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ECOSYSTEMS

Mercury concentrations in coastal Elasmobranchs (*Hypanus guttatus* and *Rhizoprionodon porosus*) and human exposure in Pernambuco, Northeastern Brazil

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Abstract: Elasmobranchs are long-lived predatory fish that show high Hg concentrations generally reflecting environmental levels, notwithstanding they are widely consumed in Brazil increasing Hg exposure to humans. This study reports on Hg concentrations in largely consumed sharks (*Rhizoprionodon porosus*) and rays (*Hypanus guttatus*) from the Pernambuco coast, NE Brazil and the risk associated with their consumption. Muscle tissue concentrations of Hg in *H. guttatus* and *R. porosus* varied from 40 to 1,020 $ng.g^{-1}$ w.w. (median = 125; mean = 124 ± 48 $ng.g^{-1}$ w.w.) in sharks and from 129 to 2,130 $ng.g^{-1}$ w.w. (median = 976; mean = 919 ± 139 $ng.g^{-1}$ w.w.) in rays. Concentrations of Hg positively correlated with size in sharks, but not in rays. Concentrations reflect the local environmental contamination of a large urban center and industrial park concentrated in a short extension of mangrove-dominated coastline (50 km) and are higher compared to other Brazilian sites where Hg concentrations in these species have been reported. Sharks had a risk coefficient (HQ) range of 0.04 to 1.1, not surpassing the reference level of exposure. On the other hand, rays' HQ ranged from 0.14 to 2.3, and exceeds the reference level of exposure and suggests adverse effects to consumers.

Key words: trace metal, bioaccumulation, stingray, shark, age, human exposure.

INTRODUCTION

The quality of aquatic ecosystems plays an outstanding role in maintaining seafood resources, especially in high diversity zones as coastal and estuarine waters used for feeding and rearing of marine fish (Lotze et al. 2006, Woodland et al. 2011). Anthropogenic pressures like urbanization, industrialization, port activities, and tourism over coastal environments have increased eutrophication and pollution (Nixon 1995, Kemp et al. 2005), resulting in habitat degradation, fragmentation of native populations, biodiversity loss, as well as high levels of pollutants, including highly toxic mercury (Hg) (Levin et al. 2001, Meyer & Medeiros 2017).

Trace concentrations of Hg occurs naturally in the environment, but abnormal concentrations are due to anthropogenic actions, mostly from chemical and electro-electronic industry, solid waste disposal, mining, and burning of fossil fuels. These activities increase Hg concentrations particularly in coastal ecosystems (Ferreira et al. 2004, Fitzgerald et al. 2007). Owing to its high toxicity, strong bioaccumulation and biomagnification through food chains, Hg is recognized as one of the most potentially hazardous pollutant in the marine environment (Dias et al. 2008). Therefore, the use of long-lived, high trophic level aquatic organisms represents an essential tool to monitor changes in Hg environmental levels, as well as Hg exposure to humans consuming them (Verhaert et al. 2019).

Elasmobranchs, a long-lived, predatory group of fish, often show high Hg concentrations (Wang & Wang 2019, Bezerra et al. 2019). Characteristics like slow growth, late maturation, and high trophic level presented by elasmobranchs contribute to increasing the accumulation of contaminants (Gelsleichter & Walker 2010). Despite that, elasmobranchs are widely consumed in Brazil (Bornatowski et al. 2018, Marques et al. 2019), which contribute to increasing human exposure to Hg, since diet is the main source of Hg contamination (Castro-González & Méndez-Armenta 2008). Therefore, this study investigated the occurrence and variability Hg concentrations in two coastal elasmobranchs (the ray *H. guttatus* and the shark *R. porosus*) with different life strategies, caught off the coast of Recife, State of Pernambuco, NE Brazil, where these species are the most caught elasmobranchs by local fishermen. The observed Hg contents are interpreted taking into consideration biological and geographical parameters.

The state of Pernambuco has a human population of about 4.2 million inhabitants living in the coastal zone, with a high density of 1,017 inhabitants/km^2 (IBGE 2018), such an anthropogenic pressure led to a high degree of urbanization, mostly in the metropolitan area of the state capital, Recife. Several changes in the past decades due to unplanned development have led to decreased environmental quality (Sant'Anna et al. 2001). Above all, an unusual, elevated population growth rate as well as accelerated harbor and industrial facilities occurred in the past two decades (Lima & Quinamo 1998). Notwithstanding, many estuaries, like the Santa Cruz Channel, are biological diverse and highly productive and support abundant fisheries of both finfish and shellfish. Taking this into consideration, we hypothesized that Hg concentrations in and the respective human exposure from local sharks and rays, shall be higher in the region compared to other sites along the Brazilian coast and, therefore, that elasmobranchs do reflect environmental Hg levels. We size-adjusted Hg concentrations to consider differences associated with fish age/length and to allow comparisons with previous studies.

MATERIALS AND METHODS

From 2014 to 2018, specimens of *H. guttatus* (n = 24) and of *R. porosus* (n = 24) were collected from fishers (stations 1 to 5) or acquired in fishing landings in Ponta das Pedras, Itamaraca and Brasília Teimosa, in the metropolitan area of Recife (Figure 1). Biometric data were recorded for all individuals and included total length (TL, cm) for the shark and disk width (DW, cm) for the ray, weight (g) and sex. Duplicate samples of muscle tissues were also taken from each individual. Fish age (in years) was estimated using the inverted von Bertalanffy growth model (Sparre & Venema 1997) with the equation proposed by Santos (2017) for *H. guttatus* and by Lessa et al. (2009) for *R. porosus*.

All samples were freeze-dried (Terroni, model Enterprise II), weighed (~0.5 g) in Teflon vessels adding 10 mL of HNO_3 (65%). Prior to digestion, samples were left at room temperature for 1 h. Then, digestion was carried out in a microwave accelerated reaction system (MARS, CEM Corporation) at 200 °C for 30 min. Following digestion, 1 mL of H_2O_2 was added to each vessel, transferred to 100-mL volumetric flask. Total Hg concentrations were quantified by cold vapor atomic absorption spectrometer (CV-AAS) (model NIC RA-3, NIPPON).

Under the operational conditions described, the analytical detection limit of the method

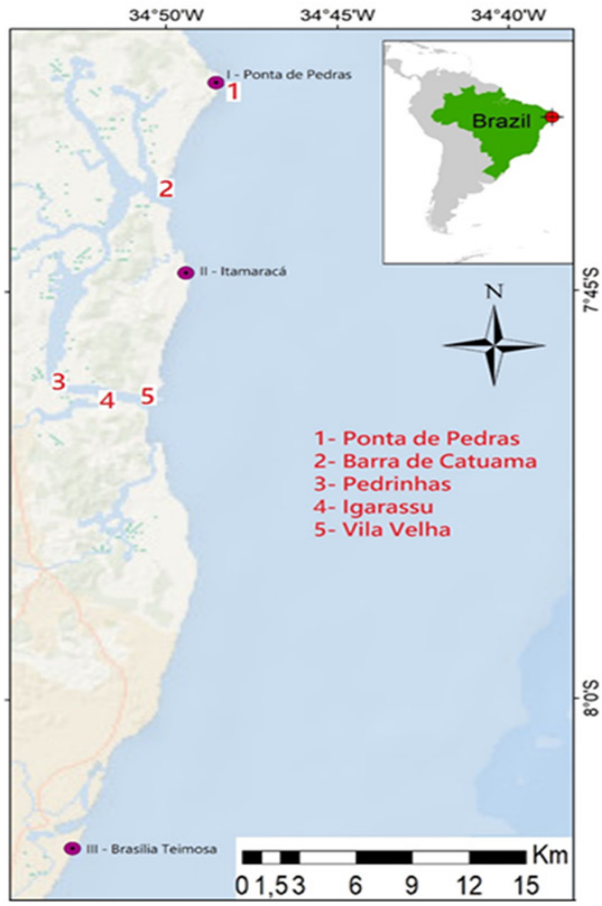

Figure 1. The Pernambuco coast where rays (*H. guttatus*) and sharks (*R. porosus*) were obtained from local fishers (stations 1 to 5) and fish landings (Villages I, II, III).

(DL) was 0.1 ng g^{-1}, based on the ratio between three standard deviation estimated by $S_{y/x}$ ($S_{y/x}$ ¼ = $\{\Sigma(y_1 - y)^2 (n - 2)^{-1}\}^{1/2}$) and the slope of the regression line of the calibration curve (Miller & Miller, 1993). Quality control was performed by the analysis of certified reference materials (TORT–2 - lobster hepatopancreas, 0.27 ± 0.06 ng.g^{-1} and DOLT-3 – dogfish liver, 3.37 ± 0.14 ng.g^{-1}) average recovery of standards was 89.1% (77.5% - 101.2%). We only accepted a minimum of 85% recovery; thus we have discarded the sample batch that gave 77.5%.

Bioaccumulation curves were built to compare biometric data and Hg concentration in each species. Concentrations on a wet weight basis, for estimation of exposure risk and literature comparisons, were obtained using the specific water content for each species: 76% in *H. guttatus* and 75% in *R. porosus* which were similar to published values for these species (Rabelo 2017, Magalhães et al. 2007, Escobar-Sánchez et al. 2016).

Health risk associated with the ingestion of fish from the studied area was assessed by equation (1), reported by Newman & Unger (2002).

Eq. 1. $$HQ = E / RfD$$

Where, HQ is the risk coefficient, E is the level of exposure or Hg intake and RfD is the reference dose for Hg (Hg = 0.47 µg.kg^{-1} body weight/day (BCS 2007). Exposure level (E) was calculated using the equation (2).

Eq. 2. $$E = C * I / W$$

Where, C is the concentration of Hg (µg.g^{-1} wet weight); I is the ingestion rate per capita (35.6 g day^{-1}; Sartori & Amancio 2012) and W is the average weight of an adult (70 kg). At HQ < 1.0 exposure level is smaller than the reference dose; meaning that daily exposure to this level is unlikely to cause adverse effects to consumers.

The normality of the data was evaluated by the Shapiro–Wilk test and the homoscedasticity by the Levene test. Spearman correlation was used for non-normal data, while Pearson correlation was used for normal and homocedastic data. ANOVA followed by the *post-hoc* Tukey test was used for comparing Hg concentrations and biometric data in *H. guttatus* from different sampling sites and a Mann-Whitney test in the case of *R. porosus*. The level of significance for all tests was 95%. Statistical tests and graphs were done with IBM SPSS v.20 and Microsoft® Office Excel 2010.

RESULTS

Table I summarizes the biometric and Hg concentration averages obtained for the two elasmobranch species studied, whereas Supplementary Material - Table SI and Table SII shows the figures for every individual analyzed. A sample of 24 individuals of *R. porosus* were collected (14 females and 10 males) with total length varying from 33.3 and 79.5 cm (mean = 42 ± 3 cm) and weight from 125 to 1,900 g (mean = 272 ± 114 g). The youngest shark was 0.3 years-old and the oldest 5.4 years (mean age = 1.0 ± 0.3 years). Muscle tissues Hg concentrations ranged from 40 to 1,020 $ng.g^{-1}$ w.w. (median = 125; mean = 124 ± 48 $ng.g^{-1}$ w.w.). The risk coefficient (HQ) varied from 0.043 to 1.104 in *R. porosus* (mean HQ = 0.220) and did not surpass the reference level of exposure. Nonetheless, the largest and oldest individual showed an HQ above the reference level (Supplementary Material - Figure S1). There was no significant difference between Hg concentrations found in male and female sharks (U = 47; $p > 0.05$). Also, no significant differences in Hg concentrations were detected between sampling sites (U = 46; $p > 0.05$) (Figure S1). The highest Hg concentrations were found in the Itamaracá site, where the oldest individuals were found. The lack of significant differences in Hg concentrations among sampling sites suggests that sharks respond to a regional "coastal-wide" geographical area, rather than local sampling sites.

A significant ($p < 0.01$) exponential relationship was obtained between age and Hg concentrations in *R. porosus* from the Pernambuco coast (Figure 2). Mercury concentrations were particularly high in large individuals older than 3.5 years. An exception was 52.7 cm individual, aged 2.5 years, that presented 485 $ng.g^{-1}$ of Hg.

Biometry of the 24 individuals (13 females and 11 males) of *H. guttatus* varied between 34 and 67 cm DW (50 ± 2 cm), whereas age varied between 2.1 to 9.1 years (4.9 ± 0.4 years). The Hg concentrations in *H. guttatus* varied between 129 to 2,130 $ng.g^{-1}$ w.w. (919 ± 139 $ng.g^{-1}$ w.w.); up to seven times higher than those measured in the shark *R. porosus*. No significant differences were found between sex (U = 49; $p > 0.05$). However, different from sharks, stingrays sampled in Ponta de Pedras and Barra de Catuama, located in the northern part of the Santa Cruz Channel, showed significantly higher Hg concentrations (H = 16; $p < 0.05$). Stingrays from Ponta de Pedras presented the highest Hg levels (1,792 ± 180 $ng.g^{-1}$), similar ($P > 0.05$) to Barra Catuama (1,580 ± 215 $ng.g^{-1}$) (Figure S1). In fact the majority of the sampled individuals of *H. guttatus* from these two sites presented Hg concentrations above the legal limits for human consumption of 1,000 $ng.g^{-1}$ w.w.

Unlike *R. porosus*, *H. guttatus* did not show significant correlations ($p > 0.05$) between Hg concentrations with size or age (Figure 3). The extremely high Hg concentrations found in rays from the inner reaches of the Santa Cruz Canal, where Ponta de Pedras and Barra de Catuama are located, would mask any relationship between Hg concentrations and animal size. This suggests that stingrays respond to local, rather than regional, Hg concentrations.

The risk coefficient (HQ) varied from 0.14 to 2.30 in rays (average 1.07). In contrast to *R. porosus*, *H. guttatus* presented a higher HQ average, exceeding the reference level of exposure. About 50% of individuals presented HQ that can cause adverse effects to consumers (HQ > 1), whereas 16% exhibited HQ two times higher than the reference dose.

Table I. **Biometrics, Hg concentrations (mean ± standard deviation) and exposure risk (HQ) from of sharks (*R. porosus*) and stingrays (*H. guttatus*) from the Pernambuco coast in Northeastern Brazil. TL= total length and DW= Disk width.**

Species	Size (cm)	Weight (g)	Age (yr)	Hg (ng.g^{-1} w.w.)	HQ
R. porosus	42 ± 3 TL	272 ± 114	1.0 ± 0.3	125 (124 ± 48)	0.220
H. guttatus	50 ± 2 DW	-	4.9 ± 0.4	976 (919 ± 139)	1.07

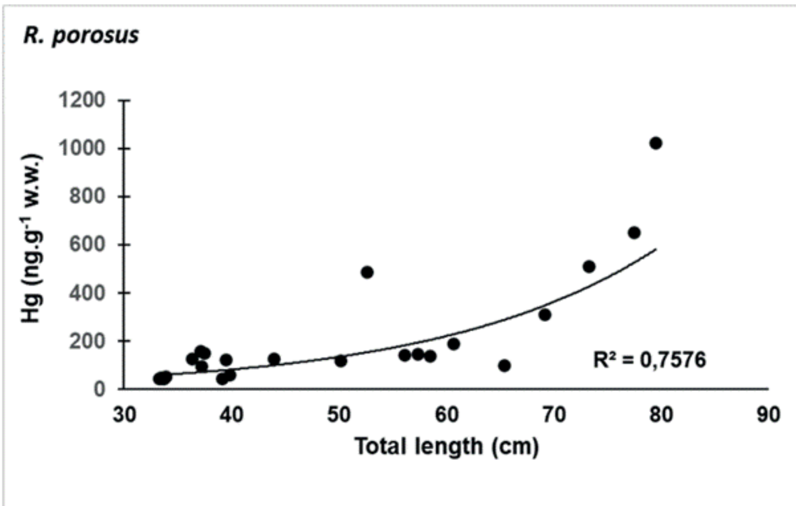

Figure 2. **Relationship between total length and Hg concentrations in *R. porosus* from different sampling sites along the Pernambuco coast in NE Brazil.**

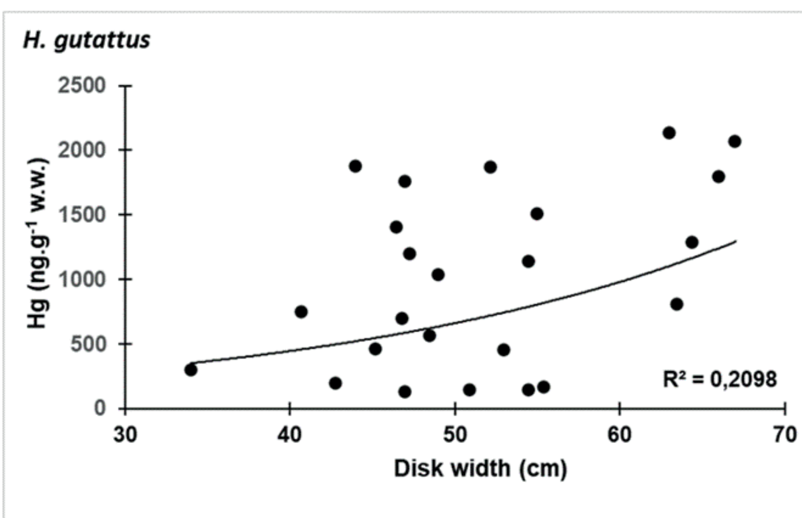

Figure 3. **Relationship between disk width and Hg concentrations in *H. guttatus* sampled from the Pernambuco coast, NE Brazil.**

DISCUSSION

The small inshore shark *Rhizoprionodon porosus* is distributed over the western *continental* shelf of the Atlantic Ocean from Florida to South America (Gomes et al. 2010). It inhabits sandy bottoms from inshore and offshore waters down to about 90 m deep (Montealegre-Quijano 2002) and is considered an opportunistic predator feeding on fish, mostly from the Stromateidae, Trichiuridae, Sciaenidae, Engraulidae, Tetraodontidae, Clupeidae and Batracoididae, squids, crabs and shrimps. Males and females do not differ in feeding habits (Silva & Almeida 2001), which may explain the non-significant difference of Hg concentrations between sexes since the main source of Hg is through diet (Hall et al. 1997). Biometric data (total length and total weight) of *R. porosus* from Pernambuco characterize a typically mature population of females and subadult males (Mattos et al. 2001, Mattos & Pereira 2002).

There was no difference in Hg concentrations between sampling locations, which is expected since this species forages along the entire coast, on the continental shelf (Montealegre-Quijano 2002). According to Gadig (2001), this shark exhibits a predominantly coastal pattern, presenting continuous distribution throughout the continental shelf, apparently without a zoogeographic barrier that interrupts its distribution. It may migrate to deeper waters during summer, coming back to shallow areas for reproduction (Menni & Lessa 1998, Mattos et al. 2001).

These ecological characteristics suggest that any eventual differences in Hg concentrations among individuals are related to biological variables, particularly size and age, as clearly shown in Figures 2 and 3. This in agreement with other studies on this species which also observed significant positive correlations between size and Hg content, as well as on shark species with similar ecology as *R. porosus* from other coastal areas worldwide (Fisk et al. 2002, Frías-Espericueta et al. 2019, Hurtado-Banda et al. 2012, Lacerda et al. 2000, Rumbold et al. 2014). As a result, *R. porosus* Hg contents reflect the regional, coastal-wide, scale environmental Hg levels of the eastern coast of NE Brazil, and thus allows interregional comparisons (Table II).

In Rio de Janeiro, SE Brazil (lat. 21º27'S; long. 41º00'W), Lacerda et al. (2000), reported total Hg concentrations in *R. porosus* varying from 1.8 to 21.3 $ng.g^{-1}$ w.w. (Average 9.9 $ng.g^{-1}$ w.w.), but individual's size varied from 26 to 50 cm, characterizing that population as juveniles. More recently, Amorim-Lopes et al. (2020) reported much higher Hg concentrations for this species in the same region (80 to 370 $ng.g^{-1}$ w.w.). Individuals, however, were much larger, but yet juveniles (43 – 52 cm). In Ceará State, in the western coast of NE, Brazil, one large individual (85 cm) of the species showed Hg concentrations of about 509 $ng.g^{-1}$ w.w. (Lacerda et al. 2016). These results suggest the Pernambuco population, considering their size range, presents higher Hg concentrations that those previously reported in SE Brazil, and similar to other NE coastal areas.

Published studies on Hg concentrations in *R. porosus* and other sharpnose sharks (*Rhizoprionodon* spp.), from other regions in the Americas (Table II), shows that sharks of similar size range of the Pernambuco population, fall into a similar range of concentrations, with a few exceptions, generally including larger individual. Mercury concentrations in Americas sharpnose sharks, however, are relatively higher than other *Rhizoprionodon* species studied in other regions. For example, Tarassoli et al. (2012) analyzed twenty-two individuals of *R. acutus* with an average body length of 73.38 cm (similar to those from this present study) from the Persian Gulf (Bandar Abbas coastal), and reported much lower Hg concentrations with an average of 70 $ng.g^{-1}$ w.w..

Hypanus guttatus is a demersal coastal marine ray, widely distributed in shallow tropical and subtropical waters down to ~35 m deep, found in estuarine sandy and muddy bottoms. Juveniles of *H. guttatus* live in higher salinity environments while adults prefer lower salinity environments, including intertidal zones (Bigelow & Schroeder 1953, Figueiredo 1977, Menni & Lessa 1998, Yokota & Lessa 2007, Gomes et al. 2010, Gianeti 2011, Melo 2016).
In Pernambuco there is a bottom gillnet fishing directed to the rays displaying an average height of 10 to 20 meshes, called "raieira" (Lira et al.

Table II. **Reported Hg concentrations, size and location of American and Caribbean sharpnose in sharks *Rhizoprionodon* spp. and stingrays *Hypanus* spp. * rounded to unit.**

Location	Species	Size (cm)*	Hg ($ng.g^{-1}$ w.w.)	Reference
Sharks				
Pernambuco, NE Brazil	*R. porosus*	33 - 79	40 - 1,020	This study
Ceará, NE Brazil	*R. porosus*	85	509	Lacerda et al. (2016)
SE Brazil	*R. porosus*	26 - 50	1.8 - 21.3	Lacerda et al. (2000)
SE Brazil	R. lalandii	23 - 49	5.1 - 65.9	
Colombian Caribbean	*R. porosus*	49 - 84	217 - 1,810	Rueda-Bernal et al. (2020)
SW Florida, USA	*R. terraenovae*	96 ± 11	1,990 ± 600	Rumbold et al. (2014)
Atlantic Florida, USA	*R. terraenovae*	22 - 86	110 – 2,300	Adams & Mcmichael (1999)
SE USA Atlantic coast	R. terraenovae	76 - 105	207 – 3,091	Ehnert-Russo & Gelsleichter (2020)
SE Brazil	*R. lalandii*	38 - 46	90 - 260	Amorim-Lopes et al. (2020)
	R. lalandii	62 - 112	170 - 240	
SE Brazil	*R. porosus*	43 - 56	70 - 380	
Sonora, Mexico	*R. longurio*	67 - 85	104 - 450	Hurtado-Banda et al. (2012)
	R. longurio	107 - 122	350 - 3,360	
Stingrays				
Pernambuco, NE Brazil	*H. guttatus*	34 - 67	129 - 2,130	This study
Ceará, NE Brazil	*H. guttatus*	84	83	Lacerda et al. (2016)
Ceará, NE Brazil	*H. guttatus*	11 - 72	1 - 1,089	Moura et al. (2020)
Ceará, NE Brazil	*H. americanus*	52 - 91	200 – 1,197	
SW Florida, USA	*H. americanus*	41 - 48	140 - 190	Adams et al. (2003)
SW Florida, USA	*H. sabinus*	19 - 31	120 - 450	
NW Florida, USA	*H. sabinus*	17 - 31	60 - 440	
SE Florida, USA	*H. sabinus*	9 - 33	10 - 440	
NE Florida, USA	*H. sabinus*	11 - 28	20 - 340	
SW Florida, USA	*H. sabinus*	21 - 28	170 - 540	
SW Florida, USA	*H. say*	20	20	
SE Florida, USA	*H. say*	15 - 38	20 - 140	
SW Florida	*H. say*	20 - 30	100 - 120	
SW Florida, USA	*H. say*	25 - 54	60 - 590	
SE Florida, USA	*H. sabinus*	13 - 30	130 – 1,080	Soulen et al. (2019)
Gulf of California, Mexico	*H. Longus*	96 - 127	400 - 1,030	García-Hernández et al. (2007)
Nayarit, Mexico	*H. Longus*	52	1,339	Ruelas-Inzunza et al. (2013)
Sonora, Mexico	*H. dipterurus*	46 ± 8	284 ± 189	
Nayarit, Mexico	*H. dipterurus*	34 ± 5	852 ± 720	

2010, Vieira 2013). Biometric data of disk width and total weight of *H. guttatus* also characterize a typical population with age range previously reported for the region, mostly constituted by adults and sub-adults (Melo 2016, Santos 2017, Queiroz 2017). It is believed that the shallower areas are visited by adult individuals for feeding and/or reproduction (Vieira 2013).

Compared to other areas in the Brazilian coast, concentrations found in stingrays from the Pernambuco coast, like sharpnose sharks, are in general higher than previously reported elsewhere and are also the highest ever reported for the Atlantic Ocean and the North Pacific Ocean (Table II).

Lacerda et al. (2016) reported average Hg concentration of 83.4 $ng.g^{-1}$ w.w. in a large (84 cm) individual of *H. guttatus* from the Ceará coast. Similarly, Moura et al. (2020) reported an average Hg concentration for a sample of 17 individuals, also from the Ceará coast, with mean DW of 34.3 cm, of 56 ng g^{-1} w.w., even considering the larger average size of the Pernambuco population (51.6 cm) the overall average Hg concentration of 993 ng g^{-1} w.w., from all sampling sites, is about 20 times higher than in the Ceará population.

Globally, Hg concentrations found in *H. guttatus* from Pernambuco is the second highest ever reported worldwide among batoid species (Bezerra et al. 2019), with values near the maximum found in the Mediterranean Sea, where Hg concentrations varied from 86 to 2,420 $ng.g^{-1}$ w.w. among 559 specimens belonging to 10 species (Rajar et al. 2007). The minimum value found in Pernambuco, however, is still 1.5 times higher than the lowest concentrations found in that study.

Figure 4 compared Hg concentrations in *R. porosus* and *H. gutattus* sampled from the Pernambuco coast. Stingrays showed significantly higher ($P < 0.05$) Hg concentrations than those observed in sharpnose sharks.

These higher Hg concentrations in *H. guttatus* reflect the relatively low mobility of the species and benthic habits, relative to *R. porosus* (Machado et al. 2016). In addition, *H. gutattus* inhabits historically Hg contaminated site of the Pernambuco coast, the Ponta de Pedras and Barra de Catuama, located in the northern part of the Santa Cruz Channel, a highly contaminated spot by past emissions Hg-rich effluents from a chlor-alkali plan, presently decommissioned. High concentrations of Hg

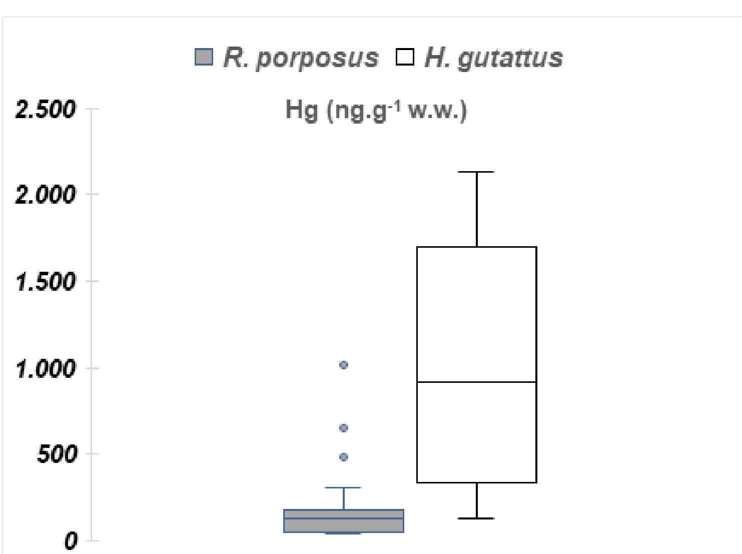

Figure 4. Box-and-whisker plots of Hg concentration in *R. porosus* and *H. guttatus* from the coast of Pernambuco, northeastern Brazil.

in sediment, oysters and suspended particles were previously reported by Meyer & Medeiros (2017). Also, the region harbors over 6,650 ha of mangroves (Guimarães et al. 2010) and these regions have been characterized as significant sources of organic-bound Hg, including methyl-Hg, to estuaries and coastal waters (Lacerda et al. 2020), and this may contribute to the high Hg burdens in rays. Adult *H. guttatus* differently for juveniles inhabit in estuarine areas, such as the Botafogo Channel, foraging in contact with the sediment and using the snout to dig for food being more exposed to Hg present in sediments (Melo 2016, Santos 2017). Also, older individuals were more frequent in the sample of *H. guttatus* than in *R. porosus*, resulting in longer Hg exposure and accumulation (Costa et al. 2009, Lyons et al. 2017, Rabelo 2017, Murillo-Cisneros et al. 2018). Trophic level may not be significant influencing the different Hg concentrations between these elasmobranchs. Trophic level of *H. guttatus* range from 2.6 (Froese & Pauly 2018) to 3.67 (Queiroz 2017) and the trophic level of *R. porosus* range from 3.5 (Froese & Pauly 2018) to 4.0 (Peña 2018). Rather preference of preys closely associated with sediment, like benthic fish, are more susceptible to Hg accumulation than consumers of pelagic fish or benthic invertebrates (Storelli et al. 1998, 2002).

Since the average Hg concentrations observed in the two species are higher than those reported for other regions along the Brazilian coast, anthropogenic Hg sources, might explain this result. *H. gutattus* reflect site-specific contamination, in particular the chlorine and caustic soda plant, which for 25 years dumped its tailings into the Botafogo River (Sant'Anna Jr et al. 2001, Cavalcanti 2003). Meyer & Medeiros (2017), based on total Hg content of sediments and oysters, concluded that about 10% of the total Hg load remained in sediments, equivalent to 1.2 to 2.5 tons of Hg. Most of the emitted Hg, however, would have been exported to the sea in association with suspended solids. In addition, the large harbor and urban development densely concentrated in a short and narrow stretch of coast, may raise environmental Hg levels, as suggested by the sharpnose shark Hg content. The response of elasmobranchs to regional Hg levels has been observed elsewhere (Marcovecchio et al. 1991, Bezerra et al. 2019).

Hg-contaminated elasmobranch flesh can cause several deleterious effects on humans, including neurological and psychological symptoms such as tremors, personality changes, restlessness, anxiety, sleep disturbance, memory loss, dementia, attention deficit, depression, and impaired hearing and vision. (Järup 2003, Zahir et al. 2005, WHO 2017). Although most Hg concentrations observed in this study were relatively low, some from stingrays, may threaten humans. Similar low concentrations may cause harm to the health of the consuming population. For example, Feitosa-Santana et al. (2018) observed an impairment of visual capability in a group of fish-eating adults living in the Brazilian Amazon exposed to low-to-intermediate concentrations.

Risk coefficients and provisionary intake are reliable safeguard indexes to evaluate population exposure to pollutants. The potential risk to humans from consumption of edible muscle of myliobatids, from the Eastern Gulf of California, Mexico (30 – 790 $ng.g^{-1}$ w.w. Hg) is low (HQ < 1.0) (Escobar-Sánchez et al. 2016), much lower than the HQ measured in stingrays from Pernambuco. Hg concentrations observed by Adams & McMichael (1999) in several commonly landed shark species, including sharpnose sharks, from SE USA, and varying in the same range of concentrations found in this study, often exceed state and federal regulatory levels, posing risk to local consumers. Dietary provisional tolerable weekly intake for sharpnose sharks *Rhizoprionodon lalandii* and *R. porosus* from Rio de Janeiro, SE Brazil, except for a single value obtained within the heavily polluted Guanabara Bay, where in the same range found in Pernambuco sharks. Risk coefficients for sharks (HQ = 0.220) and specially for stingrays (HQ = 1.07) from Pernambuco, results in higher exposure to consumers relative to published values elsewhere along the Brazilian coast.

CONCLUSION

Cartilaginous fishes (*H. guttatus* and *R. porous*) investigated in the coast of Pernambuco showed relatively high Hg concentrations in muscle tissues, compared to other regions in the South Atlantic Ocean. Contamination reflects anthropogenic Hg from point sources, as demonstrated by stingrays and diffuse emissions from urban and harbor-industrial sources, as demonstrated by sharks. Consequently, levels of Hg in fish from Pernambuco are in general higher than those reported for other fishes caught along the Brazilian coast, consequently resulting in higher exposure risk to consumers. Unfortunately, there is no statistics on the consumption rates of these species by the local population, which avoids a detailed risk analysis of human exposure. However, the observed individual values of Hg concentrations already surpassing the legal limits for safe consumption, makes a risk analysis urgent. While no permanent monitoring of Hg concentrations in elasmobranchs is available, it is important for the consumer population to diversify the fishery type in order to avoid high Hg ingestion.

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SUPPLEMENTARY MATERIAL

Figure S1.
Tables SI, SII.

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Tainá G. Julio designed the study, participated in the sampling and analysis of samples, and wrote a preliminary version of the manuscript. Rosângela P.T. Lessa designed the study, work on data interpretation and wrote a final version of the manuscript. Victor L. Moura was responsible for sample preparation and Hg analysis and collaborate on writing the manuscript. Luiz D. Lacerda worked on data interpretation, writing the manuscript and reviewed it.