doi: 10.1021/es9604931
22. Porvari P, Verta M. Methylmercury production in flooded soils: A laboratory study. Water Air Soil Pollut 1995;80:765–73. doi: 10.1007/BF01189728
23. Arrifano GPF, Martin-Doimeadios RCR, Jimenez-Moreno M, Ramirez-Mateos V, da Silva NFS, Souza-Monteiro JR, Augusto-Oliveira M, Paraense RSO, Macchi BM, do Nascimento JLM, Crespo-Lopez ME. Large-scale projects in the amazon and human exposure to mercury: The case-study of the Tucuruí Dam. Ecotoxicol Environ Saf 2018;147:299–305. doi: 10.1016/j.ecoenv.2017.08.048
24. Bastos WR, Dorea JG, Lacerda LD, Almeida R, Costa-Junior WA, Baía CC, Sousa-Filho IF, Sousa EA, Oliveira IAS, Cabral CS, Manzatto AG, Carvalho DP, Ribeiro KAN, Malm O. Dynamics of Hg and MeHg in the Madeira River basin (Western Amazon) before and after impoundment of a run-of-river hydroelectric dam. Environ Res 2020;189:109896. doi: 10.1016/j.envres.2020.109896
25. Forsberg BR, Melack JM, Dunne T, Barthem RB, Goulding M, Paiva RCD, Sorribas MV, Silva Jr. UL, Weisser S. The potential impact of

new Andean dams on Amazon fluvial ecosystems. PLoS One 2017;12(8):e0182254. doi: 10.1371/journal.pone.0182254
26. Gomes VM, dos Santos A, Zara LF, Ramos DD, Forti JC, Ramos DD, Santos FA. Study on mercury methylation in the Amazonian rivers in flooded areas for hydroelectric use. Water Air Soil Pollut 2019;230(9):211. doi: 10.1007/s11270-019-4261-3
27. Pestana IA, Bastos WR, Almeida MG, Mussy MH, Souza CMM. Methylmercury in environmental compartments of a hydroelectric reservoir in the Western Amazon, Brazil. Chemosphere 2019;215:758–65. doi: 10.1016/j.chemosphere.2018.10.106
28. Aschner M, Clarkson TW. Distribution of mercury 203 in pregnant rats and their fetuses following systemic infusions with thiol-containing amino acids and glutathione during late gestation. Teratology 1988;38:145–55. doi: 10.1002/tera.1420380207
29. Aschner M, Clarkson TW. Methyl mercury uptake across bovine brain capillary endothelial cells *in vitro*: The role of amino acids. Pharmacol Toxicol 1989;64:293–7. doi: 10.1111/j.1600-0773.1989.tb00650.x
30. Kerper LE, Ballatori N, Clarkson TW. Methylmercury transport across the blood-brain barrier by an amino acid carrier. Am J Physiol - Regul Integr Comp Physiol 1992;262(5):R761–5. doi: 10.1152/ajpregu.1992.262.5.r761
31. dos Santos-Lima C, Mourão DS, Carvalho CF, Souza-Marques B, Vega CM, Gonçalves RA, Argollo N, Menezes-Filho JA, Abreu N, Hacon SS. Neuropsychological effects of mercury exposure in children and adolescents of the Amazon Region, Brazil. Neurotoxicology 2020;79:48–57. doi: 10.1016/j.neuro.2020.04.004
32. Hu XF, Singh K, Chan HM. Mercury exposure, blood pressure, and hypertension: a systematic review and dose-response meta-analysis. Environ Health Perspect 2018;126(7):076002. doi: 10.1289/EHP2863
33. Gonzalez DJX, Arain A, Fernandez LE. Mercury exposure, risk factors, and perceptions among women of childbearing age in an artisanal gold mining region of the Peruvian Amazon. Environ Res 2019;179:108786. doi: 10.1016/j.envres.2019.108786
34. Sakamoto M, Man Chan H, Domingo JL, Kubota M, Murata K. Changes in body burden of mercury, lead, arsenic, cadmium and selenium in infants during early lactation in comparison with placental transfer. Ecotoxicol Environ Saf 2012;84:179–84. doi: 10.1016/j.ecoenv.2012.07.014
35. Zhou F, Yin G, Gao Y, Liu D, Xie J, Ouyang L, Fan Y, Yu H, Zha Z, Wang K, Shao L, Feng C, Fan G. Toxicity assessment due to prenatal and lactational exposure to lead, cadmium and mercury mixtures. Environ Int 2019;133:105192. doi: 10.1016/j.envint.2019.105192
36. da Silva Brabo E, de Oliveira Santos E, Maura de Jesus I, da Silva Mascarenhas AF, de Freitas Faial K. Mercury contamination of fish and exposures of an indigenous community in Pará State, Brazil. Environ Res 2000;84:197–203. doi: 10.1006/enrs.2000.4114
37. de Oliveira Santos EC, de Jesus IM, da Silva Brabo E, Brito Loureiro EC, da Silva Mascarenhas AF, Weirich J, Câmara V de M, Cleary D. Mercury exposures in riverside amazon communities in Para, Brazil. Environ Res 2000;84:100–7. doi: 10.1006/enrs.2000.4088
38. de Souza Azevedo J, Hortellani MA, de Souza Sarkis JE. Organotropism of total mercury (THg) in *Cichla pinima*, ecological aspects and human consumption in fish from Amazon region, Brazil. Environ Sci Pollut Res 2019;26:21363–70. doi: 10.1007/s11356-019-05303-x
39. dos Santos LDSN, Müller RCS, Sarkis JEDS, Alves CN, Brabo EDS, Santos EDO, Bentes MHDS. Evaluation of total mercury concentrations in fish consumed in the municipality of Itaituba, Tapajos River Basin, Para, Brazil. Sci Total Environ 2000;261:1–8. doi: 10.1016/S0048-9697(00)00590-8
40. Lino AS, Kasper D, Guida, YS, Thomaz JR, Malm O. Mercury and selenium in fishes from the Tapajós River in the Brazilian Amazon: An evaluation of human exposure. J Trace Elem Med Biol 2018;48:196–201. doi: 10.1016/j.jtemb.2018.04.012
41. Instituto Brasileiro de Geografia e Estatística (IBGE). Itaituba - IBGE Cidades, October 2020 [displayed 25 October 2020]. Available at https://cidades.ibge.gov.br/brasil/pa/itaituba/panorama
42. Almeida VLL, Hahn NS, Vazzoler AEA de M. Feeding patterns in five predatory fishes of the high Parana River floodplain (PR, Brazil). Ecol Freshw Fish 1997;6:123–33. doi: 10.1111/j.1600-0633.1997.tb00154.x
43. Bennemann ST, Capra LG, Galves W, Shibatta OA. Dinâmica trófica de *Plagioscion squamosissimus* (Perciformes, Sciaenidae) em trechos de influência da represa Capivara (rios Paranapanema e Tibagi) [Trophic dynamic of *Plagioscion squamosissimus* (Perciformes, Scianidae) in stretches under influence of the Capivara dam (Paranapanema and Tibagi rivers), in Portuguese]. Iheringia Ser Zool 2006;96:115–9. doi: 10.1590/S0073-47212006000100020
44. Ferreira EJG, Zuanon JAS, dos Santos GM. [Peixes comerciais do médio Amazonas: região de Santarém Pará, in Portuguese]. Brasil: Edições IBAMA; 1998.
45. Hahn NS, Agostinho AA, Gomes LC, Bini LM. [Estrutura trófica da ictiofauna do reservatório: de Itaipu (Paraná-Brasil) nos primeiros anos de sua formação, in Portuguese]. Interciencia 1998;23:299–305.
46. dos Santos LN, Gonzalez AF, Araújo FG. [Dieta do tucunaré-amarelo *Cichla monoculus* (Bloch & Schneider) (Osteichthyes, Cichlidae), no Reservatório de Lajes, Rio de Janeiro, Brasil, in Portuguese]. Rev Bras Zool 2001;18(Suppl 1):191–204. doi: 10.1590/s0101-81752001000500015
47. Granado-Lorencio C, Araujo Lima CRM, Lobón-Cerviá J. Abundance - distribution relationships in fish assembly of the Amazonas floodplain lakes. Ecography 2005;28:515–20. doi: 10.1111/j.0906-7590.2005.04176.x
48. Hoeinghaus DJ, Layman CA, Arrington DA, Winemiller KO. Movement of *Cichla* species (Cichlidae) in a Venezuelan floodplain river. Neotrop Ichthyol 2003;1:121–6. doi: 10.1590/S1679-62252003000200006
49. US Environmental Protection Agency (EPA). Water quality criterion for the protection of human health: methylmercury [displayed 18 May 2022]. Available at https://www.epa.gov/sites/default/files/2020-01/documents/methylmercury-criterion-2001.pdf
50. Schoeman K, Bend JR, Hill J, Nash K, Koren G. Defining a lowest observable adverse effect hair concentrations of mercury for neurodevelopmental effects of prenatal methylmercury exposure through maternal fish consumption: A systematic review. Ther Drug Monit 2009;31:670–82. doi: 10.1097/FTD.0b013e3181bb0ea1
51. Marsh DO, Clarkson TW, Cox C, Myers GJ, Amin-Zaki L, Al-Tikriti S. Fetal methylmercury poisoning. Relationship between concentration in single strands of maternal hair and child effects. Arch Neurol 1987;44:1017–22. doi: 10.1001/archneur.1987.00520220023010
52. World Health Organization, United Nations Environment Programme. Guidance for Identifying Populations at Risk from Mercury Exposure, 2008 [displayed 9 may 2022]. Available at https://cdn.who.int/media/docs/default-source/chemical-safety/mercuryexposure.pdf?sfvrsn=e827b153_1&download=true

53. European Food Safety Authority (EFSA). Scientific opinion on the risk for public health related to the presence of mercury and methylmercury in food. EFSA Journal 2012;10(12):2985 [displayed 9 may 2022]. Available at https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2012.2985
54. Malm O, Branches FJP, Akagi H, Castro MB, Pfeiffer WC, Harada M, Bastos WR, Kato H. Mercury and methylmercury in fish and human hair from the Tapajós river basin, Brazil. Sci Total Environ 1995;175:141–50. doi: 10.1016/0048-9697(95)04910-X
55. US Food and Drug Administration (FDA) and Environmental Protection Agency (EPA). Advice about fish eating for those who might become or are pregnant or breastfeeding and children ages 1–11 years [displayed 18 May 2022]. Available at https://www.fda.gov/media/102331/download
56. US Food and Drug Administration (FDA). Mercury levels in commercial fish and shellfish (1990–2012) [displayed 18 May 2022]. Available at https://www.fda.gov/food/metals-and-your-food/mercury-levels-commercial-fish-and-shellfish-1990-2012
57. Akagi H, Malm O, Kinjo Y, Harada M, Branches FJP, Pfeiffer WC, Kato H. Methylmercury pollution in the Amazon, Brazil. Sci Total Environ 1995;175:85–95. doi: 10.1016/0048-9697(95)04905-3
58. Passos CJS, Da Silva DS, Lemire M, Fillion M, Guimarães JRD, Lucotte M, Mergler D. Daily mercury intake in fish-eating populations in the Brazilian Amazon. J Expo Sci Environ Epidemiol 2008;18:76–87. doi: 10.1038/sj.jes.7500599
59. Ferreira da Silva F, Lima MO. Mercury in fish marketed in the Amazon triple frontier and health risk assessment. Chemosphere 2020;248:125989. doi: 10.1016/j.chemosphere.2020.125989
60. Malm O, Guimarães JRD, Castro MB, Bastos WR, Viana JP, Branches FJP, Silveira EG, Pfeiffer WC. Follow-up of mercury levels in fish, human hair and urine in the Madeira and Tapajós basins, Amazon, Brazil. Water Air Soil Pollut 1997;97:45–51. doi: 10.1023/A:1018340619475
61. Grandjean P, White RF, Nielsen A, Cleary D, de Oliveira Santos EC. Methylmercury neurotoxicity in Amazonian children downstream from gold mining. Environ Health Perspect 1999;107:587–91. doi: 10.1289/ehp.99107587
62. Dolbec J, Mergler D, Larribe F, Roulet M, Lebel J, Lucotte M. Sequential analysis of hair mercury levels in relation to fish diet of an Amazonian population, Brazil. Sci Total Environ 2001;271:87–97. doi: 10.1016/S0048-9697(00)00835-4
63. Crompton P, Ventura AM, de Souza JM, Santos E, Strickland GT, Silbergeld E. Assessment of mercury exposure and malaria in a Brazilian Amazon riverine community. Environ Res 2002;90:69–75. doi: 10.1006/enrs.2002.4358
64. Passos CJ, Mergler D, Gaspar E, Morais S, Lucotte M, Larribe F, Davidson R, De Grosbois S. Eating tropical fruit reduces mercury exposure from fish consumption in the Brazilian Amazon. Environ Res 2003;93:123–30. doi: 10.1016/S0013-9351(03)00019-7
65. Passos CJS, Mergler D, Fillion M, Lemire M, Mertens F, Guimarães JRD, Philibert A. Epidemiologic confirmation that fruit consumption influences mercury exposure in riparian communities in the Brazilian Amazon. Environ Res 2007;105:183–93. doi: 10.1016/j.envres.2007.01.012
66. Bahia MO, Corvelo TC, Mergler D, Burbano RR, Lima PDL, Cardoso PCS, Lucotte M, Amarim MIM. Environmental biomonitoring using cytogenetic endpoints in a population exposed to mercury in the Brazilian Amazon. Environ Mol Mutagen 2004;44:346–9. doi: 10.1002/em.20054
67. Silva IA, Nyland JF, Gorman A, Perisse A, Ventura AM, Santos ECO, de Souza JM, Burek CL, Rose NR, Silbergeld EK. Mercury exposure, malaria, and serum antinuclear/antinucleolar antibodies in amazon populations in Brazil: A cross-sectional study. Environ Health 2004;3(1):11. doi: 10.1186/1476-069X-3-11
68. Pinheiro MCN, Müller RCS, Sarkis JE, Vieira JLF, Oikawa T, Gomes MSV, Guimarães GA, do Nascimento JLM, Silveira LCL. Mercury and selenium concentrations in hair samples of women in fertile age from Amazon riverside communities. Sci Total Environ 2005;349:284–8. doi: 10.1016/j.scitotenv.2005.06.026
69. Pinheiro MCN, Oikawa T, Vieira JLF, Gomes MSV, Guimarães GA, Crespo-López ME, Müller RCS, Amoras WW, Ribeiro DRG, Rodrigues AR, Côrtes MIT, Silveira LCL. Comparative study of human exposure to mercury in riverside communities in the Amazon region. Braz J Med Biol Res 2006;39:411–4. doi: 10.1590/S0100-879X2006000300012
70. Pinheiro MCN, Crespo-López ME, Vieira JLF, Oikawa T, Guimarães GA, Araújo CC, Amoras WW, Ribeiro DR, Herculano AM, do Nascimento JLM, Silveira LCL. Mercury pollution and childhood in Amazon riverside villages. Environ Int 2007;33:56–61. doi: 10.1016/j.envint.2006.06.024
71. Pinheiro MCN, Macchi BM, Vieira JLF, Oikawa T, Amoras WW, Guimarães GA, Costa CA, Crespo-López ME, Herculano AM, Silveira LCL, do Nascimento JLM. Mercury exposure and antioxidant defenses in women: A comparative study in the Amazon. Environ Res 2008;107:53–9. doi: 10.1016/j.envres.2007.08.007
72. Fillion M, Mergler D, José C, Passos S, Larribe F, Lemire M, Rémy J, Guimarães D. A preliminary study of mercury exposure and blood pressure in the Brazilian Amazon. Environ Health 2006;5:29. doi: 10.1186/1476-069X-5-29
73. Grotto D, Valentini J, Fillion M, Passos CJS, Garcia SC, Mergler D, Barbosa F Jr. Mercury exposure and oxidative stress in communities of the Brazilian Amazon. Sci Total Environ 2010;408:806–11. doi: 10.1016/j.scitotenv.2009.10.053
74. Ortiz-Roque C, López-Rivera Y. Mercury contamination in reproductive age women in a Caribbean island: Vieques. J Epidemiol Community Health 2004;58:756-7. doi: 10.1136/jech.2003.019224
75. Björnberg KA, Vahter M, Grawé KP, Berglund M. Methyl mercury exposure in Swedish women with high fish consumption. Sci Total Environ 2005;341:45–52. doi: 10.1016/j.scitotenv.2004.09.033
76. Elhamri H, Idrissi L, Coquery M, Azemard S, El Abidi A, Benlemlih M, Saghi M, Cubadda F. Hair mercury levels in relation to fish consumption in a community of the Moroccan Mediterranean coast. Food Addit Contam 2007;24:1236–46. doi: 10.1080/02652030701329611
77. Díez S, Delgado S, Aguilera I, Astray J, Pérez-Gómez B, Torrent M, Sunyer J, Bayona JM. Prenatal and early childhood exposure to mercury and methylmercury in Spain, a high-fish-consumer country. Arch Environ Contam Toxicol 2009;56:615–22. doi: 10.1007/s00244-008-9213-7
78. Oken E, Wright RO, Kleinman KP, Bellinger D, Amarasiriwardena CJ, Hu H, Rich-Edwards JW, Gillman MW. Maternal fish consumption, hair mercury, and infant cognition in a US cohort. Environ Health Perspect 2005;113:1376–80. doi: 10.1289/ehp.8041
79. Oken E, Radesky JS, Wright RO, Bellinger DC, Amarasiriwardena CJ, Kleinman KP, Hu H, Gillman MW. Maternal fish intake during pregnancy, blood mercury levels, and child cognition at age 3 years in

a US cohort. Am J Epidemiol 2008;167:1171–81. doi: 10.1093/aje/kwn034
80. Gao Y, Yan C-H, Tian Y, Wang Y, Xie HF, Zhou X, Yu XD, Yu XG, Tong S, Zhou QX, Shen XM. Prenatal exposure to mercury and neurobehavioral development of neonates in Zhoushan City, China. Environ Res 2007;105:390–9. doi: 10.1016/j.envres.2007.05.015
81. Davidson PW, Strain JJ, Myers GJ, Thurston SW, Bonham MP, Shamlaye CF, Stokes-Riner A, Wallace JM, Robson PJ, Duffy EM, Georger LA, Sloane-Reeves J, Cernichiari E, Canfield RL, Cox C, Huang LS, Janciuras J, Clarkson TW. Neurodevelopmental effects of maternal nutritional status and exposure to methylmercury from eating fish during pregnancy. Neurotoxicology 2008;29:767–75. doi: 10.1016/j.neuro.2008.06.001
82. Baldewsingh GK, Wickliffe JK, van Eer ED, Shankar A, Hindori-Mohangoo AD, Harville EW, Covert HH, Shi L, Lichtveld MY, Zijlmans WCWR. Prenatal mercury exposure in pregnant women from Suriname's interior and its effects on birth outcomes. Int J Environ Res Public Health 2020;17(11):4032. doi:10.3390/ijerph17114032
83. Xue F, Holzman C, Rahbar MH, Trosko K, Fischer L. Maternal fish consumption, mercury levels, and risk of preterm delivery. Environ Health Perspect 2007;115:42–7. doi: 10.1289/ehp.9329
84. de Oliveira Corvelo TC, Oliveira ÉAF, de Parijós AM, de Oliveira CSB, do Socorro Pompeu de Loiola R, de Araújo AA, da Costa CA, de Lima Silveira LC, da Conceição Nascimento Pinheiro M. Monitoring mercury exposure in reproductive aged women inhabiting the Tapajós River Basin, Amazon. Bull Environ Contam Toxicol 2014;93:42–6. doi: 10.1007/s00128-014-1279-5
85. Bourdineaud JP, Durrieu G, Sarrazin SLF, da Silva WCR, Mourão RHV, de Oliveira RB. Mercurial exposure of residents of Santarém and Oriximiná cities (Pará, Brazil) through fish consumption. Environ Sci Pollut Res 2015;22:12150–61. doi: 10.1007/s11356-015-4502-y
86. Boischio AAP, Henshel D. Fish consumption, fish lore, and mercury pollution - Risk communication for the Madeira River people. Environ Res Section A 2000;84:108–26. doi: 10.1006/enrs.2000.4035
87. Hacon S, Rochedo ER, Campos R, Rosales G. Risk assessment of mercury in Alta Floresta. Amazon Basin - Brazil. Water Air Soil Poll 1997;97:91–105. doi: 10.1007/BF02409648
88. Kehrig HA, Malm O, Akagi H, Guimarães JRD, Torres JPM. Methyl mercury in fish and hair samples from the Balbina Reservoir, Brazilian Amazon. Environ Res 1998;77:84–90. doi: 10.1006/enrs.1998.3836
89. Martín-Doimeadios RCR, Berzas Nevado JJ, Guzmán Bernardo FJ, Jiménez Moreno M, Arrifano GPF, Herculano AM, do Nascimento JLM, Crespo-López ME. Comparative study of mercury speciation in commercial fishes of the Brazilian Amazon. Environ Sci Pollut Res 2014;21:7466–79. doi: 10.1007/s11356-014-2680-7

Navike u konzumaciji ribe u trudnica iz Itaitube, grada na slijevu rijeke Tapajós u Brazilu – rizici od kontaminacije živom procijenjeni mjerenjem ukupne žive u piscivornim ribljim vrstama koje se često konzumiraju i u kosi trudnica

Slijev rijeke Tapajós u amazonskom području u Brazilu jedno je od najaktivnijih područja iskopavanja zlata na svijetu. U ovoj smo studiji procijenili navike konzumiranja ribe i razinu izloženosti metil-živi u 110 stanovnica Itaitube u peripartumu mjerenjem ukupne koncentracije žive u kosi (THg). Osim toga, istražili smo sezonske razlike u koncentracijama žive u dvjema najčešćim vrstama konzumnih piscivornih riba: tucunaré (*Cichla* spp.) i pescada (*Plagioscion squamosissimus*). U tih je ribljih vrsta THg tijekom sušne sezone iznosio 0,62±0,07 mg/kg za *Cichla* spp. te 0,73±0,08 mg/kg za *P. squamosissimus*. Tijekom kišne sezone koncentracija THg bila je 0,39±0,04 mg/kg za *Cichla* spp. i 0,84±0,08 mg/kg za *P. squamosissimus*. Sudionice su izjavile da su konzumirale *Cichla* spp. (44 %) i *P. squamosissimus* (67 %). Srednja koncentracija THg izmjerena u kosi bila je 1,6±0,2 mg/kg±std. Prosječna koncentracija THg u kosi bila je viša od referentne doze Američke agencije za zaštitu okoliša (krat. US EPA) koja iznosi 1 mg/kg, a čak u 48 % sudionica izmjerena je viša koncentracija. Također, srednja vrijednost koncentracija THg u ribi bila je iznad sigurnosne granice (0,5 mg/kg) za *P. squamosissimus* i tijekom sušne i kišne sezone, a za *Cichla* spp. samo tijekom sušne sezone. Rezultati istraživanja pokazuju da bi trudnice trebale izbjegavati konzumaciju ovih piscivornih ribljih vrsta. Stoga je razvidna potreba za redovitim programom praćenja razine žive na tom području.

KLJUČNE RIJEČI: *Cichla* spp.; metil-živa; *Plagioscion squamosissimus*; ukupna živa