Chapter

Mercury in the Colombian Caribbean: The Bay of Cartagena, A Model in Resilience

N. H. Campos-Campos and José Luis Marrugo-Negrete

Abstract

The Caribbean Sea in Colombia maybe being subjected to discharges of terrigenous solid waste and with these probably, the natural metallic constituents of the sediments, through the discharges of the Magdalena River since the time of the conquest. With the opening of the Dique canal in the mid-seventeenth century, which linked pipes, swamps, and branches from the Magdalena River to its mouth at the southwestern end of the bay, great changes could be caused from the point of view of mixing the fresh and turbid water of the channel with the clear and marine waters of the bay, which led to the beginning of the deterioration of the coral ecosystems present in the bay. Mercury contamination in the Colombian Caribbean has different origins. Artisanal gold mining has the greatest impact and has generated mercury contamination in many ecosystems, particularly in Bolívar and the Mojana region (department of Sucre and Cordoba). In this study, published information on mercury contamination along the Colombian Caribbean coast is compiled. The concentrations present differences between different areas of the coast. The bay of Cartagena is one of the areas most impacted by this pollutant, mainly due to the discharge of waste from a salt processing plant. Other areas are impacted by mercury, the product of the artisanal exploitation of gold, the discharges as a result of this activity are transported mainly to the Magdalena River, and through the different arms that form the delta, they are deposited in the Colombian Caribbean.

Keywords: mercury, Caribbean, Colombia, marine pollution, biota

1. Introduction

Marine pollution has received great attention a long time ago. In 1959, the first international conference on marine pollution problems was held in Berkley (United States) [1]. This problem is of great importance because the oceans have become the place of deposit and storage of a large part of the waste of all kinds, produced by man. These residues drain into the main river arteries and are transported by this means to their final destination in the marine environment. An important role in the transport of pollutants occurs through the lower layers of the atmosphere, which by precipitation or deposition reach the marine environment.

Mercury is, in very small amounts in seawater, a poison and a danger to life processes. Where an enrichment of this metal occurs, catastrophic consequences occur. It is a ubiquitous environmental toxicant. It exists in three forms, elemental (Hg(0)), inorganic (Hg^{2+}), and organic forms. Hg (0) takes a liquid form at room temperature but readily evaporates into mercury vapor. Hg^{2+} occurs naturally in the environment in the form of divalent cationic salts of mercury, such as HgCl2 and $Hg(OH)_2$, among others. Among the three forms, organic mercury, primarily methylmercury (MeHg), is the most dangerous form.

Methylmercury is a bioavailable form and can bioaccumulate through food webs. Shellfish consumption, especially fish consumption, is the main source of human exposure to MeHg. In 1956, "Minamata methylmercury poisoning" (MPM) was recognized, this being the first incident in the world, although there were some events in which several people had suffered direct health damage from exposure to mercury. organic mercury in a laboratory or factory [2].

According to Yokoyama [2], MPM is a neurological syndrome that was caused by the ingestion of fish and shellfish contaminated by methylmercury compounds, generated in the acetaldehyde production process. The first and second outbreaks of this type of disease in Japan were caused by effluent discharged from a Shin-Nippon Chisso Hiryo (hereinafter referred to as Chisso) factory in Minamata, Kumamoto Prefecture, and a Showa Denko factory in Kanose Town, Prefecture of Niigata, respectively.

MeHg is a stable organic mercury compound and is the most toxic form of mercury in the environment not only for humans but also for wildlife (Wolfe et al. 1998, Henriques et al. 2015, in [2]). Because methylmercury is lipid-soluble, it crosses the blood-brain barrier and accumulates in the brain. Methylmercury in the brain causes lysis of central nervous system cells, resulting in irreversible, permanent cell damage (Rabenstein 1978, in [2]). Therefore, MPM is widely recognized as a disorder in the brain, while Shiraki (1979, in [2]) suggested that MPM produces lesions not only in the brain but also in the vascular and endocrine systems.

In 2005, the European Environmental Bureau and the Mercury Policy Project formed "The Zero Mercury Working Group" (ZMWG), an international coalition of more than 95 public interest non-governmental organizations defending the environment and health. from more than 52 countries. The ZMWG strives to eliminate mercury supply, demand, and emissions from all anthropogenic sources, in order to minimize the presence of mercury in the global environment. Its mission is to advocate and support the adoption and implementation of a legally binding instrument containing the necessary obligations to eliminate, as far as possible, and if not minimize, the global supply and trade of mercury, its global demand, the release anthropogenic release of mercury into the environment, and human and wildlife exposure to mercury, these actions gave rise to the "Minamata Convention" [3].

In the agreement, in article 19, it establishes the research, development, and monitoring of the contaminant, especially with the elaboration of models and the geographically representative monitoring of the levels of mercury and its compounds in vulnerable populations and the environment, including biotic media such as fish, marine mammals, sea turtles, and birds, as well as assessments of the effects of mercury and its compounds on human health and the environment, as well as the social, economic, and cultural effects, especially with regard to vulnerable populations, among others [4].

2. The bay of Cartagena

The bay of Cartagena is located in the middle part of the Colombian Caribbean coastline, between 10°16′–10°26′ N and 75°30′–75°36′ W.

The bay of Cartagena is a semi-enclosed body of water, in which two parts stand out, an external one that connects it with the Caribbean Sea through two mouths (Bocachica and Bocagrande); and the internal one located in the northeastern part and is not directly connected to the sea. The bay of Cartagena has estuary characteristics due to the contributions of continental waters from the Canal del in Pasacaballos.

The first studies focused on the study of mercury contamination in the bay were carried out with the support of the National Institute for the Defense of Renewable Resources—Food and Agriculture Organization of the United Nations (INDERENA-FAO, Acronym in Spanish) [5]. Between 1978 and 1979, a study was carried out with the support of the Oceanographic and Hydrological Research Center of the Colombian Navy (CIOH) to evaluate the dynamics and the chemical and sedimentological characteristics, in the study mercury was analyzed, and eight samplings were carried out quarterly; however, they only present the results of two contrasting periods.

Figure 1 shows the results of the two seasons [6]. According to these authors, in the December–April, dry period, the maximum concentrations were measured in the southwestern part, at stations E37 and E31, in the Mamonal industrial zone and where the Petrochemical and Acalis de Colombia were located, with values between 2.0 and 1.4 μg Hg/l, respectively. In the August–December, rainy seasons, a three-year period, three important foci were detected, one in the Internal Bay (E3) where the

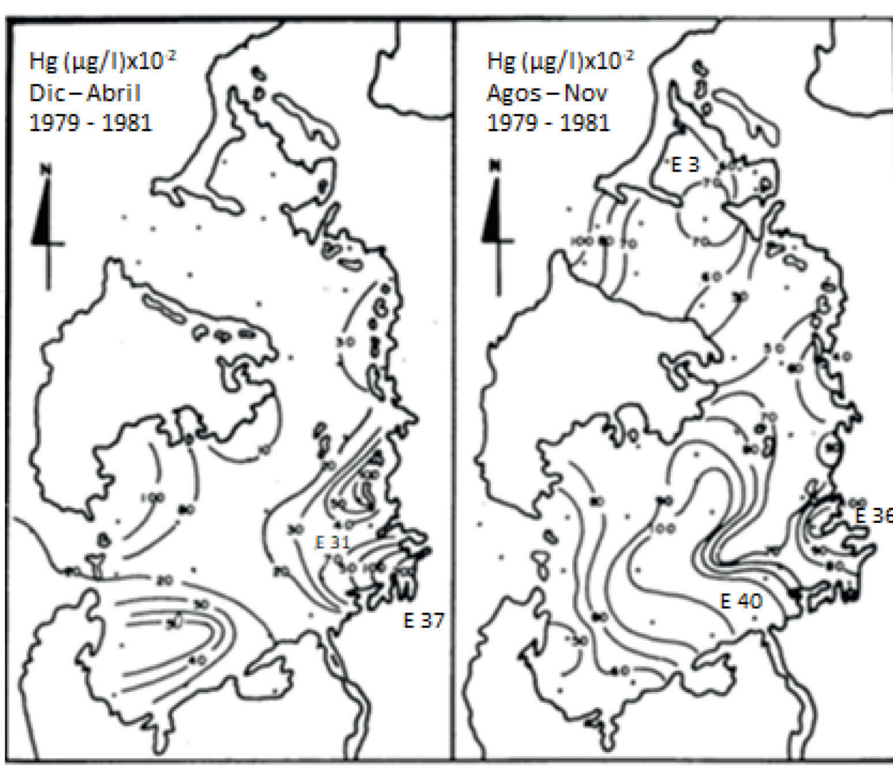


Figure 1.
Mercury content in μg l^{-1} < in water samples at 42 stations in the Bay of Cartagena, in two seasons, December–April and August–November, 1979–1981. Modified from Pagliardini et al. [6].

Los Pegasos dock is located with heavy traffic and possibly strongly influenced during this time of year by the currents, with contents of 1445 μg l^{-1}. The second in Mamonal with contents of 1180 μg l^{-1}, slightly lower than those measured during the windy period. The third is the mouth of the Canal del Dique with a content of 1 μg l^{-1}, which corroborates the importance of the semi-artificial canal in the discharge of sediments and pollutants into the bay. This was corroborated with the horizontal profile that allowed us to observe that the Canal del Dique during the rainy season is the main factor in the distribution of pollutants due to the amount of sediment it transports (see fig 46 and 47, page 86).

In 1996 [7] conducted a study to compare the Hg concentration in two species of estuarine fish, between the Bay of Cartagena and the Ciénaga Grande de Santa Marta, in addition to the content of sediments of these two ecosystems.

The results in sediments (**Figure 2**) clearly show a difference between the stations of the Bahía de Cartagena and the Ciénaga Grande de Santa Marta (CGSM), being the contents measured in the Bay were substantially higher than in the CGSM. The average content for the bay was 1876 ± 578 μg Hg g^{-1} p.s., with extreme values of 94–10,293 μg Hg g^{-1} p.s. A heterogeneous distribution was determined between the different stations of the bay. The maximum values were determined in sediments from station 3, which corresponds to the area of influence of the old chlor-alkali plant, and a decrease in the contents towards the north (stations 3–5) was determined. It is noteworthy that these authors determined the lowest concentrations at station 1 located on the southwestern side, to the right of the mouth of the Clarín Channel, and to the south of the area of influence of the Alcalis discharge, with values of 154 ± 21 μg Hg g^{-1} p.s., which corresponds to station E37, also with the highest values in water published by Pagliardini *et al*. [6].

Compared to the concentrations measured in the Ciénaga Grande (20–109 μg Hg g^{-1} d.w.), they are very low, to the point that the maximum concentration measured is compared to the lowest value in the Bahía de Cartagena (94–10 293 μg Hg g^{-1} d.w.).

Cogua *et al.* [8] determined the contents of total mercury (HgT) and methylmercury (MeHg) in sediments and seston (Suspended organic and inorganic matter) of the Cartagena Bay, in five stations, collected quarterly for one year in 2006. The average content of HgT was 0.18 ± 0.001 μg Hg g^{-1} d.w. The highest contents were measured in front of the industrial zone (0.55 ± 0.03 μg Hg g^{-1} d.w.), with concentrations

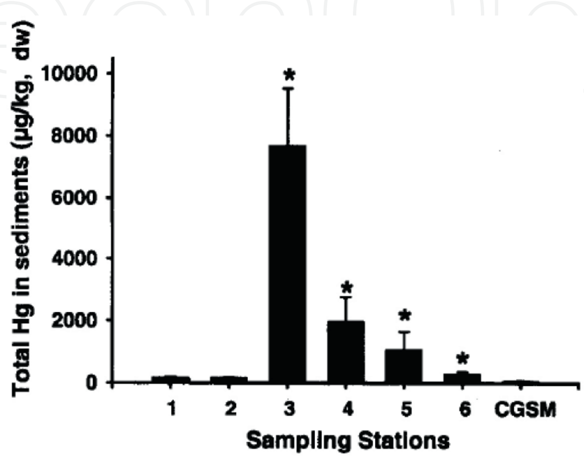


Figure 2.
Average content and standard deviation of total mercury (μg Hg g^{-1} d.w.) in sediments of Bahía Cartagena (six stations) and Ciénaga Grande de Santa Marta (three stations), between March and October 1996. Modified from Alonso et al. [7].

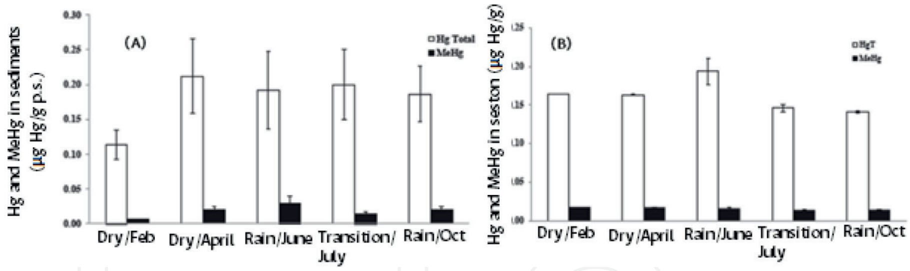


Figure 3.
HgT and MeHg contents (µg Hg g^{-1}) in sediments (A) and seston (B) during the four sampling periods. Modified from Cogua et al. [8].

decreasing towards the north and east. Likewise, it was observed that the highest contents corresponded to the months of influence of the rainy season (April to October), being higher in April at the beginning of the rains. According to these authors, 10% of HgT corresponds to MeHg and they are positively related ($r = 0.87$, $p < 0.04$).

For the contents in the suspended material, a similar behavior was presented, although with a lower average content (0.16 µg Hg g^{-1} d.w.), with the highest concentrations in the rainy season (June 0.19 µg g^{-1} p.s.), and a process of dilution from the station in front of the industrial zone (**Figure 3**).

Although the contents measured in sediments in the study by Cogua *et al.,* [8] are lower than those of Alonso *et al.* [7], the values were always higher in the area of influence of the industrial zone, where the chlorine—alkali was located, which discharged its waste through the Casemiro pipe to the Bay.

3. Organisms

Table 1 shows the mercury content measured in the two species of fish, the mullet and the silver mojarra (*Mugil incilis* and *Euguerres plumieri*), during the sampling period.

The contents in the two species of fish showed large fluctuations, which is to be expected, since they are two resident species in the bay, but they move throughout the study area and are, therefore, subjected to different concentrations for short periods of time. The highest concentrations for the two species occurred during the March sampling followed by November. During the four samplings, the contents were higher in the mojarra. According to the authors, significant differences were determined in the contents ($p < 0.001$), and the differences were 7.3 times greater in *E. plumieri* than

	Mugil incilis		***Euguerres plumieri***	
	X ± SX	**Extremps**	**X ± SX**	**Extremps**
March	87 ± 22	30–166	334 ± 117	37–852
May	10 ± 2	LD–16	160 ± 74	19–582
August	19 ± 10	LD–77	104 ± 22	29–194
November	41 ± 11	LD–89	255 ± 104	43–837

Values are taken from Alonso et al. [7]. X = average value; SX = standard deviation.
The mean value and standard error are given. LOD Limit of detection (7.4 µg Hg g^{-1} < d.w.).

Table 1.
Total mercury content (µg Hg g^{-1} d.w.) in two species of fish from the Bay of Cartagena, collected between March and November 1996.

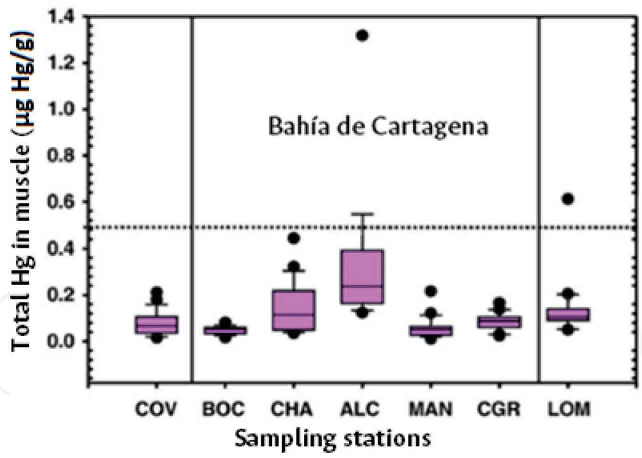


Figure 4.
Total mercury concentrations in muscle of two species of crab of the genus Callinectes in two areas of the Colombian Caribbean, Gulf of Morrosquillo and Bahía Cartagena. COV: Coveñas, BOC: Bocachica; CHA: Puerto Charcoal; ALC: Planta de cloro-alkalis; MAN: Manga; CGR: Castillo Grande; LOM: Lomarena in the Departamento del Atlántico. From Oliveros et al. [9].

in *M. incilis*. These results are understandable, taking into account that the mojarra is a secondary consumer, while the mullet is a detritivore. The contents in the fish from the bay were 7.3 times higher than those from the swamp.

The content of HgT has also been measured in species of crab for human consumption, crabs or swimming crabs (*Callinectes sapidus* and *C. bocourti*) from different collection points (Cartagena and Coveñas), along the Caribbean coast in Colombia [9]. Unfortunately, these authors did not include the HgT content in the crab samples, they only give the values of the percentage of crabs in which Hg was determined.

Figure 4 shows the HgT contents in crab muscle. The highest contents were measured in the specimens collected in the area of influence of the old chlor-alkali plant, followed by those collected in the Charcoal port, on the western side of the mouth of the Clarín Channel. The contents of the crabs collected in the other stations were lower. These results show that despite the chlor-alkali plant having been closed for so long, the presence of Hg in the environment is still notorious.

4. The coastal region of the department of Magdalena

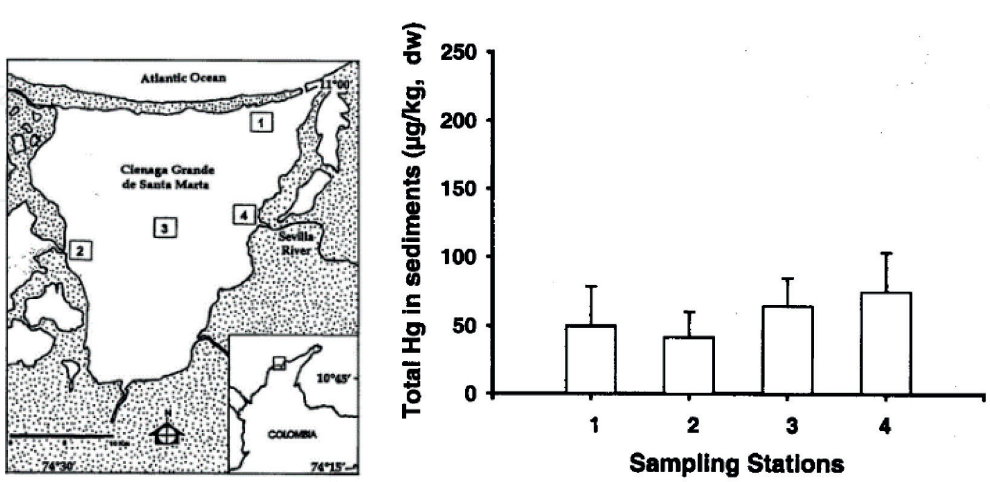
The coastal marine zone of the Department of Magdalena is located between 11°15′33″ N and 73°34′48″ W on the border with the Department of La Guajira and 11°05′42″ N and 74°50′55″W, in Bocas de Ceniza, on the eastern bank of the Magdalena River. There is a great diversity of ecosystems, from sandy beaches, coral reefs, seagrasses, mangroves, rocky coastlines, and sedimentary bottoms, which are considered strategic for the region and the country and provide environmental goods and services that influence the culture. and the economy of the human population of the department, due to its importance in tourism, fishing, and port activities. This region is influenced by the presence of the Sierra Nevada de Santa Marta (SNSM) in which numerous rivers are born and flow into the coastal area of the department and determine the structure of the coast in a series of cliffs and bays.

The outer delta of the Magdalena River is located on the western side of the strip, giving shape to the Ciénaga Grande de Santa Marta (CGSM), the largest lagoon-coastal system in the country and in which the Magdalena River and several rivers from the SNSM interact, and the surrounding seawater.

Even though numerous studies on marine pollution have been carried out on this coastal strip, there are few in which Hg content has been measured. Since 2000, the Marine and Coastal Research Institute [10] has been leading the "Diagnosis and Evaluation of the Quality of Marine and Coastal Waters in the Colombian Caribbean and Pacific" program, with the participation of several government entities (CARs: Autonomous and Regional Corporations), only in the period between June and November 2017 and between February and July 2018, determinations of Hg content in sediments were made [11]. The content of Hg in sediments from 18 points along the coastal strip of the department and during the two sampling periods (rainy 2017 and dry 2108) was determined. The contents fluctuated between values lower than the detection limit of the method (<3.0 ngHg g^{-1} p.s.) up to 496 ngHg g^{-1} p.s. During the rainy season, the contents were low and in nine of the stations, the presence of Hg was not detected, while in the dry season it could be measured in most of the stations. The highest contents were determined in the Bay of Santa Marta and the highest value corresponding to the station in the north of the bay near the cabotage dock of the port of Santa Marta (205 in the rainy season and 296 ngHg g^{-1} d.w., in the dry season) and 192 ngHg g^{-1} p.s. at the south bay station.

5. La Ciénaga Grande de Santa Marta

This physiography comprises the eastern sector of the great delta of the Magdalena River and extends between the same river and the Ciénaga Grande de Santa Marta and up to the foothills of the Sierra Nevada de Santa Marta. On the other hand, this region extends from the Caribbean Sea on the Island of Salamanca, to the Caño Ciego, which later flows into the Fundación River, taking before flowing into it, the name of Caño Schiller.



(A) (B)

Figure 5.
(A) Location of the sampling stations in the Ciénaga Grande de Santa Marta. (B) Average content and standard deviation of total mercury (µg Hg g^{-1} d.w.) in sediments of the Ciénaga Grande de Santa Marta (four seasons), between March and October 1996. 1. Islas del Rosario. 2. Boca de Caño Grande, 3. Centro, 4. Boca del Río Sevilla. Modified from Alonso et al. [7].

In the REDCAM program [10], six stations were included in the area of influence of the CGSM, apparently, they were only measured in the dry season and the contents fluctuated between 8.0 and 89.4 ng Hg g^{-1} d.w. The maximum value was measured in front of the mouth of the Sevilla River in the central part of the eastern side (**Figure 5A** Station 4), which drains from the SNSM, followed by the sediments collected near the mouth of the Fundación River, which, in addition to being born in the SNSM, receives the discharges of the Magdalena River, followed by the concentrations determined in sediments from other rivers of the SNSM fluvial system.

According to Alonso *et al*. [7], the Hg content in sediments fluctuated between 20 and 109 μg Hg g^{-1} d.w., with an average value of 58±6. These values are close to natural values (**Figure 5**). Although the authors did not determine significant differences, a slightly greater influence on Hg discharge is observed at the mouth of the Sevilla River, which belongs to the SNSM water system, which is consistent with the REDCAM results.

6. Organisms

Alonso *et al.* [7] determined Hg contents in sediments and fish (*Eugerres plumieri* mojarra and *Mugil curema* mullet) in the CGSM.

E. plumieri is a resident species in the CGSM, a secondary consumer, predominantly of the bivalve *Mytilopsis sallei* that forms banks on the bottom of the swamp, a filter-feeding species, while the mullet (*M. incilis*) is purely detritivorous. In the first, the contents were always about twice as high as in the second. The highest contents corresponded to the samples at the beginning of the year, corresponding to the end of the dry season and the beginning of the rainy season. As mentioned for the bay of Cartagena, the contents in the two species were 7.3 times lower than in BC (**Table 2**).

Campos [12] made the first determinations of Hg in the oyster Crassostrea rhizophorae, in samples collected in January 1987 at two stations located in the northern fringe, one on the western side at the mouth of the Clarín channel that transports and discharges water from of the Magdalena River and the second in the eastern part of the strip, near the mouth of the CGSM in the sea. The contents fluctuated between 0.04 and 0.18 μg Hg g^{-1} p.s., the latter corresponding to the samples from the Clarín channel.

	Mugil incilis		***Euguerres plumieri***	
	X ± SX	**Extremps**	**X ± SX**	**Extremps**
March	15.7 ± 7	LD–51	26 ± 8	LD–68
May	10 ± 2	LD–17	28 ± 6	13–52
August	8 ± 2	LD–17	9 ± 3	LD–22
November	6 ± 1	LD–10	12 ± 3	LD–20

Values taken from Alonso et al. [7]. X = average value; SX = standard deviation.
The mean value and standard error are given. LOD Limit of detection (7.4 μg Hg g^{-1} d.w.).

Table 2.
Total mercury content (μg Hg g^{-1} d.w.) in two species of fish from the CGSM collected between March and November 1996.

Species of fish	Sample	Hg
Eugerres plumieri	Muscle	18.7 ± 5 μg/kg
Cathorops mapale		18.1 ± 14.6 μg/kg
Centropomus undecimalis		28.2 ± 10.1 μg/kg
Elops smithi		36.6 ± 44.0 μg/kg
Eugerres plumieri		13.1 ± 11.3 μg/kg
Mugil incilis		16.1 ± 21.4 μg/kg
Values taken from Pinzón-Bedoya et al. [13].		

Table 3.
Total mercury content (μg kg^{-1} fresh weight) in fish species from the CGSM collected between January and December 2018.

Pinzón-Bedoya *et al.* [13] determined the concentrations of Hg (μg/kg f.w, fresh weight) contained in the muscle of fish species usually consumed by inhabitants of the area (**Table 3**). The compilation of the data shows that the results presented by Alonso *et al.* [7] an increase in the concentrations of Hg has been presented, which could demonstrate that the contributions of this metal persist, whether due to anthropic or natural origin, to the ecosystem; Likewise, it is possible to affirm the existence of accumulative and magnifying processes of Hg from the sediments to fish and bivalves.

Alonso *et al.* [7] indicated that the concentrations of Hg measured in the ecosystem components of the Ciénaga Grande de Santa Marta could be attributed to atmospheric deposition processes since this area did not present a significant industrial development. However, Caballero-Gallardo *et al.* [14] warn that the CGSM receives contaminants from intensive agriculture, especially bananas and African palm. Regardless of the source, the truth is that in the results of Pinzón-Bedoya *et al.* [13] Hg concentrations were positively correlated with morphometric variables (weight and length), evidencing Hg bioaccumulation processes in the aquatic biota of this ecosystem.

7. Cispatá Bay

For this coastal ecosystem, Burgos-Núñez *et al.* [15] reported that the bay of Cispatá-Colombia has been affected by chemical fertilizers, herbicides, pesticides, domestic wastewater, and spillage of substances such as hydrocarbons and heavy metals; These reasons were enough for them to determine the polycyclic aromatic hydrocarbons and heavy metals present in the tropical marine ecosystem of this bay (**Table 4**).

The results allowed us to observe that Hg concentrations increased with the trophic level in environments with very low levels of this metal, indicating bioaccumulation in the Cispatá Bay ecosystem. The distribution of Hg in the food web was: sediments < fish < birds. Seabirds can tolerate high concentrations of Hg, due to their ability to demethylate Hg in the liver and then store it as inorganic Hg [15, 16]. Lucia *et al.* [17] pointed out that the feathers in birds serve to excrete excess metals such as Hg; However, Tsipoura *et al.* [18] assured that concentrations higher than 5.0 μg Hg g^{-1} could impair the reproductive performance of birds.

Type of sample	Species of Fish	Sample	Hg
Sediments			31.7 ng/g d.w. (1.63–135.6)
Fish	*Cetengraulis edentulus*	Muscle	0.10 μg/g f.w.
	Eugerres plumieri		0.14 μg/g f.w.
	Centropomus undecimalis		0.38 μg/g f.w.
	Trichirus lepturus		0.67 μg/g f.w.
Birds		Blood	0.23 ± 1.09 μg/L
	Pelecanus occidentalis	Feathers	Juveniles (1.77 ± 0.71 mg/kg f.w) Adults (5.15 ± 1.52 mg/kg f.w)
	Phalacrocorax brasilianus		Juveniles (1.76 ± 0.65 mg/kg f.w) Adults (4.99 ± 1.47 mg/kg f.w)
	Fregata magnificens		Juveniles (2.10 ± 1.36 mg/kg f.w) Adults (10.2 ± 4.99 mg/kg f.w)
	Thalasseus maximus		Juveniles (0.96 ± 0.46 mg/kg f.w) Adults (3.57 ± 1.37 mg/kg f.w)

Values taken from Burgos-Núñez et al. [15].

Table 4.
Concentrations of THg in sediments, fish, and birds of the Bay of Cispatá-Colombia.

8. Mercury and malformation in crabs

In two recent studies, the impact that Hg can have on marine organisms was evaluated. The first is related to the high incidence rate of malformation in crabs collected in Cispatá Bay [19]. According to these authors, malformations occurred throughout the sampling year, fluctuating between 2.78% and 25.09% (**Table 5**).

Figure 6 shows the malformations of two specimens of the Xanthoidea superfamily, multiple malformations are observed in both. In (A) malformations in the two anterolateral borders. (B) The left side shows the separated teeth, the fifth reduced, the third subquadrate projected posteriorly, and the first and second fused. (C) The

	06/05		09/05		12/05		03/06	
	No. D	**% D**	**No. D**	**% D**	**No. D**	**% D**	**No. D**	**% D**
C. Salado	0	0	9	9.68	0	0	0	0
C. Mocho	2	10.91	0	0	0	0	3	4.11
P. Nisperal	69	25.09	13	6.34	8	2.78	28	11.62
% Total		55.8		15.94		5.8		22.46

Information taken from Campos et al. [19].

Table 5.
Number of crabs of the superfamily Xanthoidea with deformities (No. D) and percentage in relation to the number of individuals collected (% D) of the superfamily, in three stations of Cispatá Bay, in four seasons of one year.

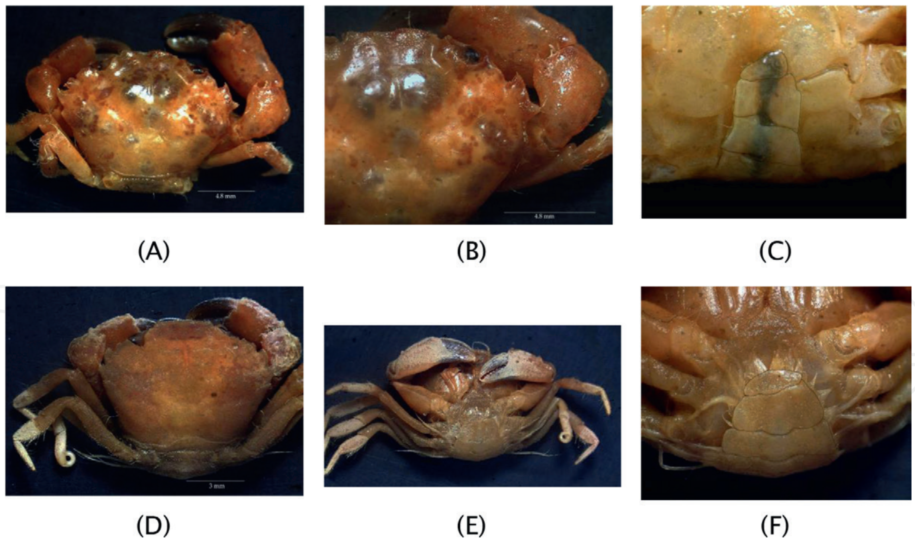


Figure 6.
Two examples of multiple malformations in crabs. (A) Dorsal view of a crab of the Xanthoidea superfamily. (B) Approach to the malformation of the right anterolateral border of the specimen. (C) Malformations in the abdomen. (D) Dorsal view of another crab of the superfamily Xanthoidea, the formation of the dactyl of the third left pereopod is observed. (E) Abnormal growth of the pleopods. (F) Malformation of the abdomen [19].

deformed abdominal segments do not cover the abdominal cavity; the telson ends in a subtriangular shape, the right edge longer than the left. (D) Malformation of the dactyl of the third left pereopod and of the orbits and teeth of the right anterolateral border. (E) The right sternites, fifth and sixth, separated, and those of the left side completely fused. (F) There is an overgrowth of the appendages of the abdomen (pleopods) protruding and the abdomen is twisted to the right due to shortening of the right border of the sixth abdominal segment (**Figure 6**).

The highest incidence of malformations occurred during the sampling of June, with 55.8% of the total malformations and corresponds to the period immediately after the first rainy season (April-May). While the lowest incidence was determined in December, in the full dry season. In Punta Nisperal, crabs with malformations were collected throughout the three sampling periods and with a high prevalence (25.9% in June and 11.62% in March 2006). December was the only season in which specimens with malformations were captured, although with the lowest incidence (2.78%).

9. Methylmercury in sharks

In a recent study Rueda *et al.* [20], evaluated the methylmercury content (μg MeHg kg^{-1} w.w.) in muscle and stomach content of the Antillean dogfish shark (*Rhizoprionodon porosus*), in three different areas in the Colombian Caribbean. The first in Cabo de la Vela north of the Caribbean coast, scarcely intervened by man and influenced by the upwelling of the same name. The second is in the Las Flores station, near the mouth of the Magdalena River, and the third is in the southern part of the Caribbean on Isla Fuerte.

Figure 7 shows the MeHg contents in the dogfish shark. The highest contents were determined at the Las Flores station (B) and the lowest at Cabo de la Vela (A). Regarding the sampling periods, it was observed that the maximum values occurred in the rainy season in Las Flores and in the dry season in Isla Fuerte and Cabo de la

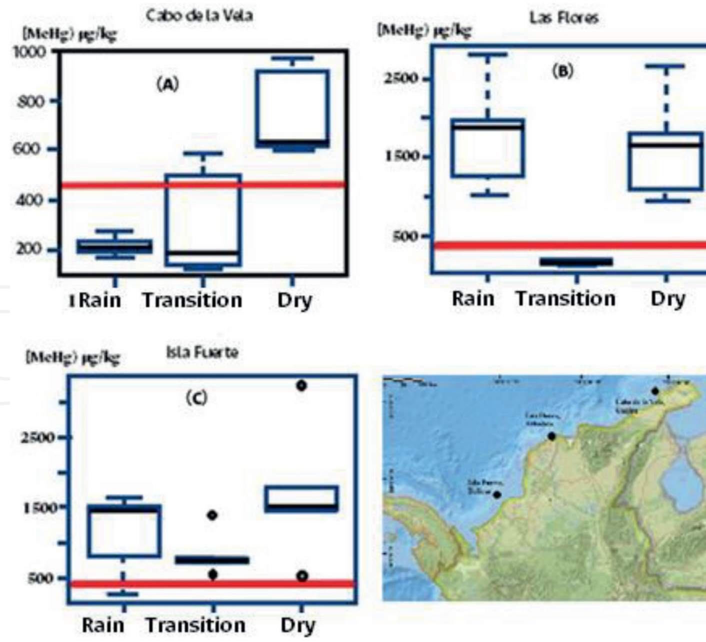


Figure 7.
MeHg content in µg kg^{-1}(w.w.) in Rhizoprionodon porosus muscle according to the season and at each of the study sites. Due to the values obtained, the Y axis of the graph belonging to Cabo de la Vela presents a different scale than the others. Red line indicates the maximum concentration recommended by the WHO (2000) for food consumption. Modified from Rueda et al. [20].

Vela. The lowest values in MeHg concentrations in shark tissues occurred, in general, during the transition period (July to August). For the three samplings in Isla Fuerte and in Las Flores in the dry and rainy seasons and only in the dry season in Cabo de la Vela, the contents exceeded the limits given by the World Health Organization (WHO, 2000) as permissible for the daily consumption per person. It is probable that the intensification of the upwelling by the trade winds, which are stronger, has transported the Hg from the sediments (**Figure 7**).

Figure 8 shows the concentrations of MeHg in µg kg^{-1}(w.w.) in the stomach content of *Rhizoprionodon porosus* according to the season and at each of the study sites. Only one sample was presented in a single sampling site in which the contents exceeded the permissible limits for daily human consumption (500 µg kg^{-1} WHO, 2000). The lowest concentrations were measured at Cabo de Vela, while the maximum was measured at Las Flores station in the dry season (408.6 µg k^{-1} g w.w.), while in the remaining samples, the contents were less than 200 µg/kg w.w., additionally and

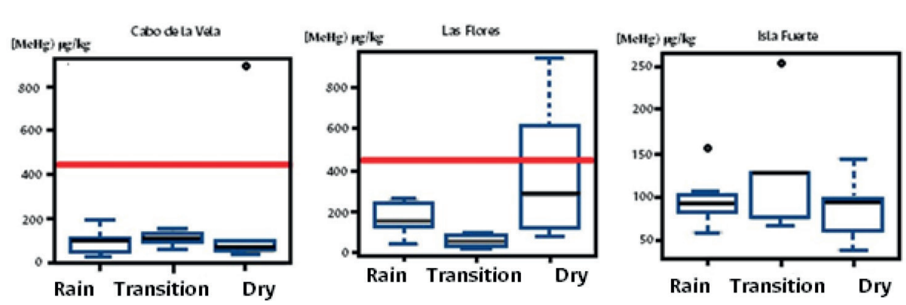


Figure 8.
MeHg concentrations in µg/kg(w.w.) in the stomach content of Rhizoprionodon porosus according to the season and in each of the study sites. The red line indicates the maximum concentration recommended by the WHO (2000) for food consumption. Modified from Rueda et al. [20].

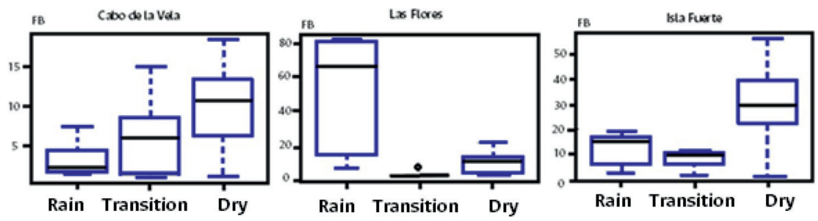


Figure 9.
Biomagnification factor (FB) in Rhizoprionodon porosus according to the season in each of the study sites. Modified from Rueda et al. [20].

with the exception of the flowers in the dry season, there were no significant differences between the samplings and the seasons.

Based on the MeHg concentrations in the muscle and stomach contents of the sharks, the biomagnification factor was determined for each of the sampling sites (**Figure 9**). Regarding the total data from the Colombian Caribbean, the Kruskal-Wallis test showed significant differences ($p = 0.05$) between the values of this factor in the different seasons. However, when doing the analysis with the data from each site separately, the only place where there were significant differences between the seasons was the Las Flores station. In Cabo de la Vela and Isla Fuerte, the temporal variation was not significant, although when analyzing the average values of each site in their respective seasons, they coincided in terms of the notable increase during the dry season.

10. Conclusions

Due to its ubiquity, mercury can be present in a wide range of spaces and environmental matrices that, due to its presence, can alter the balance in aquatic and terrestrial ecosystems. The concentrations, reported in the different studies addressed for this compilation, reveal the diversity of the possible sources for the marine environment of the Colombian Caribbean, generating a cause for concern due to the connotations that this metal has for human and environmental health.

Despite the limitations in accessing financial and logistical resources to carry out each of these investigations, the scientific community has been able to join efforts to show the current status of mercury contamination in coastal ecosystems, understanding that it is necessary to continue with the efforts to understand or elucidate in greater depth the impacts that mercury is having on marine-coastal organisms and on the human population of the Caribbean region. In this sense, the environmental control and surveillance authorities must seek mechanisms to control mercury emission or contamination sources for the protection of marine ecosystems, as established in article 12 of the Minamata Agreement. Also, the same agreement in its article 19, establishes the need to carry out monitoring studies in the environment and in the vulnerable population for the evaluation of the impacts on ecosystems [4].

Contribution No. of the Institute for Studies in Marine Sciences, CECIMAR, of the National University of Colombia, Caribbean Campus.

Author details

N. H. Campos-Campos[1]* and José Luis Marrugo-Negrete[2]

1 Institute of Studies in Marine Sciences – CECIMAR, National University of Colombia, Caribbean Campus

2 Universidad de Córdoba, Colombia

*Address all correspondence to: nhcamposc@unal.edu.co

References

[1] Gerlach SA. Meeresverschmutzung. Berlin: Springer Verlag; 1976. p. 145

[2] Yokoyama H. Mercury Pollution in Minamata. Singapore: Springer Briefs in Environmental Science; 2018. p. 74

[3] Lennett D, Gutiérrez R. Convenio de Minamata sobre el Mercurio Manual de ratificación y aplicación. Natural Resources Defense Council y BAN Toxics. 2015

[4] UNEP (United Nations Environment Programme). Minamata Convention on Mercury-Text and Annexes. 2017

[5] Escobar JJ, Granados J, Polensky E, Valle V. Estudio de la contaminación por mercurio en la Bahía de Cartagena. Colombia: Invest; 1977. p. 39

[6] Pagliardini JL, Gómez MA, Gutierrez H, Zapata SI, Jurado A, Garay JA, et al. Síntesis del proyecto Bahía de Cartagena. Boletín Científico CIOH. 1982;**4**:49-110

[7] Alonso D, Pineda P, Olivero J, González H, Campos NH. Mercury levels in muscle of two fish species and sediments from the Cartagena Bay and the Ciénaga Grande de Santa Marta, Colombia. Environmental Pollution. 2000;**109**:175-163

[8] Cogua P, Campos NH, Duque G. Concentración de mercurio total y metilmercurio en sedimento y seston de la Bahía de Cartagena, Caribe colombiano. Bol. Invest. Mar. Cost. 2012;**41**(2):267-285

[9] Oliveros Verbel J, Johnson-Restrepo B, Baldiris-Avila R, Güette-FernándezJ,Magallanes-CarreazoE, Vanegas-Ramírez L, et al. Human and crab exposure to mercury in the Caribbean coastal shoreline of Colombia: Impact from an abandoned chlor-alkali plant. Environmental International. 2008;**34**:476-482

[10] INVEMAR. Diagnóstico y evaluación de la calidad de las aguas marinas y costeras en el Caribe y Pacífico colombianos. Luisa F. Espinosa y Ostin Garcés (Eds). Red de vigilancia para la conservación y protección de las aguas marinas y costeras de Colombia – REDCAM: INVEMAR, MinAmbiente, CORALINA, CORPOGUAJIRA, CORPAMAG, CRA, CARDIQUE, CARSUCRE, CVS, CORPOURABÁ, CODECHOCÓ, CVC, CRC y CORPONARIÑO. Informe técnico 2018. Serie de Publicaciones Periódicas No. 4 del INVEMAR, Santa Marta. 2019

[11] INVEMAR. Diagnóstico y evaluación de la calidad de las aguas marinas y costeras en el Caribe y Pacífico colombianos. In: Espinosa LF, Garcés O, editors. Red de vigilancia para la conservación y protección de las aguas marinas y costeras de Colombia – REDCAM: INVEMAR, MinAmbiente, CORALINA, CORPOGUAJIRA, CORPAMAG, CRA, CARDIQUE, CARSUCRE, CVS, CORPOURABÁ, CODECHOCÓ, CVC, CRC y CORPONARIÑO. Informe técnico 2018. Santa Marta: Serie de Publicaciones Periódicas No. 4 del INVEMAR; 2019. p. 212

[12] Campos C, N. H. La contaminación por metales pesados en la Ciénaga Grande de Santa Marta, Caribe colombiano. Caldasia. 1990;**16**(77):231-244

[13] Pinzón-Bedoya C, Pinzón-Bedoya M, Pinedo-Hernández J, Urango-Cárdenas I, Marrugo-Negrete J. Assessment of

potential health risks associated with the intake of heavy metals in fish harvested from the Largest Estuary in Colombia. International Journal of Environmental Health Research and Public Health. 2020;**17**:1-13

[14] Caballero-Gallardo K, Alcala-Orozco M, Barraza-Quiroz D, De la Rosa J, Olivero-Verbel J. Environmental risks associated with trace elements in sediments from Cartagena Bay, an industrialized site at the Caribbean. Chemosphere. 2020;**242**:125173

[15] Burgos-Núñez S, Navarro-Frómeta A, Marrugo-NegreteJ,Enamorado-MontesG, Urango-Cárdenas I. Polycyclic Aromatic Hydrocarbons and Heavy Metals in the Cispata Bay. Colombia: Marine Pollution Bulletin; 2017

[16] Burger J, Gochfeld M. Effects of Chemicals and Pollution on Seabirds, Biology of Marine Birds. Boca Raton, FL: CRC Press; 2001. pp. 485-526

[17] Lucia M, Andre J, Gontier K, Diot N, Veiga J, Davail S. Trace element concentrations (mercury, cadmium, copper, zinc, lead, aluminium, nickel, arsenic, and selenium) in some aquatic birds of the southwest Atlantic coast of France. Archives of Environmental Contamination and Toxicology. 2010;**58**:844-853

[18] Tsipoura N, Burger J, Newhouse M, Jeitner C, Gochfeld M, Mizrahi D. Lead, mercury, cadmium, chromium, and arsenic levels in eggs, feathers, and tissues of Canada geese of the New Jersey Meadowlands. Environmental Research. 2011;**111**:775-784

[19] Campos-Campos NH, Dueñas-Ramírez PR, Genes N. Malformación en cangrejos de la superfamilia Xanthoidea (Crustacea: Brachyura) en la bahía de Cispatá (Córdoba, Colombia). Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales. 2015;**39**(150):91-99

[20] Rueda-Bernal R, Acero P, et al. Determinación del rol del tiburón cazón antillano *Rhizoprionodon porosus* (Carcharhinidae) en el flujo de metilmercurio en las redes tróficas del Caribe colombiano. Rev. Acad. Colomb. Cienc. Ex. Fis. Nat. 2020;**44**(170):169-181