Environ Monit Assess (2016) 188: 259
DOI 10.1007/s10661-016-5262-y

Cadmium and lead in seafood from the Aratu Bay, Brazil and the human health risk assessment

Cecilia Freitas Silva da Araújo · Mariângela Vieira Lopes · Mirian Rocha Vasquez · Thiago Santos Porcino · Amanda Santos Vaz Ribeiro · Juliana Lima Gomes Rodrigues · Sérgio Soares do Prado Oliveira · José Antonio Menezes-Filho

Received: 21 July 2015 / Accepted: 22 March 2016 / Published online: 31 March 2016

Abstract This study aimed to evaluate cadmium (Cd) and lead (Pb) levels in seafood and perform a risk assessment based on individual food consumption frequency of inhabitants of the Aratu Bay, Brazil. From December 2013 to November 2014, ready-to-market seafood, including fish [pititinga (*Lile piquitinga*) and small green eel (*Gobionellus oceanicus*)], mollusks [mussel (*Mytella guyanensis*) and oyster (*Crassostrea rhizophorae*)], and crustaceans [white shrimp (*Litopenaeus schmitti*) and blue crab (*Callinectes exasperatus*)], were purchased bi-monthly from a local artisanal shellfish harvester. Metal levels were analyzed by graphite furnace atomic absorption spectrometry (GFAAS). Based on the volunteer' seafood consumption, estimates of the non-carcinogenic target hazard quotients (THQs) were calculated. The annual concentrations (μg/g, *w*/*w*) of Cd were 0.007 (±0.001) in crustaceans, 0.001 (±0.0003) in fish, and 0.446 (±0.034) in mollusks. Lead levels were <limit of detection (LOD) in crustaceans, 0.044 (±0.0032) in fish, and 0.111 (±0.009) in mollusks. All values were within the international guidelines. We observed that 90.9 % of the responders presented an average THQ < 1, which is classified as negligible risk; however, 9.1 % presented THQs between ≥1 and <9.9. These data are important to inform the community of the imminent exposure risk through communication strategies, with the purpose of minimizing exposure and, consequently, the health effects associated with it.

C. F. S. da Araújo · J. A. Menezes-Filho
College of Pharmacy, Graduate Program in Food Science, Federal University of Bahia, Av. Barão Jeremoabo, s/n, Ondina, 40170-115 Salvador, Bahia, Brazil

C. F. S. da Araújo
e-mail: cecilia.fsaraujo@gmail.com

C. F. S. da Araújo · T. S. Porcino · A. S. V. Ribeiro · J. L. G. Rodrigues · S. S. d. P. Oliveira · J. A. Menezes-Filho (✉)
College of Pharmacy, Laboratory of Toxicology, Federal University of Bahia, Av. Barão Jeremoabo, s / n, Ondina, 40170-115 Salvador, Bahia, Brazil
e-mail: antomen@ufba.br

T. S. Porcino
e-mail: thiagoporcinoo@hotmail.com

A. S. V. Ribeiro
e-mail: mandinha.svribeiro@hotmail.com

J. L. G. Rodrigues
e-mail: juuhrodrigues@icloud.com

S. S. d. P. Oliveira
e-mail: sergiosprado.33@gmail.com

M. V. Lopes · M. R. Vasquez
Analytical Chemistry Laboratory, State University of Bahia, Silveira Martins Av., 2555. Cabula, 41150-000 Salvador, Bahia, Brazil

M. V. Lopes
e-mail: mlopesuneb@hotmail.com

M. R. Vasquez
e-mail: mrvazquez@terra.com.br

Keywords Cadmium · Lead · Seafood · Environmental contamination · Risk assessment · THQ

Introduction

The *Todos os Santos* Bay (TSB) is the largest bay on the Brazilian coast. It is characterized by the presence of small bays, coves, and about 30 islands (Ferreira 2011; Hatje et al. 2009). The most inner bay to the BTS, the Aratu Bay, is located approximately 20 km north of Salvador, the capital of State of Bahia, Brazil, and northeast of the TSB (Bahia 1980). Among the companies located on the banks of the Aratu Bay, there is one giant multinational chemical company, several cargo terminals and ports and a ferro-manganese alloy plant, which dumps its wastewater into the mangrove ecosystem (Brito 1997). The Aratu Bay waters reach several communities; among them is the Santa Luzia village.

This community is part of Simões Filho district with a small population of approximately 1000 inhabitants. Among other economic activities, fishing and harvesting shellfish are the main sources of income and protein of this population. Previous studies have reported that the sediment, water, and biota in this area have high levels of pollutants, such as heavy metals and persistent organic compounds (Antunes 2006; Bonfim 2005; Celino and Queiroz 2006; Costa et al. 2008; Garcia et al. 2008; Hatje et al. 2009; Santos et al. 2013). In recent decades, numerous studies on heavy metal contamination in aquatic environments have provided increasing evidence of the adverse effects on aquatic biota and human health (Krishna and Madhusudhana Rao 2014; Ali et al. 2016; Kibria et al. 2016; Mendoza-Carranza et al. 2016). The coastal areas generally act as dumping ground for pollutants, and in estuaries, this problem is magnified due to the concentration of the human population, industrial activities, and dredging in ports (Horta et al. 2011; Olmedo et al. 2013; Storelli 2008; Viana et al. 2005).

Some heavy metals are naturally required in small amounts as constituents of fish enzymes that are essential for healthy development. On the other hand, they may also be toxic to fish and other organisms in elevated doses. Moreover, metals can be bioconcentrated through the food chain and reach humans, thus producing health risks (Viana et al. 2005). Consequently, the potential risks to health from the dietary exposure to these pollutants continue to be a mandatory subject of investigation, regulation, and debate (Storelli 2008).

Cadmium (Cd) is a heavy metal that bioaccumulates in animal tissues. Mollusks accumulate the metal in their tissues, in addition to many microorganisms. The bioconcentration factors, on the order of thousands, can cause serious damage to contaminated organisms (Cowi 2002; WHO 1991). One of the main adverse effects observed in chronic exposure in humans is kidney damage. Recently, our research group observed that individuals of the same community presented Cd urinary levels that were significantly associated with increased urinary excretion of β2-microglobulin (β-2M), low molecular weight protein, and the cell enzyme *N*-acetyl-β-glucosaminidase (NAG), which may reflect subclinical lesions in the kidney cells (data not yet published).

Lead (Pb) is not bioaccumulated in most organisms, but it can accumulate in feeding particles of mussels and larvae; therefore, it contaminates the organisms that occupy a crucial place at the base of the aquatic food chain, which can compromise the entire chain (Martins 2004). According to several studies, Pb has been shown to cause adverse effects on various organs and systems in all species under experimental conditions, including the blood, central nervous, reproductive, and immune systems and kidneys (WHO 1989, 1995).

Dietary exposure to heavy metals has attracted great interest because of the health risks associated with the ingestion of residues of heavy metals, such as Cd and Pb. The United States Environmental Agency (US EPA) establishes the extent *target hazard quotient* (THQ) associated with the ingestion of toxins and various heavy metals using risk-based concentrations. This concern includes an estimate of the life risk assessment based on the oral safe reference dose as an upper limit for the hazardous substance and regular intake throughout life (Liu et al. 2010; Petroczi and Naughton 2009).

Elevated levels of Cd and Pb in the benthic organisms from the TSB, Cd (8.29 ± 2.43 μg g^{-1}), and Pb (13.6 ± 2.0 μg g^{-1}) have been reported (Amado-Filho et al. 2008). Later, Horta et al. (2011) reported the risk of Cd intake by a community in Sepeitiba Bay, Rio de Janeiro based on their fish consumption, which was 110 times greater than that found in the control population. The estimated Cd level in fish was 0.04 μg g^{-1}. The authors concluded that this increased risk could reflect in renal diseases, although these have not been shown to be associated with exposure to Cd. In a study of another

area of the TSB, Santos et al. (2013) investigated the Cd and Pb contamination in fish (*Centropomus undecimalis* and *Mugil brasiliensis*), mussels (*Mytella guyanensis*), and shrimp (*Penaeus brasiliensis*). It was observed that the Cd levels in most of the samples were within legal limits (1.04 μg g^{-1}), while the measured Pb contents of some samples of mussels (2.20 and 5.40 μg g^{-1}) and shrimp (2.20 and 3.40 μg g^{-1}) were above the Brazilian legislation's limit (Brazil 2013).

The knowledge of metal content in food is an important issue for many reasons. The presence of metals at certain levels in food plays an important role in human health, due to its essentiality or its toxicity at high levels. Therefore, to obtain accurate data on the elemental composition of foods, it is necessary to establish an adequate intake of essential nutrients, as well as an adequate assessment of the exposure levels to toxic elements via food consumption (Brandão 2010). Thus, the objectives of this study were to determine the levels of heavy metals (Cd and Pb) present in seafood in the estuary of Aratu Bay near the village of Santa Luzia, Bahia, Brazil and estimate the risks to human associated with it.

Materials and methods

Area of study

The Santa Luzia village is located in the estuary of the Aratu Bay, in the municipality of Simões Filho, in a defined area between Cotegipe and Mapele (Fig. 1). This community was selected a study area because it is located approximately 3 km from a ferro-manganese alloy plant and has been evaluated in different studies by our research group (Menezes-Filho et al. 2009, 2011, 2014; Viana et al. 2014).

Seafood sampling

Seafood samples were acquired in Santa Luzia directly from an artisanal shellfish harvester woman, known locally as "marisqueira." Seafood samples were composed of two species of mollusks, i.e., Sururu (*Falcata mytella*) and oyster (*Crassostrea rhizophorae*), two species of crustaceans, i.e., white shrimp (*Litopenaeus schmitti*) and blue crab (*Callinectes exasperatus*), and two species of fish, i.e., pititinga (*Centengraulis edentulus*) and Miroró (*Gobionellus oceanicus*). These species were selected for analysis on the basis of relevant consumption by the community due to their local occurence and its economic importance.

All seafood (approximately 1.0 kg each) was purchased in the form presented for commercialization in the local market. They were sold frozen to consumers packed in plastic bags. The mollusks were sold without shells after boiling, the crabs, without the carapace, shrimp in natura, and fish were gutted. The samples were transported to the laboratory in coolers, frozen, and stored in the lab until processing. These samples were purchased every 2 months starting in November 2013 and ending in September 2014. Thirty-six different seafood samples were obtained for this analysis.

Equipments and reagents

A lyophilizer (Freeze L101 Liotop, Sao Paulo, Brazil) was used to dehydrate the seafood samples. Sample mineralization was performed by an open system on a heating plate (New ethical model 208D). Analysis for Cd and Pb was performed on a graphite furnace atomic absorption spectrometer (GFAAS) equipped with a Zeeman background corrector (AAS-Varian Spectra AA 240FGZ, Mulgrave, Victoria, Australia). A 2 % (*w*/*v*) magnesium nitrate solution from Sigma-Aldrich (Sao Paulo, Brazil) was used as a chemical modifier. Working standards of lead and cadmium were prepared at the microgram per liter level from their corresponding 1000 mg L^{-1} stock standards (AccuStandard®).

Sample processing

All glassware used were previously washed with a 3 % (*v*/*v*) Extran neutral solution (Merck, Darmstadt, Germany) for 24 h and then rinsed with ultra-pure water (Milli Q, Millipore, Bedford, USA). The glassware was then acid decontaminated in a 20 % (*v*/*v*) nitric acid solution (Vetec PA, São Paulo, Brazil) for 24 h and rinsed again with ultra-pure water to eliminate any inorganic contaminants.

The seafood samples were lyophilized to dehydration until obtaining a full dehydrated sample. Wet and dry weights were recorded to calculate the average humidity of each seafood species. The resulting dried material was ground in a mortar, obtaining a homogeneous powder. Finally, the samples were placed in sterile polyethylene bags and stored in a moisture-free environment until further processing.

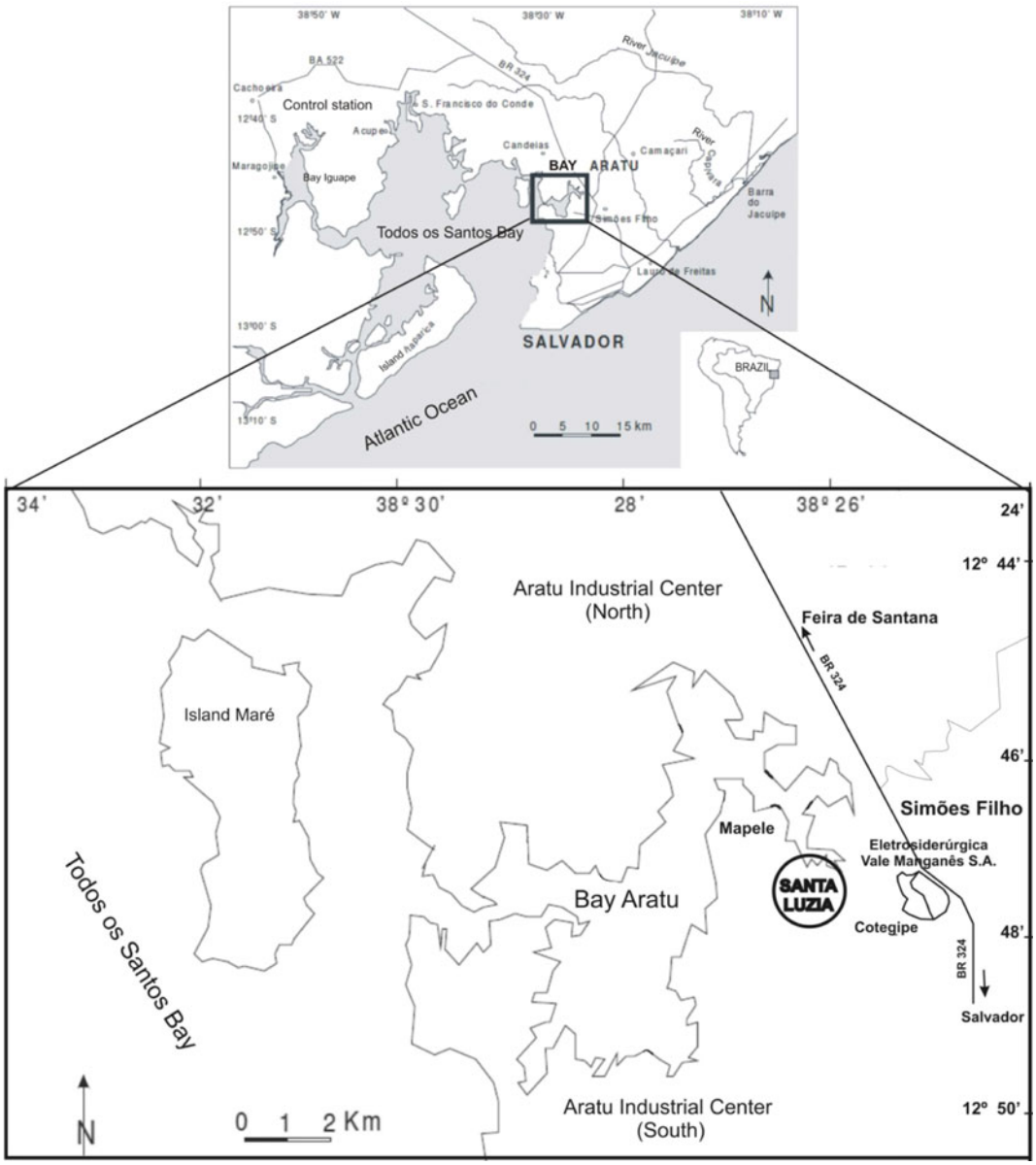

Fig. 1 Geographical location of the study area and the community of Santa Luzia

Analytical quality assurance

To ensure the quality of the metal analyses, standard certified reference material (CRM) Oyster tissue NIST-1566b (National Institute of Standard and Technology, USA) was used. The method's precision and accuracy were calculated based on the coefficient of variation of six replicate analyses of this CRM, run during 2 weeks by the same analyst and on the ratio of the obtained result by the certified value established on the CRM certificate. Reagent blank readings in six analytical runs were used to calculate the limit of detection (LOD) and the limit of quantification (LOQ). The LOD was established as the blank's mean plus three times the standard deviation (SD), and the LOQ was the blank's mean plus ten times the SD, according to Lupac (1997).

Sample mineralization

The sample processing was similar to the procedure described by Noël et al. (2009). Seafood samples were mineralized in triplicate. Each dehydrated sample

(approximately 200 mg) was weighed directly into the 50-mL beakers. Acid digestion was achieved by adding 5 mL of concentrated HNO_3, covering with a glass watch and allowing refluxing on a heating plate at 100 °C for approximately 4 h. After cooling at room temperature, 2 mL of H_2O_2 was added. The CRM and reagent blanks were processed in each battery. When mineralization was completed, the clear acid solution was transferred to 15-mL polypropylene graduated centrifuge tube (CentriStar Corning™ brand), and the volume was brought up to 10 mL with ultra-pure water.

Determination of Cd and Pb

The concentrations of Cd and Pb in the mineralized seafood samples were determined by GFAAS. For Cd, the instrument was calibrated at concentrations of 0, 0.5, 1.0, 2.0, and 4.0 μg mL^{-1}. The 0.5 % ammonium dehydrogen phosphate solution was used as a chemical modifier. For Pb determination, a calibration curve was prepared at concentrations of 0, 2.0, 4.0, 10, 16, and 20 μg mL^{-1}. Cd readings were performed with wavelength of 228.8 nm and lamp current of 4 mA while Pb with wavelength of 283.3 nm and lamp current of 10 mA. Furnace temperature program followed the prescribed programs in the equipment's operation manual (Varian Inc., Australia).

Data analysis

The metal concentrations in wet weight (*w*/*w*) at each bimonthly sampling represent the average of three replicates. The results were grouped by the type of seafood, and the annual arithmetic average was obtained ($n = 6$) for Cd and Pb in the three seafood groups. These data were used in the risk assessment approach. The results are expressed as the mean and standard deviation.

Risk assessment of fish consumption

The risk analysis of this study aimed to consider the possible adverse effects on health associated with exposure to the metals Cd and Pb due to consumption of seafood from the Aratu Bay. The values of toxicity used were obtained and adapted from the American reference institutions (ATSDR 2013; US EPA 2013).

A survey of the frequency and the amount of fish consumption was conducted among the volunteers from the community of Santa Luzia using a food frequency questionnaire. We interviewed 55 individuals in the community: adults and adolescents, residents for at least 2 years in the community, who reported the frequency of daily, weekly, monthly, or annual fish and shellfish consumption. Before carrying out the interviews, the approval from the Federal University of Bahia ethical research committee was obtained (UFBA ERC No. 054/2011). The volunteers signed the written informed consent form, after being thoroughly explained the objectives of the study.

A semi-structured questionnaire was also applied that included socioeconomic and demographic information. Anthropometric measurements such as weight and height were performed using portable scale and stadiometer.

The ingestion of Cd and Pb (mg/day) was estimated based on the concentrations of these metals quantified in the three seafood groups. The daily intake of metals (mg/day and mg/kg body weight/day) was calculated by dividing the daily dose by the individual body weight (kg).

THQ

Although the methodology used for estimating the THQ (Copat et al. 2013; Petroczi and Naughton 2009; Storelli 2008; Wang et al. 2013) does not provide a quantitative estimate of the likelihood of a health experience of the exposed population, it provides an indication of the risk level due to exposure to contaminants. This quotient was calculated using Eq. 1:

$$\mathrm{THQ} = \frac{\mathrm{Ef} \times \mathrm{ED} \times C \times \mathrm{FIR}}{\mathrm{RfD} \times W\mathrm{AB} \times \mathrm{TA}} \times 0.001 \qquad (1)$$

where Ef is the frequency of exposure (days/year), ED is the exposure duration (years), FIR is the rate of food intake (g/person/day), C is the metal concentration in seafood (μg g^{-1}), RfD is the oral reference dose (Cd = 1.0×10^{-3} μg g^{-1}/day and Pb = 4.0×10^{-3} g g^{-1}/day) (US EPA 2013), W_{AB} is the body weight (kg), and TA is the average time of exposure to non-carcinogenic compounds (365 days/year × ED).

For the assessment of exposure, the levels of metals in three seafood groups (mollusks, crustaceans, and fish) were considered, and two critical scenarios were simulated: scenario 1 (SC1) and scenario 2 (SC2). The first scenario considers as a reference the data collected directly from the volunteers from the study community, and in the second scenario (SC2), the data used were the

estimates by the US EPA (2013) for the general population. In SC1, the ED was considered the lifetime of each individual, i.e., the age in years of the respondents. At SC2, the ED corresponded to the average lifetime of a person in the general population (70 years). For SC1, the FIR used was that reported by the volunteers, and the W_{AB} used was the weight of each individual measured at the time of the interview. The FIR in the SC2 corresponded to the sum of the average intake of fish in the general population, and the W_{AB} was the average weight of the population (70 kg). The other parameters are the same for both scenarios (RfD and TA). The oral route was considered the main route of exposure for this study population because none of them were smokers, and very few reported living or working with a smoker. The aim of this study was to evaluate the non-carcinogenic risks for both scenarios as represented by the equation of target risk hazard (THQ), which intends to estimate the oral daily exposure of the exposed population to certain chemicals. The RfD of each metal were retrieved from the toxicological database (US EPA's) Integrated Risk Information System (IRIS) (US EPA 2013), which were derived from the dose at which there are no observed adverse effects (NOAEL) and lowest dose where there is an adverse effect (LOAEL) data.

Results and discussion

Analytical quality assurance

The precision of the method was assessed by the coefficient of variation of three analytical replications, using the same measurement procedure, analyst, and equipment. The precision of the method proved to be satisfactory for the obtained results. For all elements, the value of the coefficient of variation was below 8 % (Table 1) and was in accordance with the Normative Instruction 24/2009 of the MAPA (Brazil 2009).

The evaluation of the method's accuracy was performed by recovery and comparison with CRM values. The results obtained for the recovery test, in three fortification levels of the inorganic contaminants (0.5, 1.0, and 1.5 μg g^{-1} for Cd and Pb), were satisfactory, ranging from 96 to 100 %. The use of CRM showed consistent results for all elements (Table 1).

The analytical sensitivity for Cd determination was considered good, with an LOD value on the order of 0.001 μg g^{-1} dry weight. This value is comparable with data reported by Morgano et al. (2011), which found 0.01 μg g^{-1} wet weight, and Morgano et al. (2014), which related the LOD for Cd of 0.006 μg g^{-1} for seafood. In relation to Pb, the analytical sensitivity can also be considered good because the LOD value was 0.042 μg g^{-1}, as that found by Morgano et al. (2014) was 0.018 μg g^{-1}, and it was much better than the result of Sanches Filho et al. (2013) who reported LOD for Pb at 1.50 μg g^{-1}. Psoma et al. (2014) reported results for Cd and Pb with greater sensitivity, the method's LOD were 0.0005 and 0.018 μg g^{-1} for the simultaneous determination of Cd and Pb in seafood samples, respectively.

Heavy metal levels

The annual average concentrations of Cd and Pb (mean ± SD) in the edible portion of seafood are presented in Table 2. Cd levels (*w*/*w*) were detected in every seafood and were highest in mollusks (0.446 ± 0.034 μg g^{-1}), followed by crustaceans (0.007 ± 0.001 μg g^{-1}) and fish (0.001 ± 0.0003 μg g^{-1}). Pb concentrations were found in fish (0.044 ± 0.003 μg g^{-1}) and mollusks (0.111 ± 0.009 μg g^{-1}). In crustaceans, the levels were below the method's LOD (<0.042 μg g^{-1}). All levels observed were below the limits set for human consumption, both by the Brazilian legislation (RDC 42/2013-ANVISA, Cd = 0.50, 0.05, and 2.00 μg g^{-1} and Pb = 0.50, 0.30, and 1.50 μg g^{-1} for crustaceans, fish, and bivalve mollusks, respectively) and by the international legislations, such as the European Commission Regulation (CE) no. 629/2008, as well as by ATSDR (2013) and US EPA (2013).

The temporal analyses show that the concentrations of Cd and Pb in crustaceans and mollusks collected in the region, between November 2013 and September 2014, were in detectable levels throughout the sampling period, as shown in Fig. 2a, b. The mean concentrations of Cd in bivalve mollusks ranged from 0.238 to 0.636 μg g^{-1} (Fig. 2a). These concentrations were substantially higher than those observed in crustaceans (0.0046 to 0.011 μg g^{-1}). The bivalve ability to concentrate large amounts of Cd is well known (Storelli 2008). It was also observed that Cd levels were found in fish, in two periods, March and May, with similar values (0.0006 μg g^{-1}). These data confirm that there is no tendency of biomagnification of Cd in fish tissues along the food chain; however, these results are within the

Table 1 Figures of merit of the analytical methods for the determination of Cd and Pb in seafood

Metal	CV (μg g^{-1})	MV (μg g^{-1})	LOD (μg g^{-1})	LOQ (μg g^{-1})	Precision (CV) (%)	Accuracy (%)
Cd	2.48 ± 0.08[a]	2.48	0.001	0.001	0.93	100
Pb	0.31 ± 0.009[a]	0.30	0.042	0.102	7.07	96

CV certified value, *MV* measured value, *LOD* limit of detection, *LOQ* limit of quantification

[a] The Certified Reference Material used was oyster tissue (SRM) 1566b, NIST, USA

[b] The Certified Reference Material used was human hair spiked (IAEA 085) International Atomic Energy Agency, Vienna, Austria

range of values reported for marine mangrove organisms (Storelli 2008).

As can be seen in Table 2, significant levels of Pb were observed only in fish and mollusks, while in crustaceans, the levels observed were below the LOD. The Pb in fish was only detected in May (0.044 μg g^{-1}); in mollusks, it was present throughout the monitoring period, ranging from 0.086 to 0.151 μg g^{-1} (Fig. 3). This behavior is similar to other data that report a decrease in Pb levels in the marine environment (Kim et al. 2013; Storelli 2008).

Guérin et al. (2011) reported an average value of 0.011 μg g^{-1} for Pb in the fish types snapper, eel, scorpion fish, and sardines, which were the most contaminated species (ranging from 0.024 to 0.047 μg g^{-1}); however, none of them exceeded the maximum levels set by the European Regulation (CE) no. 629/2008 (0.30 μg g^{-1} in the fish muscle). The authors also found Pb at a mean level of 0.068 μg g^{-1}, with the crustacean species being the most contaminated (0.351 μg g^{-1}), followed by mollusks (between 0.101 and 0.148 μg g^{-1}). Similarly, none exceeded the maximum level established by the same regulation, 0.50 μg g^{-1} for crustaceans and 1.5 μg g^{-1} for bivalve mollusks).

In a study conducted by the environmental agency of the State of Bahia, INEMA (CRA 2005), the levels of Cd and Pb in crustaceans, fish, and mollusks captured in the same bay of the current study did not exceed the limits established by the Brazilian regulation, ANVISA No. 685/98 (Brazil 1988).

Table 2 Annual average concentrations (μg g^{-1} wet weight) of heavy metals found in seafood captured from the Aratu Bay

	Crustaceans		Fish		Mollusks	
Analyte	Mean	SD	Mean	SD	Mean	SD
Cd	0.007	0.001	0.001	0.0003	0.446	0.034
Pb	<0.042	–	0.044	0.003	0.111	0.009

SD standard deviation

Risk analysis

For the purpose of estimating the community's seafood consumption risk, 55 volunteers were interviewed with full data collection. From a total 350 adults, our sample size represents only 15.7 % of the adult population. The large majority (96 %) of them were women. The average age was 35 years, ranging from 17 to 62 years.

According to the interviewees, the majority (78.3 %) used to consume three types of seafood, i.e., crustaceans, fish, and mollusks, throughout the year. The consumption of only one type of seafood was restricted to 12.7 % of the people and two types to 9 % of them. It was identified that 14.5 % of the responders consumed some type of seafood at least once a year, 40 % monthly, 67.3 % weekly, and only 5.5 % reported consuming at least one type of seafood daily. It was also observed that approximately 54.5 % of the volunteers reported consuming more than 12.0 kg of seafood per year, which is the targeted seafood consumption stipulated by the World Health Organization (Sartori and Amancio 2012).

According to the Brazilian Population Census Agency (IBGE 2010), who conducted the Family Budget Survey (POF) 2008–2009, the average per capita of household purchases of seafood in Brazil was estimated at 4.0 kg per year; in urban areas, this figure was 3.3 kg and in rural areas 7.6 kg. The Statistical Bulletin of Fisheries and Aquaculture—Brazil (2010) reports that seafood consumption in Brazil in 2009 was 9 kg/per capita/year (Brazil 2010), and the Ministry of Fisheries and Aquaculture (MPA 2013) reported a yearly average below the per capita in the country, which reached 11.2 kg in 2011. Overall, there was an increase of 14.5 % during the period. In 2 years (2010 and 2011), the growth in demand for fish and seafood increased, on average, 23.7 % (MPA 2013).

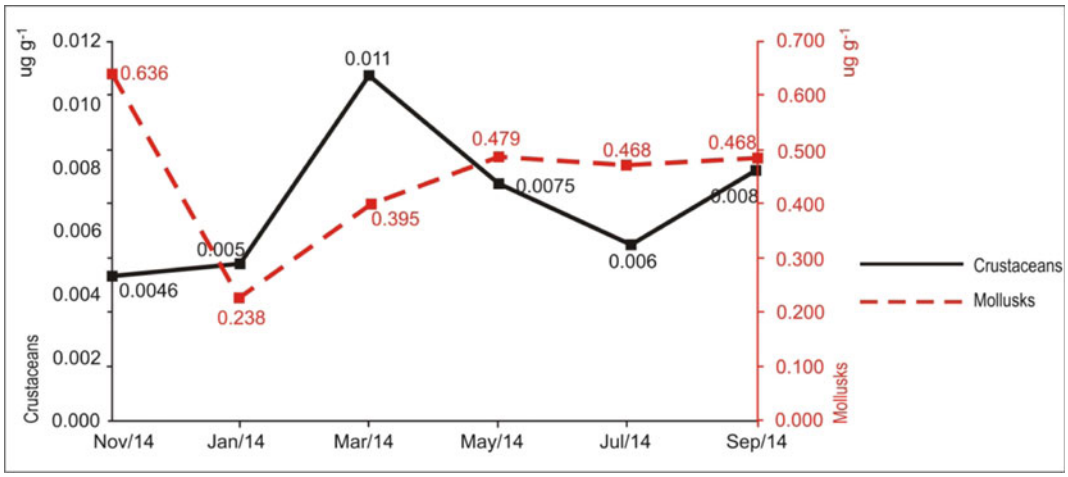

Fig. 2 Bimonthly average Cd concentrations in crustaceans and mollusks

For calculation purposes and comparison of the SC1 with the scenario normally used by the US EPA (2013) (SC2), we used the average of individual THQ that was calculated for each interviewed individual. From the individual THQ calculations (SC1), it was observed that 90.9 % of the people presented a THQ <1.0, i.e., a risk classified as insignificant, and 9.1 % had a risk considered low, i.e., THQ ≥1.0 to <9.9. The higher risk values were precisely observed in individuals who reported higher seafood consumption. Individuals who had the THQ between 1.07 and 1.12 declared the consumption of some type of seafood twice a day to five times a week, which was equivalent to the consumption of 122 to 175 g/day of seafood. At the upper limit of this range, two individuals had an estimated THQ of 4.29 and 8.07 due to the daily consumption of seafood, two to four times a day, or 572 to 758 g/day, respectively.

As the results of the metal levels found in each species were below the limits established by the Brazilian regulations (Brazil 2013), the associated THQ was calculated with multiple exposure situation (TTHQ), i.e., taking into account the sum of consumption of all types of seafood, i.e., crustaceans, fish, and mollusks, and according to each responder consumption.

According to the data presented in Table 3, the TTHQ estimated for seafood consumption in SC1 was 0.58 and 0.44 in SC2. In both cases, a negligible risk was characterized (THQ <1.0).

The results of the TTHQs, although both negligible, indicate that the risk was higher in SC1 than in SC2, and this was due to the elevated consumption reported by

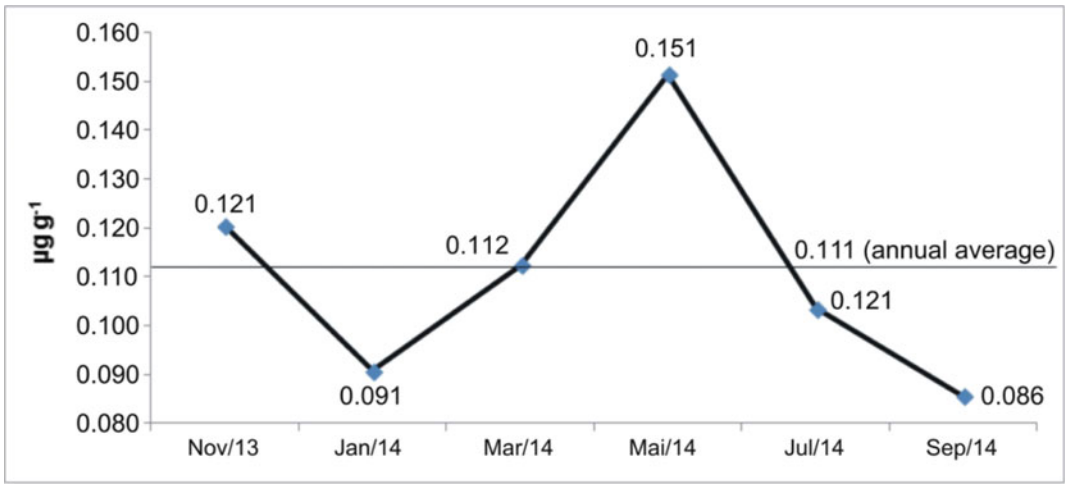

Fig. 3 Bimonthly average of Pb concentrations in mollusks

Table 3 Quotient of non-carcinogenic risk in each scenario

Scenarios	THQ (Cd)	THQ (Pb)	TTHQ[a]
SC1	0.532	0.050	0.582
SC2	0.409	0.035	0.444

[a] Sum of THQs of individual metals

certain individuals in the community. Because of the higher concentration in seafood, especially mollusks, Cd represents the largest source of risk to human health in populations whose main sources of protein are seafood, especially mollusks (Table 4).

In a study carried out in the community of Mapele, near the Village of Santa Luzia, by the environmental agency of the State of Bahia, INEMA (CRA 2005), the THQ values associated with Cd and Pb levels present in consumed mollusks and crustaceans were 5.0 and 1.4, respectively, which were classified as low risks of exposure to these metals due to the consumption of such seafood. The quotient of non-carcinogenic risk associated with fish consumption was classified as negligible for both Cd (THQ = 0.1) and Pb (THQ = 0.04). These data are very similar to the data reported in this current study.

These heavy metals may be associated with several effects on the biota, including human health (Krishna and Madhusudhana Rao 2014; Ali et al. 2016; Kibria et al. 2016; Mendoza-Carranza et al. 2016). The extent of the impact may vary among and between species. Depending on a metal's intrinsic toxicity, the risk to human health may be very different. Thus, environmental agencies and public health decision makers are responsible for setting regulatory reference values.

The risk estimate reported here was strongly influenced by the capacity of heavy metal bioaccumulation by each fish or shellfish species evaluated. The crustacean group represents the lowest risk of consumption, followed by fish and, lastly, by the mollusks. This later seafood group presented the highest possibilities of risks associated with heavy metal contamination, mostly due to cadmium levels.

Table 4 Quotients of non-carcinogenic risk due to consumption of each group of seafood

Metals	THQ (Cd)	THQ (Pb)	TTHQ
Crustaceans	0.006	–	0.006
Fish	0.001	0.010	0.011
Mollusks	0.401	0.025	0.426
Total	0.408	0.035	0.443

Scenario 2 was used to obtain this THQ

The major limitation of our study is the small number of volunteers from the studied community, which represented less than 20 % of the adult population. More importantly is the fact that almost all of them were women. The difficulty to have male participation in studies has been reported previously, especially in those that are health-related investigations (Harrison et al. 2016; Glass et al. 2015). However, the information provided by these female volunteers was probably more accurate than those that would have been provided by the male ones.

Conclusions

This study provided an evaluation of the Cd and Pb levels in crustaceans, fish, and mollusks from the Aratu Bay, in Bahia, Brazil, along with an estimate of the risk derived from the seafood consumption by the local community in two different scenarios. The metal levels observed in this study were below the limits established by the Brazilian and international guidelines (Brazil 2013) for the studied seafood groups; however, the cadmium levels observed here suggest that some people may be exposed to elevated doses and, thus, may be at a greater risk. This finding was observed in both designed scenarios.

Populations who report relatively high seafood consumption, such as this one from the community of Santa Luzia in Bahia, may be more likely to develop toxic damage from heavy metal contamination, such as chronic renal injury. The calculated risk for the majority of this population (90.9 %) was considered at a negligible risk; however, 9.1 % of the population presented higher hazard quotient values, which were classified as at low risk. These findings should be taken into consideration for future assessments, and they indicate a greater chance of risk if associated with the consumption of the toxic metal in other groups of seafood or in other food types that are rich in these elements, such as animal organs (kidney, liver, etc.) or contaminated grains.

The risk assessment has assumed a growing importance in recent years, considering the concern about food safety, public health, and environmental problems. Based on these results, especially with the high consumption reported by populations like this, it is strongly

recommended that studies be carried out with larger samples and a wider variety of food groups that represent the ecosystem biota and the population's protein source.

Acknowledgments We would like to express our thankfulness to the inhabitants of the Santa Luzia community who participated as volunteers in this study. This investigation was partially supported by the Federal University of Bahia Bolsa de Produtividade em Pesquisa grant number 7081/2014 and a master's scholarship to Araujo, C.F.S. from Fundação de Apoio a Pesquisa do Esato da Bahia (FAPESB).

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest.

References

Ali, M. M., Ali, M. L., Islam, S., & Rahman, Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring and Management*. doi:10.1016/j.enmm.2016.01.002.

Amado-Filho, G. M., Salgado, L. T., Rebelo, M. F., et al. (2008). Heavy metals in benthic organisms from Todos os Santos Bay, Brazil. *Brazilian Journal of Biology, 68*(1), 95–100.

Antunes, C. G. C. (2006). *Analysis of Rhizophora mangle L. leaves submitted to the environmental impacts of the municipality of Santo Amaro–Bahia* (p. 75). Bahia: Monograph, Catholic University of Salvador.

ATSDR - Agency for toxic substances and disease registry. (2013). Minimal risk levels for hazardous substances. Washington. Available at: http://www.atsdr.cdc.gov/mrls.html. Access jan 2015.

Bahia. (1980). Department of Industry and Trade. Department of Industry and Trade. Master Plan CIA (Industrial Centre Aratu). Salvador, Bahia, Brazil, 67

Bonfim, I.C.V. (2005). Environmental quality assessment of mangrove areas impacted by industrial activities of the Todos os Santos Bay. Dissertation (master), Federal University of Ceara, Brazil, 116.

Brandão, G.C. (2010). Sample preparation alternative strategies for the determination of metals in foods by atomic absorption spectrometry flame. Dissertation (master)—Federal University of Bahia, Institute of Chemistry, Salvador, Bahia, Brazil, 95.

Brazil (1988). Ministry of Health. Health Surveillance Secretariat. Approves the technical regulation: general principles for maximum levels of establishment of chemical contaminants in food and its annex maximum tolerance limits for inorganic contaminants. Ordinance 685, 27/08/1998

Brazil (2009). Ministry of Agriculture, Livestock and Supply. Instruction 24, 14/07/2009. Defines the requirements and criteria for operation of the waste analysis laboratories and contaminants in food members of the National Agricultural Laboratory Network. Official Gazette. Brasília, Section I, 138, 7

Brazil. (2010). Ministry of Fisheries and Aquaculture. Statistical bulletin of fisheries and aquaculture—Brazil 2010. Brasília: MPA

Brazil. (2013). National Health Surveillance Agency. Mercosur technical regulation on maximum contaminant inorganic in food. RDC 42, 29/08/2013

Brito, R.R.C. (1997). Capítulo I: Ambientes aq. Chapter I: aquatic environments. Part II: the Bay of All Santos today—natural Scenery. In: UFBA-NIMA. Todos os Santos Bay: environmental diagnosis and allowance for management. Bahia: Germen, 69–78

Celino, J. J., & Queiroz, A. F. S. (2006). Source and degree of contamination by polycyclic aromatic hydrocarbons (PAHs) Low molecular mass of sediment. Todos os Santos Bay, Bahia. *REM: Copper Mines School, 59*, 265–270.

Copat, C., Arena, G., Fiore, M., Ledda, C., Fallico, R., Sciacca, R., & Ferrante, M. (2013). Heavy metals concentrations in fish and shellfish from eastern Mediterranean Sea: consumption advisories. *Food Chemical Toxicology, 53*, 33–37. doi:10.1016/j.fct.2012.11.038.

Costa, A.B., Zucchi, M.R., Azevedo, A.E.G., Santos, V.L.C.S., Azevedo, E.R., Bonagamba, T.J., (2008). Characterization of organic matter in sediments of Todos os Santos Bay. In: Queiroz, A.F., Celino, J.J. (Eds.). Environments evaluation in Todos os Santos Bay. RECUPETRO_PROAMB. 173–187.

CRA (2005). Preliminary analysis of risk to human health. Summary report. Consortium BTS Hydros CH2MHILL. State Government of Bahia. 43.

European Commission - Cowi. (2002). Heavy metals in waste: final report. Denmark: Cowi A/S. Available at: <http://ec.europa.eu/environment/waste/studies/pdf/heavy_metalsreport.pdf>. Access: 12 dez. 2014.

Ferreira, A.N. (2011). Dredging impact assessment on phytoplankton association Porto de Aratu, Todos os Santos Bay–Salvador. Dissertation (master) Postgraduate Program in Geochemistry: Oil and the Environment - POSPETRO, Institute of Geosciences, University Federal da Bahia, 73.

Garcia, K. S., De Oliveira, O. M. C., & De Araújo, B. R. N. (2008). Leaves of biogeochemistry Avicennia Schaueriana in the northern Todos os Santos Bay. In A. F. Queiroz & J. J. Celino (Eds.), *Environment evaluation in Todos os Santos Bay* (pp. 213–232). Salvador: PROAMB, UFBA.

Glass, D. C., Kelsall, H. L., Slegers, C., et al. (2015). A telephone survey of factors affecting willingness to participate in health research surveys. *BMC Public Health*. doi:10.1186/s12889-015-2350-9.

Guérin, T., Chekri, R., Vastel, C., Sirot, V., Volatier, J.-L., Leblanc, J.-C., & Noël, L. (2011). Determination of 20 trace elements in fish and other seafood from the French market. *Food Chemistry, 127*, 934–942.

Harrison, J. M., Jung, M., Lennie, T. A., et al. (2016). Refusal to participate in heart failure studies: do age and gender matter? *Journal of Clinical Nursing*. doi:10.1111/jocn.13135.

Hatje, V., Bícego, M. C., Carvalho, G. C., & Andrade, J. B. (2009). *Todos os Santos Bay: oceanographic aspects/chemical contamination* (p. 306). Salvador: EDUFBA.

Horta, M. A. P., Ferreira, A. P., Luzardo, A. J. R., Brignol, V., Brasil, V. I., Faro, A. R. M. C., et al. (2011). Risk analysis of cadmium intake by fish consumers in a sub-tropical coastal Lagoon, Sepetiba Bay-Se, Brazil. *Journal of Health Promotion, 24*(1), 46–53.

IBGE, Brazilian Institute of Geography and Statistics. (2010). Consumer Expenditure Survey 2008–2009: household food acquisition per capita. Rio de Janeiro. Available at: http://www.ibge.gov.br/home/estatistica/populacao/condicaodevida/pof/2008_2009_encaa/pof_20082009_encaa.pdf. Access 09/12/2014.

Iupac, International Union of Pure and Applied Chemistry. (1997). Chemistry compendium of chemical terminology. 2. Available at: http://old.iupac.org/publications/compendium/. Access 12/12/2014.

Kibria, G., Hossain, M., Mallick, D., et al. (2016). Trace/heavy metal pollution monitoring in estuary and coastal area of Bay of Bengal, Bangladesh and implicated impacts. *Marine Pollution Bulletin*. doi:10.1016/j.marpolbul.2016.02.021.

Kim, D., Bloom, M. S., Parsons, P. J., Fitzgerald, E. F., Bell, E. M., Steuerwald, A. J., & Fujimoto, V. Y. (2013). A pilot study of seafood consumption and exposure to mercury, lead, cadmium and arsenic among infertile couples undergoing in vitro fertilization (IVF). *Environmental Toxicology Pharmacology, 36*, 30–34. doi:10.1016/j.etap.2013.02.006.

Krishna, P. V., & Madhusudhana Rao, K. M. (2014). Human health risk assessment of heavy metal accumulation through fish consumption, from Machilipatnam Coast, Andhra Pradesh, India. *International Research Journal of Public and Environmental Health, 1*(5), 121–125.

Liu, P., Wang, C.-N., Song, X.-Y., & Wu, Y.-N. (2010). Dietary intake of lead and cadmium by children and adults—result calculated from dietary recall and available lead/cadmium level in food in comparison to result from food duplicate diet method. *International Journal of Hygiene Environmental Health, 213*, 450–457. doi:10.1016/j.ijheh.2010.07.002.

Martins, R.J.E. (2004). Accumulation and release of heavy metals by aquatic bióftas. Thesis (PhD in Chemical Engineering)—University of Porto, Porto, Portugal. 650.

Mendoza-Carranza, M., Sepúlveda-Lozada, A., Dias-Ferreira, C., & Geissen, V. (2016). Distribution and bioconcentration of heavy metals in a tropical aquatic food web: a case study of a tropical estuarine lagoon in SE Mexico. *Environmental Pollution*. doi:10.1016/j.envpol.2015.12.014.

Menezes-Filho, J. A., Paes, C. R., Pontes, A. M. C., Moreira, J. C., Sarcinelli, P. N., & Mergle, D. (2009). High levels of hair manganese in children living in the vicinity of a ferro-manganese alloy production plant. *Neurotoxicology*. doi:10.1016/j.neuro.2009.04.005.

Menezes-Filho, J. A., de Novaes, C. O., Moreira, J. C., Sarcinelli, P. N. S., & Mergler, D. (2011). Elevated manganese and cognitive performance in school-aged children and their mothers. *Environmental Research*. doi:10.1016/j.envres.2010.09.006.

Menezes-Filho, J. A., Carvalho-Vivas, C. F., Viana, G. F. S., Ferreira, J. R. D., Nunes, L. S., Mergler, D., & Abreu, N. (2014). Elevated manganese exposure and school-aged children's behavior: a gender-stratified analysis. *Neurotoxicology*. doi:10.1016/j.neuro.2013.09.006.

Morgano, M. A., Oliveira, A. P. F., Rabonato, L. C., Milani, R. F., Vasconcellos, J. P., Martins, C. N., et al. (2011). Evaluation of inorganic contaminants (As, Cd, Cr, Hg e Pb) species of fish. *Journal Institute Adolfo Lutz., 70*, 497–506.

Morgano, M. A., Rabonato, L. C., Milani, R. F., Miyagusku, L., & Quintaes, K. D. (2014). As, Cd, Cr, Pb and Hg in seafood species used for sashimi and evaluation of dietary exposure. *Food Control*. doi:10.1016/j.foodcont.2013.07.036.

MPA. (2013). Ministry of Fisheries and Aquaculture. Statistical bulletin of fisheries and aquaculture, Brazil. Brasília. Available at: http://www.mpa.gov.br/images/Docs/InformacoeseEstatisticas/Boletim%20MPA%202011FINAL.pdf. Access 14/12/2014.

Noël, L., Vastel, C., Chekri, R., Chafey, C., Testu, C., & Guérin, T. (2009). Evaluation of 10-years French NRL proficiency tests for lead, cadmium and mercury analysis in foodstuff of animal origin. *Microchemical Journal*. doi:10.1016/j.microc.2009.01.001.

Olmedo, P., Pla, A., Hernández, A. F., Barbier, F., Ayouni, L., & Gil, F. (2013). Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. *Environment International*. doi:10.1016/j.envint.2013.05.005.

Petroczi, A., & Naughton, D. P. (2009). Mercury, cadmium and lead contamination in seafood: a comparative study to evaluate the usefulness of Target Hazard Quotients. *Food Chemical Toxicology*. doi:10.1016/j.fct.2008.11.007.

Psoma, A. K., Pasias, I. N., Rousis, N. I., Barkonikos, K. A., & Thomaidis, N. S. (2014). Development, validation and accreditation of a method for the determination of Pb, Cd, Cu and As in seafood and fish feed samples. *Food Chemistry*. doi:10.1016/j.foodchem.2013.11.045.

Sanches Filho, P. J., Da Fonseca, V. K., & Holbig, L. (2013). Metals assessment in fish of the region Pontal da Barra, Lagoon dos Patos, Pelotas-RS. *Ecotoxicology And Environmental Contamination*. doi:10.5132/eec.2013.01.015.

Santos, L. F. P., Trigueiro, I. N. S., Lemos, V. A., et al. (2013). Assessment of cadmium and lead in commercially important seafood from São Francisco do Conde, Bahia, Brazil. *Food Control*. doi:10.1016/j.foodcont.2013.02.024.

Sartori, A. G. O., & Amancio, R. D. (2012). Fish: nutritional importance and consumption in Brazil. *Food and Nutrition Security, 19*, 83–93.

Storelli, M. M. (2008). Potential human health risks from metals (Hg, Cd, and Pb) and polychlorinated biphenyls (PCBs) via seafood consumption: estimation of target hazard quotients (THQs) and toxic equivalents (TEQs). *Food Chemical Toxicology*. doi:10.1016/j.fct.2008.05.011.

US EPA—United States Environmental Protection Agency. (2013). Risk assessment information system—RISK. Available at: <http://rais.ornl.gov/cgi-bin/prg/RISK_search?select=chem>. Access: January 2015.

Viana, F., Huertas, R., & Danulat, E. (2005). Heavy metal levels in fish from coastal waters of Uruguay. *Environmental Contamination and Toxicology, 48*, 530–537.

Viana, G. F. S., Carvalho, C. F., Nunes, L. S., et al. (2014). Noninvasive biomarkers of manganese exposure and neuropsychological effects in environmentally exposed adults in Brazil. *Toxicology Letters*. doi:10.1016/j.toxlet.2014.06.018.

Wang, S.-L., Xu, X.-R., Sun, Y.-X., Liu, J.-L., & Li, H.-B. (2013). Heavy metal pollution in coastal areas of South China: a

review. *Marine Pollution Bulletin*. doi:10.1016/j.marpolbul.2013.08.025.

World Health Organization—WHO. (1989). *Environmental health criteria 85: lead—environmental aspects*. Geneva: ONU.

World Health Organization—WHO. (1991). *Environmental health criteria 118: inorganic mercury*. Geneva: ONU.

World Health Organization—WHO. (1995). *Environmental health criteria 165: inorganic lead*. Geneva: ONU.