Journal of Toxicology and Environmental Health, Part A
Current Issues

ISSN: 1528-7394 (Print) 1087-2620 (Online) Journal homepage: http://www.tandfonline.com/loi/uteh20

Metals and Metalloid in Eight Fish Species Consumed by Citizens of Bogota D.C., Colombia, and Potential Risk to Humans

Ellie Anne López-Barrera & Rafael G. Barragán-Gonzalez

JOURNAL OF TOXICOLOGY AND ENVIRONMENTAL HEALTH, PART A
http://dx.doi.org/10.1080/15287394.2016.1149130

Metals and Metalloid in Eight Fish Species Consumed by Citizens of Bogota D.C., Colombia, and Potential Risk to Humans

Ellie Anne López-Barrera[a] and Rafael G. Barragán-Gonzalez[b]

[a]Instituto de Estudios y Servicios Ambientales, Universidad Sergio Arboleda, Bogotá, Colombia; [b]Facultad de Ingeniería Ambiental, Universidad Santo Tomas, Bogotá, Colombia

ABSTRACT
The risk imposed upon society by consumption of foods contaminated with metals and metalloids is an environmental problem attributed to the increasing number of mining extraction activities currently underway in Colombia. The aim of the current study was to determine concentrations of mercury (Hg), lead (Pb), cadmium (Cd), and a metalloid arsenic (As) found in the species of most consumed fish species by citizens of Bogota D.C. (Colombia), and the consequent potential risk to human health was also calculated. Muscle samples of 8 fish species were obtained from 203 individuals collected through 2014. The highest metal concentrations detected were as follows: Pb in *Oncorhynchus* sp. (0.0595 mg/kg), Cd and Hg in *Pimelodus* sp. (0.0072 and 0.0579 mg/kg, respectively), and As in *Scomberomorus* sp (0.0471 mg/kg). Further, the levels of metal accumulation from consumption of fish were calculated utilizing the metal pollution index (MPI), with elevated values noted in *Pseudoplatystoma* sp (0.06 mg/kg), followed by *Scomberomorus* sp. and *Centropomus* sp. (0.05 and 0.04 mg/kg, respectively). The multiple species exposure index ($E_{m.j}$) denotes the level of exposure associated with consumption of various contaminated fish species, and this level occurred in decreasing order as follows: As > Pb > Cd > Hg. The multiple chemical exposure index ($E_{j.m}$), which accounts for exposure to multiple metals, identified *Prochilodus* sp. as the species displaying the highest level of exposure per consumption (8×10^{-6} mg/kg-d). The target hazard quotient (THQ) for human health indicated high levels for Hg and Cd in *Prochilodus* sp. (0.026 and 0.005, respectively), Pb in *Oncorhynchus* sp (0.025), and As in *Pseudoplatistoma* sp. and *Centropomus* sp. (0.023). Data emphasize the need for adequate nationwide public policies that promote assessment of exposure levels and potential adverse health risks associated with dietary consumption of different fish species in Colombia.

ARTICLE HISTORY
Received 10 November 2015
Accepted 28 January 2016

In Colombia, contamination of water sources associated with indiscriminate use of chemical substances in agricultural, industrial, and mining extraction activities such as mineral ores and building extractions, gold extraction, and fossil fuels is a latent and underreported problem. The mining industry has been the most highly developed sector of the Colombian economy over the last 5 years; however, driven by public policy, growth has created environmental problems, such as contaminated water sources in 80 municipalities due to the irresponsible use of Hg in illegal gold ore extraction, which subsequently resulted in elevated exposure risks to the ecosystem on a national scale (Contraloria General de la Republica [CGR], 2013).

As a consequence of exposure to heavy metals, the adverse health risks associated with consuming contaminated foods by humans is a concern and may be considered a global issue. Subsequently, the Food and Agriculture Organization (FAO) of the United Nations, along with the World Health Organization (WHO), established the *Codex Alimentarius* in 1963 as a collection of international food standards for primary worldwide nutrition sources (FAO, 2006).

Extractive processes release compounds into the environment, including mercury (Hg), cadmium (Cd), lead (Pb), and arsenic (As), which are known to exert adverse effects, and consequently the risk of human exposure to these metals rises. Water transports these metals over long distances;

CONTACT Ellie Anne López-Barrera ellie.lopez@usa.edu.co Instituto de Estudios y Servicios Ambientales, Universidad Sergio Arboleda, Calle 74 #11-51, Bogotá, Colombia.
Color versions of one or more figures in the article can be found online at www.tandfonline.com/uteh.

thus, activities performed in the center of the country may affect a wide variety of aquatic animals, even those found at sites distal to the origin (De Campos et al., 2015). Humans may consume fish that are contaminated due to long-range transport. In Colombia, diet includes several fish species; retail sales account for 81% of the national market (Perucho, 2010), with an annual nationwide consumption of approximately 256,266 metric tons of fish and an average annual consumption of approximately 6.1 kg per person (Autoridad Nacional de Pesca y Acuicultura [AUNAP], 2013).

Heavy metals and metalloids are found in different compartments of the environment and may remain due to processes of bioconcentration and bioaccumulation in human food, in most seafood, bovine meat, and meat products and milk (Van Der Oost et al., 2003; Pack et al, 2014). Exposure to heavy metals is a potential threat to human health because chronic exposure at relatively low concentrations produces immune system dysfunction, hepatotoxicity, and neurotoxicity, as well as teratogenic manifestations (Bernstam and Nriagu, 2000; Sweet and Zelikoff, 2001; Cooke 2014) Consequently, there is increasing concern regarding exposure, intake, and absorption of heavy metals by ingestion through feeding, predominantly fish products (Carneiro et al., 2014; Nancano et al., 2014). Communities are demanding a cleaner environment and food with lower levels of contaminants attributed to industrial activities (Morais et al., 2012).

Contamination from industrial wastes, attributed particularly to Hg in Colombian rivers over the last 40 years, has garnered attention (Mancera-Rodríguez and Álvarez-León, 2006). Various investigators reported fish contamination from heavy metals in the basins of the Magdalena, Cauca, Amazon, and Orinoco rivers (Olivero and Johnson, 2002; Tassinari and Diaz, 2008; Olivero-Verbel et al., 2008, 2011; Cordy et al., 2011; De Miguel et al., 2014). In addition, studies noted the presence of heavy metals in freshwater ichthyofauna (Ruiz et al., 1996; Olivero et al., 1997; Olivero and Solano, 1998; Alonso et al., 2000; Mancera-Rodríguez and Álvarez-León, 2006; Olivero-Verbel et al., 2013; Lancheros, 2013; Galeano, 2013) and in canned food for human consumption (De Miguel et al., 2014).

Given this environmental landscape and the concern regarding the safety of food resources, the aim of this investigation was to determine the presence and concentration of three heavy metals and one metalloid in fish that are consumed by residents in Bogota D.C. city. Results of this study noted the presence of Pb, Hg, Cd, and As in fish, demonstrating potential for human exposure by consumption of these products. This study focused on determining the presence and total concentrations of four contaminants in fresh and frozen fish products, which are the foods most consumed in the city. The study also established levels of accumulation (MPI), exposure ($E_{m,j}$ and $E_{j,m}$), and health risks (THQ) linked to fish consumption.

Material and methods

Sampling and sample preparation

Based on the report from INFOPESCA (Perucho, 2010) on fish sales in the city of Bogotá D.C. (Colombia), stratified sampling was used to include wholesale and retail distribution centers. For analysis, 203 samples were obtained from 2 sampling events performed in 2014, in marketplaces, hypermarkets, supermarket chains, and neighborhood stores that sell both local and imported goods. In total, 120 samples from each of the 8 most commonly consumed fish species in Bogotá D.C., Colombia, were analyzed. The fish species were selected to include different feeding habits (Froese and Pauly, 2015): nicuro—*Pimelodus* sp., tilapia—*Oreochromis* sp., bocachico—*Prochilodus* sp., tiger catfish—*Pseudoplatystoma* sp., sergeant fish—*Centropomus* sp., sierra—*Scomberomorus* sp., salmon—*Oncorhynchus* sp., and basa fish—*Pangasius* sp. Each specimen weighing at least 700 g was bought and kept under refrigeration (4°C) until the arrival at the lab within the next 2 h; then at least 200 g of muscle tissue was collected from the dorsal part of fish. If the fish were small, muscle tissue was pooled from as many individuals as was necessary. Tissues samples were homogenized and refrigerated (4°C) for subsequent analysis.

Metal detection

The total concentrations of Cd, Hg, Pb, and As were determined from each sample according to the classification of the Codex Alimentarius Commission (2014). Duplicated subsamples of muscle were processed by acid digestion (HNO_3) treatment using protocols for determination of metals in environmental samples (U.S. Environmental Protection Agency [EPA], 1991).

Chemical analysis was performed at a certified lab by atomic absorption spectrometry (GFAAS) model AA 6300 Shimadzu and graphite furnace (GFA-EX7i) to detect Pb and Cd, and cold vapor generation (HVG-1) to detect As and Hg. Instrument limits of detection (LOD) were 0.02 for As, Hg, and Pb, and for Cd 0.0004. All concentrations are expressed as milligrams per kilogram wet weight (mg/kg ww). Recoveries accepted to validate determinations were between 93.5 and 100.4% for Hg (concentration range: 0.03 to 0.19 mg/kg); between 98.8 and 105.5% for As (concentration range: 0.02 to 0.33 mg/kg); between 93.4 and 103.5% for Pb (concentration range: 0.03 to 0.27 mg/kg); and between 99.4 and 102.3% for Cd (concentration range: 0.001 to 0.013 mg/kg); all specimens in the recovery experiment were randomly spiked. All samples were run in batches that included blanks, and a standard calibration curve made of solution traceable to NIST Certified Reference Materials for each contaminant, and duplicates.

Data analysis

Values of chemical determinations for each metal and metalloid were assessed using the statistical software package R (R Core Team, 2013). Data were excluded if the values reported were below the LOD as recommendations for data analysis for values that fell below detection LOD. The worst-case scenario was assumed since values below LOD were dropped (Gochfeld et al., 2005).

Principle component analysis (PCA) was performed on the standardized values of xenobiotic concentration to determine the pattern of metal distribution with respect to feeding habits of selected fish species.

Determination of risk by fish consumption

Following the guidelines for evaluating chemical contaminants for use by fishery consulting services (U.S. EPA, 2000); the risk was characterized based on the evaluation of exposure limits and consumption of each metal. To determine the consumption risk to the various exposed metals, information was obtained from a survey on the following variables: (i) most commonly consumed species in Bogotá D.C., Colombia, and (ii) frequency of consumption. Information was generated from 695 surveyed homes. Using the collected data from the surveys and the oral reference doses (U.S. EPA, 2007) for each metal studied (As = 0.0003 mg/kg-d, Cd = 0.001 mg/kg-d, Hg = 0.0005 mg/kg-d, Pb = 0.004 mg/kg-d), indices were calculated to determine the consumption risk.

Metal Pollution Index (MPI)

The metal pollution index (MPI) was used to estimate the levels of accumulation of heavy metals to identify the species that showed the highest concentrations. This index allows comparison of the levels of accumulation across different fish species (Hao et al., 2013). The MPI was calculated with a formula developed by Sharma et al. (2008):

$$\mathrm{MPI(mg/kg)} = (C_{f1} \times C_{f2} \times \ldots C_{fK})^{1/K}$$

where C_{f1} is the concentration value of the first metal, C_{f2} is the concentration value of the second metal, and C_{fk} is the concentration value of the kth metal.

Multiple species exposures ($E_{m,j}$)

The multiple species exposures ($E_{m,}$) index was used to evaluate the risk represented by each metal due to the frequency of consumption of multiple fish species, levels of contamination, and quantity consumed (U.S. EPA, 2000). The value of $E_{m,j}$ is calculated using the following formula:

$$E_{m,j} = \Sigma(C_{m,j} \times CR_j \times P_j)/BW$$

where $E_{m,j}$ is the individual exposure to chemical contaminant *m* from ingesting fish (mg/kg-d), $C_{m,j}$ is the concentration of chemical contaminant *m* in the edible portion of fish species *j* (mg/kg),CR_j is

Table 1. Average concentrations of Pb, Cd, As, and Hg (mg/kg ww) in eight commonly consumed fish species in Bogotá D.C., Colombia.

Species/Feeding habits	Pb (mg/kg)	*n*	% (<DL)	Range (min–max)	Cd (mg/kg)	*n*	% (<DL)	Range (max–min)	As (mg/kg)	*n*	% (<DL)	Range (min–max)	Hg (mg/kg)	*n*	% (<DL)	Range (min–max)
Omnivorous fish																
Oreochromis sp.	0.0281 (±0.0128)	7	63.2	0.016–0.043	0.0042 (±0.0061)	6	68.4	0.0007–0.0164	0.0311 (±0.0111)	5	73.7	0.0161–0.0433	0.0313 (±0.0108)	14	26.3	0.018–0.0472
Pimelodus sp.	0.0199 (±0.0019)	4	42.9	0.0173–0.0217	0.0072 (±0.0074)	5	28.6	0.0012–0.0165	0.0277 (±0.0072)	2	71.4	0.0226–0.0328	0.0579 (±0.0269)	4	42.9	0.0245–0.0879
Pangasius sp.	0.029 (±NA)	1	80.0	0.029–0.029	0.0004 (±NA)	1	80.0	0.0004–0.0004	0.038 (±NA)	1	80.0	0.038–0.038	0.0215 (±0.0019)	4	20.0	0.019–0.023
Carnivorous fish																
Pseudoplatystoma sp.	0.0264 (±0.0116)	6	71.4	0.02–0.0499	0.0032 (±0.0045)	8	61.9	0.0004–0.0142	0.0469 (±0.0508)	8	61.9	0.014–0.168	0.0447 (±0.0295)	17	19.0	0.018–0.1058
Centropomus sp.	0.0289 (±0.0134)	8	57.9	0.0163–0.0518	0.0028 (±0.0015)	7	63.2	0.0005–0.0047	0.0458 (±0.0445)	10	47.4	0.016–0.167	0.041 (±0.0263)	16	15.8	0.016–0.0895
Scomberomorus sp.	0.034 (±0.0162)	7	63.2	0.0196–0.0643	0.0038 (±0.0048)	5	73.7	0.0006–0.0122	0.0471 (±0.0299)	5	73.7	0.0216–0.096	0.0358 (±0.0202)	14	26.3	0.019–0.0868
Oncorhynchus sp.	0.0595 (±0.0417)	2	80.0	0.03–0.089	0.0003 (±NA)	0	100.0	0.0003–0.0003	0.023 (±NA)	1	90.0	0.023–0.023	0.0212 (±0.0025)	5	50.0	0.019–0.025
Iliophagous fish																
Prochilodus sp.	0.0254 (±0.0071)	8	46.7	0.016–0.036	0.0048 (±0.0065)	6	60.0	0.0004–0.0174	0.0312 (±0.0086)	3	80.0	0.022–0.039	0.0412 (±0.0263)	13	13.3	0.017–0.0933

Note. n, Number of samples over detection limit. % (<DL): Sample proportion under detection limit. NA, not applicable.

the consumption rate of fish species *j* (kg/d), P_j is the proportion of a given fish species *j* in an individual's diet (dimensionless), and BW is the consumer body weight (kg).

Multiple chemical exposure ($E_{j,m}$)

The multiple chemical exposure ($E_{j,m}$) index indicates the risk represented by each species, which combines the concentration of all metals analyzed due to the risk of exposure to multiple metals in each species consumed. The index is calculated according to the recommendations of the U.S. EPA (2000) as

$$E_{j,m} = \Sigma(C_{j,m} \times CR_j \times P_j)/BW$$

where $E_{j,m}$ is the individual exposure from ingesting fish *j* to chemical contaminant *m* (mg/kg-d), $C_{j,m}$ is the concentration in the edible portion of fish species *j* of chemical contaminant *m* (mg/kg), CR_j is the consumption rate of fish species *j* (kg/d), P_j is the proportion of a given fish species in an individual's diet (dimensionless), and BW is the consumer body weight (kg).

Target Hazard Quotient (THQ)

The target hazard quotient (THQ) index is the ratio between measured concentration and oral reference dose and is weighted by the duration and frequency of exposure, ingested portion size, and body weight (U.S. EPA, 2000). If the ratio is less than 1, it is unlikely that the exposed population might manifest adverse health effects to the contaminant. The THQ risk estimation method developed by Wang et al. (2005) and modified by Bortey-Sam and collaborators (2015) was used:

$$THQ = \frac{EFxEDxFIRxC*}{RFDxBWxTA} 10^{-3}$$

where THQ is the target hazard quotient, EFr is the exposure frequency (365 d/yr), ED is the exposure duration (70 yr), FIR is the food ingestion rate (0.227 kg/person-d), MC is the average concentration of metal in food (mg/kg, on fresh weight basis and highest value measure), RfD is the oral reference dose for each metal (mg/kg-d) (U.S. EPA, 2007), BW is the average body weight of an adult (70 kg), amd AT is the average exposure time (365 d/yr times number of exposure years, assuming 70 yr).

Results

Heavy metals and metalloid concentrations

The average concentrations of the 3 metals and 1 metalloid from all analyzed samples ranged from 0.0006 to 0.096 mg/kg in the investigated fish species. The concentration of As was highest, followed by Hg, Pb, and Cd in decreasing order (Table 1). The levels of Pb ranged between 0.016 and 0.089 mg/kg across all samples. The highest concentration of Pb was found in *Oncorhynchus* sp., followed in diminishing order for specimens *Scomberomorus* sp., *Centropomus* sp., *Pangasius* sp., *Oreochromis* sp., *Pseudoplatystoma* sp., *Prochilodus* sp., and *Pimelodus* sp. The concentration of Cd in different species was highest in *Pimelodus* sp., followed by *Prochilodus* sp., *Oreochromis* sp., *Scomberomorus* sp., *Pseudoplatystoma* sp., *Centropomus* sp., *Pangasius* sp., and *Oncorhynchus* sp. in decreasing order. The levels of Cd in all samples ranged between 0.0006 and 0.0174 mg/kg. The As data demonstrated a different concentration pattern: *Scomberomorus* sp. showed the highest level, followed by, in diminishing order, *Pseudoplatystoma* sp., *Centropomus* sp., *Pangasius* sp., *Prochilodus* sp., *Oreochromis* sp., *Pimelodus* sp., and *Oncorhynchus* sp. The levels of As across all samples ranged from 0.0161 to 0.096 mg/kg. The concentration of Hg was highest in *Pimelodus* sp., followed in decreasing order by *Pseudoplatystoma* sp., *Prochilodus* sp., *Centropomus* sp., *Scomberomorus* sp., *Oreochromis* sp., *Pangasius* sp., and *Oncorhynchus* sp. The levels of Hg ranged from 0.016 to 0.0933 mg/kg.

Pimelodus sp. contained the highest concentrations of Hg and Cd but the lowest level of Pb. *Oncorhynchus* sp. (salmon) possessed the lowest As, Cd, and Hg concentrations but the highest level of Pb. The varying metal distribution pattern by fish species stresses that the diet of a particular species exerts an influence on type of exposure to contaminants.

The sample proportions with concentrations lower than LOD for the spectrometric technique (0.02 mg/kg for Hg, Pb, and Cd, and 0.0004 mg/kg for As) were significant. In several cases they were

90% of the samples. These values showed that metal levels in a majority of the analyzed fish samples most commonly consumed in Bogotá D.C. were found at levels too low to be detected by atomic absorption for As, Cd, Pb, and Hg, using the standard extraction protocol. None of the concentrations reported in the study for the 8 species included were higher than the permitted maximal levels for fish muscle given by the current *Codex Alimentarius* report (Codex Alimentarius Commission, 2014), which are Cd = 0.05 mg/kg, As = 0.002 mg/kg, Hg = 1 mg/kg, and Pb = 0.3 mg/kg.

Relation of feeding habits and metal concentration

The PCA, was applied to identify distribution patterns related to feeding habits of fish species related to metals and metalloid concentrations (Figure 1); analysis corroborates that species exposure to metals depends on type of fish diet. The two components explain 91% of the variation reported in the data.

As can be seen in Figure 1, the carnivorous species (*Scomberomorus* sp., *Pseudoplatystoma* sp., *Centropomus* sp., and *Pangasius* sp.) tended to present high concentrations of As except for *Oncorhynchus* sp.; this last one was related to high Pb concentrations. The omnivorous species (*Oreochromis* sp. and *Pimelodus* sp.) and iliophagous species (*Prochilodus* sp.) were related to higher concentrations of Hg and Cd.

Determination of risk by fish consumption

Based on survey information, the total weight of fish consumed was 27.5 kg/yr assuming a portion size of 227 g/portion (U.S. EPA, 2000); the most consumed items were *Oncorhynchus* sp., *Oreochromis* sp., and *Prochilodus* sp., accounting for 5.4 kg/yr each, followed by *Scomberomorus* sp., *Pseudoplatystoma* sp., *Centropomus* sp., and *Pimelodus* sp. with a registered consumption of 2.7 kg/yr for each one, and finally *Pangasius* sp. with 0.2 kg/yr. The consumption risk was

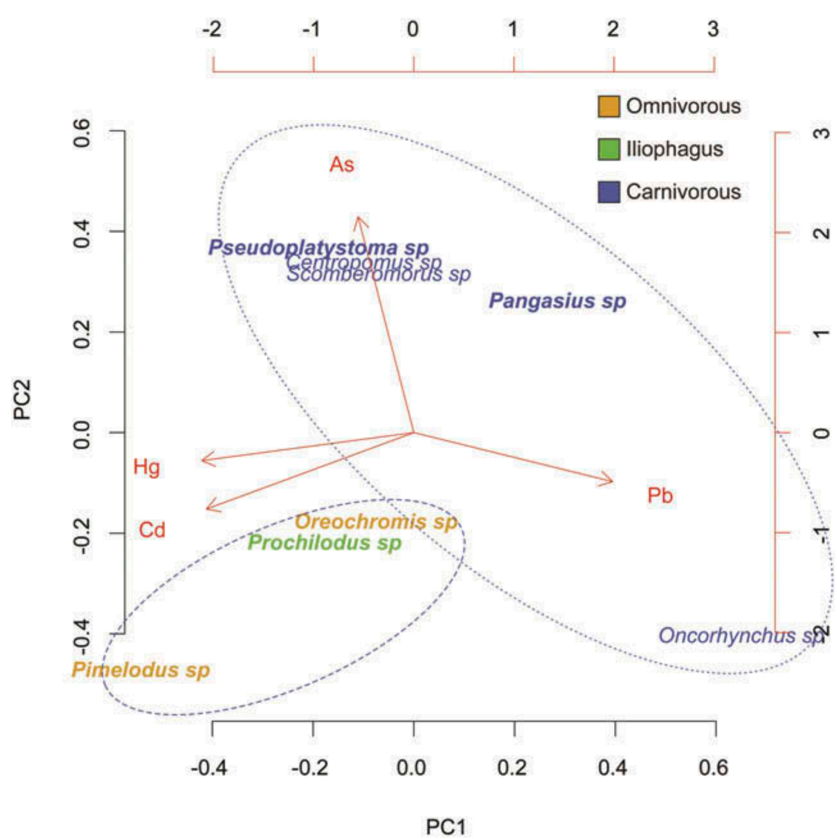

Figure 1. Distribution pattern of fish species related to metal concentrations indicating feeding habits based on PCA correlation matrix.

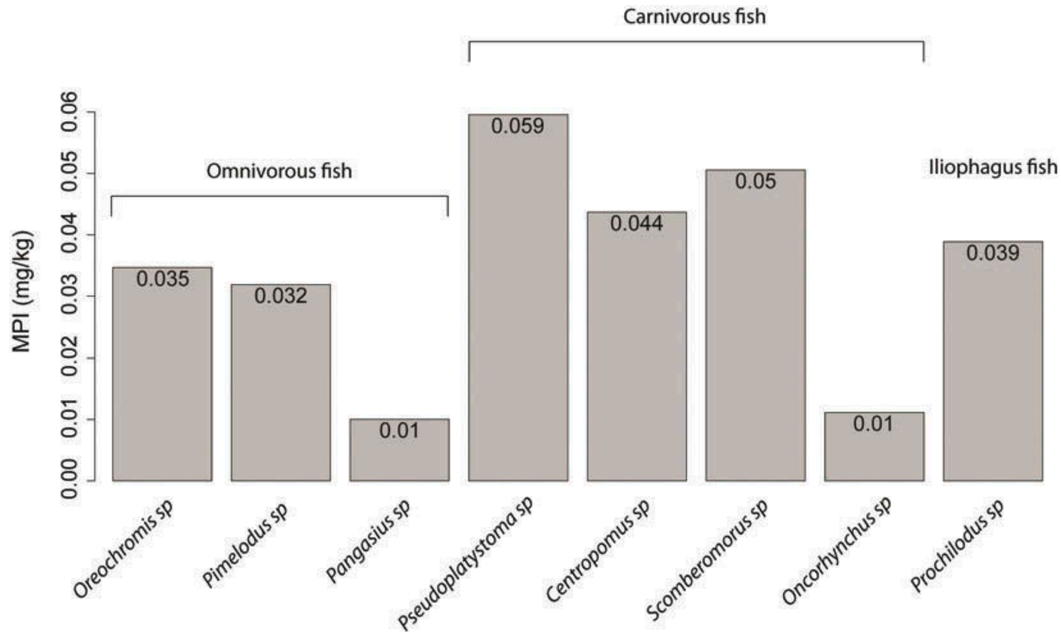

Figure 2. Metal pollution index showing the accumulation levels of metals in different species related to feeding habits.

calculated using MPI to estimate the accumulation levels of metals in different species (Figure 2). MPI values were between 0.01 and 0.059. *Pseudoplatystoma* sp. showed the highest MPI (0.059), followed by *Scomberomorus* sp. and *Centropomus* sp. with 0.05 and 0.04, respectively. The species with the lowest MPI values measured were *Pangasius* sp. and *Oncorhynchus* sp. There were no significant differences due to feeding habits or origin of the species (fresh water or saltwater).

The multiple species exposures ($E_{m.j}$) index was calculated for each metal to assess the health risks based on frequency of consumption of multiple species of fish with different levels of contamination. The $E_{m.j}$ was highest for As, followed by Pb, Cd, and Hg, with values ranging between 2×10^{-6} mg/kg-d and 1×10^{-5} mg/kg-d. This result determines that the risk from consuming various contaminated species is one order of magnitude higher for As, while the lowest value was calculated for Hg.

Similarly, the multiple chemical exposure ($E_{j.m}$) index was calculated (Figure 3). The $E_{j.m}$ values ranged between 7×10^{-9} mg/kg-d and 8×10^{-6} mg/kg-d; the highest value was calculated for *Prochilodus* sp., followed in decreasing order by *Oreochromis* sp., *Oncorhynchus* sp., *Pseudoplatystoma* sp., *Centropomus* sp., *Scomberomorus* sp., *Pimelodus* sp., and *Pangasius* sp. Data suggest that *Prochilodus* sp. displayed the highest exposure risk to multiple metals per consumption. Among the species with low values of $E_{j.m}$ index, *Pimelodus* sp. demonstrated the lowest health risk for exposure to multiple metals. This species has relatively high concentrations of Hg and Cd; however, these fish are not consumed frequently.

The values for THQ index for each metal explain the risk reported by $E_{j.m}$., and are presented in Figure 4. All values reported were below 1 by two orders of magnitude; the highest value was for Hg in *Prochilodus* sp. (THQ = 0.026), followed by Pb in *Oncorhinchus* sp. (THQ = 0.025), As in *Pseudoplatistoma* sp. and *Centropomus* sp. (THQ = 0.023), and Cd in *Prochilodus* sp. (THQ = 0.005).

Discussion

Colombia has been ranked as the second largest gold producer in South America after Brazil principally for activities of amalgamation and mining of gold, which result in environmental degradation due to release of heavy metals. The National Study of Water Development in 2014 revealed that approximately 230 tons (27.5%) of spilled Hg was related to exploitation of silver and 606 tons (72.5%) to gold mining activities. The highest Hg

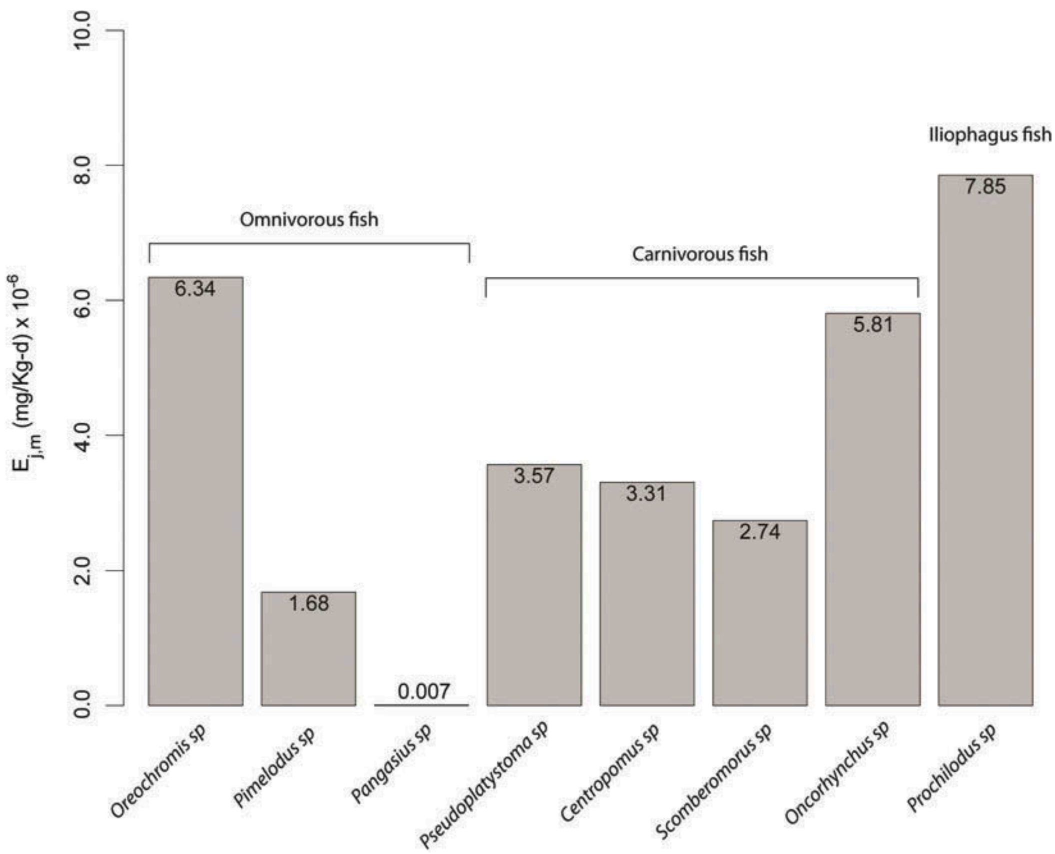

Figure 3. Multiple chemical exposure index by species indicating feeding habits showing the health risk for exposure to multiple metals.

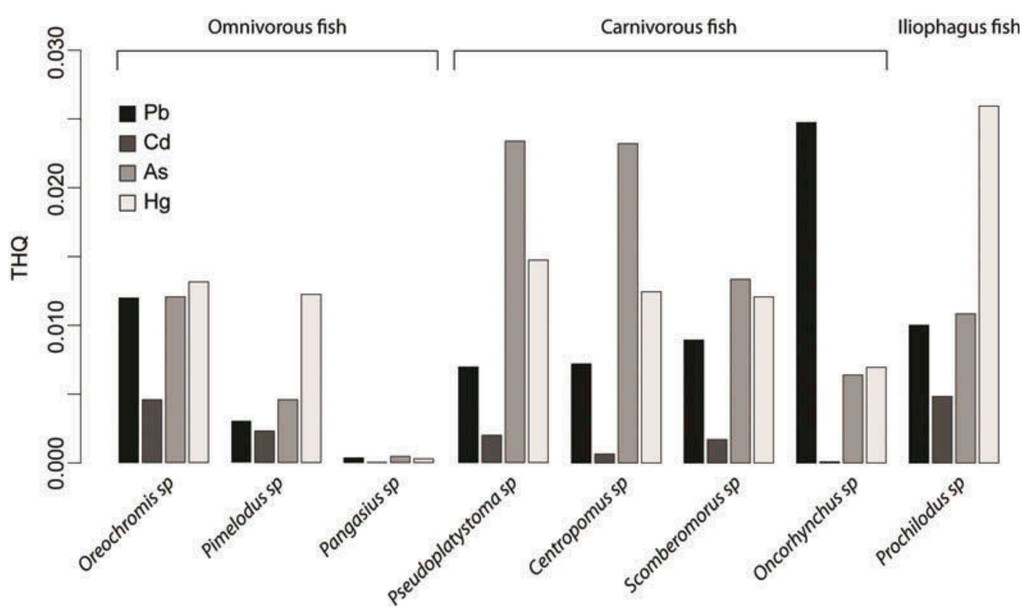

Figure 4. Quotient between concentration and oral reference dose for each metal by species category indicating feeding habits.

concentration in water was found in three areas of the country, Choco, Antioquia, and Nariño (Estudio Nacional Del Agua [ENA], 2015), that have fisheries as a principal economic activity. However, Bogotá D.C. city receives food supplies from various national and even international sources and thus it is difficult to identify the source of fish species that are consumed in the Bogotá.

Levels of exposure ($E_{m,j}$ and $E_{j,m}$) and probability of health risks (THQ) were calculated; these indices take into account the frequency of consumption of each species. The value of $E_{m,j}$ was lower than the reference dose (RfD) for each of the metals studied. Due to the high frequencies of consumption of species such as *Oreochromis* sp., *Prochilodus* sp., and *Oncorhynchus* sp., these species showed the highest levels of exposure. THQ values for each metal represent high exposure levels due to frequent consumption of species that indicated low metal concentrations in *Oreochromis* sp.; however, in species such as *Pseudoplatystoma* sp., *Centropomus* sp., and *Scomberomorus* sp., the higher probability of health risks is linked to enhanced presence of As and Hg. It is remarkable that the only species included in this study whose market is completely import dependent, *Oncorhynchus* sp., had the highest THQ values for Pb and appears to be external to the pattern of contamination for species that are obtained locally. This issue establishes a tendency of contamination based upon both human feeding habits of fish and the country of origin.

Depending on the feeding habits of each species, individuals are exposed to different levels of contamination, which manifests itself in the tendency to show specific concentrations of one metal or another. In our study, carnivorous species were associated with higher concentrations of As or Pb, whereas omnivorous or iliophagous species were associated with higher levels of Cd and Hg. This relationship emphasizes the need to consider certain factors in quality control of food, such as heavy metals to calculate exposure levels that are more sensitive and resemble the current Colombian diet.

The highest accumulation levels (MPI) of the studied metals were detected in all carnivorous species, with the exception of *Oncorhynchus* sp., which is a consequence of bioaccumulation of heavy metals at the higher ends of the aquatic food chain, in both fresh- and saltwater environments (Kojadinovic et al., 2007; Jayaprakash et al., 2015). Omnivorous and iliophagous species showed similar accumulation levels, with the exception of *Pangasius* sp. Another factor considered was that Hg concentrations increase as fish size/age (especially in predatory fish), but this trend is not relevant with other metals analyzed (Cd, As, and Pb),where a negative correlation with fish size/age in a number of fish species was noted (Bosch et al., 2016). These concentrations of accumulated metals reported in this study may be associated with intricate contamination dynamics in Colombia (AMAP/UNEP, 2013). However, it is noteworthy that although the primary fishing market in Bogotá D.C. consists of national products, this study also included samples from Argentina (*Prochilodus* sp.), Chile, and Canada (*Oncorhynchus* sp.).

In Bogotá D.C., fish consumption frequencies varied based upon consumer origins and their dietary habits, resulting in subpopulations with higher levels of exposure and higher probability of adverse health risk. There is a correlation between THQ and frequency of fish consumption. In this study the high metal concentrations were detected in muscle of fish species that are less ingested by the population, resulting in lower THQ values. Therefore, it is necessary to estimate the content of Pb, Cd, As, and Hg in other groups of food, such as greens and red meats, in order to establish a comprehensive risk assessment for all consumers.

Conclusions

The eight fish species analyzed were the most widely consumed in the city of Bogotá, and in all of these, four metals (Hg, As, Pb, and Cd) were detected, showing that consumers are exposed to these pollutants by ingestion regardless of the temporal seasonality, fishery product origins, or dietary habits of the consumer. The highest concentrations were found in the fish species as follows: Pb in *Oncorhynchus* sp., Cd and Hg in *Pimelodus* sp., and As in *Scomberomorus* sp. According to feeding habits of each species the potential consumption exposure to a specific metal concentration is variable. However, none of the reported values in the eight species was higher than the maximal value permitted for fish in the *Codex Alimentarius*. The potential risk for adverse effects due to different types of fishery foods is apparently low for the Bogotá population.

Funding

This research was financially supported by the University Sergio Arboleda and University Santo Tomas.

References

Alegria, A., Reyes, B., Lagarda Blanch, M., and Farré Rovira, R. 2012. Biodisponibilidad de sustancias tóxicas en los alimentos. In: Camean A. M; Repeto M. *Toxicol Aliment*, edited by Diaz de Santos. pp 688.

Alonso, D., Latorre, S., Catillo E., and Brandao, P. 2014. Environmental occurrence of arsenic in Colombia: A review. *Environ Pollut*. 186: 272–281.

Alonso, D., Pineda, P., Olivero, J., González, H., and Campos, N. 2000. Mercury levels in muscle of two fish species and sediments from the Cartagena Bay and the Cienaga Grande de Santa Marta, Colombia. *Environ Pollut*. 109: 157–163

AMAP/UNEP. 2013. Technical background report for the global mercury assessment 2013. Arctic Monitoring and Assessment Programme, Oslo,Norway/UNEP Chemicals Branch, Geneva, Switzerland.

Autoridad Nacional de Pesca y Acuicultura. 2013. Desarrollo de Estrategias para el incremento del consumo de pescados y mariscos provenientes de la acuicultura de Colombia, como alternativa viable de comercialización en el Mercado doméstico. Bogotá, Colombia.

Bernstam, L., and Nriagu, J. 2000. Molecular aspects of arsenic stress. *J. Toxicol. Environ. Health B* 3: 293–322.

Bortey-Sam, N., Nakayama, S. M., Ikenaka, Y., Akoto, O., Baidoo, E., Yohannes, Y. B., Mizukawa, H., and Ishizuka, M. 2015. Human health risks from metals and metalloid via consumption of food animals near gold mines in Tarkwa. Ghana: Estimation of the daily intakes and target hazard quotients (THs). *Ecotoxicol Environ. Safety* 111: 160–167.

Bosch, A. C., O'Neill, B., Sigge, G. O., Kerwath, S. E., and Hoffman, L. C. 2016. Heavy metals in marine fish meat and consumer health: A review. *J. Sci. Food Agric*, 96(1): 32–48.

Carneiro, M. F. H., Grotto, D., and Barbosa, F., Jr. 2014. Inorganic and methylmercury levels in plasma are differentially associated with age, gender, and oxidative stress markers in a population exposed to mercury through fish consumption. *J. Toxicol. Environ. Health A* 77: 69–79.

Contraloria General de la Republica. 2013. Minería en Colombia Institucionalidad y territorio, paradojas y conflictos, Vol 2. Imprenta Nacional deColombia. Bogota, Colombia.

Codex Alimentarius Commission. 2014. General Standard for Contaminants and toxins in Food and Feed. Codex Alimentarius Commission. Document (Codex Stan 193-1995), Rome, Italy.

Cooke, G. M. 2014. Biomonitoring of human fetal exposure to environmental chemicals in early pregnancy. *J. Toxicol. Environ. Health B* 17: 205–224.

Cordy, P., Veiga, M., Salih, I., Al-Saadi, S., Console, S., Garcia, O., Mesa, L. A., Velásquez-López, P. C., and Roeser, M. 2011. Mercury contamination from artisanal gold mining in Antioquia, Colombia: The world's highest per capita mercury pollution. *Sci. Total Environ*. 410–411:154–160

De Campos Júnior, E. O., Pereira, B. B., and Morelli, S. 2015. Monitoring genotoxicity potential in the Mumbuca Stream, Minas Gerais, Brazil. *J. Toxicol. Environ. Health A* 78: 1277–1287.

De Miguel, E., Clavijo, D., Ortega, M., and Gómez, A. 2014. Probabilistic meta-analysis of risk from the exposure to Hg in artisanal gold mining communities in Colombia. *Chemosphere* 108: 183–189.

Estudio Nacional Del Agua. 2014. 2015. IDEAM. Instituto de Hidrología, Meteorología y Estudios Ambientales–IDEAM. http://documentacion.ideam.gov.co/openbiblio/bvirtual/023080/ENA_2014.pdf

Food and Agriculture Organization of the United Nations. 2006. Qué es el Codex Alimentarius. Secretaría del Programa Conjunto FAO/OMS sobre Normas Alimentarias Organización de las Naciones Unidas para la Agricultura y la Alimentación. Roma, Italia.

Froese, R., and Pauly, D., eds. 2015: FishBase. Online publication. http://www.fishbase.org (accessed January 25, 2015).

Galeano, S. 2013. Acumulación de mercurio (Hg) en tejido muscular y hepático en especies ícticas de diferentes cíenagas del Magadalena medio. Tesis de Maestria en Ciencias Ambientales, Universidad de Antioquia, Antioquia, Colombia.

Gochfeld, M. Burger, J., and Vyas, V. 2005. Statistical analysis of data sets with values below detection limits. Appendix 11.D. In *Amchitka Independent Science Assessment: Biological and geophysical aspects of potential radionuclide exposure in the Amchitka marine environment*, ed. C. W. Powers, J. Burger, D. Kosson, M. Gochfeld, and D. Barnes. Piscataway, NJ: Consortium for Risk Evaluation with Stakeholder Participation. http://www.cresp.org/cresppro jects/amchitka/amchitka-final-report

Hao, Y., Chen, L., Zhang, X., Zhang, D., Zhang, X., Yu, Y., and Fu, J. 2013. Trace elements in fish from Taihu Lake. China: Levels associated risks and trophic transfer. *Ecotoxicol. Environ. Safety* 2: 89–97.

Jayaprakash, M., Senthil Kumar, R., Giridharan, L., Sujitha, S. B., Sarkar, S.,K. and Jonathan, M. P. 2015. Bioaccumulation of metals in fish species from water and sediments in macrotidal Ennore creek, Chennai, SE coast of India: A metropolitan city effect. *Ecotoxicol. Environ. Safety* 120: 243–255.

Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R. P., and Bustamante, P. 2007. Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean. *Environ. Pollut*. 146: 548–566.

Lancheros, L. 2013. Content of mercury in muscle of some commercial fish species present in eight sampling sites from the Magdalena river basin (low, medium and high). Bogotá. Esp. Planeación ambiental y administración de los recursos. Universidad Militar Nueva Granada.

Mancera-Rodríguez, N. J., and Álvarez-León, R.2006. Estado del conocimiento de las concentraciones de mercurio y otros metales pesados en peces dulceacuícolas de Colombia. *Acta Biol Col.* 11: 3–23.

Ministerio de Salud y Protección Social. 2013. Plan Nacional de Seguridad Alimentaria y Nutricional (PNSAN) 2012–2019. Comisión Intersectorial de Seguridad Alimentaria y Nutricional. República de Colombia.

Marrugo-Negrete, J., Benitez, L. N., and Olivero-Verbel, J. 2008a. Distribution of mercury in several environmental compartments in an aquatic ecosystem impacted by gold mining in northern Colombia. *Arch Environ Contamin Toxicol*. 55: 305–316.

Marrugo-Negrete, J., Verbel, J. O., Ceballos, E. L., and Benitez, L. N. 2008b. Total mercury and methylmercury concentrations in fish from the Mojana region of Colombia. *Environ*. Geochem. Health *30*: 21–30.

Morais, S., Garcia Costa, F., and Pereira, M. L. 2012. Heavy metals and human health. In *Environmental health emerging issues and practice*, ed. J. Oosthuizen, 227–246. Tech Publishers. http://www.intechopen.com/books/environmental-health-emerging-issues-and-practice

Nacano, L. R., De Freitas, R., and Barbosa, F., Jr. 2014. Evaluation of seasonal dietary exposure to arsenic, cadmium and lead in schoolchildren through the analysis of meals served by public schools of Ribeirão Preto, Brazil. *J. Toxicol. Environ. Health A* 77: 367–374.

Niencheski, L. F., and Fillmann, G. 2006. Metais. Hidrocarbonetos e Organoclorados. En: Lana. P. C et al. Avaliação Ambiental de estuarios Brasileiros: Aspectos Metodologicos.

NTC 1443 (Norma técnica Colombiana). 2009. Productos de la pesca y acuicultura. Pescado entero, medallones y trozos, refrigerados o congelados. Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC). Tercera Actualización. Bogotá, Colombia.

Olivero, J., and Solano, B. 1998. Mercury in environmental samples from a waterbody contaminated by gold mining in Colombia, South America. *Sci. Total Environ*. 217: 83–89.

Olivero, J., Navas, V., Pérez, A., Solano, B., Acosta, I., Arguello, E., and Salas, R. 1997. Mercury levels in muscle of some fish species from the Dique Channel. *Bull. Environ. Contam. Toxicol*. 58: 865–870.

Olivero, J., Johnson, B., and Arguello, E. 2002. Human exposure to mercury in San Jorge River basin, Colombia (South America). *Sci. Total Environ*. 289: 41–47.

Olivero-Verbel, J., and Johnson, B. 2002. Contaminación con mercurio y salud pública en la costa Atlántica colombiana. *Biomédica* 22 (Suppl. 1): 52–53.

Olivero-Verbel, J., Johnson-Restrepo, B., Mendoza-Marín, C., Paz-Martinez, R., and Olivero-Verbel, R. 2004. Mercury in the aquatic environment of the village of Caimito at the Mojana region, north of Colombia. *Water Air Soil Pollut*. 159: 409–420.

Olivero-Verbel, J., Agudelo, D., and Caballero, K. 2013. Morphometric parameters and total mercury in eggs of snowy egret (*Egretta thula*) from Cartagena Bay and Totumo Marsh, north of Colombia. *Mar. Pollut. Bull.* 69:105–109.

Olivero-Verbel, J., Caballero-Gallardo, K., and Marrugo-Negrete, J. 2011. Relationship between localization of gold mining areas and hair mercury levels in people from Bolivar, north of Colombia. *Biol. Trace Elem. Res*. 144: 118–132.

Olivero-Verbel, J., Johnson Restrepo, B., Baldiris Avila, R., Güette Fernández, J., Magallanes Carreazo, E., Vanegas Ramírez, L., and Kunihiko, N. 2008. Human and crab exposure to mercury in the Caribbean coastal shoreline of Colombia: Impact from an abandoned chlor-alkali plant. *Environ. Int*. 34: 476–482.

Pack, E. C., Kim, C. H., Lee, S. H., Lim, C. H., Sung, D. G., Kim, M. H., and Kim, S. W. 2014. Effects of environmental temperature change on mercury absorption in aquatic organisms with respect to climate warming. *J. Toxicol. Environ. Health A* 77: 1477–1490.

Perucho, E. 2010. El mercado del pescado en la ciudad de Bogotá. INFOPESCA. Centro para los servicios de información y asesoramiento sobre la comercialización de los productos pesqueros de América Latina.

R Core Team. 2013. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. http://www.R-project.org

Resolution 0776 de 2008. Marzo 3. *Diario Oficial* No. 46.923 De 6 de Marzo de 2008. Ministerio de la Protección Social. República de Colombia.

Ruiz, J,Fandiño, C., Romero, G., and Guevara, M. 1996. Contaminación de peces por metales pesados en el río Magdalena. *Licania Arborea* 1:18–22.

Sharma, R. K., Agrawal, M., and Marshall, F. M., 2008. Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: A case study in Varanasi. *Environ. Pollut*. 154: 254–263.

Štrbac, S., Kašanin-Grubin, M., Jovančićević, B., and Simonović, P. 2015. Bioaccumulation of heavy metals and microelements in silver bream (*Brama brama L.*), northern pike (*Esox lucius L.*), sterlet (*Acipenser ruthenus L.*), and common carp (*Cyprinus carpio L.*) from Tisza River, Serbia. *J. Toxicol. Environ. Health A* 78: 663–665.

Sweet, L. I., and Zelikoff, J. T. 2001. Toxicology and immunotoxicology of mercury: A comparative review in fish and humans. *J. Toxicol. Environ. Health B* 4: 161–205.

Tassinari, C., and Diaz, J. 2008. Age and sources of gold mineralization in the Marmato mining district, NW Colombia: A Miocene–Pliocene epizonal gold deposit. *Ore Geol .Rev*. 33: 505–518.

U.S. Environmental Protection Agency. 1991. Methods for the determination of metals in environmental samples. EPA-600/491-010. Cincinnati, OH: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. 2000. Guidance for assessing chemical contaminant data for use in fish advisories. EPA 823-B- 00-008. November. Third edition. Risk assessment and fish consumption limits, vol. 2. Washington, DC: Office of Water.

U.S. Environmental Protection Agency. 2007. Integrated Risk Information System—Database (IRIS).Philadelphia, PA: U. S. EPA.

Van Der Oos, R., Beyer, J., and Vermeulen, N. P. 2003. Fish bioaccumulation and biomarkers in environmental risk assessment: A review. *Environ. Toxicol. Pharmacol*. 13: 57–149.

Wang, X., Sato, T., Xing, B., and Tao, S. 2005. Health risk of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. *Sci. Total. Environ*. 350: 28–37.