



## Mercury in the Amazon basin: Human influence or natural geological pattern?



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### ABSTRACT

One of the main scientific discussions on Hg levels in the Amazon region concerns the possible sources of this element. This research was conducted between 1999 and 2015 in the region between the coastal zone and the Amazonian Continental Shelf (ACS). The total Hg concentration values found in the sediments in ACS ranged from 14 to 160 ng g<sup>-1</sup>. The main contribution of metallic elements to ACS comes from the sedimentary load transported by the Amazon River basin. Among the main tributaries of the Amazon River, the Negro River, which for decades has had mining activity, and the Madeira River, which is still present today, although currently in decline. The analysis of the total Hg results associated with the suspended solids load, both in the Continental Amazon and ACS, suggest that the anthropogenic influence, although evident in sites sources of pollution, is not the main source of total Hg for ACS, and in this case the participation of the natural contributions should be attributed from the natural geological activity in the regional soil, which is considered as naturally enriched in Hg.

### 1. Introduction

The discussion if the main source of mercury (Hg) contamination is natural or anthropogenic in Amazon is classic and longstanding. Anyway, the sum of these two sources resulting in an immense volume of Hg, which partly is carried by the current flow associated with suspended sediments, towards the mouth of the Amazon River following the sedimentation process.

As a part of gold mining activities in Amazonia, Hg is used to form the amalgam and after that the liberation to atmosphere is estimated in up to 80%, the remaining is liberate to soil and rivers during the different phases of the gold extraction (Lacerda and Pfeiffer, 1992). The Hg in atmosphere has a short residence time and is deposited still near the source. The interaction of the metal forms in aquatic environment depend on the chemical forms and the physical and chemical properties of the water and commonly the metallic Hg present low mobility due to its association with the sediment and favoring the sedimentation. In the bottom, the biological metilation is encouraged, and the organic forms occur. The dissolved forms showed smaller importance in relationship the particulate forms in river environment overall in function of the solubility properties. Lacerda and Pfeiffer (1992) mentioned that

Amazonian rivers not influenced by mining activities show concentrations between 0.02 and 0.1 µg g<sup>-1</sup>, while in contaminated rivers, varied between 0.5 and 4.0 and could be reaching 19 µg g<sup>-1</sup>.

The natural composition of the Amazonian soil is considered enriched in Hg as explained by researchers in 90<sup>th</sup> decade (Roulet and Locotte, 1995), while attribute this richness to iron complex formed, process not so cleared and intensively discussed. This soil composition considered in large scale could contribute to the natural Hg signals on the near continental shelf of Amazon. Added to it, the consideration of the transport associated to suspended particulate matter is the way to reach long distances, for example the inner platform, from the without effective record in the bottom rivers, those not found important concentration in the river sediment.

The consideration of the both sources i.e. natural and anthropogenic of Hg transported by the Amazon river that represent about 18% of the world fluvial discharge (average ~180 000 m<sup>3</sup> s<sup>-1</sup>) (Goulding et al., 2003) with elevated solid suspended matter associated, about ~1.2 × 10<sup>9</sup> t year<sup>-1</sup> (Meade et al., 1985; Nittrouer et al., 1995), once reaching the continental platform will submitted to a coastal dynamic, mainly the influence of northwestward flowing North Brazilian Current along the American continent toward the Caribbean Seathe upper layer

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(Bourlès et al., 1999; Oudot et al., 1999). Associated to the river discharge, the suspended particulate matter receives the upper oceanic circulation influence on the material deposition on the shallow continental shelf.

The sediments that reach the Amazon Continental Shelf (ACS) from the Amazon River basin are formed by muddy material rich in organic matter, which is eventually deposited mainly in the inner part of the shelf due to the strength of the ocean (Siqueira et al., 2004; Siqueira and Aprile, 2012; Siqueira et al., 2016). This characteristic of the environment in to accumulate finer sediments in the inner shelf has important consequences for the complexation of metals, especially Hg. Aspects such as mobility and bioaccumulation of the metallic elements are directly associated with the chemical conditions, especially pH and oxy-reduction potential of the solution, and associated load of silt and silty-clay sediments with organic matter. In this way, the fluvial regime of the Amazon River basin, which influences marginal erosive processes, is a drive force for the variation of the metals concentration in the waters and sediments. In the case of Hg, this natural drive force is added to the anthropic activity, especially mining, representative in several tributaries of the Amazon River basin, citing Madeira, Tapajós and Trombetas rivers and their respective tributaries.

This research aimed to identify and to discuss the routes of Hg deposition, and to quantify the content of the total metallic element in different types of sediments present on the ACS adjacent coastal zone for the period monitored (1999–2015).

## 2. Material and methods

### 2.1. Study area

The study was conducted in the Amazon Continental Shelf (ACS) and nearby coastal zone (47°52'W–4°19'N and 51°04'W–2°16'S) between Orange Cape (State of Amapá) and Pará River mouth (State of Pará, Fig. 1). It is a region dynamic, conditioned by the meeting of continental waters with the Atlantic Ocean on influence at the Equatorial North Current and North Brazil Current (NBC). There is also interference from atmospheric forces as the Intertropical Convergence Zone, generating trade winds and rainfall, which determining the climatic seasons and the hydrological pattern of Amazonian rivers. According to Köppen-Geiger classification the climate of the region is "Am" hot and constantly humid (monsoon climate) for Marajó Bay, and "Af" equatorial for Amazon and Pará mouths, with a mean temperature of 28 °C and rainfall exceeding 2000 mm year<sup>-1</sup>, especially between the months of December and February (Siqueira and Aprile, 2012).

### 2.2. Analytical proceedings

Samples of 500 g of superficial sediments (0.0–0.1 m) were obtained with "van-Veen" collector at 25 sampling sites between 5 and 100 m isobaths during the months of lowest flow (May and June) in the Amazon River for the years 1999–2002, 2005–2007, 2011 and 2015, totaling 141 samples analyzed (all in triplicates). After sampling, sediments were stored in plastic bag in freezer at –20 °C until the analysis. At chemistry laboratory at the UFPA, the samples were dried at 45 °C for a period of 48 h, homogenized, sieved and pulverized, and the very fine sand fraction (125–63vfs μm) was used to determine organic matter (OM) and total Hg concentrations. Grain-size analysis was determined by the gravimetric method using sodium hexametaphosphate solution. The sand fractions (2000vcs – 63vfs μm) were obtained by sieving with water jet, the clay fraction (< 4 μm) was determined in a test tube for the separation of suspended material (Donagem et al., 2011), and silt was determined by mass difference. The OM was determined by hot acidic extraction, using 1.0 g of sediment sample with excess hydrogen peroxide (30%) on heater plate at 100 °C followed by drying the material in incubator at 60 °C, and by calculating the weight difference before and after dry digestion, with the results expressed as

percentages (%).

Total mercury was determined by the cold-vapor atomic absorption method (Standard Method 3112B and 3500-HgB -APHA, 2012) modified, adding 1.0 g of dry sediment sample (< 0.063 mm), 0.1 g of V<sub>2</sub>O<sub>5</sub>, 10 ml of HCl:HNO<sub>3</sub> 3:1 and 15 ml of H<sub>2</sub>SO<sub>4</sub> in a test tube closed to preserve and to promote recycling of the volatilized fumes. The material was heated at 80 °C for 60 min. After, the samples were transferred to a 100 ml volumetric flask and completed to volume with deionized water (Milli-Q). Aliquots were removed from the flasks for reading on atomic absorption spectrometer with cold-vapor generation and detection limit of 10 ng g<sup>-1</sup> (10 ppb) at the Lakefield Geosol Laboratories LTDA (MG). The results were certified from international standards MAG-1 Geostandards Newsletter and NIST 1646a, and were expressed in ng g<sup>-1</sup>.

### 2.3. Reference values and calculus

The choice of the most appropriate reference value (RV) for the application of environmental indicators is a constant discussion, and will be addressed in this research. Considering the diversity of the environment at the ACS, especially in relation to the origin of the oceanic sedimentation load, this study established the comparative use of Upper Continental Crust (UCC) as global reference values, established by Wedepohl (1995) and Rudnick and Gao (2003) compared to values described by Mason (1971). The medium shale was used as RV for interpreting data, while was of 56 ng g<sup>-1</sup> (Bowen, 1979).

Mercury levels were compared to sediment quality guideline values (SQGs), based on empirical values obtained from studies relating the concentration of toxic substances (organic and inorganic) to multiple toxicity tests in Canada and the USA. The SQGs were initially applied in the 1980s, having been reviewed and established by USEPA (1992), MacDonald et al. (1996), Canadian Council of Ministers of the Environment (CCME, 1999), and Chapman et al. (1999). These are guideline values used as a guide for toxicity to benthic biota, especially considering the bioavailability of metallic ions, and can be applied and compared in different aquatic environments (Long et al., 2005).

Using the Al element (Selvaraj et al., 2004) as RV and Hg as estimated metal content, the following calculations were applied: 1) Enrichment Factor (EF) defined by Gresens (1967), which represents the relationship between the abundance of a metallic element in the marine sediments (sample) and its natural abundance (background) in the rocks (equation (1)); 2) Potential Contamination Index (Cp) defined by Davaulter and Rognerud (2001), which relates the maximum concentration of a metal in the sample with its natural evidence (equation (2)); 3) Geoaccumulation Index (I<sub>Geo</sub>) of Müller (1969), calculated to evaluate the contamination of the environment by metallic elements (equation (3)); 4) SQGs - Threshold Effect Level (TEL) and Probable Effect Level (PEL) based on the limits established by MacDonald et al. (1996) and CCME (2014), and by the critical environmental levels described in CONAMA Resolution N°.344 (BRASIL, 2004).

The data were normalized to the textural characteristic of sediments based on the concentration levels of Al, whose the capacity conservative has been proved efficient in aquatic environments (Selvaraj et al., 2004; Aprile and Bouvy, 2010), particularly in marine environments (Schiff and Weisberg, 1999). To test the influence of the fluvial discharge on the distribution and deposition of Hg the geochemical variables were combined in the form of axis of a principal component analysis (PCA).

$$EF = [Hg]_{sed}/[Al]_{sed}/[Hg]_{RV}/[Al]_{RV} \quad (1)$$

$$C_p = [Metal]_{max}/[Metal]_{RV} \quad (2)$$

$$I_{Geo} = \log_2 ([Metal]_{sed}/1.5 \times [Metal]_{RV}) \quad (3)$$

where RV is the background geochemical value in uncontaminated area (UCC).

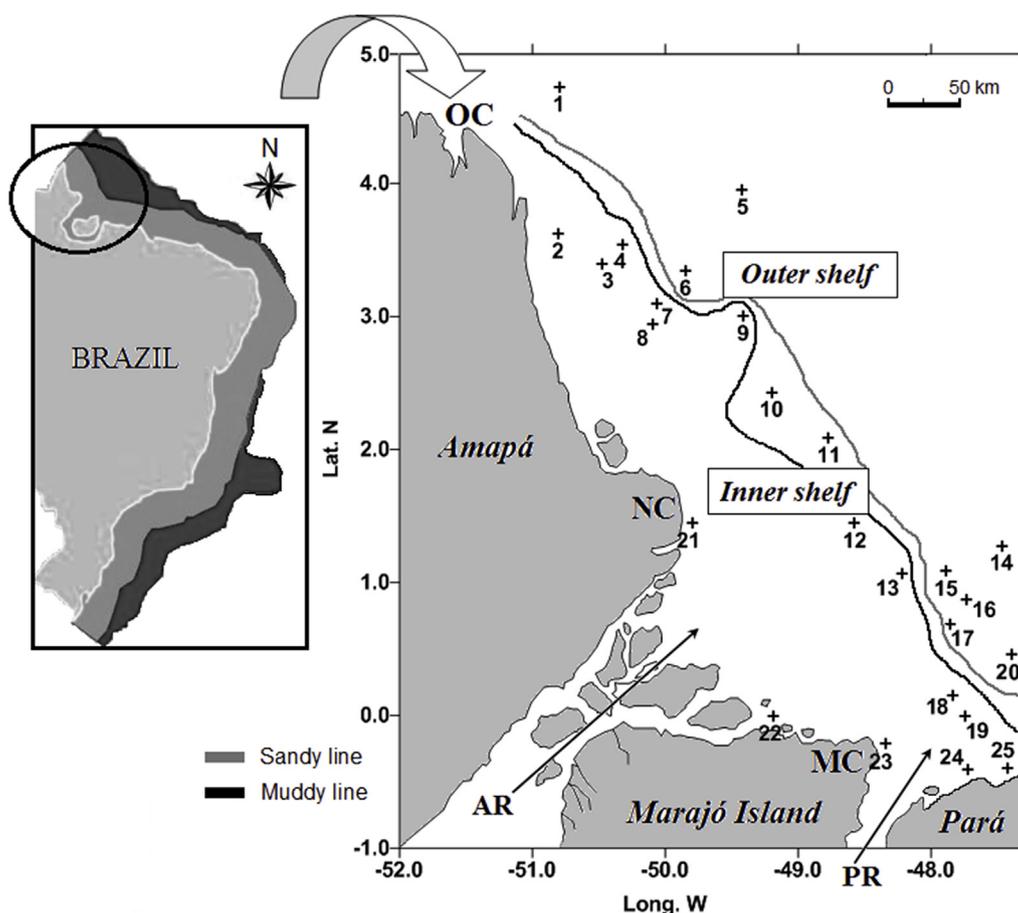


Fig. 1. Amazon Continental Shelf (ACS) between Orange Cape (OC) and Pará River mouth, with the sampling sites and their isobaths. Legend: NC = North Cape; MC = Maguari Cape; AR = Amazon River; PR = Pará River.

### 3. Results and discussion

The content of OM determined in sediments of the study area varied between 0.3 and 4.9%. The average content of OM found exclusively in the inner shelf was almost 70% higher than the average content in the outer shelf. The high concentration of OM in the inner shelf is indicative of the contribution of suspended material transported by discharges from Amazon and Pará rivers, which according to Chester (1990), indicate sediments recently deposited. Organic contents show highly variable concentrations in marine sediments due to physical processes as the degree of sediment deposition, flow of currents and biological processes, including variation in the autochthonous primary productivity. It is considered that the main source of organic contents in the sediments of the ACS is allochthonous, due to the immense load of suspended materials transported annually, mainly by the Amazon River (Meade et al., 1985; Dosseto et al., 2006). The low concentrations of organic contents that have been occasionally observed in coastal marine sediments of the region may be related to seasonal variation discharge of the Amazon River, as well as by the NBC influence, which occasionally causes a mixing of water layers and homogeneity of the surface sediments.

The concentrations of total Hg sediment ranged from 14 to 160 ng g<sup>-1</sup> dw. The highest concentrations of Hg were observed inside the ACS, particularly the sampling sites 3, 9, 13 and 18 (Fig. 2), which had concentrations greater than 100 ng g<sup>-1</sup> dw, maybe in function of the influence of the transport by the NBC on the river particulate matter deposition in northern points. In the seasonal aspect, the results had little local variation from one year to the next, with a standard deviation around 16 ng g<sup>-1</sup> dw, confirming the trend of a standard Hg concentration along the continental shelf, which may mean no metal

pollution in the region. Concentrations of total Hg determined for the coastal region remained near 77 ng g<sup>-1</sup> dw, a high value considering that the deposition rates are much lower due to remobilization from the strong tidal currents and waves. In general, the Hg levels determined in the ACS sediments were lower than those found in the Amazonian river systems (Table 1). Nevertheless, the continuous accumulation of Hg in the mud sediments, especially in the inner part of the platform, could cause, in indeterminate time, serious damages to the benthonic communities, affecting the local trophic chain. Potentially toxic metals differ from other metallic elements by their tendency to form reversible bonds with anionic components, as well as their strong capacity of bioaccumulation and non-biodegradable.

Due to the continuous exposure of the natural environment to metallic contaminants, the use of reference values (RV) is recommended, allowing comparisons between systems through the application of environmental indicators. Often, the study site is inserted in an area altered chemically by anthropogenic action, so that the reference values for comparison must be obtained in an area free of contamination. There has been a tendency to apply regional RVs, especially when working with specific areas. However, it should be noted that the use of regional RVs in accumulator compartments with more than one identified sedimentary source, such as the ACS, can generate erroneous interpretation of the indicators by the application of restrictive values.

The sediments that compose ACS are the result of two distinct sources: a terrigenous source, which mixes both naturally occurring and chemically modified silt-clay sediments, predominantly deposited in the inner part of the platform, and another marine source of sandy sediments transported to ACS by Equatorial North Current and North Brazil Current, as demonstrated by Siqueira and Aprile (2012). The fluvial sediments accumulated in the ACS are predominantly of the

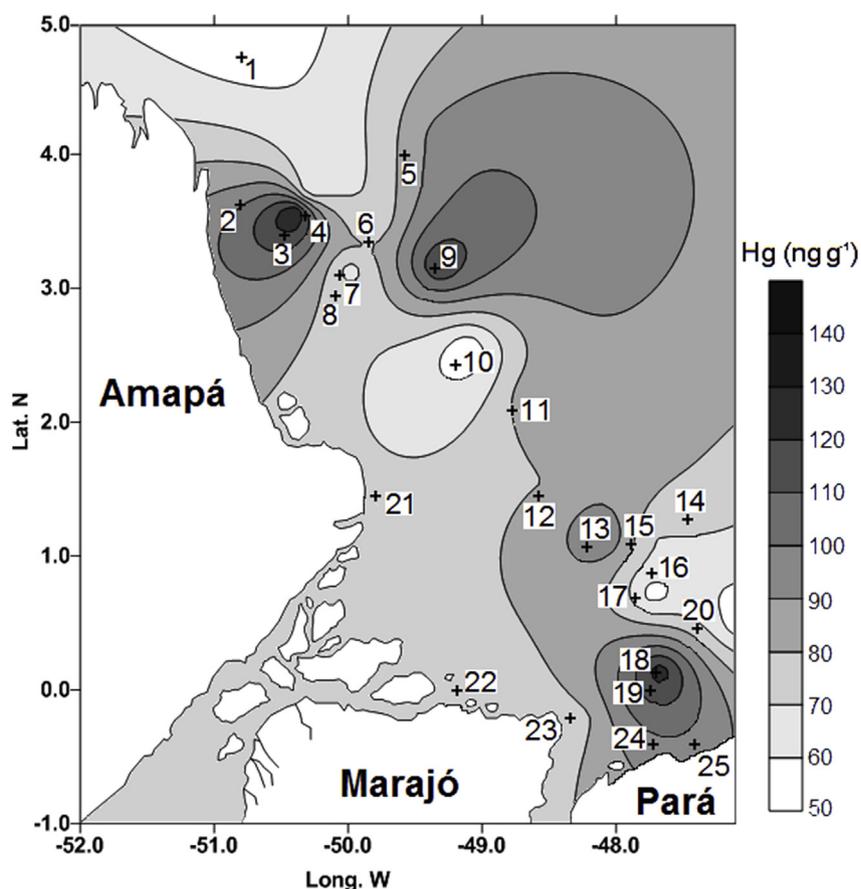


Fig. 2. Isovalues map (kriging) for total Hg in the ACS sampling sites ( $n = 141$ ).

**Table 1**

Total Hg values ( $\text{ng g}^{-1}$ ) in some river sediments (adapted from Lacerda and Pfeiffer, 1992).

Locality	Hg in sediments	reference
Madeira River, RO	50–280	(1; 2)
Mutum-Paraná River, RO	210–19 800	(1)
Carajás River, PA	40–3370	(3)
Tapajós River, PA	< 10–140	(4)
Non contaminated world rivers	< 20	(5)

(1) Pfeiffer et al., 1989; (2) Pfeifer et al. (1991); (3) Fernandes et al. (1990); (4) Padberg (1991); (5) Mitra (1986). RO = Rondônia State; PA = Pará State.

Recent Quaternary, with sedimentation rates in the platform varying as a function of the ebb and flow cycles at the mouth of the Amazon River. The grain-size analysis revealed the presence of three groups: sandy sediments ( $2000\text{vcs} - 250\text{ms}\mu\text{m}$ ) found on the outer shelf; sandy-clayey and clay-sanded sediments in transition area between the outer and inner shelf; and muddy sediments formed by particles thin, whose composition is a mixture of clay, silt and small fractions of organic matter at the inner shelf and in the near coastal zone (see Fig. 1). The result is a large variation in the concentration of Hg precipitated, documented in several studies, which makes it difficult to choose a single representative reference value for ACS.

According to Birch et al. (2000) several studies have reported that the global average ('Clarke' geochemist) and the average concentrations of metals in the shale are very high to represent the geochemical "background" in different sedimentary basins. The concentration of  $180\text{ng g}^{-1}$  of Hg for shale of Bowen (1979) does not represent the concentration measured in the ACS. That value being higher than the highest concentration obtained during the study period in the ACS, which was  $160\text{ng g}^{-1}$  in the sampling site 9. On the other hand, Mason

(1971) relates average amount of Hg in crustal rocks of  $80\text{ng g}^{-1}$ , and Wedepohl (1995) and Rudnick and Gao (2003) established for Hg a RV of  $100\text{ng g}^{-1}$ , values that are more compatible with the average concentration obtained in the sediments of the ACS. Comparatively, it is clear that the average concentration of total Hg determined in ACS between 1999 and 2015 was far below the range proposed by Pfeiffer et al. (1989, 1991) and Lacerda et al. (1990) for the Amazonian rivers, staying very close to values suggested by Mason (1971).

The enrichment factor (EF) has been shown to be a good measure to differentiate natural from anthropogenic source metal (Selvaraj et al., 2004; Aprile and Bouvy, 2010). EF calculated for the 25 sampling sites ( $n = 141$ ), according to the RVs of Wedepohl (1995), Rudnick and Gao (2003) and Mason (1971), showed varied enrichment of Hg in the marine sediments at ACS, with EF from 0.8 – deficient or no enrichment to 8.3 – significant or moderately to severe enrichment, according classifications of Taylor (1964) and Yongming et al. (2006) (Table 2). The results suggest yet that there is not a main or single source of Hg on the continental shelf, with both anthropogenic and geological contributions. The anthropogenic source is mainly from mining activities, while that the geological origin is due to erosion – leaching processes of marginal soils of the Amazon River basin, transporting sediments to the oceanic inner shelf. Mining comprises two stages: removal of the ore from the deposit and processing, which consists in the purification of the ores in order to obtain the mineral of economic interest. This is the main activity in the Amazon region involving Hg, which is used for separation of gold. Both stages generate a large quantity of residues. However, the rejects from the beneficiation process promote the reduction of the sulfate, which in the form of sulfide precipitates the Hg to the sediments. According to Zhang and Liu (2002) classification, 52% of the sediment samples show predominantly anthropogenic impact ( $\text{EF} > 1.5$ ). The sampling sites near the coastal zone, identified as

**Table 2**  
Enrichment Factor (EF), Index of potential contamination ( $C_p$ ) and Geoaccumulation index ( $I_{geo}$ ) of the Hg in sediments from Amazon Continental Shelf.

Site	Depth	EF <sup>a</sup>		C <sub>p</sub>		I <sub>geo</sub>
		Min	Max	Min	Max	
1	72	0.8	1.3	0.6	1.0	-0.7
2	22	1.5	2.3	1.1	1.8	0.1
3	20	2.2	<b>3.4</b>	1.7	<u>2.7</u>	0.7
4	37	1.0	1.6	0.8	1.2	-0.5
5	100	2.2	<b>3.4</b>	1.2	1.9	0.2
6	70	1.2	1.8	0.9	1.4	-0.2
7	26	1.4	2.1	1.0	1.6	0.0
8	22	1.1	1.6	0.8	1.3	-0.4
9	37	2.2	<b>3.4</b>	1.5	<u>2.4</u>	0.5
10	19	1.0	1.5	0.6	1.0	-0.7
11	27	1.6	2.4	1.1	1.7	0.1
12	19	1.4	2.1	1.0	1.6	-0.1
13	28	1.7	2.6	1.3	2.0	0.3
14	59	<b>5.5</b>	<b>8.3</b>	0.9	1.5	-0.2
15	48	1.3	1.9	0.9	1.4	-0.3
16	46	1.3	2.0	0.8	1.3	-0.3
17	39	1.1	1.6	0.7	1.1	-0.6
18	26	2.3	<b>3.4</b>	1.6	<u>2.5</u>	0.6
19	24	2.0	<b>3.0</b>	1.4	<u>2.3</u>	0.4
20	32	1.2	1.8	0.7	1.1	-0.6
21	8	0.8	1.2	0.9	1.4	-0.2
22	12	0.8	1.2	0.9	1.5	-0.2
23	16	0.8	1.2	1.0	1.5	-0.1
24	18	0.8	1.2	1.0	1.6	-0.1
25	20	0.8	1.2	1.1	1.7	0.0

<sup>a</sup> EF > 1 anthropogenic source; EF ≥ 3 (**bold**) moderate to significant enrichment; C<sub>p</sub> (underline) means attention to contamination.

points 21 to 25 (Fig. 1), had the lowest rates of enrichment, with EF varying between 0.8 and 1.2 suggesting a predominance of crustal contribution in the sedimentation area of the beach.

Index of Potential Contamination ( $C_p$ ) calculated for Hg changed from 0.6 (no contamination) to 2.7 (moderate – severe contamination), with 71% of the samples indicating some contamination condition between moderate to severe by Hg in the bottom sediments, specifically in the internal sampling sites 3, 5, 9, 13, 18 and 19 (Table 2). This is indicative that can be having actually a moderate source of anthropogenic contamination releasing Hg throughout the Amazon River basin, which according to Lacerda and Pfeiffer (1992), Bastos and Lacerda (2004) and Bastos et al. (2006) is due to mining activity, especially in Madeira, Tapajós and Trombetas river basins. Based on the classification of Müller (1969) and Singh et al. (2003) for the Geoaccumulation Index, the results showed that 60% of the ACS samples are classified in the category of non-contaminated sediments, and 40% show some pollution ranging from low to moderate pollution (Table 2).

The metal concentrations at each sampling site were compared with the consensus-based sediment quality guideline values (SQGs) referred to as the Threshold Effect Level (TEL) and Probable Effect Level (PEL) (Fig. 3). These guidelines have been selected for comparison as various evaluations have demonstrated that the consensus-based SQGs provide a unifying synthesis of the existing SQGs, and reflect causal rather than correlative effects (MacDonald et al., 2000). Considering the limits established by MacDonald et al. (1996) [TEL < 0.13–0.70 < PEL]; and CCME (2014) [TEL < 0.170–0.486 < PEL] 86% and 100%, respectively, remained below the reference value TEL, meaning no adverse effects. Comparing the results with the reference levels adopted in the Brazilian legislation (BRASIL, 2004), 94% of the samples remained below the TEL limit, while that the other values remained between intermediate and possible adverse effects (Fig. 3). The fact that the results indicate that most samples are below the reference value TEL does not represent a stable condition. The intense sediment load carried to the ACS, with high levels of clay and organic matter, which both

have high adsorption capacity of metals, together with intense mining activity in some Amazonian basins, may cause an increase in the adverse biological effects on the sediments.

The results showed a trend of higher concentrations of Hg in muddy sediments, maybe related to 85–90% of the sediment discharge composition of the Amazonian discharge (Gibbs and Konwar, 1986; Warne et al., 2002). This is probably due to the metal affinity of Hg to anionic clay minerals, particularly Kaolinite and Montmorillonite (Siqueira et al., 2016), and organic matter, thus forming an aggregate component. Both clay and OM have an intrinsic property of attracting elements of positive charge. Significant positive correlations ( $p < 0.050$ ) was found between concentrations of Hg and OM (Pearson  $r = 0.861$ ,  $p = 0.001$ ), while it was observed significant negative correlation between the concentrations of Hg and sand content (Pearson  $r = -0.688$ ,  $p = 0.005$ ) in the sediments of ACS. Results confirm that the metal elements have a high affinity for organic compounds, and little or no affinity for the silicates and quartzite (sandy sediments). From the viewpoint of the variation in the concentration of total Hg depending on the depth of the water column, Pearson's correlation analysis showed no significant relationship between the variables ( $r = 0.115$ ,  $p = 0.614$ ), although there is a trend saying that the higher concentrations of Hg occurred in shallow water column. The grain size difference between the inner and outer shelf was confirmed by Principal Component Analysis (PCA) of 141 samples to OM and Hg with the component axis 1 explaining 62.6% and component axis 2 explaining 12% of the behavior (Table 3). The component 1 was responsible for the separation between the fluvial and marine discharges, while the component 2 showed the sampling sites based on distance closer or farther from the Amazon River mouth. The projection of environmental variables studied from the perspective of the PCA showed that the levels of quartz as well as the EF were predominant during the isolation of the sampling sites of oceanic shelf.

The identification of the type of sediment of the Amazon River mouth, as well as the continental shelf, confirmed the evidence that the metallic elements have a special association with clay, and that this association is enhanced in the presence of organic matter. Associated with this, the high concentrations of Hg in natural soils of the basins of the Negro and Tapajós rivers and its release by the process of podzolization (Fadini and Jardim, 2001; Grimaldi et al., 2008), allow the distribution of spontaneous metal to aquatic ecosystems. Thus, justified the presence of high concentrations of Hg in distant areas of mining, and explains why the levels of total Hg in ACS are particularly high in the inner shelf, extending from the Orange Cape to Pará River mouth, where exactly occurs the process of fluvial sedimentation.

The high total Hg concentration in soils and sediments of the Amazon induces us to think that the origin and mobility of this metal are both directly related to the processes of erosion, transport and deposition. The results obtained in this study in comparison with a literature review shows a concentration of Hg from natural process caused by destruction of lateritic soil cover, which means that the Oxisols – Latosols surrounding the Amazon basin may be the main source of Hg for spodic horizons of Podzols. There are evidences that the main source of total Hg in the Oriental Amazon is of geochemical origin (erosion of the soils), with a significant contribution of the Negro and Tapajós rivers, though not ruling out mining activities in Madeira River basin, in Occidental Amazon, which have great importance in the accumulation of Hg in river sediments. In the Tapajós River basin, Roulet et al. (2000) concluded that only the concentrations of Hg from mining activity is not sufficient to explain the high levels of mercury found in soils. For the authors, the mining would contribute only 3% of total Hg found in the surface horizons of local soils. In the Amazon, particularly in the valley of the Tapajós River, there is a large reservoir of natural Hg, and the anthropogenic activities associated with deforestation and human settlement are disrupting the natural cycle of Hg, increasing surface erosion and transport of Hg associated with fine particles soil to aquatic ecosystems, especially during the rainy season (Roulet et al., 1998).

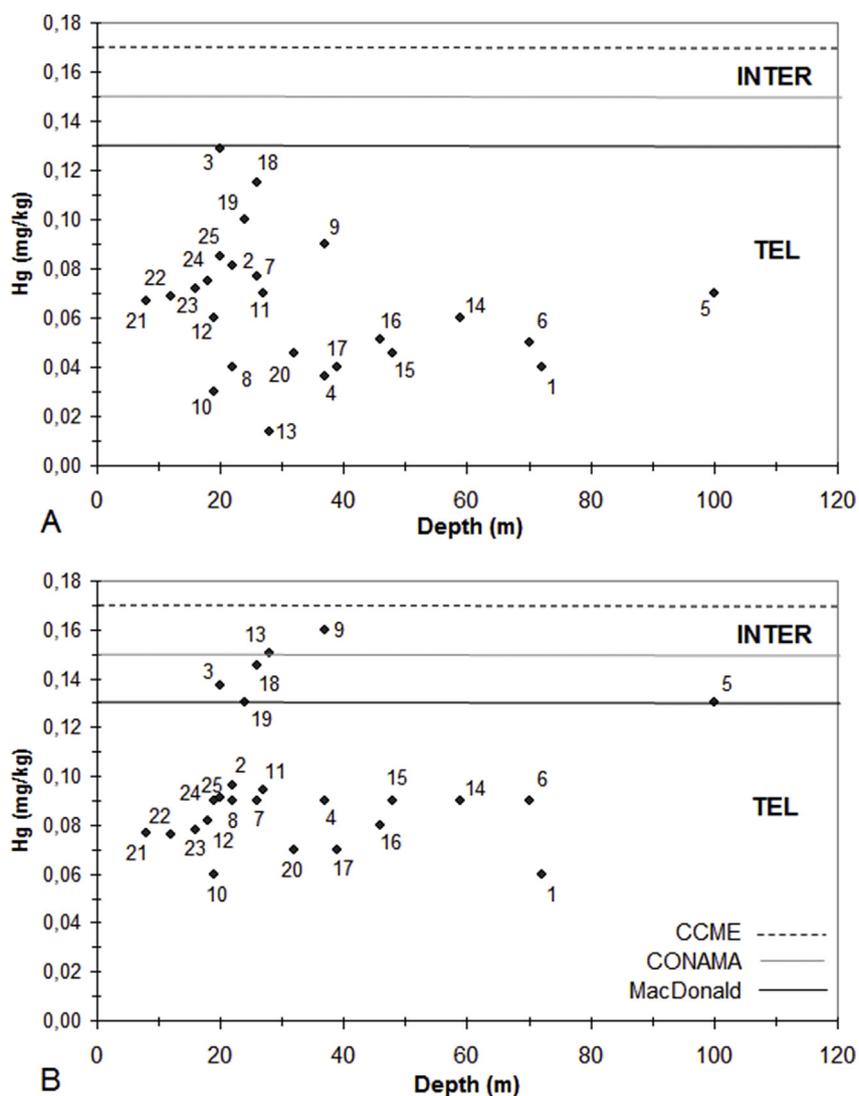


Fig. 3. Frequency of adverse biological effects TEL and PEL in sediments from ACS (n = 141) for A) minimum and B) maximum levels. Limits TEL: MacDonald et al. (1996), CONAMA (BRASIL, 2004) and CCME (2014).

**Table 3**  
PCA analysis<sup>a</sup> with projection of the variables OM and Hg on the factor-plane 1 × 2.

Axis	Eigenvalue	Total variance (%)	Cumulative Eigenvalue	Cumulative (%)	Meaning
1	16.9	62.6	16.9	62.6	discharge influence
2	3.2	12.0	20.1	74.6	discharge distance

<sup>a</sup> N = 141.

Associated to it, the circulation pattern forces the distribution of the fine discharge of Amazon river to northwestern sense, along the coast from subaqueous deposit in river mouth on the continental shelf (Gibbs and Konwar, 1986; Nitrouer et al., 1995), running northwest and parallel to the coast about 650 Km long.

#### 4. Conclusions

The Hg levels determined in this study are within the range obtained by other authors in watersheds of the Central Amazon and

Western Amazon. The results indicated a higher concentration of Hg in the Amazon Inner Continental Shelf. The increased of Hg to the ocean sediments can be directly associated with the discharge of muddy sediments of the Amazon River. Based on the results, and due to the intense mining activity in rivers of the Amazon, it is necessary to continue the monitoring of the Hg levels for the establishment of a program of coastal management in the region.

#### Declaration of interest

Conflicts of interest: none.

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