ORIGINAL ARTICLE

Fish consumption by traditional subsistence villagers of the Rio Madeira (Amazon): Impact on hair mercury

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Abstract

Background: Subsistence ribeirinhos of the Amazon Basin depend on fish for their principal source of protein, but fish availability changes with seasonal high and low waters.

Aim: To assess taxa and quantity of fish consumed and estimate attendant exposure to methyl-Hg in a traditional subsistence high fish-eating community of the Amazon Basin.

Subjects and methods: 120 villagers in 18 households were followed for 6 months (August to February) for weighed portions of fish consumed.

Results: Mean daily per capita fish consumption was high (406 g/day) with fish meals ranging from 4 to 14 times/week and an integrated yearly consumption of 148.2 kg/person. Median total-Hg concentrations in fish ranged from 0.011 to 0.409 ppm; six of the more consumed fish species comprised more than 50% of the fish consumed. The villagers mean hair-Hg concentration was high (17.4 ± 11.5 µg/g), with both inter- and intra-household variation despite similar high fish consumption; only 7% showed hair-Hg concentrations < 5 µg/g, but 75% had hair-Hg levels above 10 µg/g. Maternal hair-Hg was significantly correlated with respective children’s hair-Hg (Spearman r = 0.5390; p < 0.0001). The high daily fish intake of these villagers is predominantly of species with much lower Hg concentrations.

Conclusion: In Amazonian lifestyle of ribeirinho communities traditional fish consumption is high and depends on available species; fish is also the principal via of meHg exposure and attendant hair-Hg concentrations.

Keywords: Ribeirinhos, nutrition transition, hair, fish, Amazon
Introduction

The indigenous peasants living in the Amazon Basin are called ‘ribeirinhos’ in Brazil and have been accurately described by Piperata (2007). These riverine populations, also called ‘Caboclos’, are of mixed (Indigenous/European/African) ethnicity. Until 30 years ago they led a traditional subsistence lifestyle in the then unexplored Amazon forest; currently, transformation of the Amazon Basin is fast changing their traditional survival strategies. Today’s ribeirinhos practice a wide range of economic activities, with more contact with urban environments, so that they play a major role in the development of the region (Piperata 2007). These traditional inhabitants of the Amazon Basin rely on fish as their main source of protein and to provide those essential nutrients that are lacking in their staple starchy roots. Because of their high fish intake and accompanying methylmercury (meHg) ribeirinhos are one of the population groups most exposed to this form of Hg in the world. Furthermore, among the Rio Negro riverines, the spatial trend of increasing hair-Hg concentration was observed as a function of distance from the nearest town (Alves et al. 2006).

Mercury (Hg⁰, Hg⁺¹, Hg⁺²) is present and cycles in the environment of the Amazon; most of the Hg occurring in the Amazon is of natural origin (Fadini and Jardim 2001). The methylation reaction is the most important step for mercury to enter the aquatic food chain. As meHg it is bio-concentrated along the food chain, thereby becoming an obligatory secondary constituent of aquatic organisms. Therefore subsistence populations that depend on fish as their main source of protein are exposed to levels of meHg in their daily diet. We have shown that bioaccumulation of meHg in Amazonian fish depends on the trophic level, i.e. the length of food chain, but it is also influenced by fish age/body mass (Dórea et al. 2006). Fish-meHg is easily absorbed by the gastrointestinal tract of humans but its retention depends on dietary and physiological factors. In exposed fish-eating individuals meHg is preferentially taken up by hair as the organic form while the inorganic form is excreted in urine (Barbosa et al. 1995).

Amazonian ribeirinhos with high fish consumption are exposed to high meHg levels (Barbosa et al. 1995; Dórea et al. 2003, 2005a,b) but with no overt clinical signs of neurotoxicity (Dórea et al. 2003). In most of the Amazon Basin, the water level rises considerably during the rainy season, causing extensive flooding; subsistence agricultural patches are inundated and certain fish species become more or less available, thus affecting the availability of fish and some types of food. In this human ecology, ribeirinhos’ ability to secure food protein through the hydrological cycle depends on fishing; therefore, food habits based on fish consumption have been shown to affect changes in fish intake marker (hair-Hg) without affecting the overall characteristic of a fish-dominant diet. Indeed, studies with ribeirinhos of the Rio Tapajós have reported seasonal hair-Hg variation. Women consuming carnivorous fish showed a clear seasonal variation in meHg intake (Akagi et al. 1995; Kehrig et al. 1997) while variations in hair-Hg levels were attributed to different meHg content within types consumed during rainy and dry seasons (Lebel et al. 1997; Dolbec et al. 2001).

Mercury is a potent toxic element (Clarkson et al. 2003) and because of its widespread occurrence humans can be exposed to its different chemical forms – organic (meHg and ethylmercury) and inorganic Hg (Clarkson and Magos 2006). In the Amazon, studies have shown that different populations can be exposed to all three chemical forms of mercury. Inorganic Hg is essentially a result of occupation in gold mining activities (Barbosa et al. 1995; Fréry et al. 2001). However, organic mercury exposure can result from ethylmercury in thimerosal-containing vaccines (Dórea et al. 2009) and methylmercury from frequent
consumption of fish (Guimarães et al. 1999; Passos and Mergler 2008), or both (Marques et al. 2007, 2008a,b).

There is uncertainty about the association between maternal fish-meHg exposure during pregnancy and postnatal neurobehavioural effects, hence the recommendations to limit consumption of species with high meHg contents. Although important for affluent societies with alternative means of nutrition, these recommendations are challenging for subsistence communities of the Amazon (Dórea 2004; Barbieri et al. 2009). Therefore, clarifying meHg-exposure issues in subsistence fish-eating populations is crucial for public health policies. The main objective is to assess the type and quantity of fish consumed and estimate attendant exposure to meHg in a traditional subsistence community of the Amazon Basin.

Materials and methods

The study was designed to follow (a) daily patterns of fish consumption during 6 months representing ascending and descending waters, and (b) to determine levels of Hg exposure of an entire subsistence village. The study protocol was approved by the Research Ethics Committee of the Fundação Universidade Federal de Rondônia (056194/2005) in accordance with Brazilian Laws. Informed consent was obtained in writing from all households participating in the study.

Background contextualization

The community of Puruzinho Lake is a relatively isolated subsistence community of the Amazon Basin. It is made up of 20 households with 170 individuals with an age range of 6 months and 69 years of age; the mean age was 18.8 years and 68% of the population was under 21 years of age. Family size ranged from 2 to 15 members. Puruzinho Lake is located near the border with the state of Rondônia (Figure 1), in the municipality of Humaitá (Amazonas State), which is the nearest town and can be reached only by a 3 h boat ride. The houses are rudimentary, made of wood resting on stilts, contain minimal or no furniture and

Figure 1. Map of Puruzinho Lake and indication of the households studied.
have no water supply system, no sewage treatment or electricity; water is retrieved from the lake or streams (*igarapés*), passed through a cloth, stored and consumed. Intestinal parasites and malaria are endemic and significant health problems for this population.

Because of the relative isolation, Amazonia *ribeirinhos* lead a livelihood that depends on the availability of food provided by the surrounding rivers and forest. They have no regular income and subsist on planted manioc and food gathered from the surrounding forest and water bodies. Their main source of energy is derived from manioc roots that are harvested and processed around the year; this starchy root is part of all meals as flour, porridge, tapioca and sweets made with treacle. A refined starch is processed into a gruel (*gogó*) especially used for infants and small children. Either as main dish or complemented by fish, manioc products are consumed every day at all meals. To a lesser extent and depending on availability, game, fruits of the season, nuts such as ‘castanha’ (*Bertholletia excelsa*), and fruits like ‘tucumã’ (*Astrocaryum aculeatum*), ‘açai’ (*Euterpe oleracea*), ‘patoá’ (*Oenocarpus bataua*) and ‘abacaba’ (*Oenocarpus bacaba*) are harvested from the forest and are all part of their survival strategy. They do not cultivate orchards; contrary to what is expected, fruit consumption from cultivated species is limited to bananas, cashews, and limes grown around houses.

Fish is the main source of protein consumed by these villagers; fishing is done daily by traditional means; depending on the type of intended fish (season and location) they use ‘zagaia’ (a type of harpoon), bow and arrow (AmerIndian style), hook, or fish net. Game is not as frequently consumed as one might think; only a few families of this community practice occasional hunting. Livestock is mostly poultry (mainly chickens and ducks) which provide meat and eggs; only 10% of families raise pigs. There are no large animals, like cows or water buffaloes. Fish is the main source of protein, consumed on a daily basis; it is caught by families in the nearby lake and streams and prepared in a similar fashion by everyone: It is cooked in water, which makes its consumption more palatable with the dry manioc flour. Because of lack of animal fat it is rarely ever fried.

Their close dependence on the forest and river occasionally force them to restrict food, both in quantity and quality. When fish are scarce due to high water they may go without animal protein for days. Because of variable distances to the manioc gardens or nut collection sites in the forest they may endure restriction in the amount of food available for consumption. Lack of regular income and isolation limit the consumption of industrialized food or items not processed in the community. During the weekly visit to the nearest town (Humaitá) there are opportunities to trade; on such occasions, items like powdered milk (for children’s use only), beans, rice, vegetable oil, sugar and coffee can be acquired.

**Data collection and organization**

The study took place between August 2005 and February 2006: Each of the 18 families that participated in the study received a set of scales (Plenna, model Cam-00010) and a diary to keep records of the species and weight of fish consumed at each meal. There were instructions and training for each family on weighing procedures to keep records of fish species and quantities actually consumed after cleaning practices; we could not measure losses incurred by processing (and cooking methods) or left on the plate. During the first weeks of the study one of us (RCO) lived in the village, providing help and supervising information gathering. During the study the families’ diaries were replaced weekly and collected data were then inspected and issues clarified.

Fish is consumed just hours after being caught by members of the family; we sampled fish that were actually caught and consumed in the households during our weekly visit to the
community. Mercury concentration in fish muscle is the appropriate method to assess total mercury consumed (Clarkson and Strain 2003). The protocol for fish determination of Hg concentrations has appeared in previous publication (Bastos et al. 2007). Briefly, fish species were determined after comparing with the characteristics described by Santos et al. (1991).

After taxa identification, approximately 20 g of muscle samples were immediately cut, frozen and transported to the laboratory at the University of Rondônia for analysis. The samples were digested with H$_2$SO$_4$ : HNO$_3$ (1:1) solution and KMnO$_4$ (5%) for oxidation. For 500 mg of sample, 5.0 mL of acid mixture was added and digested for 60 min (Teclal, Mod. 007A, Piracicaba, São Paulo, Brazil). After digestion, 4.0 mL of a KMnO$_4$ solution (5%) was added to the sample, leaving it for 30 min more in the digestion block. After cooling until the temperature reached 25°C (room temperature), drops of hydroxylamine solution at 12% were added and sample was transferred to a volumetric flask of 10.0 mL with H$_2$O ultra-pure (Milli-Q Plus, Millipore, Bedford, MA, USA). Total Hg measurements were carried out by cold vapour atomic absorption spectrophotometry (Flow Injection Mercury System, FIMS-400, Perkin Elmer, Ueberlingen, Germany) (Malm et al. 1989; Bastos et al. 1998). Precision and accuracy of Hg determinations were ensured by the use of internal standards prepared in our laboratory against certified reference materials (Dogfish Muscle, DORM-2, National Research Council of Canada, Ottawa) and used in intercalibration exercises among Brazilian laboratories. All glassware was washed clean in 10% HNO$_3$ for 24 h and rinsed with H$_2$O ultra-pure.

Hair samples were cut from the occipital area near to the scalp, stored and taken to the laboratory for total Hg determination; all hair samples were collected at the same time. Hair chemical analysis was done according to our routine laboratory procedures (Bastos et al. 1998) at the Wolfgang C. Pfeiffer Environmental Biogeochemical Laboratory (BIOGEOEQ/ Federal University of Rondônia). After mineralization in acid-oxidant medium, Hg determination was performed with atomic absorption spectrometry in a FIMS-400® Perkin-Elmer. All analytical runs included material certified by the International Atomic Energy Agency (IAEA-085 and IAEA-086) and National Research Council Canada (DORM-2) to ensure satisfactory quality control. Recovery rates were above 80% and detection limit below 0.05 μg/g. Unlike populations of Africa that use Hg-based cosmetics to whiten the skin, ribeirinho women do not use such products.

Data were summarized with Microsoft Office Excel software (version 2007; Microsoft Corp, Redmond, WA, USA) and normality distribution of our data was determined with Shapiro–Wilk. Because of data collection for hair-Hg concentrations (individually) and fish consumption (family level) do not have the same variance structure we used the nonparametric Friedman ANOVA rank test, which assumes that the variables under consideration were measured on at least an ordinal (rank order) scale; the Kendall concordance coefficient test was used to determined the simultaneous association (relatedness) between k sets of rankings (Statistica statistical package; StatSoft, Inc., v.7.0). Non-parametric Spearman correlation tests between variables were done with PRISM software (version 4.0; San Diego, CA, USA); the significance level was set at $p < 0.05$.

Results

The ribeirinhos of Lago Puruzinho (Rio Madeira Basin) are still living a relatively traditional Amazonian life; fish is the main source of animal protein and it is still consumed in high amounts on a daily basis. The integrated monthly total fish consumption for the entire village showed a steady consumption with little variation between high and low water months: Respectively a low of 1065 kg and a high 1198 kg. The daily frequency of fish
consumption (at least one fish meal) over the study period varied from 52.2% to 95.9% among the households. Although consumed on a daily basis, there are variations in the quantity consumed as well as the fish availability, which is dependent on fishing conditions (especially water levels); overall, the mean daily per capita fish consumption was 406 g (204.1, SD).

The taxa consumed throughout the study are listed in Table I along with their respective total Hg concentrations; they represented actual species caught and used and not necessarily the species preferred. Therefore, independent of household preferences, 45 species of different feeding strategies (and Hg concentrations) made up the fish consumed. In these samples, eight species (17.8%) showed median Hg concentrations above 0.5 ppm (Table I); these species were at the top of the aquatic food chain. The means of fish-Hg concentrations as a function of feeding strategy is shown in Figure 2. Despite inherent variation there is a distinct pattern of Hg bioaccumulation clearly indicating Hg biomagnification as a function of fish feeding strategy. However, the eight species with the highest Hg concentrations were not among the ones most consumed (Figure 3).

The frequency of species consumed is shown in Figure 3: ‘curimatã’ (Prochilodus spp.), ‘pacú’ (Mylossoma spp.), ‘tucunaré’ (Cichla monochus), ‘cará’ (Astronotus spp.), ‘chora’ (Potamorhina spp.), and ‘jaraquí’ (Semaprochilodus ocellaris) comprised more than 50% of the fish caught and consumed. In these sampled species (as consumed) median total-Hg concentrations ranged from 0.011 to 0.409 ppm. The availability of species for consumption is determined by fishing opportunity which is modulated by weather conditions and the flood patterns; on a monthly basis it seems that the highest water month of December had the lowest number of available taxa (18) compared to lowest water level of September (28 species).

Figure 4 illustrates the limits of recommendations of fish-Hg exposure according to taxa consumed. Except for four species (bodó, pacú, curimatã, jutuarama), due to high levels of consumption, these villagers exceeded recommended Hg exposure in all species. Therefore, hair-Hg concentration (marker of fish consumption), regardless of type of fish consumed, was relatively high in most sampled individuals (Figure 5a); only 7% showed hair-Hg concentrations <5 μg/g, but 75% had hair-Hg levels above 10 μg/g. In these villagers, a significant correlation (Spearman r = 0.3635; p < 0.0001) was observed between age of individuals and hair-Hg concentrations (Figure 5b). Hair-Hg concentrations were also highly correlated within families (Figure 5c); maternal hair-Hg was significantly correlated with children’s hair-Hg (Spearman r = 0.539; p < 0.0001).

Figure 6 displays within each household the mean fish consumption and the mean hair-Hg concentrations. The Friedman test estimated a Chi-square = 4.40, p = 0.036, with a low Kendall coefficient of concordance, 0.04, indicating a significant association at the household level between fish consumption and hair-Hg.

Discussion

Traditional subsistence living of the Amazonian ribeirinhos precludes a dependence on fish consumption as a survival strategy to guarantee animal protein to complement their starch-root staples. As a result, these traditional villagers consume large amounts of fish (per capita fish consumption ca 148.2 kg/year). In tandem with fish availability ribeirinhos change their daily rate of fish consumption; however, seasonal variability in fish consumption (and respective taxa availability) is relatively small (when amortized monthly) and because of the high quantity consumed has little impact on changes in hair-Hg concentrations (marker of fish consumption) in this subsistence fish-eating community. Fish mass as eaten is based on
daily annotation for each household of the portions taken after cleaning, without considering other factors such as leftovers and cooking methods. Furthermore, each family fish and consume their catch independently. When considering such sources of variability, coupled with heterogeneity of the household members (more children than adults) and important

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Feeding behaviour</th>
<th>n</th>
<th>[Hg], median</th>
<th>Min–max</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acestrorhynchus falcirostris</em></td>
<td>Arubaraña</td>
<td>carnivorous</td>
<td>4</td>
<td>0.211</td>
<td>0.107–0.311</td>
</tr>
<tr>
<td><em>Ageneiosus sp.</em></td>
<td>Mandubé</td>
<td>carnivorous</td>
<td>6</td>
<td>0.274</td>
<td>0.206–0.297</td>
</tr>
<tr>
<td><em>Ageneiosus brevifilis</em></td>
<td>Mandubé</td>
<td>carnivorous</td>
<td>2</td>
<td>0.453</td>
<td>0.358–0.548</td>
</tr>
<tr>
<td><em>Anodus melanopogon</em></td>
<td>Charuto</td>
<td>planktivorous</td>
<td>14</td>
<td>0.555</td>
<td>0.177–0.762</td>
</tr>
<tr>
<td><em>Anodus imaculatus</em></td>
<td>Charuto</td>
<td>planktivorous</td>
<td>3</td>
<td>0.321</td>
<td>0.295–0.610</td>
</tr>
<tr>
<td><em>Astronotus crassipinnis</em></td>
<td>Cará</td>
<td>omnivorous</td>
<td>5</td>
<td>0.106</td>
<td>0.042–0.610</td>
</tr>
<tr>
<td><em>Astronotus ocellatus</em></td>
<td>Cará</td>
<td>omnivorous</td>
<td>3</td>
<td>0.270</td>
<td>0.093–0.406</td>
</tr>
<tr>
<td><em>Boulengerella maculata</em></td>
<td>Bicuda</td>
<td>carnivorous</td>
<td>5</td>
<td>0.684</td>
<td>0.225–1.141</td>
</tr>
<tr>
<td><em>Bycon melanopterus</em></td>
<td>Jatuarana</td>
<td>frugivorous</td>
<td>17</td>
<td>0.040</td>
<td>0.013–0.228</td>
</tr>
<tr>
<td><em>Catoprinia mento</em></td>
<td>Pacú</td>
<td>frugivorous</td>
<td>1</td>
<td>0.057</td>
<td></td>
</tr>
<tr>
<td><em>Cichla monoculus</em></td>
<td>Tucunaré</td>
<td>carnivorous</td>
<td>19</td>
<td>0.409</td>
<td>0.001–1.488</td>
</tr>
<tr>
<td><em>Geophagus sp.</em></td>
<td>Cará</td>
<td>omnivorous</td>
<td>1</td>
<td>0.154</td>
<td></td>
</tr>
<tr>
<td><em>Hemiodus maculatus</em></td>
<td>Charuto</td>
<td>detritivorous</td>
<td>1</td>
<td>0.039</td>
<td></td>
</tr>
<tr>
<td><em>Hemiodus imaculatus</em></td>
<td>Charuto</td>
<td>detritivorous</td>
<td>13</td>
<td>0.301</td>
<td>0.039–1.131</td>
</tr>
<tr>
<td><em>Hemiodus sp.</em></td>
<td>Charuto</td>
<td>detritivorous</td>
<td>3</td>
<td>0.195</td>
<td>0.189–0.217</td>
</tr>
<tr>
<td><em>Hemiodus unimaculatus</em></td>
<td>Charuto</td>
<td>detritivorous</td>
<td>4</td>
<td>0.284</td>
<td>0.217–0.405</td>
</tr>
<tr>
<td><em>Hoplias malabaricus</em></td>
<td>Traira</td>
<td>carnivorous</td>
<td>15</td>
<td>0.608</td>
<td>0.213–1.249</td>
</tr>
<tr>
<td><em>Hydrolycus armatos</em></td>
<td>Pirandirá</td>
<td>carnivorous</td>
<td>1</td>
<td>0.116</td>
<td></td>
</tr>
<tr>
<td><em>Hypothalbus marginatus</em></td>
<td>Mapará</td>
<td>planktivorous</td>
<td>14</td>
<td>0.457</td>
<td>0.185–0.777</td>
</tr>
<tr>
<td><em>Laemolyta proxima</em></td>
<td>Piau</td>
<td>omnivorous</td>
<td>4</td>
<td>0.353</td>
<td>0.309–0.439</td>
</tr>
<tr>
<td><em>Liposarcus pardalis</em></td>
<td>Bodó</td>
<td>detritivorous</td>
<td>1</td>
<td>0.061</td>
<td></td>
</tr>
<tr>
<td><em>Lipostomus marginatus</em></td>
<td>Bodó</td>
<td>detritivorous</td>
<td>1</td>
<td>0.100</td>
<td></td>
</tr>
<tr>
<td><em>Mylossoma durirentre</em></td>
<td>Pacú</td>
<td>frugivorous</td>
<td>11</td>
<td>0.038</td>
<td>0.004–0.167</td>
</tr>
<tr>
<td><em>Mylossoma sp.</em></td>
<td>Pacú</td>
<td>herbivorous</td>
<td>5</td>
<td>0.011</td>
<td>0.008–0.052</td>
</tr>
<tr>
<td><em>Mylossoma aureum</em></td>
<td>Pacú</td>
<td>herbivorous</td>
<td>13</td>
<td>0.040</td>
<td>0.001–0.103</td>
</tr>
<tr>
<td><em>Pellona flavipinnis</em></td>
<td>Apapa branco</td>
<td>carnivorous</td>
<td>5</td>
<td>0.585</td>
<td>0.111–1.044</td>
</tr>
<tr>
<td><em>Pellona castelnaeana</em></td>
<td>Apapa amarelo</td>
<td>carnivorous</td>
<td>2</td>
<td>1.148</td>
<td>1.024–1.272</td>
</tr>
<tr>
<td><em>Pimelodus blocki</em></td>
<td>Mandi</td>
<td>carnivorous</td>
<td>2</td>
<td>0.122</td>
<td>0.102–0.142</td>
</tr>
<tr>
<td><em>Plagioscion squamosissimus</em></td>
<td>Pescada</td>
<td>carnivorous</td>
<td>2</td>
<td>0.628</td>
<td>0.150–1.106</td>
</tr>
<tr>
<td><em>Potamorhina latior</em></td>
<td>Chora</td>
<td>detritivorous</td>
<td>58</td>
<td>0.131</td>
<td>0.030–0.436</td>
</tr>
<tr>
<td><em>Potamorhina altamazonica</em></td>
<td>Chora</td>
<td>detritivorous</td>
<td>13</td>
<td>0.176</td>
<td>0.097–0.310</td>
</tr>
<tr>
<td><em>Prochilodus nigricans</em></td>
<td>Curimatá</td>
<td>detritivorous</td>
<td>23</td>
<td>0.036</td>
<td>0.014–0.131</td>
</tr>
<tr>
<td><em>Plectroaster amazonica</em></td>
<td>Branquinha</td>
<td>detritivorous</td>
<td>6</td>
<td>0.213</td>
<td>0.131–0.299</td>
</tr>
<tr>
<td><em>Pseudoplatystoma tigrinus</em></td>
<td>Caparari</td>
<td>carnivorous</td>
<td>5</td>
<td>0.197</td>
<td>0.101–0.518</td>
</tr>
<tr>
<td><em>Pseudoplatystoma fasciattum</em></td>
<td>Surubim</td>
<td>carnivorous</td>
<td>4</td>
<td>0.419</td>
<td>0.283–0.938</td>
</tr>
<tr>
<td><em>Pseudorinelepis genibarbis</em></td>
<td>Bodó</td>
<td>detritivorous</td>
<td>5</td>
<td>0.018</td>
<td>0.006–0.020</td>
</tr>
<tr>
<td><em>Rhaphiodon vulpinus</em></td>
<td>Pirandirá</td>
<td>carnivorous</td>
<td>6</td>
<td>0.701</td>
<td>0.467–0.782</td>
</tr>
<tr>
<td><em>Schizodon fasciatus</em></td>
<td>Piau</td>
<td>omnivorous</td>
<td>5</td>
<td>0.181</td>
<td>0.024–0.270</td>
</tr>
<tr>
<td><em>Schizodon ssp.</em></td>
<td>Piau</td>
<td>herbivorous</td>
<td>7</td>
<td>0.082</td>
<td>0.020–0.121</td>
</tr>
<tr>
<td><em>Semaprochilodus taeniurus</em></td>
<td>Jaraqui</td>
<td>detritivorous</td>
<td>13</td>
<td>0.126</td>
<td>0.001–0.230</td>
</tr>
<tr>
<td><em>Serrasalmus sp.</em></td>
<td>Piranha</td>
<td>carnivorous</td>
<td>9</td>
<td>0.803</td>
<td>0.555–1.013</td>
</tr>
<tr>
<td><em>Serrasalmus rhombeus</em></td>
<td>Piranha</td>
<td>carnivorous</td>
<td>1</td>
<td>1.097</td>
<td></td>
</tr>
<tr>
<td><em>Surubim lima</em></td>
<td>Bicu de pato</td>
<td>carnivorous</td>
<td>4</td>
<td>0.879</td>
<td>0.140–1.014</td>
</tr>
<tr>
<td><em>Triportheus flavus</em></td>
<td>Sardinha</td>
<td>omnivorous</td>
<td>2</td>
<td>0.267</td>
<td>0.226–0.308</td>
</tr>
<tr>
<td><em>Triportheus elongatus</em></td>
<td>Sardinha</td>
<td>omnivorous</td>
<td>19</td>
<td>0.117</td>
<td>0.047–0.604</td>
</tr>
</tbody>
</table>
Figure 2. Box-plot of fish-Hg concentrations as consumed and as a function of fish type (feeding strategy).

Figure 3. Illustration of the absolute frequency of fish species consumed during the studied period.
differences in the species eaten, there is still a weak but significant coefficient of concordance in patterns of fish consumption and hair-Hg.

Most of the studies of fish intake rate of *ribeirinhos* have been done by food consumption surveys. Studies have reported mean daily fish-consumption rates of 200 g at the Rio Madeira (Boischio and Henshel 1996), 110 g at Alta Floresta (Hacon et al. 1997) and at Balbina reservoir (Kehrig et al. 1998); the most recent study showed a variation of 115–171 g in several communities of the Rio Tapajós (Passos et al. 2008). However, others have showed high consumption rates of 500–800 g (Batista et al. 1998; Fabré and Gonzales 1998). Only two studies based on weighed portions showed 369 and 243, respectively for *Ribeirinhos* of the Rio Madeira (Boischio et al. 2000) and Lago Grande de Monte Alegre (Cerdeira et al. 1997). Fish consumption rates derived from hair-Hg concentration showed 170 g/day for Rio Negro *ribeirinhos* (Dórea et al. 2003). Except for fish consumption estimates derived from hair-Hg, it should be noted that in these studies it is impossible to discern factors such as cleaning practices, leftovers, processing and cooking methods that might overestimated total fish consumption. Nevertheless, our estimated daily mean per capita of 406 g is within limits of the cited Amazonian studies.

The pattern of fish consumption showed by the *ribeirinhos* of this study far exceeds fish consumption advisories adopted by the USA (104 fish meals a year); the lowest reported consumption could add up to a total 204 days a year (frequently with more than one meal a day). With an integrated total fish consumption of 148.2 kg/year, communities like Puruzinho Lake are among the highest consumers in the world; they consume 50% more than French Polynesians (Dewailly et al. 2008). Subsistence communities, like Puruzinho, do not have the choice of giving up fish (which guarantees their survival). As
Figure 5. Representation of villagers’ hair-Hg: (a) per cent frequency of hair-Hg concentrations; (b) scatter plot of villagers’ age and hair-Hg concentrations; (c) scatter plot of hair-Hg concentrations in mothers and respective children.
a consequence, children consume the same family food and also show high hair-Hg values. It has been shown before that hair-Hg of individuals is reflected in the family hair-Hg profile (Boischio et al. 2000) which supports our present findings.

In this subsistence community meals are consumed by the entire family at the same time. Homogeneity of lifestyle still persists in these investigated communities of the Amazon Basin. Therefore, it not surprising that maternal hair was significantly correlated with children’s hair, which agrees with previous observations in indigenous populations (Barbosa et al. 1998). Although we previously reported no significant difference between adults and children regarding hair-Hg concentrations (Barbosa et al. 2001), this time we explored the correlation between hair-Hg and age; indeed a scatter plot showed a wide variation related to all age groups but a significant correlation was seen (Figure 5b).

There are legitimate concerns about meHg exposure through fish consumption of indigenous populations (Peplow and Augustine 2007; Mertens et al. 2008; Passos and Mergler 2008). Community directed risk assessments of fish-Hg exposure in the Amazon are often based on particular fish species; adult predator fish of high weight that bioaccumulate the most Hg are often targeted to be avoided (Peplow and Augustine 2007; Mertens et al. 2008). However, it is clear from our study that fish intake amortized against the whole year shows that most fish consumed are not necessarily the ones with highest Hg concentrations. Whether subsistence high fish consumption (and attendant Hg exposure) in these populations can cause functionally perceived (neurological) effects remains to be determined (Fonseca et al. 2008). However, it has been noticed that well-adapted subsistence Amer-Indians of Amazonia seem to have a better nutritional status than settlers (Benefice and Barral 1991).

Subsistence riverine populations depend on the catch for the species consumed. Although the taxa may vary with location and season, our results are in agreement with others; Cerdeira et al. (2000) reported for riverside communities (practising subsistence and commercial fishing), out of a total of more than 70 fish species, 10 taxa comprised 75% of the catch. In our study, out of the 45 taxa caught and consumed, 17.7% exceeded the 0.5 mg/g WHO (1990) limit but were not among the 50% of the species most consumed. Cerdeira et al. (2000) observed also that the catch in the Monte Alegre...
community concentrated on smaller species for local consumption. Therefore, the development of risk-prediction assessment based on specific fish species (usually large predators) may not be suitable for risk assessment of subsistence populations of the Amazon Basin. Although we need to delineate preventive and interventional strategies for any type of human disease, we need more research to clarify what we are preventing (which neurological risks are present).

Strategies that target fish species with high Hg may not be effective in subsistence Amazonian populations. The goal of fish advisories is to reduce meHg exposure but it may end up with unintended reduction in fish consumption (Arnold et al. 2005). Harper and Harris (2008) have noticed that when reduction in fish consumption happens in traditional populations (such as tribal communities) it constitutes an additional burden with health impacts on socio-economics, culture, and nutrition. The role of fish to combat micronutrient deficiencies in developing countries has been emphasized (Roos et al. 2007) and its importance to other native communities of the Rio Madeira has been recently demonstrated (Monroy et al. 2008; Barbieri et al. 2009).

The delicate balance of nutrition and toxicity in the diet of native Amer-Indians and ribeirinhos of the Brazilian Amazon has been previously discussed (Dórea 2003, 2004); the two most important staple foods (cassava and fish) in their diet (Dufour 1991) contain recognized neurotoxins (linamarin and meHg, respectively). Linamarin abundantly present in unprocessed manioc is destroyed before consumption by proper processing methods used by native Amer-Indians (Dufour 1991), but it may cause ‘konzo’ (tropical ataxic neuropathy) when combined with low-protein diets in parts of Africa (Dórea 2004); this disabling neuropathy can reach epidemic proportions due to consumption of cyanogenic substances as result of incomplete detoxification of cassava (Onabolu et al. 2001). Indeed, in protein-deficient populations of Africa, neurological disorders attributed to exposure to cyanogenic substances are exacerbated by a lack of sulphur amino acids (Tor-Agbidye et al. 1999). Small amounts of the toxin absorbed by manioc consumers of the Amazon can be effectively metabolized by the high fish consumption which carries protein-containing sulphur amino acids (Dórea 2004). The susceptibility to ‘konzo’ and the aggravation of iodine deficiency disorders (due to cassava consumption) reported in other parts of the world seem to be associated with undernutrition or lack of essential nutrients that in Amazonia are provided by fish (Dórea 2003).

**Conclusion**

Fish is the main source of protein (and attendant nutrients) in the starchy diet of ribeirinhos and it is also the principal via of meHg exposure shown as elevated hair-Hg concentrations. Although predatory species carry the highest concentrations of Hg, the predominant taxa in the ribeirinhos’ daily diet have much lower Hg concentrations.

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**References**


Fish consumption by Amazon villagers


