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Mercury in Fish-eating Communities of the Andean Amazon, Napo River Valley, Ecuador

Jena Webb,[1,2] Nicolas Mainville,[1] Donna Mergler,[2] Marc Lucotte,[3] Oscar Betancourt,[4] Robert Davidson,[1,5] Edwin Cueva,[4] and Edy Quizhpe[6]

[1]*Institute of Environmental Sciences (ISE), University of Québec in Montréal (UQAM), PO Box 8888, Succursale Centre-Ville, Montreal, Quebec H3C 3P8, Canada*
[2]*Centre for Interdisciplinary Research on Biology, Health, Society and Environment (CINBIOSE), UQAM, Montreal, Quebec, Canada*
[3]*Centre for Research on Geochemistry and Geodynamics (GEOTOP), UQAM, Montreal, Quebec, Canada*
[4]*Health, Environment,and Development Foundation (FUNSAD), Quito, Ecuador*
[5]*Biodôme of Montréal, Montreal, Quebec, Canada*
[6]*Manuel Amunarriz Epidemiology and Community Health Institute, Coca, Ecuador*

Abstract: This exploratory study aimed to examine the relationship between fish eating habits, human mercury levels, and mercury levels in fish in three communities of the Napo River Valley, Ecuadorian Andean Amazon, a region without gold mining but with significant deforestation and volcanic soils with naturally high mercury levels. By recognizing the politicoeconomic factors which cause deforestation, the cultural factors which influence diet, and the biogeochemical factors which contribute to mercury levels, this study employs an ecosystem approach. Interviews on diet were conducted, hair samples from 99 individuals were collected, and samples of commonly eaten fish were taken. Samples were analyzed using cold vapor atomic fluorescence spectrometry (CVAFS). Two rural communities were found to have higher fish consumption and hair mercury levels (8.71 μg/g and 5.32 μg/g) as compared to an urban community (1.87 μg/g). A sequential analysis of hair established mercury levels by month. No seasonal tendencies were noted. Piscivorous fish (0.36 μg/g) were found to be more contaminated in mercury than herbivorous fish (0.05 μg/g). The study shows that socio-cultural factors are important in determining mercury exposure. The two village communities consume different species of fish with different frequencies, leading to differential exposure and mercury concentrations in hair samples. The levels of mercury in these two villages were similar to those found in Brazil where neuro-behavioral tests showed a correlation between these relatively low levels of mercury and decreased psychomotor capacities. These findings are concerning and should be followed by further studies on the multiple factors that affect the health status of these exposed communities.

Key words: fish mercury, fish consumption, mercury exposure, hair mercury, Andean Amazon, Ecuador

INTRODUCTION

Studies on mercury in the Amazon have proliferated in recent years. What is now missing is an ecosystem approach

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Correspondence to: Jena Webb, e-mail: webb.jennifer@uqam.ca

to see how environmental, political, and social factors are affecting mercury concentrations and dynamics in the various subregions, microenvironments, and communities of the Amazon. Recent studies have shown that erosion resulting from deforestation is introducing mercury into aquatic ecosystems of the Amazon (Roulet et al., 1998, 1999, 2000; Fostier et al., 2000). The Napo River Valley in the Ecuadorian Amazon is experiencing extremely rapid and extensive land clearing due to pipeline and road construction and spontaneous colonization on access roads, both results of petroleum exploitation (Kimerling, 1993; Rudel and Horowitz, 1993; Sierra, 2000). The high rates of deforestation in this valley, coupled with heavy rains and mountainous relief, are contributing to large-scale erosion (Zebrowski et al., 1997). Moreover, the Andes is one of the most active mercury belts in the world (Roulet, 2001). The volcanic soils, found at the headwaters of the Napo River, could contain substantial amounts of mercury (Mainville et al., 2003). These sociodemographic and environmental factors could be accentuating the mercury load delivered to the aquatic ecosystem.

Naturally occurring mercury exists in inorganic (elemental and metallic) and organic states. Conversions among these states are common and facilitate transfer between terrestrial, aquatic, and atmospheric residence (Roulet, 2001), as well as between inanimate and animate substrates. Once elemental mercury is introduced into aquatic environments, it can be converted to methylmercury (MeHg) by the bacterial activity of species living in the anoxic spaces surrounding aquatic plants (Guimarães et al., 2000ab; Mauro et al., 2001) and in the sediments (Pfeiffer et al., 1989). Suspended MeHg is easily absorbed by aquatic organisms because of its strong affinity for sulfhydryl groups (NRC, 2000). The majority of MeHg absorbed by fish concentrates in the muscle and the gills (WHO, 1989). MeHg is biomagnified up the aquatic food chain, concentrating in piscivorous fish (Malm et al., 1995, 1997; Maurice-Bourgoin et al., 2000; Souza Lima et al., 2000; Castilhos et al., 2001; Sampaio da Silva et al., 2004).

Amazonian riparian communities have been shown to possess Hg levels that are associated with fish consumption (Akagi et al., 1995; Boischio et al., 1995; Lebel et al., 1996, 1997; Kehrig 1997, 1998; Boischio and Henshel, 2000; Maurice-Bourgoin et al., 2000; Santos et al., 2000; Dolbec et al., 2001; Passos et al., 2003). Recent studies in central Amazonian regions have shown that neurobehavioral capacities of adults (Lebel et al., 1998; Dolbec et al., 2000; Yokoo et al., 2003) and children (Grandjean et al., 1999; Cordier et al., 2002) are compromised at hair total Hg concentrations much below the value associated with a 5% risk of neurological damage cited by the WHO (50–125 μg/g) (WHO, 1990); there is general agreement that the fetus is more vulnerable to lower exposure levels of Hg (for a review, see Castoldi et al., 2004).

In addition to naturally occurring mercury, the Amazon is known to be subject to the addition of large amounts of anthropogenic mercury through the processes of artisanal gold mining. Most of the gold mining in Ecuador is concentrated in the southern Sierra, although one region in the Andes on the oriental side is involved in this practice. Studies in this region, roughly 400 km and several catchments away from the Napo River Valley, have shown that soils, stream sediments, and mine tailings are contaminated by metallic Hg (Ramírez Requelme et al., 2003), that blood Hg levels are high in local populations (Counter et al., 1998, 2002), that children are at risk for neurodevelopmental disabilities (Counter, 2003), and that auditory neurosensory capacities are diminished in the exposed population (Counter et al., 1998, 2002). The extensive petroleum extraction taking place in the Northern Ecuadorian Amazon could also be contributing to mercury loads though the discharge of toxic wastes, numerous spills, and the burning of excess gas (Kimerling, 1993; IESC, 2000). Several studies have shown that oil spills and the uncontrolled burning of gases at oil wells lead to heavy metal contamination of surrounding ecosystems (Sadiq and Mian, 1994ab; Sadiq and Zaidi, 1994; Bou-Olayan et al., 1995; Al-Muzaini and Jacob, 1996; Banat et al., 1998), and another study identified neurobehavioral effects as a health risk of the open-burning of crude oil at wells (Osman, 1997).

The present study is part of a larger project which used an ecosystem approach in order to provide an integrated view of the sociocultural, politiceconomic, and biogeochemical factors that affect mercury dynamics and land clearing in the Napo River Valley (Webb, 2004). The aims of this specific aspect of the project were to: 1) evaluate, through a questionnaire, the pattern of fish consumption in rural and urban communities on the Napo River; 2) identify the distribution (spatial and temporal) of Hg levels in hair samples of the inhabitants of three communities living in this valley; and 3) determine the levels of Hg in commonly eaten fish of this river.

Methods

Study Area

Recent and unrestrained colonization of the Ecuadorian Amazon, particularly the Napo River Valley, has led to the establishment of half a million people in this region (Witt et al., 1999), a population increase of 277% from 1950 to 1982 (Lobao and Brown, 1998). Deforestation rates in this Valley are among the highest in South America (Rudel and Horowitz, 1993; Sierra, 2000), and the region is considered one of the 14 deforestation fronts of the world (Myers, 1993). Petroleum extraction is the main economic activity in the area and is opening up new frontier zones of colonization and deforestation by building roads into previously inaccessible areas, providing jobs for migrants and making possible the influx of necessities and consumer goods (Kimerling, 1993; Rudel and Horowitz, 1993; Sierra, 2000). Little, if any, artisanal gold mining takes place along the Napo River. Petroleum extraction could be augmenting the Hg levels in the region via the numerous spills which have occurred, unregulated disposal of waste water, and/or the burning of excess gases in open flames, a practice which is widespread (Kimerling, 1993).

The Ecuadorian Amazon is considered a biological hotspot, meaning that it is an area with considerable endemism and biodiversity which are under serious threat from anthropogenic activities (Myers, 1993). The aquatic ecosystem, likewise, is extremely diverse. There is no clear distinction between wet and dry seasons per se in this region; however, water levels can change radically from one day to the next. Fish abundance is based on water levels; thus, people refer to favorable fishing periods corresponding to low water levels and unfavorable fishing periods during high water periods. Water in the main rivers flows rapidly; however, still-water lagoons, home to a myriad of macrophytes, exist as offshoots. The average temperature is 28.1°C and the yearly rainfall is around 3 m (Romero-Saltos et al., 2001).

Communities

The three communities included in this study are all located directly on the Napo River (Fig. 1). Coca (also known as Francisco de Orellana) (00° 28’ 20’’ S, 76° 58’ 49’’ W) is an epicenter of petroleum activity and the major urban center along the Napo River with a population of 18,500 (Arréghini et al., 1997) and a flourishing market

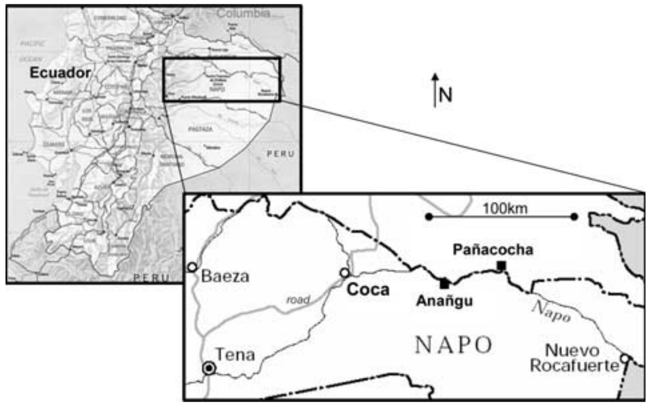

Figure 1. Study area: Ecuador and the Napo River Valley.

economy. Sampling was conducted in a low income neighborhood, Las Americas, with a population of 1000 people. Little is known about the demographics of this locality. Añangu (00° 31–32’ S, 76° 23’ W) is a small indigenous community with an adult population of 55 (total population 175) and little access to market goods. Pañacocha (00° 27’ 54’’ S, 76° 04’ 06’’ W), 165 inhabitants, on the other hand has a mixed population (indigenous and *mestizo* [mixed race]) and slightly better, nonetheless limited, access to market goods. The two villages are accessible only by boat, whereas Coca is connected to the rest of the country via roads and plane, as well. In Añangu and Pañacocha, most inhabitants are involved in family farming (including some cattle ranching in Pañacocha), fishing, and, to a limited extent, work with the petroleum companies, whereas in Coca a gamut of occupations in the service and production industries are available.

The study was carried out during three field campaigns. A reconnaissance campaign, from December 2001 to January 2002, allowed us to establish contacts with local communities and to determine the feasibility of research in the region. Through an informal questionnaire conducted with people from several communities, we were able to establish the importance of fish in the diet and appraise the levels of deforestation in the region. Fishing trips with local fishermen allowed us to collect samples and evaluate Hg levels in several commonly eaten fish. A sampling campaign was conducted from June to August 2002 to administer questionnaires, collect hair samples, and collect more fish samples. By working with the mayors of the two communities, we were able to gain the support of the community members. In Coca, contact was made with residents with the assistance of local health care workers. The final campaign, from May to July 2003, permitted us to conduct workshops and return the results of the study to the participating communities, universities, and local and national authorities.

Recruitment of Study Participants

Given the different population size and structure of the two types of communities sampled, two sampling strategies were employed. In the two smaller villages, an open invitation to participate in the study was made to all adults of the community during one of their monthly meetings, held at the local school. In Añangu, 13 women and 14 men (49% of the adult population) agreed to participate, and in Pañacocha, 15 women and 12 men (approximately 50% of all adults). This method was impossible in Coca where no accessible community structure exists; therefore, in order to explore possible seasonal variations in exposure, we recruited only women with long hair through random sampling door-to-door and at a community clinic, with the help of local health care workers; 46 women were thus recruited. In the two villages, where the populations were smaller, women as well as men had to be recruited in order to have a large enough sample size (Añangu: $n = 27$; Pañacocha: $n = 27$). The total study population was 100 people, aged between 18 and 76. One woman, contacted in Coca, was excluded because she did not live permanently in any of the three communities. Participants were asked to sign a statement of informed consent before continuing with the interview and hair sampling.

Questionnaires

An interview-administered questionnaire of 14 open-ended and choice-driven questions was used to assess personal and dietary information. Information on sex, age, social group, education level, occupation, and length of residence in the current location were collected. A series of questions and a partial 7-day recall allowed us to evaluate fish consumption (number of fish meals per month in favorable fishing periods and unfavorable fishing periods, fishing frequency, and top three most consumed fish), and consumption of wild animals and fruit.

Hair Sampling

Hair is commonly used as a bioindicator of Hg. Since Hg binds to the sulfhydryl groups in the hair, and since hair grows approximately 1 cm a month (Cernichiari et al., 1995; Clarkson et al., 1988), cutting the hair samples into centimeters, beginning at the root, and analyzing each centimeter separately gives an accurate sequential analysis of Hg exposure (Cernichiari et al., 1995). Moreover, Hg concentrations in hair have been shown to remain constant over time (Phelps et al., 1980). Samples of hair were taken at the same time as the questionnaire was administered. A small locket of hair was cut at the root from the occipital region of the head. The hair was stapled at the base and stored in plastic, Ziploc® bags, until analysis. Since sampling was done over a 3-month period, the results of Hg levels in the centimeters corresponding to the months of June and July 2002 were used for comparison purposes. Twenty-four consecutive centimeters, which represent 2 years of exposure, were analyzed for 46 women. For the rest of the participants, all of whom had less than 24 cm of hair, all centimeters of hair were analyzed.

Fish Sampling

Samples of commonly eaten fish were collected with the help of local fisherman in preferred fishing spots in Añangu and Pañacocha (rivers, $n = 13$; lagoons, $n = 30$; and creeks, $n = 2$) using local techniques during both favorable ($n = 20$) and unfavorable ($n = 75$) fishing periods. The majority of the samples from Coca were collected at the local market ($n = 50$). A total of 195 fish, representing 32 species, were collected. Less than 10 g of flesh was cut from the tail muscle. Fish samples were placed in Nalgene scintillation vials (Apogent, Welwyn Garden City, UK) and frozen until analysis.

Hair and Fish Mercury Analyses

The Hg analyses for fish and hair samples were performed by cold vapor atomic fluorescence spectrometry (CVAFS) following a modification of the method developed by Bloom and Fitzgerald (1988). Total Hg was determined. The technique is described in greater detail in Pichet et al. (1999). Briefly, after an acid digestion, total Hg is reduced to elemental Hg in the presence of $SnCl_2$ and then vaporized and transported by argon into an atomic fluorescence spectrophotometer, where Hg levels are measured. The detection limit was 0.001 μg/g for hair and 0.002 μg/g for fish. Analytical quality was ensured by including samples of powdered hair (IAEA 086 from the International Atomic Energy Agency, Analytical Quality Control Services Division, Vienna, Austria) and fish (tort-2 from the National

Research Council of Canada, Institute for National Measurement Standards, Calibration Services, Ottawa, Canada), as well as acid blanks in the series.

Statistical Analysis

Characteristics of the population were examined using descriptive statistics as well as the chi square and Kruskal–Wallis tests. Since fish consumption and hair Hg (HHg) were not normally distributed, nonparametric statistics and log scales were used. Comparisons of fish consumption HHg levels between men and women in the two villages were carried out using the Mann–Whitney. The paired signed-rank Wilcoxon test was used to test for differences in fish consumption during favorable and unfavorable fishing periods. A pair-wise comparison with Bonferronni adjustment using mean rank (Woolson, 1987) was used to identify differences in fish consumption between the three locations. A one-factor ANOVA with a 5% Tukey multiple-range test was used to evaluate the differences in mean HHg concentrations over the three locations. A polynomial regression model was used to describe the chronological hair sequence. An autocorrelation function was used to analyze tendencies in HHg levels in time. Since fish Hg values were not normally distributed, they were log transformed and a Student's *t*-test was used to compare Hg concentration in piscivorous and nonpiscivorous fish. A simple regression analysis was used to relate Hg concentrations in piscivorous fish species and fish length. All statistical analyses were performed using the StatView statistical package (version 5.0.1; SAS, Cary, NC), except the autocorrelation which was done in SAS (version 8.02; SAS).

Table 1. Demographic Characteristics of the Study Populations

Community	Demographic	*n*	%
	Sex		
Coca	Women	45	100
	Men	0	0
Añangu	Women	13	48
	Men	14	52
Pañacocha	Women	15	56
	Men	12	44
	Social group		
Coca	*Mestizo*	40	89
	Indigenous	1	2
	Black	4	9
Añangu	*Mestizo*	0	0
	Indigenous	27	100
	Black	0	0
Pañacocha	*Mestizo*	11	41
	Indigenous	15	56
	Black	1	4
	Education		
Coca	None	2	4
	Primary school	25	56
	Secondary	14	31
	Post-secondary	4	9
Añangu	None	1	4
	Primary school	21	78
	Secondary	4	15
	Post-secondary	1	4
Pañacocha	None	1	4
	Primary school	21	78
	Secondary	5	19
	Post-secondary	0	0

RESULTS

Population Characteristics

Relevant information collected through the questionnaire on the sex, social group, and education for the participants of the three communities are presented in Table 1. The three populations distinguished themselves from one another with respect to sex (chi square [$df = 4$] = 28.58, $P < 0.0001$), social group (chi square [$df = 4$] = 69.93, $P < 0.0001$), and education (Kruskal-Wallis, $P = 0.0052$).

Dietary Habits

Because of the small size of the rural villages, we first compared fish consumption between villages for both men and women, and during favorable and unfavorable fishing periods, in order to determine whether they could be grouped for purposes of analysis. There was no difference for fish-eating consumption between men and women, and the data was combined.

In Añangu, the indigenous village, on average 17.19 fish meals/month (median = 10) were consumed in favorable fishing periods (range: 4–60) whereas only 6.85 were consumed per month during periods of unfavorable fishing (median = 4). A highly significant difference was noted between fish consumption depending on fishing conditions in Añangu (Wilcoxon test; $P < 0.0001$). In Pañacocha, the mixed race village, people reported eating 33.93 fish meals per month (median = 30) during months favorable for

Table 2. Frequency of Fish Meals Consumed per Month in Favorable Fishing Periods by Location

Community	n	Mean fish meals/month	SD	Minimum fish meals/month	25%	50%	75%	Maximum fish meals/month
Coca	45	7.54	8.65	1.00	2	4	8	34.00
Añangu	27	17.19	13.20	4.00	8	10	30	60.00
Pañacocha	27	33.93	19.89	3.00	30	30	30	84.00

fishing (range: 3–84) and 7.15 when fishing is more difficult (median = 4). A highly statistical difference was noted between fish consumption according to fishing conditions in Pañacocha (Wilcoxon test; $P < 0.0001$). In the urban center, Coca, women reported a mean of 7.54 (median = 4) fish meals per month when fishing is favorable (range: 1–34) and 6.61 otherwise (median = 4). A significant difference was noted between fish consumption in the two periods in Coca (Wilcoxon signed rank: $P = 0.04$).

The frequency of fish consumption during favorable fishing conditions in the three locations is represented in Table 2. Fish consumption per month was significantly different between the villages and the city during favorable fishing periods (Añangu vs. Coca: $P < 0.01$; Pañacocha vs. Coca: $P < 0.01$); whereas only a slightly significant difference was found between the two villages, Añangu and Pañacocha ($P < 0.05$). On the other hand, no statistical difference in fish consumption was found between any of the three communities during periods unfavorable for fishing. Frequency of fish consumption during favorable fishing periods was lowest in Coca (mean = 7.54 fish meals per month) and highest in Pañacocha (mean = 33.93 fish meals per month), with Añangu falling roughly in between the two (mean = 17.19 fish meals per month). Over half of the population of Pañacocha eats fish everyday.

When asked to report their most frequently consumed fish species, 54% of the people interviewed in Añangu reported a piscivorous species, while no one reported an herbivorous species. In Pañacocha, on the other hand, only 19% cited a piscivorous species and 30% reported an herbivorous species. In Coca, 76% of respondents reported coastal fish, which were not surveyed in the present study, as their most commonly consumed fish. Other than fish, people eat primarily rice, yucca, plantain, onions, and bananas. Eggs, canned tuna, chicken, pork, and beef are also consumed to a varying degree among rural populations, according to income and availability, and extensively in the urban population.

Mercury in Hair

The results from the analysis of HHg levels for the mean of 2 cm of 98 individuals (one woman) in Coca was excluded because her hair was too short and, therefore, no value for June 2002 existed) are shown in Figure 2. No significant statistical differences between the mean HHg concentrations of men and women were noted (Mann–Whitney: Añangu, $P = 0.92$; Pañacocha, $P = 0.77$) in the two villages. The average Hg level in hair samples in Coca was 1.87 μg/g (range: 0.03–10.03 μg/g, median = 1.46); in Añangu, 8.71 μg/g (range: 2.20–20.51 μg/g, median = 7.79), and in Pañacocha, 5.32 μg/g (range: 1.46–13.55 μg/g, median = 4.99).

The results from a one-factor ANOVA with a 5% Tukey multiple range test show that there is a significant statistical difference between the mean HHg concentrations in Coca and Añangu ($P < 0.05$), and between Coca and Pañacocha ($P < 0.05$), however, that no significant difference exists between the HHg concentrations in the two rural populations, Añangu and Pañacocha.

Longitudinal analysis of the hair samples of 72 women in Coca, Añangu, and Pañacocha, 46 of whom had 24 cm of hair, indicates that there are differences between the three communities but that no clear seasonal tendencies exist (Fig. 3). Levels in Coca showed a stable upward tendency over the 2-year period, whereas the levels in Añangu and Pañacocha fluctuated over the months and showed no general trend from August 2000 to August 2002. One outlier in Coca was excluded from the longitudinal hair analysis because levels in her hair were extremely high for several months (for 1 month, her hair contained 51 μg/g).

An autoregressive model of the first order (using only women who had 24 cm of hair) described well each of the series. For Coca, a slight upward slope is statistically significant after having taken into consideration the presence of autocorrelation, but this is not the case in the two villages.

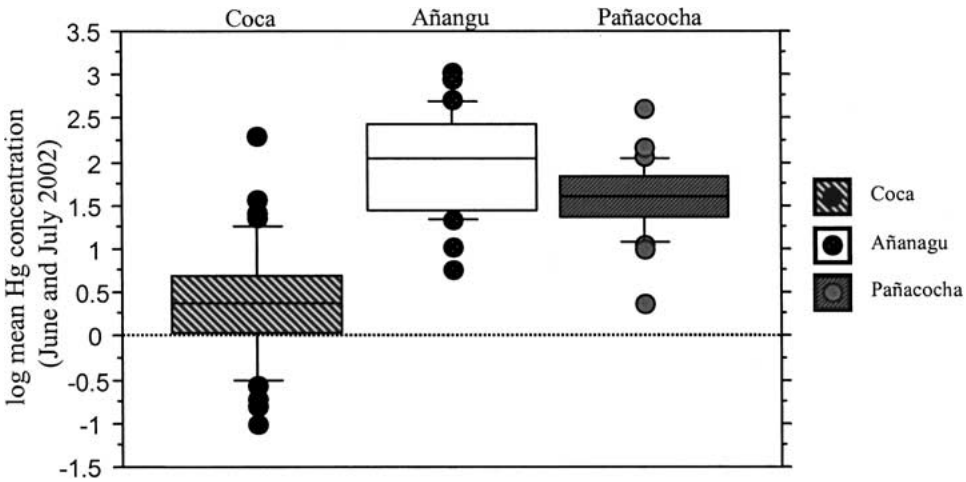

Figure 2. Percentile distribution of hair mercury concentrations in three communities: Coca, Añangu, and Pãnacocha of the Napo River Valley, Ecuador. The midline of the each box represents the median; the 25th and 75th percentiles are indicated by the lower and upper edge, respectively, of each box; the 10th and 90th percentiles are demarcated by the lower and upper lines lying outside the box.

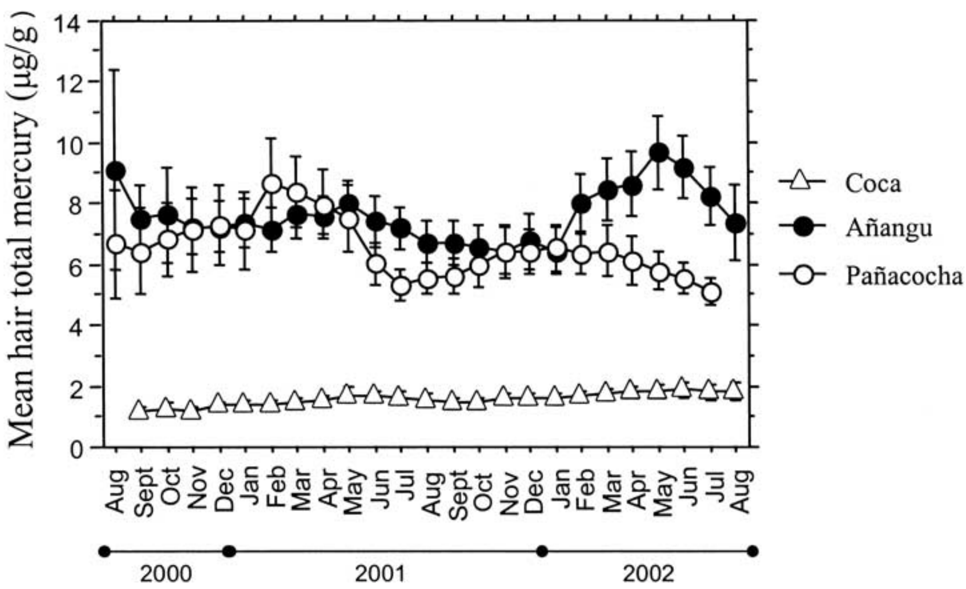

Figure 3. Sequential representation of hair total mercury levels in three communities: Coca, Añangu, and Pañacocha of the Napo River Valley, Ecuador. Means and standard errors are shown.

Mercury in Fish

Dietary habits of the fish were determined through the literature and the knowledge of local people (Webb, 2004). The fish species were grouped into piscivorous and nonpiscivorous. Hg concentrations were statistically analyzed with respect to the dietary habit of the fish. Levels in piscivorous fish (n = 80) ranged from 0.015 to 2.97 µg/g, with an average of 0.36 µg/g (median = 0.22), while in nonpiscivorous fish (n = 115), the range was from 0.004 to 0.29 µg/g with an average of 0.05 µg/g (median = 0.04). Figure 4 shows the concentration of Hg in piscivorous vs. nonpiscivorous fish on a log scale. The Student's t-test for logged Hg concentration in piscivorous and nonpiscivorous fish shows that the difference between these two categories is highly significant ($t_{193} = -14.529$; $P < 0.0001$).

A relationship between length and Hg levels was found in piscivorous fish ($r^2 = 0.214$; Fig. 5). No such relationship was noted for nonpiscivorous species ($r^2 = 0.002$).

Discussion

The present study is the first to look at the mercury levels in commonly eaten fish species and riverside communities not involved in small-scale gold mining of the Ecuadorian Andean Amazon. The results of this exploratory study show that people living in rural areas of the Napo River Valley depend on fish as an important protein source, and that certain fish species contain levels of mercury considerably higher than the safety limit set by the WHO, based on a diet

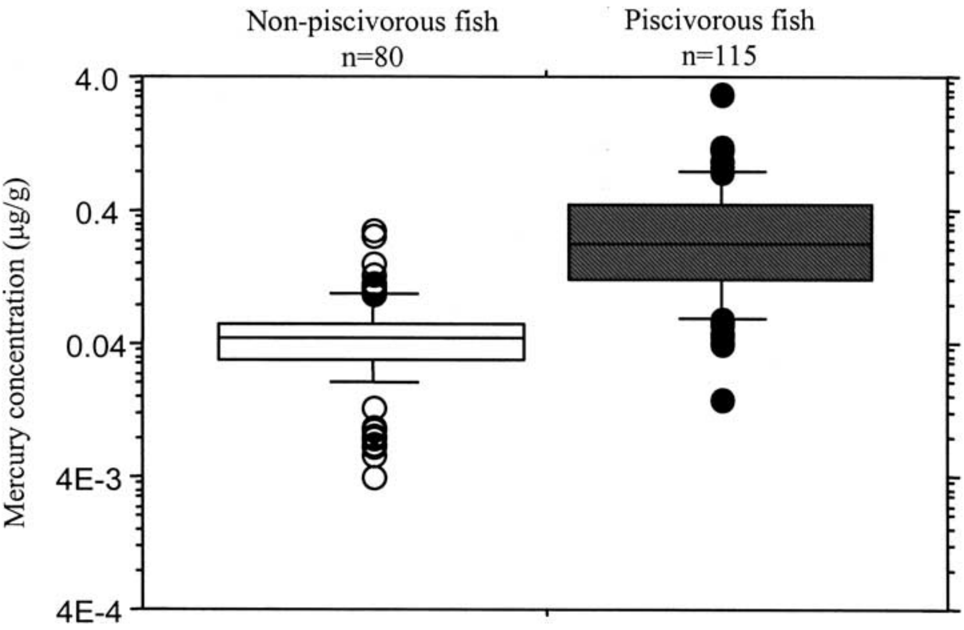

Figure 4. Percentile distribution of mercury concentrations in piscivorous and nonpiscivorous fish of the Napo River, Ecuador. The midline of the each box represents the median; the 25th and 75th percentiles are indicated by the lower and upper edge, respectively, of each box; the 10th and 90th percentiles are demarcated by the lower and upper lines lying outside the box.

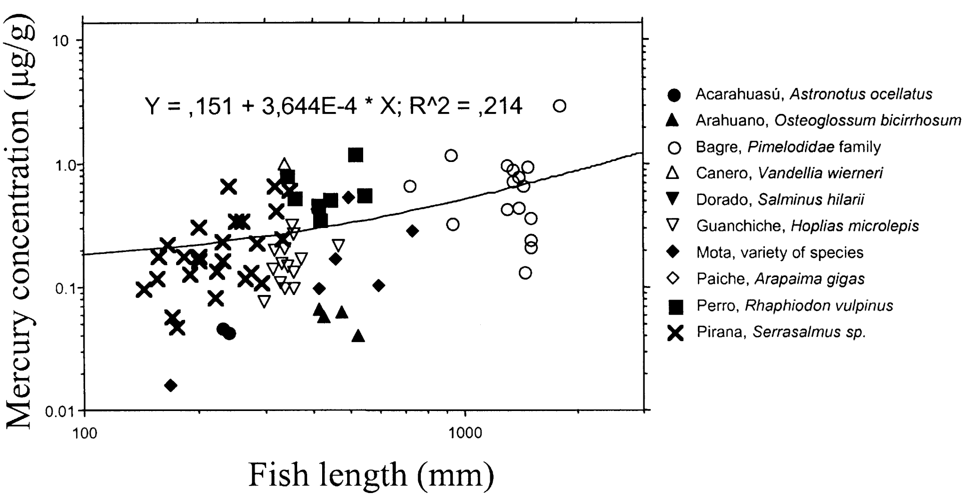

Figure 5. Bivariate scattergram with simple regression for Hg concentrations (μg/g, wet weight) and length of fish by class of piscivorous fish on a log scale. Common and scientific names are given.

containing 400 g of fish per week (0.5 μg/g). These findings also show that hair mercury levels in rural communities of the Napo River Valley are slightly lower than those found in several studies conducted in the Brazilian Amazon where neurobehavioral tests have correlated fish consumption, Hg levels, and decreased neurobehavioral functions (Lebel et al., 1998; Grandjean et al., 1999; Dolbec et al., 2000), but higher than the values found in a recent study by Yokoo et al. (2003) in Mata Grosso, Brazil, which correlated Hg levels (mean = 4.2 μg/g) to alterations in fine motor speed, dexterity, and concentration.

Data from questionnaires shows that fish-eating behavior is not uniform across the three communities (Table 2). On average, Pañacocha reported the highest frequency of fish meals per month (17), but also showed the greatest variation in responses (2–45). The variability of responses in Añangu was lower, reflecting the homogeneity of the population; however, contrary to what was anticipated, this indigenous village reported eating less fish than the mixed village of Pañacocha. This might be explained by the period of relatively poor fishing that immediately preceded and continued into the month in which the interviews were conducted. Rural populations in the Brazilian Amazon have been found to consume more fish than the populations studied here: Cerdeira et al. (1997) found that fish occurred in the diet 8 out of 10 days on average and, in a study conducted in the community of Cametá on the Tapajés River, Brazil, by Dolbec et al. (2001), it was found that 10 out of 36 participants ate fish on a daily basis, and 26 out of 36 consumed fish on a weekly basis.

In Coca, a population primarily of immigrants from the Sierra, where fish is less important in the diet, people reported eating considerably fewer fish meals per month than in the two villages. In addition to cultural factors, the market economy of Coca provides wage jobs as well as a variety of alternatives to fish as a protein source, notably beef, pork, and chicken. The two villages do not have ready access to these foods. In Pañacocha, pigs, chickens, and cattle are kept in several of the households; however, in Añangu, no households had pigs or cattle, and very few kept chickens. In a study evaluating fish consumption based on economic indicators in an urban center in the Brazilian Amazon, Manaus, Giugliano et al. (1978) found that people with lower incomes relied more on fish in their diet. Similarly, in a recent study conducted in Santerem, Brazilian Amazon, people with lower socioeconomic standing were found to eat fish more frequently as a result of its availability and low cost (Passos et al., 2004).

The results of HHg analysis show that there is a significant difference between the Hg levels of the rural populations and the urban population; this is likely due to a significant difference in fish consumption in the two settings (urban: mean = 7.54 fish meals per month; rural: mean = 24.04 fish meals per month) (see Fig. 2). No differences in HHg levels in men and women, or between the two rural populations, were found. Hair samples were examined in function of time by analyzing each centimeter separately. Contrary to what was found in the Brazilian Amazon (Lebel et al., 1997; Dolbec et al., 2001), where there is a marked wet and dry season, no distinct seasonality was found in HHg levels of the three populations investigated in this study (Fig. 3). HHg levels in the two villages fluctuated, however, with no apparent regularity. The Andes act as a block to clouds coming from the Amazon basin, therefore, there is considerable precipitation in the Ecuadorian Amazon throughout the year, although there are periods which are rainier than others. When the waters are high, many of the fish migrate into the inundated forests to feed, making them harder to catch. Moreover, the concentration of fish is lower when waters are high. These factors make fishing more difficult in rainy periods and are probably responsible for the irregular variations in mercury concentrations seen in the longitudinal analysis. Many people in Coca did not report varying fish consumption throughout the year; the main source is a steady importation from the costal regions, whereas the villagers eat mostly fish from the Napo River, and did report that fish consumption is dependant on water conditions. There was a highly significant difference in fish consumption in favorable and unfavorable fishing conditions in the two villages.

From the results of the Hg content in fish, it can be seen that certain species contain elevated levels whereas others contain very little Hg. Generally, the piscivorous fish contain more Hg than the nonpiscivorous fish (Fig. 4). Furthermore, larger piscivorous fish were found to have more mercury than smaller ones (Fig. 5), although this relationship is not as strong as has been noted in other studies in the Amazon (Souza Lima et al., 2000; Sampaio da Silva et al., 2004). This could be due to the use of several sampling sites as well as particularly difficult fishing during one of the sampling campaigns. There is a need for a good systematic study of fish mercury levels in this region. The class of large catfish, an opportunistic feeder which includes other fish in its diet (*bagre*, in Spanish, e.g., *Brachyplatystoma filamentosum*) (n = 16), sold on the market in Coca, were found to have the highest levels of Hg (67% of these fish had Hg levels above 0.5 μg/g). These fish are, by far, the largest fish readily available in the region. Being a market economy, Coca has both professional fishermen and professional fishmongers. Fishermen have the capital to purchase larger fishing equipment and are in contact with middlepeople to which they can sell their large catch. Villagers rarely catch large fish because it is more difficult and they are not well equipped. Moreover, without electricity and refrigeration, a large catch is more likely to spoil (McGrath et al., 1993). Fortunately, few people in Coca, if any, eat the large *bagre* sold at the market in Coca on a regular basis. The majority of these large fish is cut up and sold to restaurants, who make large quantities of soup containing relatively little *bagre* per bowl, and the rest goes to the occasional independent buyer. The fish market in Coca is probably composed of over 50% sea fish, brought frozen from the coast.

In order to explain the Hg concentration of each community, both the frequency of consumption and the type of fish consumed must be considered. In Coca, fish consumption is sporadic. Napo River fish with extremely high Hg levels are available, but represent a minor constituent of the fish market. The low frequency of fish consumption is a logical explanation for the low Hg levels found in Coca residents. Despite the fact that people in

Añangu reported fewer fish meals than in Pañacocha, their HHg levels were found to be slightly higher. This can be explained by a look at the composition of the fish being consumed. In Añangu, people report eating less fish, but the most consumed fish were piscivorous fish with higher Hg levels. In Pañacocha, where fish is reported as being more consumed, the varieties which are preferred are herbivores containing less Hg.

Work conducted in the Brazilian Amazon has shown that modifications in neurobehavioral capabilities are observed in populations with mercury levels much lower than the level associated with a 5% risk of neurological damage (50–125 μg/g), cited by the WHO (1990) (Lebel et al., 1998; Grandjean et al., 1999; Dolbec et al., 2000; Cordier et al., 2002; Yokoo et al., 2003). Dolbec et al. (2000) found that motor performance was compromised in a population with a mean Hg level of 10.8 μg/g, and that there was a significant relationship between performance and HHg levels. The mean HHg concentration in Añangu was found to be 8.71 μg/g. It is not unreasonable to assume that the inhabitants of Añangu could be experiencing diminished motor performance as a result of their Hg levels. Further studies are needed to determine if problems similar to those noted in Brazil are occurring in the Napo River Valley.

Conclusions

This exploratory, ecosystem study informs us on the links between mercury exposure of riparian communities and the presence of mercury in fish in the Andean Amazon of Ecuador. This work complements extensive work conducted in the lower-lying Amazon of Brazil by providing data for a region where little was known about mercury. The results indicate that some species of piscivorous fish are contaminated in Hg. Given the Hg levels in fish and fish consumption, Hg exposure in rural communities could pose a health threat. Hence, steps need to be taken to reduce the introduction of mercury into aquatic ecosystems.

The high rates of deforestation in the region leads to concerns of rising Hg levels in aquatic ecosystems because of the factors particular to the region which exacerbate erosion (Mainville et al., 2003; Webb, 2004). High temperatures and high humidity levels facilitate the deposition of atmospheric Hg (Mason et al., 1994). In addition, steep river banks and high levels of precipitation accentuate erosion rates. Knowing that deforestation contributes significantly to the Hg load in aquatic systems, that the deforestation rates in the Napo River Valley are among the highest in the world, and that many thousands of people in this region depend on fish as their main protein source, conservation in the Napo River Valley should become a health priority.

In conclusion, the use of the ecosystem approach allowed us to identify potential sources of Hg and propose solutions. We returned to the study area in June and July 2003, 1 year after the samples were taken, to explain the results to community members, the government, universities, and local doctors and development workers. Through three interactive workshops with community member, we encouraged agricultural methods which could reduce the amount of Hg introduced into the aquatic environment and suggested that villagers opt for smaller, herbivorous species, when possible, especially while pregnant. Returning results to communities is a challenging, yet essential, part of the ecosystem approach. For success, it is crucial to enlist the help of local people in order to produce, and effectively communicate, suggestions which are viable and compatible with the existing political ecology of the region.

Résumé: Cette étude exploratoire visait à examiner la relation entre les habitudes de consommation de poisson, les concentrations de mercure chez les humains et la teneur en mercure des poissons dans trois collectivités de la vallée du fleuve Napo, dans l'Amazonie andine, une région de l'Équateur oú il n'y a pas de mines d'or mais qui est sujette à une déforestation importante et dont les sols volcaniques contiennent des concentrations naturellement élevées de mercure. Cette étude adopte une approche écosystémique en abordant les facteurs politiques et économiques qui causent la déforestation, les facteurs culturels qui influent sur le régime alimentaire et les facteurs biogéochimiques qui contribuent aux concentrations élevées de mercure. On a precédé à une série d'entretiens portant sur le régime alimentaire, ainsi qu'à la collecte d'échantillons de cheveux auprès de 99 individus et à celle d'échantillons des poissons consommés le plus communément. L'analyse des échantillons a été effectuée par spectrométrie de fluorescence atomique à vapeur froide. Dans les deux collectivités rurales, tant la consommation de poisson que la teneur en mercure des cheveux (8.71 μg/g et 5.32 μg/g) se sont révélées plus élevées que dans la collectivité urbaine (1.87 μg/g). Une analyse séquentielle des échantillons de cheveux a établi les concentrations de mercure sur une base mensuelle. Aucune tendance saisonniére n'a été relevée. Les poissons piscivores étaient plus contaminés (0.36 μg/g) par le mercure que les poissons herbivores (0.05 μg/g). L'étude montre que les facteurs socioculturels jouent un rôle important dans la détermination de l'exposition au mercure.

Les deux collectivités villageoises consomment des espèces différentes de poissons à des fréquences différentes, d'où une exposition et des concentrations de mercure dans les échantillons capillaires qui different. Les concentrations de mercure dans ces deux villages étaient semblables à celles qui ont été observées au Brésil, où des tests neurocomportementaux ont démontré une corrélation entre ces teneurs relativement faibles en mercure et une atteinte de la fonction psychomotrice. Ces constatations sont préoccupantes et devraient être suivies d'autres études sur les facteurs multiples qui influent sur l'état de santé des populations exposées.

Mots clés: mercure dans le poisson, consommation de poisson, exposition au mercure, mercure dans les cheveux, Amazonie andine, Équateur

Resumen: Este estudio exploratorio se proponía examinar la relacién entre los hábitos alimenticios de los peces, los niveles de mercurio en seres humanos y los niveles de mercurio en el pescado que se consume en tres comunidades del Valle del Río Napo, en la amazonía andina del Ecuador, regién que presenta una deforestacién significativa y suelos volcánicos con niveles naturalmente altos de mercurio, sin minería de oro. El estudio se vale de un enfoque ecosistémico que permite reconocer los factores político-econémicos subyacentes a la deforestacién, así como los factores culturales que inciden en los patrones de alimentatién y los factores biogeoquímicos relacionados con los niveles de mercurio. Se realizaron entrevistas sobre el régimen alimenticio, se tomaron muestras del cabello a 99 personas y muestras del pescado que se consume con mayor frecuencia. Las muestras fueron analizadas mediante espectrometría de fluorescencia atémica de vapor frío. Dos comunidades rurales mostraron un mayor consume de pescado y más altos niveles mercurio en el cabello (8.71 μg/g y 5.32 μg/g) en comparacién con una comunidad urbana (1.87 μg/g). Un análisis secuencial de cabello establecié niveles de mercurio por mes, pero no se observaron tendencias según la estacién. Se encontré mayor contaminacién de mercurio entre los peces piscívoros (0.36 μg/g) que entre los herbívoros (0.05 μg/g). El estudio demuestra que los factores socioculturales son importantes para determinar la exposicién al mercurio. Las dos comunidades rurales consumen especies diferentes de peces con distinta frecuencia y, por ende, las concentraciones varían en lo que respecta a la exposicién al mercurio y su presencia en las muestras de cabello. Un estudio en Brasil arrojé resultados similares a los de estas dos aldeas en cuanto a niveles de mercurio. Las pruebas neuroconductuales demostraron una correlacién entre niveles relativamente bajos de mercurio y una disminucién de las capacidades psicomotoras. Estos resultados son inquietantes y se les debe dar seguimiento con otros estudios sobre los múltiples factores que inciden en la salud de las comunidades expuestas al mercurio.

Palabras clave: mercurio en peces, consumo de pescado, exposicién a mercurio, mercurio en el cabello, Amazonía andina, Ecuador

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