METALS IN MUSCLES OF MULLET (*Mugil curema*) FROM A CONTAMINATED ESTUARY: EVIDENCES OF POTENTIAL RISKS TO PUBLIC HEALTH

ABSTRACT

The São Vicente Channel and Estuary (SVCE) system is located in Baixada Santista metropolitan region (São Paulo State, Brazil) that contains fairly degraded areas where metal-contaminated waters and sediments are observed. Many of these metals can be incorporated into the aquatic food webs by accumulation into organisms such as filter feeders and fishes, with unpleasant consequences for public health. The present study aimed to assess the concentrations of Fe, Cr, Ni, Zn, Mn and Cu in the muscle tissues of mullets (*Mugil curema*) collected in two tributaries of SVCE and to estimate the risks of intoxication resulting of human consumption of this species. Sampling sites were Branco and Mariana rivers while the Itaguaré River was used as reference area. Fishes were collected with casting nets and Atomic Absorption Spectroscopy (AAS) methods were used for chemical analyses. The mean concentrations of Cr and Ni exceeded the limits established by Brazilian and International standards. The long-term risks for human health associated with fish consumption were estimated for different exposure sceneries, following the method proposed by the United States Environmental Protection Agency. In both rivers, the results evidence risks for human health due to Cr contamination, in sceneries of for frequent consumption of M. curema.

PALAVRAS-CHAVE: Mugil curema; Metals; São Vicente; Risk Assessment; Bioaccumulation.

METAIS EM MÚSCULOS DE PARATI (*Mugil curema*) DE UM ESTUÁRIO CONTAMINADO: EVIDÊNCIAS DE RISCOS POTENCIAIS PARA A SAÚDE PÚBLICA

RESUMO

O estuário e o canal de São Vicente localizam-se na região metropolitana da Baixada Santista, Estado de São Paulo, Brasil e podem ser considerados exemplos de ambientes degradados, com contaminação das águas e sedimentos. A biota aquática é capaz de acumular contaminantes do ambiente e transferi-los pela cadeia trófica, incluindo os seres humanos. Assim, este estudo visou avaliar as concentrações de alguns metais (Fe, Cr, Ni, Zn, Mn e Cu) em músculos de Paratis coletados em dois tributários do estuário de São Vicente e estimar riscos de intoxicação associados ao consumo deste peixe pelas populações locais. Os pontos de coleta foram os Rios Branco e Mariana e o Rio Itaguaré como referência não poluída. Os peixes foram coletados com redes e as análises químicas feitas por Espectroscopia de Absorção Atômica. Os níveis médios de Cr e Ni foram considerados altos e acima dos limites estabelecidos pela legislação brasileira e internacional. Além disso, riscos de longo-prazo devido ao consumo desse peixe foram estimados para diferentes cenários, de acordo com abordagem proposta pela Agência de Proteção Ambiental Norte-Americana (USEPA). Para o Cromo, nos rios Branco e Mariana, foram evidenciados riscos possíveis nos cenários de consumo frequente.

KEYWORDS: *Mugil curema*; Metais; São Vicente; Avaliação de Risco; Bioacumulação.

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INTRODUCTION

Metals are naturally present in the environment, as chemical components of rocks, soils, sediments, waters and atmosphere, and also participating of some biological reactions and structures of the living organisms (CLARK, 1997). However, high concentrations of heavy metals in the environment have been reported as a result of anthropic activities (AGUIAR et al., 2008; ACOSTA et al., 2002; LUIZ-SILVA et al., 2006; BIDONE et al., 2001; FRAZIER, 1972; CORRILL and HUFF, 1976), such as industries, ports, mining, solid wastes dumping and sewage disposal, among others; in order that they are considered important contaminants in coastal areas all over the world (AGUIAR et al., 2008; ABESSA et al., 2005; ABESSA et al., 2008; BENEDICTO et al., 2008).

Fishes have been widely used as models to evaluate the aquatic contamination by metals (DOĞAM-SAĞLAMTIMUR and KUMBUR, 2009; KEHRIG et al., 1998; LIMA Jr et al., 2002). The concentration of contaminants, including metals, in fish tissues is commonly reported as dependant of age, feeding habits and position in the food chain (TRUCCO et al., 1990). The contaminants accumulated in the biota may be further transferred to the man through the consumption of contaminated seafood (TAVARES and CARVALHO, 1992; SANTOS-FILHO et al., 1993; METIAN et al., 1998). Afterwards, short- and long-term effects may occur, and normally involve cellular, biochemical (enzymes regulation), physiological and behavioral disturbances, reproductive disorders, cognitive disturbances and even cancer (STORELLI, 2008; LIAO and PING, 2003; GOYER et al., 2004).

In Brazil, the São Vicente Channel and Estuary (SVCE) are located within Santos Estuarine System (SES), and is influenced by multiple contamination sources installed along the drainage basin (LAMPARELLI et al., 2001). Metals are among the main SVCE contaminants, thus it is important to monitor their presence in tissues of local fishes, aiming to evaluate the risks of consumption by the population (CID et al., 2001).

The fish mullet *Mugil curema* is found all over the Brazilian coast, in special in shallow waters and estuaries. This fish is filter feeding, grazing on microalgae and small zooplankton organisms. Adult individual lengths range from 22.3 to 90 cm. This species is abundant in SVCE, being captured all along the year, besides it is the most consumed fish by traditional population. Moreover, due to its abundance and broad distribution, *M. curema* is a suitable species to be employed in environmental studies, filling the pre-requisites proposed by Kang et al. (2000) for a sentinel species.

The present paper aimed to evaluate the concentration of some metals (Fe, Cr, Ni, Zn, Mn and Cu) in muscle tissues of *M. curema* individuals collected in two SVCE contributors (Branco and Mariana Rivers, respectively) and to provide initial estimations on the risks for public health due to the consumption of such animals by the local population.

MATERIAL AND METHODS

The São Vicente Channel and Estuary (SVCE) is situated within the Santos Estuarine System (SES), in Baixada Santista Metropolitan Region, on the central coast of São Paulo State (Figure 1). The fish collections were made in the summer 2006, in Branco (BR) and Mariana (MR) rivers, at their respective confluence to the São Vicente Channel (Figure 1). The control group was collected at the estuary of Itaguaré River (IR), a clean site located in Bertioga, about 50 km Northeast from SVCE.

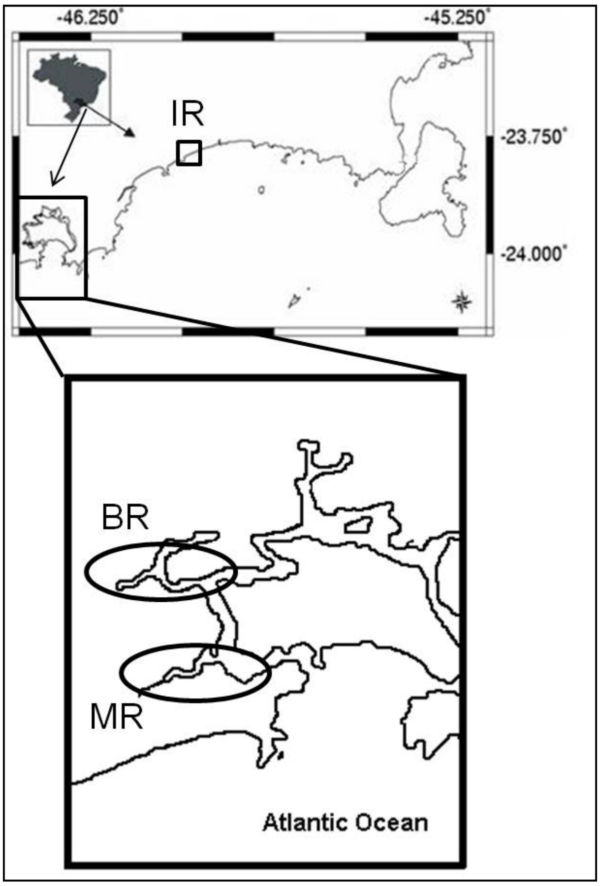

Figure 1: Map showing the studied estuaries within SES (BR and MR) and the respective reference site (Itaguaré River - IR), a clean site situated in Bertioga, about 50km Northeast from SVCE.

In each site, 15 adult individuals of *M. curema* were collected, by using a small gillnet (10 cm mesh), operated from a large canoe. The animals were immediately sacrificed by immersion in liquid nitrogen (-80ºC), transferred to boxes containing ice and taken to the laboratory, where they were stored frozen at -20ºC. In laboratory, pieces of the muscle tissues of each fish were analyzed according to Watson (1994). The quantification of the metals in each sample was made in a GBC® Atomic Absorption Spectrophotometer (AAS), model 932 AA. The following metals were analyzed: iron, chromium, zinc, copper, manganese and nickel. Results were statistically analyzed by student t'test (ZAR, 1984), to compare mean concentrations observed in samples from the two rivers. The same procedure was used to compare the control to the contaminated areas.

The collected fishes were classified for the risk of human acute intoxication due to the ingestion, based on the criteria adopted by the Brazilian Health Ministry (BRASIL, 1977); when such criteria was lacking, the United States Environmental Protection Agency (USEPA) and United States Food and Drug Administration (USFDA) (USEPA, 1997) criteria were used (Table 1).

Moreover, a Human Health Risk Assessment was conducted considering the potential long-term risks from the consumption of contaminated fishes from both rivers. Such evaluation employed the protocol described in the Manual for Managing Contaminated Areas, published by the São Paulo State Environmental Agency (CETESB, 2001). To achieve that, 3 hypothetical exposure scenarios were established, considering the data from a survey conducted by CETESB (2006), which regarded to fish and seafood consumption by urban and traditional populations in several localities of SES.

Scenery 1 regards to the daily ingestion of 300g fish meat, by an adult of 70Kg weight, for a period of 30 years. This scenery describes the subsistence consumption, by traditional communities and people for which fish is the main dietary item.

The Scenery 2 regards the ingestion of 300g fish three times week, during 30 years, by and adult of 70kg weight. This scenery represents the fish consumption as a dietary complement, which related to people who have an economic activity which is not related to fishing but obtain protein from the estuary.

The Scenery 3 regards to the ingestion of de 300g fish, once in a month, during 30 years, by a 70kg adult individual. This scenery represents the consumption of *M. curema* by the local population and the tourists, which have a diversified diet.

The sceneries did not concern for the concomitant consumption of other fishes or seafood items obtained from the SVCE, thus risks may be underestimated. Besides, the exposure duration (ED) proposed by the State Environmental Agency for the calculation is 30 years (CETESB, 2001), thus the risks may be underestimated for longer periods of exposure duration. Finally, for children and other critical groups, the estimated risks are not applicable.

Regarding the effective accessibility of consumers to the ingested metals, there is not a consensus on the amount of metals in ingested food which is effectively absorbed in the digestive tube producing an effective exposure (METIAN et al., 1998; STORELLI, 2008; LIAO and PING, 2003), thus we adopted a conservative approach which considered that all the metals contained in the fish muscles would be potentially available and could be involved in exposure (STORELLI, 2008).

The non-carcinogenic risk was estimated for each contaminant, using wet weights values, following the hazard quotient approach proposed by CETESB (2001) which was adapted from that developed by USEPA Region III Risk-based Concentration table (USEPA, 2000), and starts by the calculus of the uptake doses (I), in mg/kg/day, according to the equation (1):

(1) $$I = Cw \times \frac{IR \times EF \times ED}{Bw} \times \frac{1}{AT}$$

where Cw is the concentration of the contaminant in the fish meat (mg/kg w/w); IR is the ingestion rate of fish (0,300 kg/day); EF is the exposure frequency (365 days/year for scenery 1; 156 days/year for scenery 2; 12 days/year for scenery 3); ED is the exposure duration (30 years); Bw is the body weight (70 kg); and AT is the exposure period (12775 days).

Then, the non-carcinogenic risk (HR) was calculated, according to (2) (CETESB, 2001).

(2) $$HR = \frac{I}{RfD}$$

where I is the Uptake Dose; and R_fD is the Reference Dose, obtained from the USEPA database (IRIS) (USEPA, 1997).

If HR < 1, the risk of ingesting *M. curema* is not significant, for the respective scenario.

If HR ≥ 1, the risk of ingesting *M. curema* is significant for the respective scenario.

RESULTS AND DISCUSSION

The studied estuary is characterized by the presence of many contributors, as Mariana, Branco and Piaçabuçu rivers, and by the installation of shantytowns and inhabitations not attended, till the present, by a sewage collection system; also SVCE receives contributions from multiple contamination sources (LAMPARELLI et al., 2001; SANTOS-FILHO et al., 1993). Investigations conducted in 1970’s and 1980’s indicated that the SVCE waters and sediments were not strongly polluted (CETESB, 1981), whereas recent studies detected moderated to high levels of contamination, especially in sediments and biota (AGUIAR et al, 2008; LAMPARELLI et al., 2001; HORTELLANI et al., 2005; SANTOS-FILHO et al., 1993). Sampaio et al. (2008) and Pereira et al. (2008) recently demonstrated that nowadays SVCE is the SES sector that is more polluted by sewage.

According to the State Environmental Agency (LAMPARELLI et al., 2001), both Branco and Mariana rivers receive inputs from industrial landfills containing organochlorines and metals, as well as leachates from the Sambaiatuba domestic landfill, untreated sewage from slums and urban areas and urban drainage and stormwaters runoff. Branco River is also influenced by the effluents of a petrochemical industry, which contain Mn, Zn and Ni (LAMPARELLI et al., 2001). By its time, Mariana River receives contributions of a municipal sewage treatment plant.

Although pollution in SVCE and its contributors has increased along the recent decades, fishing and extraction of invertebrates are still made by the local population; for them, fishes and seafood constitutes the main source of proteins, and risks may occur due to consumption of contaminated food (PEREIRA et al., 2002).

Presence of metals occurs in almost all the marine organisms, but top predators and benthic fishes, as mullets, often present higher concentration of contaminants (STORELLI, 2008). The mean concentrations of metals in muscle tissues of *M. curema* are presented in the Table 2.

Table 1: Mean concentrations of Fe, Cr, Ni, Zn, Mn and Cu (± standard deviations) in muscle tissues of *Mugil curema*; and maximum consumption limits established for fishes by Brazilian and U.S. legislations and used to estimate acute risks of acute intoxication by consumption of collected fishes.

	Concentrations ($\mu g.g^{-1}$ dry weight)			
Metals	BR	MR	IR (reference)	Standards
Iron (Fe)	108.97 ± 34.77	183.05 ± 109.22	71.42 ± 61.32	-
Chromium (Cr)	4.78 ± 7.25	6.53 ± 13.11	ND	11.0[b]
Nickel (Ni)	4.09 ± 0.49	4.24 ± 0.41	1.67 ± 0.12	5.0[a]
Zinc (Zn)	28.09 ± 3.20	25.87 ± 5.34	25.60 ± 3.86	50.0[a]
Manganese (Mn)	1.34 ± 0.48	0.95 ± 0.13	1.95 ± 0.42	54.0[b]
Copper (Cu)	0.05 ± 0.14	0.07 ± 0.18	1.03 ± 1.78	30.0[a]
	Concentrations ($\mu g.g^{-1}$ wet weight)			
Iron (Fe)	28.44 ± 9.07	47.78 ± 28.51	18.64 ± 16.00	
Chromium (Cr)	1.25 ± 1.89	1.70 ± 3.42	(<0.05) ND	
Nickel (Ni)	1.07 ± 0.13	1.11 ± 0.11	0.44 ± 0.03	
Zinc (Zn)	7.33 ± 0.84	6.75 ± 1.39	6.68 ± 1.01	
Manganese (Mn)	0.35 ± 0.13	0.25 ± 0.03	0.51 ± 0.11	
Copper (Cu)	0.01 ± 0.04	0.02 ± 0.05	0.27 ± 0.46	

Where [a] Brazil (1977); [b] USEPA (1997); ND = not detectable.

Mean concentrations of Fe, Cr. Ni and Mn were higher in muscle tissues of fishes from MR and BR when compared to animals from the reference site. The concentrations of Zn were similar for fishes from all sites. The mean copper levels were much higher in the animals from the reference site (about 100 times greater that BR values and 50 times greater than MR values); however, the observed values for this element still can be considered low (LIMA Jr et al., 2002). Such results suggest that animals from SVCE are accumulating some elements in their tissues; however the higher Cu concentrations in fishes from IR should be further investigated.

When animals from BR and MR are compared, the muscle tissues of fishes from MR presented statistically higher concentrations of iron, when compared with BR fishes. However, Carmo et al (2011) observed higher concentrations of Cu and Fe in fishes from BR, whereas for other elements, concentrations of metals in fish tissues from both sites were similar. In the present investigation, the levels observed for both sites were comparable to those reported by Lima Jr et al. (2002) and Pfeiffer et al. (1985) for mullets from Sepetiba Bay. Despite iron is found naturally in soils, waters and atmosphere, its high levels in animals from SVCE may be related to industrial processes, as reported in the literature (LIMA Jr et al., 2002).

The Ni concentrations in fishes from BR and MR were significantly higher than in the reference fishes, but did not differ among themselves. Such concentrations were higher than those reported to mullets from Sepetiba Bay (LIMA Jr et al., 2002). The highest concentrations reached up to 5.15 $\mu g.kg^{-1}$ (dry weight) and were possibly related to environmental contamination (ABESSA et al., 2008; LAMPARELLI et al., 2001), and the same pollution sources indicated for Cr. Nickel is important to the cell biochemical metabolism, but may be toxic and carcinogenic, when in high concentrations (GOYER et al., 2004).

Regarding the Zn concentrations, the values found in BR, MR and IR were similar and may be considered low, although the observed values were above those reported by the State Environmental Agency (LAMPARELLI et al., 2001). Concentrations in muscle tissues were also below those reported to mullets from Sepetiba and Ilha Grande (LIMA Jr et al., 2002; PFEIFFER et al., 1985).

The manganese concentrations were significantly higher in the fishes from the reference area. However, such observed concentrations could be considered low, and were within the range observed in fishes from SES by Lamparelli et al. (2001). Still according to these authors, Mn is not of main concern contaminant, because its concentrations are low in waters, sediments and organisms and also because under estuarine conditions (high pH, low Eh, changing salinities) Mn tend to precipitate and become less mobile.

The Cu concentrations in muscle tissues of *M. curema* from the 3 sites were low, and were below those reported previously for SES (LAMPARELLI et al., 2001; CETESB, 1981) and the intervals indicated for Sepetiba Bay (LIMA Jr et al., 2001). The majority of samples exhibited values below the analytical detection limit, and the higher concentration was observed in one sample from MR (0.65 $\mu g*g^{-1}$). The Cu concentrations in muscle tissues from the 3 sites were statistically similar. However, high variation was observed among replicates collected in each site (Variation coefficients were calculated as 264.06% for BR, 280.31% for MR and 173.21% for IR).

The mean chromium concentrations were higher in fishes from both BR and MR, in comparison to fishes from the reference area (not detectable concentrations). The concentrations ranged from <0.05 (not detectable) to 23.78 $\mu g*g^{-1}$, and from not detectable to 48.43 $\mu g*g^{-1}$, for BR and MR, respectively. The concentrations in muscle tissues of fishes from BR and MR did not differ statistically. The Cr levels observed in the present study were slightly higher than those observed recently by the state environmental agency in SES fishes (LAMPARELLI et al., 2001) and were much higher than those observed previously for the same area (CETESB, 1981) and for Sepetiba Bay, which is metal-contaminated area (LIMA Jr et al., 2002). Thus, our data suggest that the Cr levels are increasing in SVCE, which is agreement to that reported by Abessa et al. (2008) for sediments.

Chromium is essential to some living organisms (BIELICKA et al., 2004). In the environment, it is found predominantly in the trivalent form, which is weakly toxic and not easily absorbed by the cells (PANDA and PATRA, 1997). The hexavalent form also occurs in the environment and is easier absorbed by the cells, producing thus higher toxicity (PANDA and PATRA, 1997; PANDA and CHOUDHURY, 2005). This element is employed in different industrial processes, in stainless steel production and in the leather treatment (LIMA Jr et al., 2002). Its presence in aquatic ecosystems affects negatively the biota, because this metal is easily adsorbed by sediment particles and penetrates into the biological membranes (NORWOOD et al., 2006).

The possible sources of chromium for SVCE may be related to the leachates from irregular industrial and domestic dumping sites, direct discharge of untreated sewage and contaminated urban drainage waters, and contributions from industrial effluents. However, further studies must be conducted to identify other possible sources and to confirm the role of the already identified ones.

The observed concentrations were also compared to the maximum consumption limits established by Brazilian and North-American Standards (Table 1). For chromium, mean concentrations in tissues from all sites were below the maximum consumption limits. However, for BR, from the 15 evaluated samples, 4 (or 36.4%) exceeded the criteria for acute human intoxication by chromium due to the consumption, according to the Unites States Food and Drug Administration (USFDA). From MR, 3 samples (27.3%) presented levels of Cr above such limits. Thus, even the sporadic consumption of *M. curema* from SVCE may cause intoxication. In addition, there must be highlighted that the current Cr contamination is greater than that observed previously (CETESB, 1981; HORTELLANI et al., 2005), when no organism exhibited Cr concentrations above the limit established by the USFDA (USEPA, 1997). High doses in humans produce several health damages, from skin ulcers to corrosion of digestive tube epithelium and kidneys necrosis (GOYER et al., 2004).

Regarding to nickel, the mean concentrations were slightly below the limits for human consumption, and for both BR and MR, from the 15 evaluated samples, one exceeded the criteria for acute human intoxication for nickel (5.0 $\mu g.kg^{-1}$), according to the Brazilian legislation (BRASIL, 1977). In humans, high doses of nickel are harmful, causing weight loss, heart and liver damage and skin problems (GOYER et al., 2004).

For Zinc, Brazil does not have a specific risk value for aquatic organisms used for human consumption, thus we adopted the concentration recommended for “other kinds of food” (50 $\mu g*g^{-1}$) according to the legislation (BRASIL, 1965); however, the measured concentrations in fishes from the 3 sites were below such value, indicating that the possibility of acute intoxication due to this element is virtually inexistent.

Acute intoxication risks were equally inexistent to Cu and Mn, since all the measured concentrations were below the limits established by the Brazilian legislation for human consumption for Cu (30.0 $\mu g*g^{-1}$) and by the US laws for Mn (54.0 $\mu g*g^{-1}$) (BRASIL, 1977; USEPA, 1997). On the other hand, for iron, there are not safe concentrations of Fe in fish tissues for human consumption, thus the risks were not estimated for such element.

The chronic risks to the human health due to the consumption of contaminated fishes were also estimated. For both rivers, significant threats due to Cr were detected for daily consumption of fishes (Table 2), and possible risks related to frequent consumption (since superior values estimated this scenery were higher than 1.

In summary, the concentrations of Cr in muscle tissues of *M. curema* may be considered high, and the consumption of this species may eventually led to intoxication episodes. Since this species is easily found in the local market, and may be consumed by the urban population, any risk may exist for these populations.

Similarly to the biota, the effects of metals in humans are influenced by the dose (i.e. concentration and exposure period), the predominant form of the metal and way of exposure. The toxicity depends also of the 1) metal uptake and absorption; 2) target tissues where transport, distribution, accumulation, bio-transformation, metabolization and effect will occur; 3) depuration and excretion capability. In each of such three phases, the element may present different forms, which may react with the biological structures (TAVARES and CARVALHO, 1992).

Table 2: Non-carcinogenic human health hazard risks due to consumption of *Mugil curema* from SVCE. For Chromium, inferior and superior intervals are shown since some risk was evidenced.

	Sampling site	Non Carcinogenic Threat					
		Cr	Ni	Zn	Mn	Cu	Fe
Scenario 1	**BR**	**2.55 (0-6.41)**	0.33	0.15	0.02	NC	NC
	MR	**3.47 (0–10.47)**	0.34	0.14	0.01	NC	NC
	IR (Reference)	>0.01	0.13	0.14	0.02	NC	NC
Scenario 2	**BR**	**0.65 (0–1.64)**	0.08	0.04	> 0.01	NC	NC
	MR	**0.89 (0–2.89)**	0.09	0.04	> 0.01	NC	NC
	IR (Reference)	> 0.01	0.03	0.03	0.01	NC	NC
Scenario 3	**BR**	0.05	0.01	> 0.01	> 0.01	NC	NC
	MR	0.07	0.01	> 0.01	> 0.01	NC	NC
	IR (Reference)	>0.01	> 0.01	> 0.01	> 0.01	NC	NC

Legend: NC= not calculated since there is not available reference dose (Rfd) for the respective element.

The Environmental Agency of São Paulo State (CETESB) has established increasing enforcements and regulations to control and eliminate the environmental contamination, which include the monitoring of coastal waters quality (CETESB, 2009; 2010). Main concern has being dedicated to the central coast of São Paulo, in special the Santos Estuarine System (SES), which presents multiple contamination sources and has some of its parts severely contaminated by metals and organic compounds (AGUIAR et al., 2008; ABESSA et al., 2008; LAMPARELLI et al., 2001; CESAR et al., 2006; MEDEIROS and BÍCEGO, 2004). As previously mentioned, within SES, the São Vicente Estuary and Channel is highlighted due to the presence of artisanal fishermen in some localities, who depend intensely on the estuary resources (CETESB, 2006), and due to urbanization at its banks, which are related to pollution in the last decades and increasing threats for fisheries.

Moreover, the daily or frequent consumption of fishes from SVCE may represent a threat to human health, in special to those people who eat *M. curema* 3 times a week or more often. Such problem becomes more complex when it is considered that both rivers are important fishing sites for local fishermen and that *M. curema* is one of the most explored species, constituting an important source of proteins for the traditional fishermen, especially those inhabiting the SVCE banks. Despite only about 5% population from SES eat fishes captured inside the estuary once in a week or more frequently, for the traditional families the consumption rates are much higher (CETESB, 2006), thus these populations cannot be considered together with others because their exposure pattern is quite higher, i.e., they are more fragile and susceptible to the contamination. Moreover, the meaning of such 5% must be brought into light: it represents more than 6,886 families, which possibly indicates that more than 25,000 people are potential targets to contaminated fishes from SES, including children, pregnant women and ancients. Therefore, the local fishermen who consume frequently *M. curema* from SVCE are exposed to chronic threats, at least for Cr.

In addition, this investigation did not concern to other contaminants, as hydrocarbons and organochlorines, which are more bioaccumulative and are present in fish and seafood from SVCE (LAMPARELLI et al., 2001; MARTINS et al., 2007; 2008; 2008a; 2011; BÍCEGO et al., 2006). Thus, there is a chance to the human health threats and risks to be higher for the local populations.

Further studies are required to measure the contamination levels in the different organisms used for local consumption, as well as to detail the consumption patterns. Additionally, efforts to properly manage the estuary must be made, as the identification and control of all contamination sources. Education programs aiming to avoid an excessive consumption of local fishes by the traditional populations will also be necessary; as part of a larger socio-environmental education program.

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