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Fish Consumption, Fish Lore, and Mercury Pollution—Risk Communication for the Madeira River People

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Fish is an important food resource in Amazonian aquatic ecosystems. There is a strong cultural background regarding fish consumption (fish lore) among indigenous people in the Amazon. Mercury (Hg) ingestion through fish consumption has been a major route of Hg exposure among the riverside people along the Upper Madeira River. In this paper a diet questionnaire was used to identify patterns of fish consumption. The amount of fish consumed during the dry season and Hg levels in fish were combined to estimate Hg ingestion. Using as guidance hair Hg levels below 5 and 10 ppm as acceptable to protect the fetus and adult, respectively, along with an average daily fish consumption of 243 g per capita, we estimated the maximum acceptable number of fish meals per week for different fish species. Based on this analysis, it is suggested that there is a need to address risk communication for this exposed population in the context of health in terms of a fish advisory. For the fish advisory it is necessary to recommend to fish consumers, fishermen, and fish sellers an acceptable number of fish meals to be consumed according to species.

Key Words: **fish; consumption; mercury; advisory; Amazon.**

INTRODUCTION

The richness of ichthyofauna and dependence upon fish consumption in the diet have been part of the culture of riverside people (*ribeirinhos*) in the Amazon. Before the European conquest the riverside and floodplain areas (which correspond to 2–3% of the Amazon Basin) were more heavily populated by indigenous peoples (Amerindian) than the Terra Firme (terrestrial ecosystems, covering around 98% of the Amazon) (Meggers, 1984). The *ribeirinhos* people are mostly descendents of Amerindians, Europeans, and Africans, and they inherited many of their cultural practices regarding fishing and fish consumption from the Amerindians (Parker, 1985; Moran, 1993). The *ribeirinhos* have been heavy fish consumers because of the plentiful availability of fish, the relative depletion of game, and difficulties of raising cattle (Hiraoka, 1992).

Many of the Amazonian ecosystems are now polluted with mercury (Hg) from soil erosion, gold mining, and forest fires (Roulet *et al.*, 1999a). The aquatic food chain is unevenly polluted by organic Hg (methylmercury, MeHg), and fish consumption appears to constitute a major route of MeHg exposure among Amazonian riverside people (Akagi *et al.*, 1994; Boischio *et al.*, 1995; Harada, 1997; Lebel *et al.*, 1997). These studies have shown a predictable pattern of Hg distribution in the aquatic food chain. Usually, piscivorores have higher Hg concentrations than herbivores and detritivores.

Methylmercury is a neurotoxic agent that affects the developing nervous system at lower doses than it affects the mature nervous system (Choi, 1989). Reduction of Hg exposure during the prenatal stage of life is an environmental health concern (IPCS, 1990). The maternal doses of Hg exposure associated with adverse health effects among exposed children have been recently examined in different exposed populations (Faroe and Seychelles) (Grandjean *et al.*, 1995, 1997; Cernichiari *et al.*, 1995; Myers *et al.*, 1995), as well as in previous studies of other exposed populations from Japan, Iraq, and Canada (Harada, 1976; Cox *et al.*, 1989; McKeown-Eyssen *et al.*, 1983). Their results indicate that maternal Hg exposures (associated with hair Hg concentrations in the range

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of 10 to 20 ppm) may adversely affect the motor and cognitive development of children exposed during prenatal life (Kjellstrom *et al.*, 1989; Grandjean *et al.*, 1995, 1997).

To mitigate levels of Hg exposure in the Amazon, risk communication focused on fish advisories must be promulgated. To develop a fish advisory, knowledge about the pattern of fish consumption and the distribution of Hg in the aquatic food chain must be used. Previous studies in the Amazon have suggested that the pattern of fish consumption must be understood in order to reduce Hg exposure in the Amazonian ecosystems (Akagi *et al.*, 1994; Boischio *et al.*, 1995; Padovani *et al.*, 1995; Harada, 1997; Lebel *et al.*, 1997).

This paper presents data on the quantitative and qualitative patterns of fish consumption among 276 households along the Upper Madeira River. The frequency of consumption of fish (36 different species) and other foods was investigated by interview and observational methods. The distribution of Hg in fish was evaluated by trophic level. The combination of fish consumption with fish Hg concentrations was used to estimate average Hg ingestion. These estimates were, in turn, used to develop risk communication and fish advisories, i.e., how often to consume different fish species in order to cope with Hg pollution in these contaminated ecosystems.

Perceptions regarding fish consumption within the context of the cultural background are addressed in this paper as "fish lore". The general concept in fish lore is that thick blood is unhealthy, whereas thin blood may cause lassitude and weakness (Elisabetsky and Setzer, 1985). *Reimoso* fish species are those supposed to thicken blood, whereas safe fish species are those that make the blood thinner (Smith, 1981). Maues and Maues (1977) observed that people perceived *reimoso* food as worsening health during vulnerable stages of life, such as illness, pregnancy, and breast feeding. Thus, during these vulnerable stages people are encouraged to consume other fish species. It is important to understand how fish consumption is affected by fish lore in order to develop an effective risk communication that takes into account the peoples' perceptions and beliefs about eating fish.

This paper aims to provide such information and suggestions for risk communication/fish advisory for a particular population along the Upper Madeira river. There are reasons to believe that a fish advisory can manage fish Hg pollution and reduce human Hg consumption. First, there is a wide variation of fish species available for individual consumption, sometimes in a single meal. Second, fish species differ in Hg concentrations. The purpose of the fish advisory must be to provide comprehensible information about Hg toxicology, so that fish consumers can make responsible decisions about their eating habits to minimize Hg exposures. In order to do this, it is necessary to combine knowledge about Hg risks, including the bioaccumulation of Hg up the aquatic food chain, with the *ribeirinhos*' knowledge about fish ecology.

In the context of a fish advisory, we suggest that the maximum number of fish meals per week according to the fish species may be placed in categories, which can be pictorially represented to acceptable exposures during pregnancy and adult life. These categories have been developed based on the mean Hg levels in each species. The fish advisory must be designed to appeal to women, given the vulnerability of the fetus and young infant to Hg. In addition, women play a major role in the everyday routines of fishing and food preparation, which influence patterns of fish consumption.

MATERIALS AND METHODS

The Upper Madeira River is a southwestern tributary of the Amazon river (Fig. 1). The study area was located along 180 km downstream from Porto Velho, the capital town of Rondonia state. Information on the number of households in each community was taken from local institutions (National Health Foundation and the State Support Committee for the Populations from the Madeira, Guapore, and Mamore Basins) and adjusted by enumerating the actual households within each community. The communities were plotted in a 1:100,000 scale map from the Brazilian Institute of Geography and Statistics. The study area included 1055 households distributed in about 70 communities. The community size varied from as low as 3 to as many as 300 households, with an average of 7.0 individuals per household. The households were located along the Upper Madeira River, on the bluffs or at the edges of sand or mud beaches exposed during the low water season (July to November—Goulding, 1979).

In the three largest communities (São Carlos, Nazaré, and Calama), local electricity, produced from petroleum, was available for a few hours during the night. The lack of electricity made food storage in refrigerators unavailable, so fishing was an almost daily activity. Sun-dried fish were observed to be used. Water for domestic use was mostly taken from the Madeira River without chemical treatment. The Madeira River is a white-water river in which Andean sediments are suspended. As a cleaning

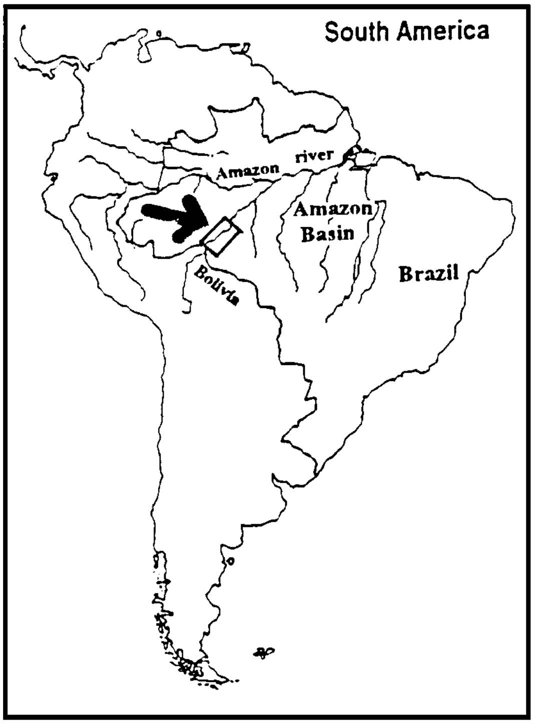

FIG. 1. The Upper Madeira River area. Modified from Boischio *et al.* (1995).

process, it was a common practice to store water in containers to let the sediments settle. Butane gas and charcoal were used for cooking. Schools, health centers, and churches were differently available according to the community and time. Boats (public and private) were the single means of transportation for most communities.

Field data were collected over the course of 2 different years (1991 and 1993) from a total of 276 households (Boischio, 1996). In 1991, the sample design and size were established according to the results of a pilot study evaluating fish consumption and hair Hg concentrations. A systematic random sampling procedure was used in order to collect data within the whole study area, although it was inevitable that more households were sampled in villages with a higher population density. In 1991, a total of 133 households were sampled and interviewed, corresponding to approximately 13% of the total population in the area. In 1993, in the same communities, only households with infant members were visited ($n = 143$).

The interviewers (undergraduate students from the Federal University of Rondônia) were trained to administer the questionnaires, to collect biological samples (hair and fish), and to make anthropometric measurements. Data from the 1991 field season were gathered during eight trips, for a total of 41 days along the river, between May and September. One trip was made for collection of fish samples in December 1991. Data from the 1993 field season were gathered during four trips for a total of 22 days during July and August. The same dietary questionnaire was used in 1991 and 1993. The interviews (in 1991 and 1993) usually took an average of 1 h, and covered demographic information, dietary habits, and anthropometric measurements. Pilot studies among riverside people near Porto Velho were used to field test the questionnaire. During the field test, questionnaire review was conducted by the coordinator, in order to ensure a consistent quality of information. The interviewers' training ensured that both interviewers and interviewees understood each other and that all measures were standardized, including behavior during the interviews, reading measurements, identification of fish species and body weight, and use and calibration of the scales.

Data input, was done using Dbase IV (Borland International Inc., Scotts Valley, CA). Data tabulation and analysis were conducted with Quattro Pro 4.0 (Novell Inc. Provo, UT) and SAS 6.1 (Statistical Analysis System Institute Inc, NC). For statistical analyses the SAS procedure used included analysis of variance, a general linear model, and *t* tests.

To assess fish consumption, the interviewer presented verbally a list of 36 fish species, and the interviewee was asked to grade weekly consumption of each species on a scale of one to five. On a spreadsheet (Quattro Pro), the weighted mean was taken by multiplying each grade by the number of quotations. These weighted means were used to distribute fish species into four quartiles according to the frequency of consumption (Fig. 2). Fish species consumed during the previous 7 days were also recorded in response to an open-ended question. Fish consumption during the interview day was observed and recorded by the interviewers.

Whenever possible, the fish to be consumed by all family members (with age/gender and body weight variables collected) were weighed on a domestic scale (Bender, 5 kg maximum with a precision of 100 g). The scales were calibrated using 119 records of standard weights of 200, 500, 700, and 2000 g. The inaccuracy of these scales (i.e., the difference between the reading and the standard weight) had a mean of 9% (sd of 10%) above the standard weights. For the anthropometric measurements, four domestic scales (Bender, 120 kg maximum with a precision of 500 g) were used. The accuracy of these scales were checked by using standard weights of 20, 40, and 60 kg. From 75 test measurements, the mean error was observed to be 7% below the standard weights (sd of 5%). For infants and children under 24 months old, calibrated suspended scales were used.

Information on fish consumption (Table 1 and Fig. 2) may be affected by the subjective nature of the question and the interviewees' recall bias (Dennis and Shifflett, 1985). In this study results obtained using interview and observational strategies were consistent, indicating that subjectivity and memory were not major factors.

Mercury analyses were performed by the Environmental Chemistry Laboratory at the University of Brasilia, under the direction of Dr. Antonio Barbosa. Fish samples were digested under reflux at 85°C with a concentrated H_2SO_4–HNO_3 mixture for 3 h and then left to stand at room temperature for at least 1 h. At the end of the digestion procedure, 2 ml of hydrogen peroxide was added and the digest was transferred into a 50-ml volumetric flask. Samples were then analysed using cold vapor atomic absorption spectroscopy (Perkin–Elmer Model 403 Spectrometer) with a modfied spectrophotometric

1991

0.25 Hg ppm 1st most consumed 4.5–3.7*	0.59 Hg ppm 2nd most consumed 3.6–3.2	0.33 Hg ppm 3rd most consumed 3.1–2.8	0.53 Hg ppm Least consumed ≤ 2.7
Mandi-OI**	**Pintado-P**	**Matrincha-H**	Bacu-H
Curimata-D	Jatuarana-H	Filhote-P	Piramutaba-P
Pacu-H	**Traira-P**	Cuiu-Cuiu-D	**Dourada-P**
Sardinha-OI	Pirapitinga-H	Pirarucu-P	Cubiu-OI
Surubim-P	Aruana-OII	Piraiba-P	Jau-P
Branquinha-D	Peixe Cachorro-P	Mapara-Pk	
Cara-OI	Tamoata-P	Boco-Pk	
Tucunare-P	Apapa-P	Pirarara-P	
Bico-Pato-P	Piranha-P	Tambaqui-H	
Bodo-D	Pescada-P	Jaraqui-D	
Aracu-OII			

1993

0.26 Hg ppm 1st most consumed 4.2–3.0	0.35 Hg ppm 2nd most consumed 2.9–2.5	0.74 Hg ppm 3rd most consumed 2.4–1.9	0.50 Hg ppm Least consumed ≤ 1.8
Curimata-D	Aracu-OII	Bacu-H	Pirarucu-P
Mandi-OI	**Pintado-P**	Aruana-OII	Peixe Cachorro-P
Pacu-H	Tucunare-P	Tamoata-D	Boco-Pk
Surubim-P	**Traira-P**	Tambaqui-H	**Dourada-P**
Sardinha-OI	Bico de Pato-P	**Matrincha-H**	Mapara-Pk
Barba-Chata-P	Bodo-D	Pescada-P	Filhote-P
Jatuarana-H	Cara-OI	Piranha-P	Piraiba-P
Caparari-P	Jaraqui-D	Apapa-P	Pirarara-P
Branquinha-D	Cuiu-Cuiu-D		
Pirapitinga-H			

*Weighted value of fish consumption, determined according to the following grading system:
5. ≥ 5 days per week
4. 3 to 4 days per week
3. 1 to 2 days per week
2. ≤ 3 days per month
1. Never eaten

**Legend for fish trophic level:
H-Herbivore
D-Detritivore
Pk-Planktophagus
OI-Omnivore I-prey: invertebrates
OII-Omnivore II-prey: vertebrates
P-Piscivore

FIG. 2. Fish species grouped according to the descending order of the grades expressing their frequency of consumption during the dry seasons of 1991 (36 fish species) and 1993 (35 fish species) as reported by the interviewees from 122 households in 1991 and 143 households in 1993. Following each fish name, the trophic level is indicated. Fish names written in bold indicate that these species were presented in their respective counterpart group in the other year. For example, Curimata was among the first most consumed group in both 1991 and 1993.

TABLE 1

Frequency Score of Food Consumption by Season (Dry and Flood) for Data Gathered in 1991 ($n = 130$ Households) and in 1993 ($n = 143$ Households) along the Upper Madeira River

	1991		1993	
Food items	Dry	Flood	Dry	Flood
Fish[a]	4.7	4.4	4.8	4.7
Chicken/duck	3.4	3.6	3.5	3.4
Beef	2.4	2.4	2.1	1.9
Game	1.8	1.9	2.5	2.7
Pork	1.6	1.5	1.6	1.4
Cassava flour	5.0	5.0	5.0	5.0
Rice	4.2	4.2	4.5	4.4
Beans	4.1	4.1	4.2	4.2
Pasta	3.5	3.5	3.1	2.9
Fruits	4.2	4.1	3.6	3.6

Note. 5, equal to and above 5 days per week; 4, 3 to 4 days per week; 3, 1 to 2 days per week; 2, less than 3 days per month; 1, never eaten.

[a] The average number of fish meals per day (ranging from 1 meal to 2 meals) was 1.8 and 1.9 depending on the season, year, and place.

cell specially made for this purpose (East *et al.*, 1990).

The University of Brasilia laboratory is a participant in the Mercury Quality Assurance Program for Fish (Dept. of Fisheries and Oceans, Central and Arctic region, Freshwater Institute, Winnipeg, Manitoba, Canada). Its performance was considered "acceptable" with 83% (10 of 12) of analyses of the standards less than two standard deviations different from the expected values (Boischio *et al.*, 1995).

RESULTS

1. Dietary Habits and Fish Consumption

Table 1 presents information gathered in 1991 and 1993 (from a total of 273 household interviews) on the frequency of consumption of major food items. Fish and cassava flour were the most important staple food reported. It is interesting to observe the relatively high importance of chicken and duck in the diet for both years. In 1991 a total of 1921 chickens and 503 ducks were reported by the 1045 sampled individuals. Thus, there was an average of 2.3 chickens or ducks available per individual.

During both the 1991 and the 1993 field studies, information was gathered about how many fish meals per day the interviewees usually had during the past and current seasons. The observed means ranged between 1.8 and 1.9 fish meals/day, depending on season and location (bottom of Table 1). During the 1993 interviews, the interviewers asked how often the same fish species were consumed at midday and dinner time. By using a grading system (4: usually the same fish species for both meals; 3: occasionally; 2: rarely; and 1: never the same fish species for both meals), we observed the mean of 3.0, which indicated that the same fish species were usually but not always consumed at both meals. This is consistent with field observations that dinners included leftovers from the midday meal.

1.1. Fish species consumed during the past and current seasons. In order to understand the pattern of fish consumption, each interviewee was asked to grade the fish species consumed during the past season and during the present season. The interviews were carried out during the dry season, and the "previous season" referred to the last flood season. For the dry season (Fig. 2) the weighted means of fish species were listed in descending order and categorized according to the quartile distribution into four categories of consumption (first most frequently consumed fish species, second most frequently consumed, etc.).

The t test procedure in SAS was used for a paired comparison of these data on frequency of consumption of each fish species by season (dry and flood), for the 1991 and the 1993 data separately. Results showed that the mean difference between the weighted grades given for each season was significantly different from zero ($P < 0.05$) for both years. This indicated that the pattern of fish consumption changes according to the season. At the same time, the mean differences in the weighted grade of fish consumption between the two years of study, during either the dry or the flood seasons, were also significantly different from zero. These data indicated that the pattern of fish consumption also changed over time. However, from the quartile categories of consumption, it was observed that certain species (Mandi, Curimata, Pacu, Sardinha, Branquinha, and Surubim—fish names in bold in Fig. 2) were among the first most often consumed during both years of field work.

Because Hg is bioaccumulated up the aquatic food chain, the ratio of high trophic level fish species (such as Piscivore and Omnivore II) to low trophic level species (Herbivore, Detritivore, Planktophagus, and Omnivore I) was compared in each category. From Fig. 2, it can be seen that these ratios were around 1.0 : 1.7 and 1.0 : 2.0 for the most consumed fish species during 1991 and 1993, respectively, whereas these ratios were around 1.5 : 1.0 and 3.0 : 1.0 for the least consumed fish species for the same years. This information indicated that for this particular population, the most consumed fish species were from low trophic level fish species, whereas the least consumed fish species were from the high trophic level fish species. As a consequence, the mean Hg concentrations among the most consumed fish species in 1991 and 1993 were 0.25 and 0.26 ppm, whereas the mean Hg concentrations among the least consumed fish species were 0.50 and 0.53 ppm. Further details on the pattern of Hg exposure are addressed below.

1.2. Fish species consumed during the week before the interview and on the interview day. Figure 3 reports information gathered by asking people to list the animal and/or fish food consumed during the previous seven days (a) and on the interview day (b). These findings confirm the previous patterns in Fig. 2. The fish species consumed during the week before the interview day were mostly the same as the ones observed being consumed during the interview day. These were mostly the same fish species reported as most frequently consumed during the dry season (Fig. 2). The consistency of these data confirms that the fish species most often consumed among this study population were Curimata, Pacu, Jatuarana, Mandi, Surubim, and Tucunaré. However, around 70 and 80% of the households sampled in 1991 and 1993, respectively, consumed other fish species (including 30 other species) during the week before the interview day, which indicates the wide variety of fish species available for consumption. In addition, we observed that one meal for a household could include up to 7 different fish species of different trophic levels. For example, a single meal could easily include Mandi, Curimata, Tucunaré, and Surubim. The mean Hg concentrations among these species ranged from 0.16 to 0.68 ppm (Table 3).

From 1991 to 1993 the percentage of people consuming non-fish meals increased as reported for both the interview week and the interview day (Figs. 3a and 3b). In 1993, almost 60% of 142 households had a non-fish meal in the week before the interview day, compared to 1991 when only around 20% of 131 households had a non-fish meal in the week before the interview. This feature may reflect improvements in river transportation, which could increase access to purchased food.

1.3. Quantitative daily fish consumption. The fish to be consumed by the household members were weighed to evaluate the average amount of daily fish consumption per capita. From field work conducted in 1991 and 1993, fish were weighed from 89 households with 607 individuals. These measurements of fish per meal per capita resulted in a log normal distribution with a mean of 243 g, standard deviation of 135 g and median of 200 g. Also, 60% of per capita consumption was between 100 and 300 g. We converted these fish weights into daily consumption because we observed during the field work that most of the food dinners were leftovers from lunch.

In order to measure the edible portion we calculated the distribution of weights by the condition of the fish into four different categories: whole fish (22%), cleaned (48%), cooked (14%), and sun dried (13%). We assumed that the edible portions of cleaned and cooked fish were similar and that the sun-dried fish counterbalanced the whole fish measurements. Thus no weight was included in this estimate of quantitative fish consumption.

The amount of fish consumed per capita is strongly influenced by the gender/age and body weight distributions in the population. From 607 fish eaters, around 19% were young children below 5 years old; 19% were children between 5 and 10 years old; 15% were young teenagers between 10 and 15 years old; 23% were females equal to or above 15 years old; and 24% were males equal to or above 15 years old. This age/gender distribution is comparable to the same distribution among the subsampled population whose body weights were measured (Table 2).

Thus, this estimate of per capita fish consumption is propably more precise for individuals who were equal to or above 15 years old. This amount may be overestimated for young children and underestimated for fast-growing teenagers, when food consumption per body weight is usually high. Further studies are needed to refine this information.

2. Fish Mercury

The total concentrations of Hg in fish were analyzed in 576 samples of fish from 46 species (Fig. 4 and Table 3). These samples were collected along the study area from the ecosystems used for subsistence fishing by the study population.

Given the pattern of Hg bioaccumulation up the aquatic food chain and the changing trophic level for some fish species according to stage of life, season, and habitat, fish species were grouped by the most predominant trophic level during adult life. The variation in Hg concentration for most of the species may be due to several factors: different habitats, different community structures, and different physiology, body weight, and age. The high Hg concentrations observed in some of the herbivore and

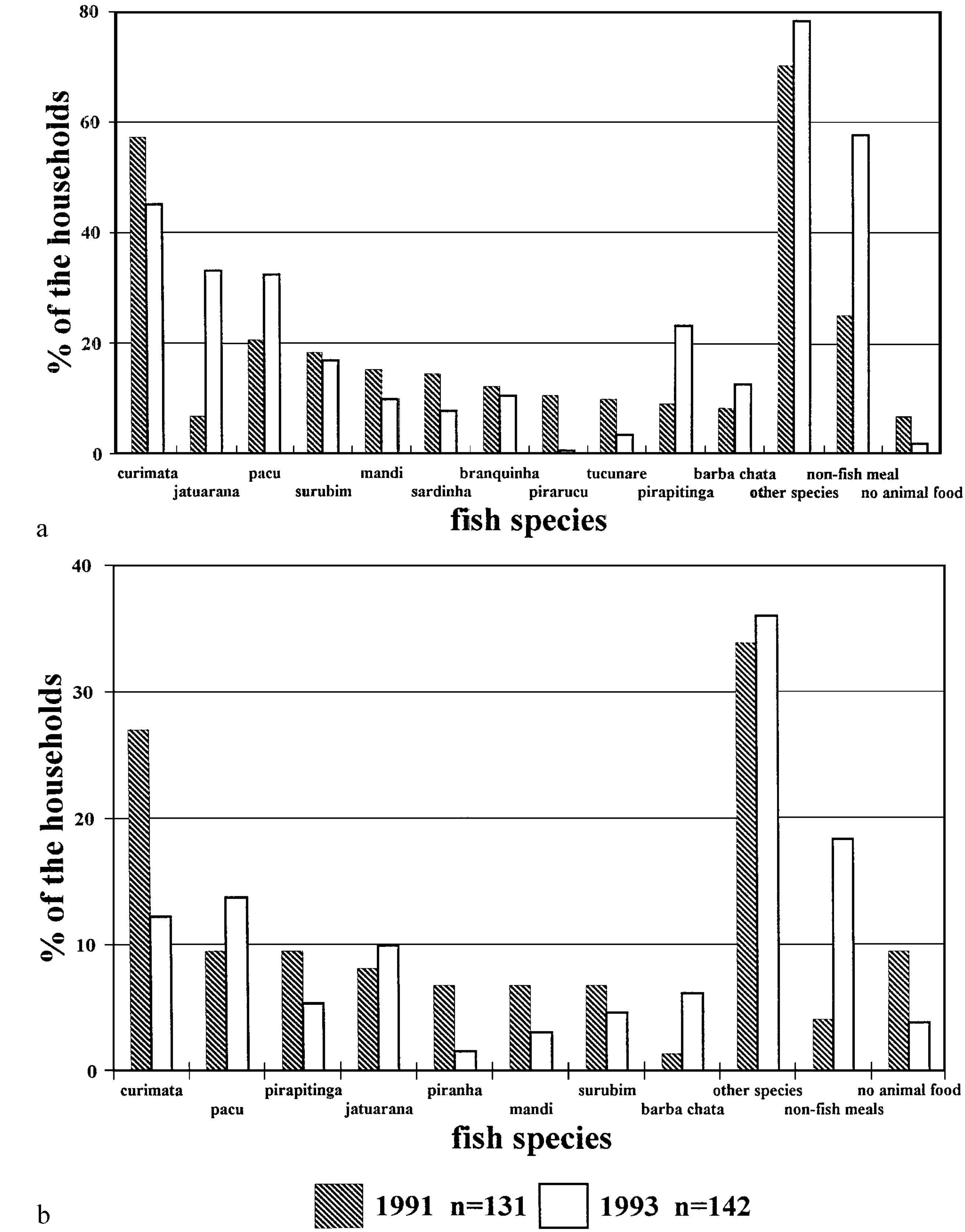

FIG. 3. Fish species consumed during the week before the interview (a) and on the interview day (b) for 1991 and 1993. The number of households responses (n) per year is given.

TABLE 2

Percentage Distribution and Body Weight (in kg) According to Gender/Age Distribution of the Subsampled Population ($n = 830$ Individuals) along the Upper Madeira River

Gender/age	%	Body weight
Infants–5 years old	18	11
5–10 years old	22	20
10–15 years old	18	33
$\geq$ 15 years old, females	22	53
$\geq$ 15 years old, males	20	59
Total	100	36

Note. Obs: only the lower limits are included in each interval.

detritivore species are worthy of attention in the context of a fish advisory (Table 3).

Figure 4 shows the Hg concentrations in fish species by trophic level. The omnivore group was divided into two subgroups because of the wide variation in prey consumed by different species. Those omnivore fish species eating invertebrate prey were placed in the omnivore I subgroup, and those eating vertebrate prey were placed in the omnivore II subgroup. It was previously reported that both Mandi and Aruana (with mean Hg concentrations of 0.24 and 1.44 ppm, respectively—Table 3) were in the same trophic level, i.e., omnivore (Boischio *et al.*, 1995). However, Mandi feed on aquatic immature invertebrates, whereas Aruana may feed on terrestrial invertebrates and even vertebrates, such as big snakes (Goulding, 1980). Thus, the food webs supporting Mandi and Aruana are very different, which is relevant to understanding patterns of Hg bioaccumulation.

Data on fish Hg concentration (Table 3 and Fig. 4) were analyzed statistically using ANOVA. The results indicate that 28% of the variability in fish Hg concentrations is explained by species ($P < 0.0001$). Fish species grouped by trophic level were subjected to a multiple comparisons of means test via ANOVA.

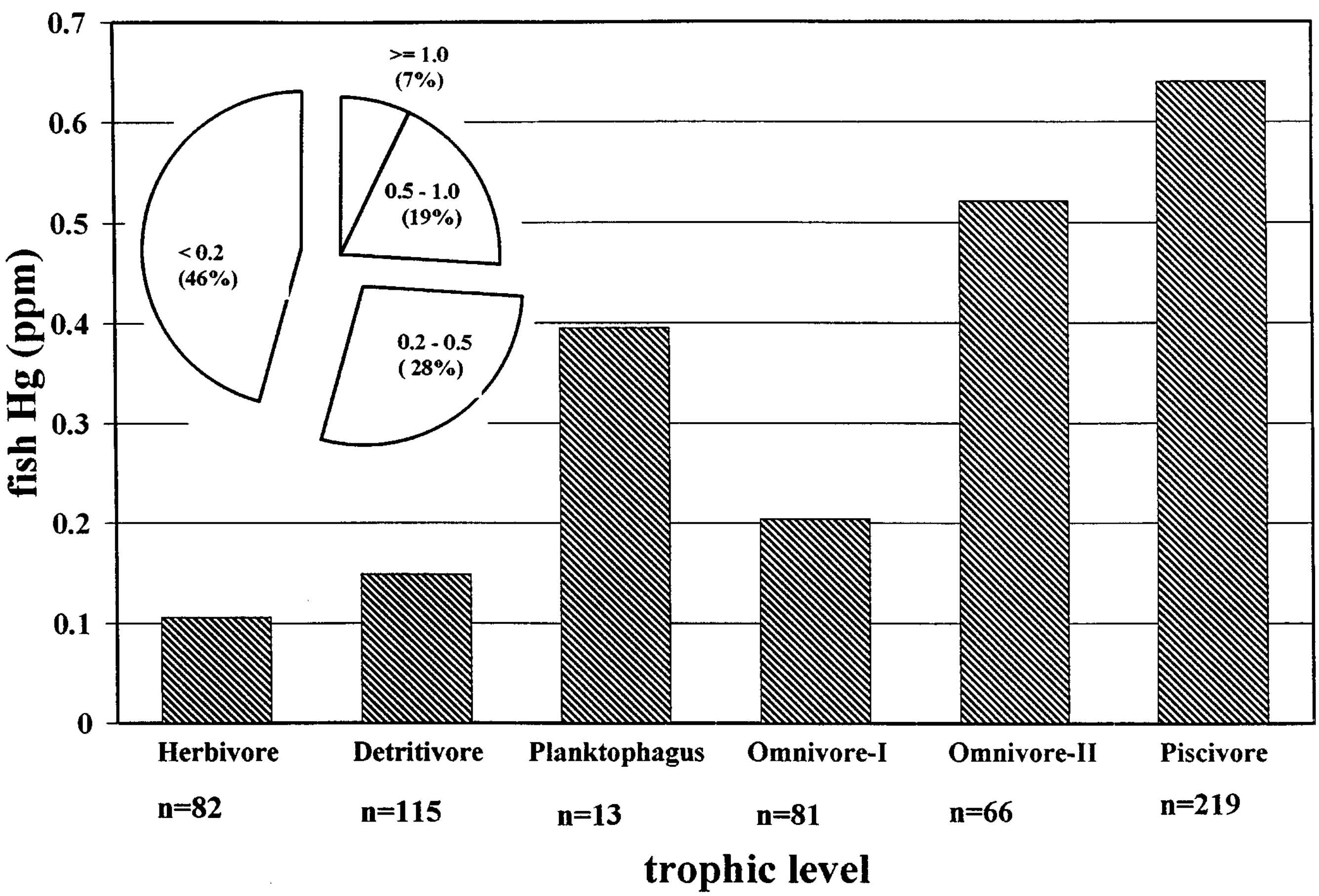

FIG. 4. Fish mean Hg concentration (ppm) by the most predominant trophic level during fish adult life. The trophic levels omnivore I and II are based on their respective prey: invertebrates and vertebrates. The pie chart represents the percentage of fish samples grouped by range of Hg concentration.

TABLE 3

Fish Hg Concentration (in ppm) and Body Weight (in g) by Fish Species According to the Most Predominant Trophic Level during Adult Life from the Upper Madeira River—1991 and 1993

Fish species		Mercury concentration		Body weight
Latin name (Portuguese name)	*N*	Mean	Range	Mean
Herbivore				
Colossoma macropomum (Tambaqui)	6	0.36	ND–1.21	8300
Brycon spp. (Jatuarana)	18	0.14	0.05–0.51	1500
Colossoma bidens (Pirapitinga)	13	0.09	ND–0.17	2100
Mylossoma sp. (Pacu)	41	0.06	ND–0.12	310
Lithodoras dorsalis (Bacu)	4	ND	—	1850
Subtotal	82	0.10	ND–1.21	1500
Detritivore				
Locariidae (Tamoata)	4	0.28	ND–0.81	120
Curimatus spp. (Cascuda)	2	0.23	0.13–0.34	70
Semaprochilodus brama (Jaraqui)	5	0.19	ND–0.50	400
Prochilodus nigricans (Curimata)	56	0.16	ND–0.96	430
Locariidae (Bodo)	6	0.11	ND–0.27	320
Curimatus spp. (Branquinha)	42	0.11	ND–0.88	170
Subtotal	115	0.15	ND–0.96	310
Planktophagus				
Anodus elongatus (Ubarana)	2	0.90	0.77–1.03	100
Hypophthalmus marginatus (Mapara)	5	0.46	0.05–0.83	530
Colossoma macropomum (young)	6	0.11	ND–0.25	170
Subtotal	13	0.36	ND–1.03	300
Omnivore I				
Megaladoras sp. (Cubiu)	2	0.82	0.60–1.03	180
Pimelodus sp. (Mandi)	36	0.24	ND–0.56	110
Cichlasoma sp. (Cara)	12	0.17	ND–0.39	210
Oxydoras niger (Cuiu-Cuiu)	13	0.17	ND–0.23	1700
Triportheus spp. (Sardinha)	18	0.15	ND–0.57	160
Subtotal	81	0.21	ND–1.03	400
Omnivore II				
Osteoglossum bicirrhosum (Aruana)	11	1.44	0.23–11.15	960
Callophysus macropterus (Pintadinho)	12	0.73	0.37–1.47	520
Phractocephalus hemiliopterus (Pirarara)	8	0.64	0.32–1.40	4900
Anostomidae (Aracu/Piau)	29	0.17	ND–0.78	340
Brycon sp. (Matrincha)	6	0.17	0.08–0.26	340
Subtotal	66	0.55	ND–11.15	1000
Piscivore				
Astronotus ocellatus (Cara Acu)	4	1.34	0.54–1.71	180
Brachyplatystoma sp. (Filhote)	4	0.99	0.47–2.00	8250
Miscellaneous[a]	5	0.96	0.47–1.38	720
Serrasalmus sp. (Piranha)	13	0.89	0.21–3.83	260
Rhaphiodon vulpinus (Peixe Cachorro)	10	0.87	0.38–1.08	500
Plagioscion sp. (Pescada)	10	0.81	0.09–1.20	1200
Crenicichla sp. (Jacunda)	4	0.79	0.41–1.25	300
Pellona castelnaeana (Apapa)	6	0.73	0.29–1.33	1500
Pseudoplatystoma sp. (Surubim)	23	0.68	ND–1.59	1620
Pinirampus pirinampu (Barba Chata)	36	0.68	0.28–2.00	1060
Cichla ocellaris (Tucunaré)	22	0.66	0.12–2.21	720
Sorubim lima (Bico de Pato)	12	0.65	0.29–1.07	240
Erythrinus sp. (Jeju)	3	0.65	0.60–0.68	400
Brachyplatystomas sp. (Piramutaba)	5	0.56	0.21–1.24	1450
Brachyplatystoma flavicans (Dourada)	17	0.51	ND–2.07	8020
(Jandira)	5	0.23	ND–0.28	970
Pseudoplatystoma sp. (Caparari)	5	0.41	0.34–0.45	10,040
Hoplias malabaricus (Traira)	14	0.38	0.08–1.06	420
Arapaima gigas (Pirarucu)	21	0.27	0.08–0.43	26,000
Subtotal	219	0.64	ND–3.83	3100
Total	576	0.39	ND–11.15	1540

[a] One of each: Pirandira, Mandube, Piraiba, Croata, Jau.

Trophic level (the independent variable) accounted for around 15% of the variability in the fish Hg concentration (taken as the dependent variable, $P < 0.0001$). The mean Hg concentration by trophic level was compared using the Waller and Duncan tests, which demonstrated that fish Hg concentrations among the piscivore and omnivore II groups were not significantly different, but were significantly different from all other trophic groups ($P < 0.05$). Similarly, the mean Hg concentrations difference between the planktophagus and omnivore I groups were not statistically significant but were statistically different from all other groups ($P < 0.05$). The same was true for detritivores and herbivores.

Comparisons were made across the 2 years of the study using a difference of means test (procedure t test). The Hg levels in fish for the 2 years were not significantly different.

It is important to understand the specific ecological features of fish in these ecosystems, as this affects the fate of Hg in the aquatic food chain. For example, Traira had a much lower Hg concentration than Tucunaré (average 0.39 ppm to compare with 0.68 ppm, respectively). However, both species are piscivores, living mostly in streams, flooded forests, and lake ecosystems (Goulding, 1980). As mentioned above, a reason for such Hg differences may include the environmental pathways, fish physiology, and body weight and ecological features of the prey, such as trophic level, ecosystems, and migratory patterns.

Another relevant concern is that the planktophagus fish species, especially specimens of Mapara, had Hg concentrations above 0.40 ppm, which is relatively high. It may be that plankton plays an important role in the transfer of Hg from the atmospheric compartment into the aquatic ecosystem or from sediment into the aquatic food chain. Further research on this issue is necessary to clarify the fate of Hg compounds in the aquatic food chain in the Amazon (Forsberg, personal communication).

The correlation between fish body weight and Hg concentrations was weak (below 0.35, with P values below 0.6920) for many piscivore fish species (Pescada, Barba Chata, Surubim, Tucunaré, and Peixe Cachorro). Only Traíra had a correlation of 0.79 (P value of 0.0024).

Another noteworthy finding was the low Hg content (0.27 ppm) observed in 21 specimens of Pirarucu. Pirarucu is a piscivore mostly living in lake ecosystems, and its adult body weight may average around 100 kg (Goulding, 1980). It is possible that the low Hg content of Pirarucu in this study was related to its preferred fish prey, Tamoata, which is a sedentary lake detritivore. These specific aspects of Hg distribution up the aquatic food chain must be taken into account when considering a fish advisory strategy.

The highest fish Hg concentration observed was 11.15 ppm in one Aruana specimen (omnivore II). Aruana is a surface fish species, usually at the shore zone, which feeds on a wide variety of food from both terrestrial and aquatic ecosystems: insects and spiders, crustaceans and mollusks, fish, terrestrial and arboreal vertebrates (including birds and snakes), and plant material (Goulding, 1980).

This Aruana sample was taken from a particular lake in which other species were also heavily contaminated. In this lake a distinct pattern of bioaccumulation could be observed. The mean fish Hg concentrations of omnivore II and piscivore species ($n = 20$) were 2.28 and 1.18 ppm, respectively, while the mean fish Hg concentrations of herbivore and detritivore species ($n = 13$) were 0.07 and 0.35 ppm, respectively. These results indicate that this lake was heavily contaminated with Hg. A local fish advisory may advise no fishing until the lake sediments and biota are cleaned up. In addition, the Hg concentrations in the biotic and abiotic environmental compartments of this lake and basin need to be further investigated.

3. *Mercury Ingestion Estimates*

Mercury ingestion through fish consumption must be understood in order to control Hg exposure by managing fish consumption. Hg ingestion is be affected by the amount of fish consumed and by the species of fish being eaten.

In order to understand which fish species were the major sources of Hg ingestion, we have used our data on qualitative fish consumption (Fig. 2) in combination with fish Hg concentrations (Table 3). Fish species were grouped according to the consumption quartile and the means of the Hg concentrations were subjected to multiple comparisons using ANOVA. The means of Hg concentration by category of consumption were compared using the Waller and Duncan tests. The mean Hg levels of 0.25 and 0.26 ppm ($n = 296$ and 287 for 1991 and 1993) from the category of species most often consumed were significantly different ($P < 0.05$) from the mean Hg levels of 0.53 and 0.50 ppm ($n = 31$ and 73 for 1991 and 1993) from the category of fish species least often consumed. The categories of the second and third most frequently consumed fish species were also significantly different for both years. These differences were probably related to the placement of fish species with high Hg levels—Aruana, Apapá, Piranha, and Pescada—in these two intermediate categories of consumption.

The information about the average amount of fish daily consumed per capita and fish mean Hg concentrations from 1991 and 1993 research data were used to estimate the daily Hg ingestion through fish consumption according to Eq. (1). In addition, Eqs. (2) and (3) were used to evaluate Hg ingestion levels in the context of maximum acceptable hair Hg levels. These Hg ingestion estimates were used with the average Hg levels by fish species to estimate the maximum number of fish meals per week according to fish species (Table 4). These equations were used under the assumption that the population was exposed for more than 5 years, under steady-state conditions (Clarkson *et al.*, 1988). Among this study population, the body weight for 830 individuals of all ages was on average of 36.0 kg (Boischio *et al.*, 1995). This low body weight was probably due to the population distribution by age. Indeed, from Table 2, around 58% of these individuals ($n = 830$) were under 15 years old.

$$\text{Hg daily intake } (\mu\text{g}) = \text{fish (g)} \times \text{fish Hg } (\mu\text{g/g})/\text{body wt (kg)} \quad (1)$$

$$\text{Blood Hg (ng/ml)} = 0.95 \times \text{daily intake } (\mu\text{g}) \quad (2)$$

$$\text{Hair Hg (ng/g)} = 250 \times \text{blood Hg (ng/ml)} \quad (3)$$

By using the means of fish consumption (243 g), fish Hg (0.39 ppm), and human body weight (36.0 kg) in Eq. (1), the average daily Hg intake is calculated to be 95 μg, or 2.60 μg/kg average body weight. Alternatively, by using the medians of fish consumption (200 g), fish Hg (0.23 ppm), and body weight (33.0 kg), the average daily Hg intake is 46 μg, or 1.39 μg/kg body wt. By comparison, the World Health Organization recommended that the permissible tolerable weekly Hg intake for adults is no more than 400 g of fish with a maximum Hg concentration of 0.50 ppm. This is equal to a weekly intake of 200 μg (3.30 μg/kg body wt) or a daily Hg intake of around 30 μg (0.48 μg/kg body wt) (IPCS, 1990). The WHO assumes an average body weight of around 60 kg per person, which is different from our observed mean body weight measurements for this study population (36.0 kg). These estimates of daily Hg intake among this study population exceed those recommended by WHO.

4. *Risk Communication: Developing a Fish Advisory*

In order to reduce Hg exposure, the pattern of fish consumption must be managed to reduce population ingestion of Hg to WHO recommended levels. We suggest that fish advisories are needed and that these fish advisories should be based on average fish Hg concentrations by species and the average amount of fish consumption for the population.

For this purpose, we assume that acceptable Hg levels in these polluted areas may be reflected in

TABLE 4

Maximum Number of Fish Meals per Week by Fish Species Reccommended to Protect Reproductive Life (Pregnant and Breast Feeding Women) and to Protect the Whole Population in General

Fish species (Hg conc.—ppm)	Max Hg intake 0.40 μg/kg bw, pregnant and breast feeding, No. meals/week (category)	Max Hg intake 1.17 μg/kg bw, whole population, No. meals/week (category)
Curimata, Branquinha, Sardinha, Pacu, Jatuarana, Pirapitinga, Jaraqui, Cara, Cuiu-cuiu, Aracu, Matrincha, Bodo, Boco, Bacu (below 0.20 ppm).	3 (eat less)	6 (eat more)
Mandi, Pirarucu, Tamoata, Cascuda (0.20 to 0.29 ppm)	2 (eat less)	4 (eat more)
Tambaqui, Traira (0.30 to 0.39 ppm)	1 (eat rarely)	3 (eat less)
Mapara, Caparari (0.40 to 0.49 ppm)	1 (eat rarely)	2 (eat less)
Piramutaba, Dourada (0.50 to 0.59 ppm)	0 (do not eat)	2 (eat less)
Pirarara, Surubim, Barba Chata, Tucunaré, Bico de Pato, Jeju (0.60 to 0.69 ppm)	0 (do not eat)	1 (eat rarely)
Jacunda, Apapa, Pintadinho (0.70 to 0.79 ppm)	0 (do not eat)	1 (eat rarely)
Cubiu, Piranha, Peixe Cachorro, Pescada (0.80 to 0.89 ppm)	0 (do not eat)	1 (eat rarely)
Filhote, Piraiba, Jau, Pirandira, Ubarana (0.90 to 1.00 ppm)	0 (do not eat)	1 (eat rarely)
Aruana, Cara-Açu (above 1.00 ppm)	0 (do not eat)	1/month (eat rarely)

hair Hg concentrations below 5 or 10 ppm (Stern, 1993; Grandjean *et al.*, 1995, 1997). By using Eqs. (2) and (3), the estimate of a maximum daily Hg intake of 0.40 μg/kg body wt was reached for pregnant women. In this case, we used a mean body weight of 53.0 kg observed among women who were above 15 years old (Table 2). Similarly, by considering the hair Hg level of 10 ppm to be protective of adults, we estimated that a maximum daily Hg intake of 1.17 μg/kg body wt would protect all other age groups. We used the mean body weight of 36.0 kg observed for the whole population (Table 2).

These estimates of the maximum daily Hg ingestion were used to estimate the maximum number of fish meals per week according to the fish species (Table 4) based on the amount of daily fish consumption (243 g) and the mean Hg level in the samples from each species (Table 3). The maximum number of fish meals per week were placed into four categories: 1, eat more (four to six meals per week); 2, eat less (two to three meals per week); 3, eat rarely (no more than one meal per week); 4, do not eat.

One limitation of this strategy is that these estimates assume that no other Hg-contaminated fish species are eaten during the same weekly period. In addition, most of the fish species are only seasonaly available. Since the population relies heavily (but not only) on fish as a food staple, we also recommend that pregnant and lactating women only eat those fish species likely to be lowest in Hg and that the rest of the population eat fish more often from the low trophic levels and less often from the high trophic levels.

From Fig. 2 and Table 4, one can observe that many of the fish species most often consumed are those reccommended for a high number of meals per week (Curimata, Branquinha, Sardinha, Pacu, Jatuarana, Pirapitinga, Cara). However, certain critical fish species (Surubim, Tucunaré, Barba Chata, and Bico de Pato) are of major concern. These fish species have high Hg levels (in the range of 0.65 to 0.68 ppm) and were also referred as most often consumed. According to our estimates on Table 4, these critical fish species should be consumed by the whole population in the categories of "do not eat" and "eat rarely," according to the target population.

Given that the target population is only partially literate (based on personal observation), the information in Table 4 must be presented in a comprehensible pictorial format. Workshops are needed to introduce the fish advisories material and to train local people for follow-up activities on fish consumption management.

There are three other important considerations for the risk communication strategy. First, the exposed population must be made aware of the information about fish Hg levels by species and the risks of adverse health effects associated with Hg. This is best done by training local people in the community to be educators on risk communication. Second, the Hg data, must be considered based upon continued biological monitoring of fish Hg levels, given the above-mentioned specific ecological fish features. Finally, fish consumption is part of the cultural background of riverside people (*ribeirinhos*) in the Amazon. Thus, it is necessary to understand and acknowledge fish lore to best manage Hg exposure through fish consumption (Boischio and Henshel, 1996a).

5. *Fish Lore among the Ribeirinhos*

The cultural basis influencing fish consumption, and thus Hg intake, for his particular population has been previously addressed (Boischio and Henshel, 1996a). In summary, *reimoso* fish species are defined as those that may worsen a vulnerable stage of life (illness, pregnancy, and breast feeding), when these species must be avoided, and other fish species are encouraged to be consumed because they are considered to be safe fish. The fish species included in the categories of preferred, *reimoso*, and safe among these 142 households sampled in 1993 are presented in Table 5, along with their respective categories of consumption (from Fig. 2). Table 5 lists the fish species according to these categories of perception (fish lore) and consumption. It is interesting to observe how flexible these categories of fish perception can be. For instance, Surubim (with a mean Hg concentration of 0.68 ppm) was referred to as being preferred, safe, and *reimoso* by different interviewees (bold species in Table 5).

For example, the Aruana species is considered to be the safest fish for consumption. Thus, Aruana may be eaten during times when health needs to be protected. We observed that a woman preparing an Aruana usually indicated that she was nursing a young infant. However, as mentioned under the Results (Fish Mercury), the Aruana samples included one specimen with a peak Hg concentration of 11.15 ppm, a mean of 1.44 ppm, and 55% of 11 samples above 0.47 ppm. Thus, breast feeding has the potential to be a major route of Hg exposure during early postnatal life (Boischio and Henshel, 1999).

For this data set, ANOVA was used by considering Hg concentrations in those fish species which were included in only one category of perception. The

TABLE 5

Percentual Frequency of Fish Cited ($n = 142$ Households) According to the Categories of Perception, with Trophic Level and Level of Consumption (from Fig. 2)

Fish	%	Consumption
Preferred fish		
Tambaqui—H	49	Third
Jaturarana[a]**—H**[b]	46	Second/First
Pacu-H	35	First
Curimata—D	34	First
Pirarucu—P	24	Third/least
Sardinha—OI	23	First
Pirapitinga—H	23	Second/First
Tucunare—P	19	First/Second
Surubim—P	17	First
Mandi—OI	11	First
Others	69	—
Safe fish		
Aruana—OII	[c]	Second/Third
Sardinha—OI	[c]	First
Pescada—P	[c]	Second/Third
Young Tambaqui—Pl	[c]	Third/least
Branquinha—D	[c]	First
Traira—P	[c]	Second
Cara—OI	[c]	First/Second
Pacu—H	[c]	First
Cubiu—OI	[c]	Least
Surubim—P	[c]	First
Aracu—OII	[c]	First/Second
Reimoso fish		
Surubim—P	51	First
Jatuarana—H	44	Second
Pirapitinga—H	37	Second
Pirarucu—P	32	Third
Caparari—P	32	Least/First
Piranha—P	23	Second/Third
Mandi—OI	16	First
Dourada—P	13	Least
Curimata—D	11	First
Others	35	—

[a] Fish species in bold are included in more than one category (preferred, *reimoso*, and safe).
[b] TL (trophic level): D, detritivore; Pl, planktophagus; H, herbivore; OI, omnivore—invertebrate prey; OII, omnivore II—vertebrate prey; P, piscivore.
[c] From Smith (1981).

mean Hg concentrations assessed by category of perception were compared using the Waller and Duncan tests. The fish Hg concentration among fish species considered to be *reimoso* (0.62 ppm) were significantly different from the Hg concentrations among the categories of most preferred and safe fish species (0.28 and 0.32 ppm, respectively).

Fish species that fell into more than one category of perception (Table 5) were analyzed separately using the Waller and Duncan tests. In this case, Surubim (with mean Hg concentration of 0.68 ppm) was the single species considered to be *reimoso*, preferred, and safe. This mean of 0.68 ppm was significantly different from the mean Hg concentration of 0.19 ppm observed among those fish species (Jatuarana, Curimata, Pirapitinga, Pirarucu, Mandi — Table 5) which were considered to be both *reimoso* and preferred.

DISCUSSION

1. Fish Consumption

The importance of fish in the diet of Amazonian populations living along the rivers and floodplain areas has been previously documented (Junk, 1984; Goulding, 1980; Moran, 1993). Verissimo (1970) was probably the first author (in 1895) to describe details of fishing and fish food in the Amazonian ecosystems. The most common method of preparation is *caldeirada*, which is boiling fish with spices (onion, coentro, peppers). Fried fish is also consumed after it is slashed (*peixe ticado*). Overall, the pattern of fish consumption may be considered in two ways: (1) fish species availability, which varies according to the type and location of the ecosystem; (2) quantitative fish consumption, which is related to access and availability of other animal protein such as beef, chicken, and game. For example, Giugliano *et al.* (1978) estimated daily fish consumption per capita in the range of 100 to 150 g of fish, according to high and low income status, respectively, among an urban population (1200 households) in Manaus, Amazonas. For this urban population, the fish species more often consumed were Tambaqui and Jaraqui. Differently, among riverside people along the Solimões river, Tambaqui and Pirarucu were more often consumed, whereas the riverside people of Rio Negro consumed more Pacu and Piranha (Giugliano *et al.*, 1978). These differences in eating preferences may well reflect the availability of each species at the market or in the ecosystem.

The fish consumption by riverside people of Lago Grande, South Para, was evaluated by Cerdeira *et al.* (1997). By weighting the fish meals of 35 households during 1 week per month for 22 months, these authors estimated daily fish consumption per capita to be around 370 g during the high fish season. According to Cerdeira *et al.*, fish were consumed on 8 of 10 days. The fish species more often consumed for their study population were Curimata and Acari. These authors compared their quantitative estimates of fish consumption with those derived in other Amazonian studies, which ranged from 90 to 190 g. Differences in estimates of fish consumption may be due to methodological approach and fish availability.

Lebel *et al.* (1997) observed among 96 riverside people from the Brasilia Legal (a small village along the Tapajos River, Para) that the fish species more often consumed during the flood season was Pescada (25% of 922 meals), whereas during the dry season, Pacu and Aracu were more often consumed (18 and 9% of 807 meals, respectively). To compare, we observed that among the Upper Madeira river population, the fish species mostly consumed during the dry season were Curimatã and Pacu (Figs. 2 and 3).

Eve *et al.* (1996) investigated the number of fish meals within a 24-h period from two different communities in Amazonas. From 24 questionnaires applied in Iranduba, there were 18 mentions of piscivore consumption compared to 30 mentions of herbivore consumption. In contrast, from 50 questionnaires used in Barreirinha, there were a total of 82 mentions of piscivore consumption and 12 mentions of hervivore consumption.

2. *Fish Mercury*

Overall, the observed variation on fish Hg concentration, among fish of same and different species, appears to be related to the ecosystem, trophic levels, and body weight of the fish. A pattern of Hg bioaccumulation up the aquatic food chain has been observed in many studies (Fernandes *et al.*, 1990; Martinelli *et al.*, 1988; Vieira, 1991; Malm *et al.*, 1990; Aula *et al.*, 1994; Lebel *et al.*, 1997; Padovani *et al.*, 1995; Meili *et al.*, 1999) and it is confirmed in this study. In most studies piscivore fish species have Hg concentrations above 0.50 ppm (Fernandes *et al.*, 1990; Malm *et al.*, 1990). Vieira (1991) concluded that biomagnification was probably occurring in the aquatic food chain in the Pantanal area (located at the southwest of the Amazon basin). He found mean fish Hg concentrations above 0.50 ppm in Cachara (*Pseudoplatystoma fasciatus*, a congener of Surubim and Caparari), Pintado, Dourado, Piranha, Traira, and Peixe Cachorro (all piscivore species).

Akagi *et al.* (1994) found fish Hg concentrations above 0.50 ppm in 12 specimens of Piscivore species (Dourada, Piraiba, Jau, Peixe Cachorro, Mandube, Traira, Tucunaré, Apapa, and Pescada) from the Tapajos River. Forsberg *et al.* (1995) obtained a mean of 0.73 ppm Hg among 54 piscivore specimens from the Rio Negro. Padovani *et al.* (1995) observed fish Hg concentrations above 0.50 ppm in 19 specimens of piscivore species from the Madeira River (Bagre—*Calophysus macropterus*, Peixe Cachorro, Surubim, Barba Chata, Bico de Pato). Roulet *et al.* (1999b) observed a wide range of Hg concentrations in piscovore fish species: Tucunaré (0.10–0.80 ppm), Traíra (0.10–0.70 ppm), Piranha (0.05–1.0 ppm), and Pescada (0.07–1.4 ppm). In the current study, a mean Hg concentration of 0.64 ppm was observed in 220 specimens of the piscivore species analyzed (Table 3). The species with at least one specimen above or equal to 2.00 ppm were Piranha, Tucunaré, Dourada, Filhote, and Barba Chata.

Hg concentrations below 0.20 ppm have been observed in low trophic level fish species of small body weight. Fernandes *et al.* (1990) found mean fish Hg concentrations below 0.20 ppm among 15 specimens of Mandi, Curimata, Acari, Pacu, and Sardinha taken from the Carajas area. From the Madeira River area one specimen of Bodo, a detritivore species, presented with 0.05 ppm (Martinelli *et al.*, 1988). Vieira (1991) found low Hg concentrations (0.13 and 0.16 ppm) in 26 and 5 specimens of Bagre (*Pimelodus* sp) and Curimba (*Prochilodus lineatus*), respectively, from the Pantanal area. Malm *et al.* (1990) noted fish Hg concentrations below 0.21 ppm in 2 and 1 specimens of Curimata and Jatuarana, respectively, from the Madeira River. Also, from the Madeira River Padovani *et al.* (1995) observed an Hg concentration below 0.13 ppm from 38 specimens of low trophic level fish species (Mandi, Matrincha, Curimatã, and Pacu). Akagi *et al.* (1994) observed Hg concentrations of 0.10 ppm in Pacu from the Tapajos River. Average Hg concentrations in herbivore and omnivore species from the Rio Negro were 0.14 and 0.35 ppm, respectively (Forsberg *et al.*, 1995). In our study, most of the small and low trophic level species (Curimata, Pacu, Jaraqui, Cara, Branquinha, Sardinha, Bacu, Bodo, Mandi, Jatuarana), had mean Hg concentrations below 0.20 ppm.

We also observed low Hg concentrations in Pirarucu specimens. Pirarucu is a large piscivore species which is well-liked as a food fish in the Amazon. Hg concentrations found in Pirarucu specimens were mostly (95%) below 0.30 ppm for the samples taken from different locations in several studies (Akagi *et al.*, 1994; Pfeiffer *et al.*, 1989; Martinelli and McGrath, 1999). These results were compatible with our observed mean Hg concentration for Pirarucu of 0.27 ppm (21 samples). This is an exception to the bioaccumulation pattern, in that a large piscivore would be expected to higher levels of Hg. One possible explanation in our study is that the main fish prey of Pirarucu, Tamoata, is a sedentary lake detritivore with low Hg levels. According to Martinelli and McGrath (1999), additonal reasons for the low Hg levels in Pirarucu are the low trophic levels of its prey during the juvenile stage of life and its fasting period of 2 to 3 months during breeding.

In addition, several low trophic level fish species expected to have low Hg concentrations occasionally showed high Hg levels. For instance, Martinelli *et al.* (1988) found that Tambaqui and Pirapitinga, both herbivore species but of large body weight, had mean Hg concentrations above 0.50 ppm. Vieira (1991) also observed some low trophic level specimens of Bagre (*Pimelodus maculatus*, congener of Mandi) and Curimba with Hg concentrations as high as 7.80 and 0.59 ppm Hg, respectively. In the current study Hg concentrations above 0.50 ppm were observed in one specimen of Branquinha, Curimata, and Jatuarana (Table 3). These "outliers" pose concerns for fish advisories, since they are exceptions to the general rules that must be relied upon in fish advisories. However, fish advisories, based on average Hg tissue levels, will probably help to minimize overall Hg ingestion for the study population. It is helpful that the observed fish consumption patterns for the most part are consistent with expectations. In addition, we observed that the fish species most often consumed have lower Hg levels than the fish species least often consumed.

3. *Mercury Ingestion Estimates*

To estimate Hg exposure through fish consumption, Ponce *et al.* (1998) compared the use of Eq. (1) (as a predictive model on diet) with Eqs. (2) and (3) (as biomarkers) by using data from a diet study conducted among fish consumers in the United Kingdom. These authors concluded that measurements of fish diet intake presented the least biased estimate of Hg exposure.

Stern *et al.* (1996) used similar approaches to study the pattern of MeHg exposure in a population in New Jersey. The estimates resulted in an average fish consumption of 50 g and MeHg daily intake of 7.5 μg/kg bw. These authors observed that there were two major patterns of Hg intake: a large amount of low Hg fish and a low amount of high Hg fish. Mahaffey *et al.* (1999) also estimated MeHg intake among fish eaters in the United States by addressing fish consumption and fish Hg levels. Their results indicated a median daily fish consumption of 66 g from 24-h recall and a median daily MeHg intake of 0.10 μg/kg bw.

In order to compare estimates of Hg ingestion based on fish consumption and fish Hg levels, with estimates of Hg ingestion based on hair Hg levels, Boischio *et al.* (1995) used Eq. (1) and Eqs. (2) and (3) to observe that among an Upper Madeira River population around 47% of 216 fish species had Hg concentrations in the range of 0.2 to 1.0 ppm. A daily consumption of 200 g of fish in the study population was calculated to result in an expected hair Hg concentration in the range of 10 to 50 ppm, which was in fact observed among 53% of 237 individuals. Thus, for this study population, the use of diet data and biomarkers (fish and hair) provided concordant information.

Kehrig *et al.* (1998) conducted similar investigations among a fish-eating population in the Balbina Reservoir in the Amazon. These authors observed that in 64% of 22 fish samples analyzed Hg concentrations ranged between 0.1 and 0.5 ppm. Assuming an average daily fish consumption of 110 g, the hair Hg levels would result in 3 to 13 ppm, which was observed among 70% of 20 individuals investigated.

For the Madeira River population, a risk assessment was conducted by using the hair Hg levels in Eqs. (2) and (3). The results estimated daily Hg ingestion in the range of 0.8 to 6.4 μg/kg bw for females >49 years old and for children <5 years old, respectively (Boischio and Henshel, 1996b).

One specific case was found with high hair Hg, which was correlated with high fish Hg concentrations, in the community around a particular lake. This lake contained the Aruana specimen with the highest fish Hg concentration (11.15 ppm) in the study, as well as other highly contaminated piscivore fish. The persons from one household located next to this lake had the highest hair Hg concentrations (with a peak of 339 ppm) observed in the study population. In this family, the segmental hair Hg analyses showed a wide variation in hair Hg levels among different individuals and in the same individual over time. The wide variation of fish species from different trophic levels available for consumption in the same meal had a potentially strong influence on the wide variation of Hg exposure among this particular family (Boischio *et al.*, 2000).

4. *Risk Communication: Fish Advisory*

The Environmental Protection Agency of the United States has proposed a new reference dose for Hg exposure of 0.1 μg/day/kg bw (Mahaffey *et al.*, 1999), which corresponds to hair Hg levels <1.0 ppm using Eqs. (2) and (3). The application of this level in polluted ecosystems in Amazonia is not feasible since it would result in a total ban on consumption of any fish species by pregnant and lactating women. This is unfeasible in the Madeira River communities where fish is a significant source of protein intake.

The benefits of fish consumption must be considered in the context of local community response to proposed fish advisories. Egeland and Middaugh (1997) suggested that the replacement of local fish with commercial food has been harmful for indigenous people in Alaska. Wheatley and Paradis (1995) and Wheatley and Wheatley (1999), working with indigenous peoples in Canada, suggested that the Hg risks must be considered within the sociocultural disruption that may occur with fish advisories. Shkilnyk (1985) described that Hg concerns contributed to sociocultural disruption among the Ojibwa people in Canada. The James Bay Mercury Committee (1995) has developed a program to monitor Hg pollution and to share the information with the Cree people, in order to mitigate the health problems of Hg exposure.

In the Amazon, people are subjected to many health stresses, including malaria, intestinal parasites, and general resource limitations. Hg pollution in Amazonian ecosystems must be managed to reduce exposure by sharing relevant information about health and Hg so that individuals can make responsible decisions about Hg risks. Food alternatives, such as chicken and vegetables, must be encouraged.

A fish advisory must be targeted at consumers, fishers, and fish business people. It may be possible to ameliorate current conditions of increased risk by informing exposed populations about the hazards of Hg and providing options to mitigate these risks. A fish advisory must utilize different strategies for different groups. For example, urban populations may be subject to a different pattern of Hg exposure than *ribeirinhos*. Some urban populations may consume relatively few fish meals per week with high Hg concentrations, such as Piramutaba, Filhote, and Tucunare, whereas *ribeirinhos* primarily consume a great amount of low trophic level fish species (such as Curimata and Pacu) and a critical amount of high trophic level species (Surubim and Tucunare). Thus, the fish advisory must be designed to take into account eating habits and preferences of the exposed populations.

A fish advisory must also be sensitive to relevant gender issues. First, the fetuses and infants are in the most sensitive lifestage with regard to health effects in association with maternal Hg exposure. Second, the gender distribution of fishing activities varies according to the ecosystem and available fishing methods. Men usually go fishing by boat or canoe with nets, whereas women and children mostly fish on the shore with a line. Meal preparations are mostly carried out by women. While it is common for a single catch to include several different fish species from different trophic levels, these may be consumed in the same meal. Individual preferences and male priorities are probably the basis for decisions regarding the relative quantitative consumption of particular fish species. At each point when a decision needs to be made about which fish species is to be consumed, knowledge must be available to those making the decisions in order for them to make responsible, health-aware decisions.

5. *Fish Lore*

Food consumption by indigenous people has a strong cultural influence. Freeman (1996) observed that among the Inuit people the rules of food consumption included sharing different parts of the meat according to the age and sex of the consumers, usually based on health concerns and energy requirements.

In Brazil, the terms *reimoso* and *carregado* are used to refer to fish species that must not be consumed under specific conditions. These terms have been used among many fishing populations. For instance, people from the coast of Para, North Brazil, were studied by Maues and Maues (1977). They observed that the food categories of *reimoso* were based on the rawness of the food, the methods of preparation, and the health of the consumer.

Among people from the Tocantins River in Amazonia, Begossi and Braga (1992) observed that piscivore species were mostly not consumed (75% of 222 household interviews) or only consumed under specific conditions such as illness, pregnancy, and breast feeding [57% of 196 households]. By comparison, in 64% (of 233 households) herbivore and detritivore species were more often consumed and 62% (of 185 households) referred to herbivore and detritivore species as preferred. These observations are comparable with our findings presented in Fig. 2 and Table 5. Begossi and Braga suggested that the avoidance of piscivore species could be taken as an adaptative behavior, reflecting the knowledge that pollution may bioaccumulate at higher levels up the trophic levels of the food chain.

In general terms, *ribeirinhos* prefer to consume scale fish (locally called *peixe de escama*) rather than catfish species (called *peixe liso*). In contrast, urban populations in Amazonia tend to consume more catfish. The factors influencing this difference are probably related to cultural specificities of fish lore and practical reasons related to market availability. For example, it is easier for the *ribeirinhos* to sell large fish species without scales (such as Piramutaba and

Dourada) than the smaller scaled fish species (such as Curimata and Pacu), which are then reserved for local consumption.

The implications are that the urban population is likely to be eating a low amount of fish with high Hg concentrations, whereas the *ribeirinhos* are eating large amounts of fish with low Hg levels. These patterns of Hg exposure through fish consumption were also observed among New Jersey fish eaters (Stern *et al.*, 1996).

CONCLUSIONS

Fish consumption is a significant route of Hg exposure among riverine people along the Upper Madeira River. Given the wide variation of fish Hg concentration and fish species available for consumption, it is possible to mitigate Hg exposure among this population through risk communication and fish advisories. For this to occur, it is necessary to consider fish Hg levels by species and fish lore surrounding fish consumption. The indigenous knowledge regarding fish ecology can be combined with toxicological information about the risks of Hg exposure in order to provide information for exposed people to make responsible decisions regarding fish consumption and risks of Hg exposure.

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