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

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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 ($E_{\text{m,j}}$) 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 ($E_{\text{m.j}}$), which accounts for exposure to multiple metals, identified Prochilodus sp. as the species displaying the highest level of exposure per consumption ($8 \times 10^{-6}$ 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.

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;
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-Rodriguez 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-Rodriguez 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 (HNO₃) 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):

\[
\text{MPI (mg/kg)} = \left( \frac{C_{f1}}{C_{f2}} \times \frac{C_{f2}}{C_{f3}} \times \ldots \times \frac{C_{fk}}{C_{fK}} \right)^{1/K}
\]

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 \(E_{m,j}\) 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.

<table>
<thead>
<tr>
<th>Species/Feeding habits</th>
<th>Species</th>
<th>Pb (mg/kg)</th>
<th>n</th>
<th>% (&lt;DL)</th>
<th>Range (min–max)</th>
<th>Cd (mg/kg)</th>
<th>n</th>
<th>% (&lt;DL)</th>
<th>Range (max–min)</th>
<th>As (mg/kg)</th>
<th>n</th>
<th>% (&lt;DL)</th>
<th>Range (min–max)</th>
<th>Hg (mg/kg)</th>
<th>n</th>
<th>% (&lt;DL)</th>
<th>Range (min–max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omnivorous fish</td>
<td>Oreochromis sp.</td>
<td>0.0281 (±0.0128)</td>
<td>7</td>
<td>63.2</td>
<td>0.016–0.043</td>
<td>0.0042 (±0.0061)</td>
<td>6</td>
<td>68.4</td>
<td>0.0007–0.0164</td>
<td>0.0311 (±0.0111)</td>
<td>5</td>
<td>73.7</td>
<td>0.0161–0.043</td>
<td>0.0313 (±0.0108)</td>
<td>14</td>
<td>26.3</td>
<td>0.018–0.0472</td>
</tr>
<tr>
<td></td>
<td>Pimelodus sp.</td>
<td>0.0199 (±0.0019)</td>
<td>4</td>
<td>42.9</td>
<td>0.0173–0.0217</td>
<td>0.0072 (±0.0074)</td>
<td>5</td>
<td>28.6</td>
<td>0.0012–0.0165</td>
<td>0.0277 (±0.0072)</td>
<td>2</td>
<td>71.4</td>
<td>0.0226–0.0328</td>
<td>0.0579 (±0.0269)</td>
<td>4</td>
<td>42.9</td>
<td>0.0245–0.0879</td>
</tr>
<tr>
<td></td>
<td>Pangasius sp.</td>
<td>0.029 (±NA)</td>
<td>1</td>
<td>80.0</td>
<td>0.029–0.029</td>
<td>0.0004 (±NA)</td>
<td>1</td>
<td>80.0</td>
<td>0.0004–0.0004</td>
<td>0.038 (±NA)</td>
<td>1</td>
<td>80.0</td>
<td>0.038–0.038</td>
<td>0.0215 (±0.0019)</td>
<td>4</td>
<td>20.0</td>
<td>0.019–0.023</td>
</tr>
<tr>
<td>Carnivorous fish</td>
<td>Pseudoplatystoma sp.</td>
<td>0.0264 (±0.0116)</td>
<td>6</td>
<td>71.4</td>
<td>0.02–0.0499</td>
<td>0.0032 (±0.0045)</td>
<td>8</td>
<td>61.9</td>
<td>0.0004–0.0142</td>
<td>0.0469 (±0.0508)</td>
<td>8</td>
<td>61.9</td>
<td>0.014–0.168</td>
<td>0.0447 (±0.0295)</td>
<td>17</td>
<td>19.0</td>
<td>0.018–0.1058</td>
</tr>
<tr>
<td></td>
<td>Centropomus sp.</td>
<td>0.0289 (±0.00134)</td>
<td>8</td>
<td>57.9</td>
<td>0.0163–0.0518</td>
<td>0.0028 (±0.0015)</td>
<td>7</td>
<td>63.2</td>
<td>0.0005–0.0047</td>
<td>0.0458 (±0.0445)</td>
<td>10</td>
<td>47.4</td>
<td>0.016–0.167</td>
<td>0.041 (±0.0263)</td>
<td>16</td>
<td>15.8</td>
<td>0.016–0.0895</td>
</tr>
<tr>
<td></td>
<td>Scomberomorus sp.</td>
<td>0.034 (±0.00162)</td>
<td>7</td>
<td>63.2</td>
<td>0.0196–0.0643</td>
<td>0.0038 (±0.0048)</td>
<td>5</td>
<td>73.7</td>
<td>0.0006–0.0122</td>
<td>0.0471 (±0.0299)</td>
<td>5</td>
<td>73.7</td>
<td>0.0216–0.096</td>
<td>0.0358 (±0.0202)</td>
<td>14</td>
<td>26.3</td>
<td>0.019–0.0868</td>
</tr>
<tr>
<td></td>
<td>Oncorhynchus sp. liliophagus fish</td>
<td>0.0595 (±0.0417)</td>
<td>2</td>
<td>80.0</td>
<td>0.03–0.089</td>
<td>0.0003 (±NA)</td>
<td>0</td>
<td>100.0</td>
<td>0.0003–0.0003</td>
<td>0.023 (±NA)</td>
<td>1</td>
<td>90.0</td>
<td>0.023–0.023</td>
<td>0.0212 (±0.0025)</td>
<td>5</td>
<td>50.0</td>
<td>0.019–0.025</td>
</tr>
<tr>
<td></td>
<td>Prochilodus sp.</td>
<td>0.0254 (±0.0071)</td>
<td>8</td>
<td>46.7</td>
<td>0.016–0.036</td>
<td>0.0048 (±0.0065)</td>
<td>6</td>
<td>60.0</td>
<td>0.0004–0.0174</td>
<td>0.0312 (±0.0086)</td>
<td>3</td>
<td>80.0</td>
<td>0.022–0.039</td>
<td>0.0412 (±0.0263)</td>
<td>13</td>
<td>13.3</td>
<td>0.017–0.0933</td>
</tr>
</tbody>
</table>

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

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

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:

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

where THQ is the target hazard quotient, $EF_r$ 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), $RF$ 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), and $TA$ 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., *Prochilodus* sp., *Centropomus* sp., *Pangasius* sp., *Scomberomorus* sp., *Pseudoplatystoma* sp., *Centropomus* sp., *Pangasius* 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 by, in diminishing order, *Pseudoplatystoma* sp., *Prochilodus* sp., *Pangasius* sp., *Oreochromis* sp., *Pseudoplatystoma* sp., *Centropomus* sp., *Prochilodus* 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](image-url). Distribution pattern of fish species related to metal concentrations indicating feeding habits based on PCA correlation matrix.
calculated using MPI to estimate the accumulation levels of metals in different species (Figure 2). MPI values were between 0.01 and 0.059. *Pseudoplatsyntoma* 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 $2 \times 10^{-6}$ mg/kg-d and $1 \times 10^{-5}$ 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 $7 \times 10^{-9}$ mg/kg-d and $8 \times 10^{-6}$ mg/kg-d; the highest value was calculated for *Prochilodus* sp., followed in decreasing order by *Oreochromis* sp., *Oncorhynchus* sp., *Pseudoplatsyntoma* 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 *Oncorhynchus* sp. (THQ = 0.025), As in *Pseudoplatsyntoma* 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.

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