

Article

Mercury Levels in the Crab *Grapsus grapsus* across the Galápagos Archipelago

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Abstract: The levels of mercury (Hg) were examined in the leg muscle of the crab *Grapsus grapsus* from five sites on four islands within the Galápagos archipelago. Mercury values obtained using a Milestone DMA 80 evo direct mercury analyzer varied both within and among sites. Total mercury concentrations (mg kg^{-1} dry weight) ranged from the lowest at a protected location at Isabela Island (0.06 ± 0.02) to the highest at the San Cristóbal urban location (2.04 ± 0.069). Crabs from South Plaza Island also had surprisingly high levels of mercury with a mean of 1.2 ± 0.6 . Values from urban sites at Isabela Island and Academy Bay, Santa Cruz, had intermediate values. When converted to wet weight, crabs from both San Cristóbal and South Plaza were within or above the levels ($0.3\text{--}0.5 \text{ mg kg}^{-1}$ wet weight set by various government agencies) considered potentially harmful to human health if ingested. A lesser number of both oysters and barnacles were also analyzed for mercury at South Plaza and Academy Bay, and while the values were lower compared to the crabs, they followed the same pattern of elevated levels at South Plaza compared to Academy Bay. It is unclear as to whether the mercury comes from natural sources, such as volcanism, or anthropogenic causes.

Keywords: mercury; Hg; crab; *Grapsus*; Galápagos

Key Contribution: This study found substantially elevated mercury levels in the crab *Grapsus grapsus* at some sites in the Galápagos archipelago, including both urban and protected areas of the Galápagos National Park. Some levels obtained were high enough to be a potential health concern if consumed, especially for children and women of childbearing age.



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1. Introduction

Mercury (Hg) contamination in marine and freshwater environments continues to be an issue that has the potential to be harmful to wildlife and human health. There is now up to 10-fold more mercury in the environment since industrialization, particularly from coal combustion. In food chains, it is predominantly organic methylmercury (not ionic mercury) that accumulates in organisms, including humans, and makes mercury such a concern in biological systems. Ionic mercury is methylated by sulfate-reducing bacteria at the sediment–water interface within aquatic ecosystems [1]. Around 80–90% of organic mercury that accumulates in humans is from fish and shellfish consumption [2]. This mercury accumulation can adversely affect human health [2–4]. Today, the potential impact of mercury in aquatic food chains and the worldwide risk to human health is better understood [5,6].

Mercury in the environment is not only a result of anthropogenic activity. There are also natural sources of environmental mercury, with volcanic emissions being a potential

source for the release of large amounts of mercury into the environment [7]. Moreover, recently, it has been shown that hydrothermal vents can also release significant amounts of mercury into the deep ocean, with inputs estimated at between 3 and 11% of the anthropogenic input of mercury into the ocean [8]. Thus, mercury in marine food chains can be the result of both anthropogenic pollution as well as from natural sources.

Mercury contamination poses a problem to both marine organisms and humans because of the way it bioaccumulates up marine food chains, with organisms at higher trophic levels having higher levels of mercury [9]. Coastal areas around the world can be especially vulnerable to mercury contamination from anthropogenic sources. This includes estuaries and coastal regions such as rocky intertidal habitats. Within these coastal and intertidal habitats, benthic invertebrates can be important links for transferring mercury to higher trophic levels. Mercury has been detected in a variety of invertebrates from many nearshore environments in different parts of the world. These include polychaetes, bivalves, gastropods, octopus, amphipods, shrimp, crabs, sea urchins, and sea stars [10–15].

The distribution of the Sally Lightfoot crab *Grapsus grapsus* is widespread in the tropical Pacific and Atlantic oceans and is a native species in the Galápagos Islands. It also ranges from Baja California to Northern Chile in the Eastern Pacific. In the Atlantic, *G. grapsus* is found from the Gulf of Mexico along the Western Texas coast to Venezuela, and throughout the Caribbean. It is also found on oceanic islands off Brazil and a few locations on the Brazil coast [16]. Specimens have also been found to inhabit freshwater streams in Trindade Island, Brazil [17].

Grapsus grapsus is a brachyuran crab with a planktonic larval zoea stage and then the recruitment of a megalopae [18]. Colonization of oceanic islands is achieved by surface currents dispersing the planktonic larvae, which then settle and inhabit the supratidal rocky shores in the splash zone [19]. Individuals of *G. grapsus* in the Galápagos Islands have been reported to reach 75 mm [18]. Their diet includes scavenging as well as feeding on algae, turtles [20], cirripedes, mytilids [18], fish, bird eggs [21], and young birds, including blue-footed boobies (*Sula nebouxi*), masked boobies (*S. dactylatra*) [22] and brown boobies (*S. leucogaster*) [22]. Recorded predators of *G. grapsus* include octopus and eels [20], and we also observed predation by the striated heron *Butorides striata* in Academy Bay, Santa Cruz Island.

We were interested in exploring the level of total mercury in *G. grapsus* and other marine intertidal invertebrates in the Galápagos Archipelago. Since the Galápagos archipelago is volcanic, with active volcanoes, there is the potential for mercury input into the environment from these natural sources. There is no major industry on the islands contributing to potential sources of mercury, although some mercury pollution could result from populated regions. Due to the remote location of the archipelago, it is unlikely that atmospheric input of mercury is a substantial source of mercury [23].

While we were interested in surveying mercury in a variety of marine intertidal invertebrates, *G. grapsus* was the most ubiquitous invertebrate that could easily be collected. To assess if there might be anthropogenic sources of mercury, we sampled more heavily populated regions along with more pristine, uninhabited sites.

2. Materials and Methods

Collections were made between 11 August and 17 August 2021 at intertidal sites on the islands of Santa Cruz, South Plaza, San Cristóbal, and Isabela under the Galápagos National Park permit no. PC-60-21 (Figure 1, Table 1). We were interested in sampling sites that were relatively pristine, along with sites that were subject to human impact. The pristine sites, which were located in protected areas, were at South Plaza, as well as Isabela at Playa Del amar, which is several kilometers west of the town of Puerto Villamil, (hereafter referred to as Isabela protected). The impacted urban sites were Academy Bay off Puerto Ayora (population < 12,000); Santa Cruz Island near the main jetty of Puerto Baquerizo Moreno (population < 7000), San Cristóbal Island; and near the main jetty of Puerto Villamil (population < 3000), Isabela Island (hereafter referred to as Isabela urban). The major focus

was on *Grapsus grapsus*, although smaller numbers of the barnacle *Tetraclita milleporosa* and the oyster *Saccostrea palmula* were also collected. For the mercury analysis, we intended to collect invertebrates with different feeding modes to obtain a better idea of how mercury is incorporated into different organisms. The crabs were grazers and scavengers, while the barnacles and oysters were filter feeders.

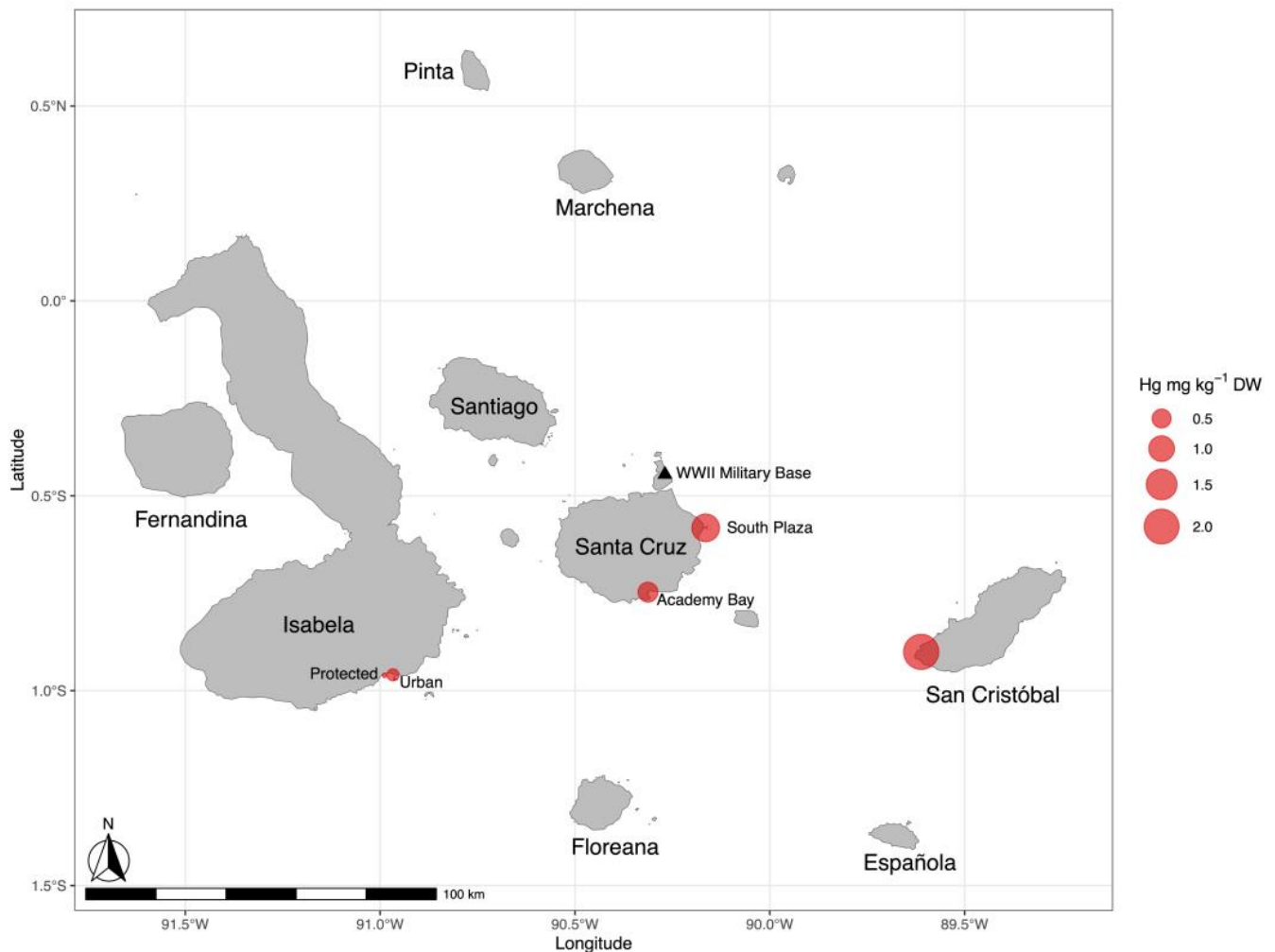


Figure 1. Sampling sites shown in red for this study within the Galápagos archipelago with the different size bubble plots showing the relative difference in mercury levels for each of the sites (mg kg⁻¹ dry weight). The triangle indicates the location of the World War II military base.

Crabs were captured by hand and a leg was removed for muscle analysis. Oysters and barnacles were removed from rocks with a hammer and chisel. The tissues were dissected and extracted on site in Puerto Ayora using clean methods. Muscle tissue was dissected from the crab while whole samples of barnacle tissue and a sub-sample of oyster tissue were taken to be used for mercury analysis. Tissue samples were placed in small zip-lock bags, dried in a small commercial food dryer at <60 °C, and were later analyzed in the laboratory at Loma Linda, California. Prior to mercury analysis, the samples were re-dried for several hours in a spin dryer to remove any moisture and to enable easier preparation of tissues. The samples were then slightly pulverized within the Eppendorf tubes using metal rods. The dry sample weights ranged from 0.014 to 0.06; from 0.007 to 0.05; and from 0.01 to 0.07 from the crabs, barnacles, and oyster samples, respectively.

Table 1. Details of species collected at the different sites in the Galápagos archipelago for mercury analysis.

Species/Location	<i>n</i>	Collection Date	Size Range (mm) *
Crabs <i>Grapsus grapsus</i>			
Santa Cruz, Academy Bay (urban)	10	17 August 2021	40.7–71.6
South Plaza (protected)	10	12 August 2021	59.2–68.1
San Cristóbal near jetty (urban)	10	13 August 2021	58.6–69.5
Isabela, rocks near jetty (protected)	10	15 August 2021	40.3–56.7
Isabela, Playa Del amar several km out of town (protected)	10	16 August 2021	43.6–66.2
Barnacles <i>Tetraclita milleporosa</i>			
Academy Bay (urban)	10	11 August 2021	26.1–29.0
South Plaza (protected)	10	12 August 2021	22.8–29.9
Oysters <i>Saccostrea palmula</i>			
Academy Bay (mangrove inlet, urban)	9	11 August 2021	46.1–62.9
South Plaza (protected)	1	12 August 2021	42.6

* Size for crabs is carapace width; for barnacles, it is the longest carapace length; and for oysters, it is the longest shell length.

Mercury levels within the tissue (mg kg^{-1}) were determined using a Milestone DMA 80 evo direct mercury analyzer. Mercury recovery was checked using NRC DOLT-5 dogfish liver and TORT-3 lobster hepatopancreas certified reference material, NRC Canada. The certified Hg concentration of DOLT-5 was 0.44 ± 0.18 , and TORT-3 was 0.292 ± 0.022 . Duplicate reference material samples were run through the DMA 80 at the beginning of each run, and then after approximately every 10 tissue samples. Unfortunately, due to the small sample sizes of the tissue, we were not able to run any duplicate tissue samples. Mercury recovery of the reference material was within the standard deviation of the certified values. Recovery of mercury ranged from 96 to 107% for TORT-3 and from 85 to 104% for DOLT-5.

Data Analysis

All data analysis and visualization were conducted using the R Statistical Software (v4.2.0; Core Team, 2021). In this study, we employed a linear regression model using the ‘lm’ function in R to examine the influence of site (South Plaza, San Cristóbal, Isabela urban, Isabela protected, and Academy Bay) within the Galápagos Archipelago on total mercury levels (mg kg^{-1}) in *G. grapsus*, while also controlling for the potential influence of carapace width (mm). Increasing carapace width of crabs has been shown to be associated with increasing total mercury levels [24]. In addition, a *t*-test was conducted to determine if there were any significant differences between total mercury levels found in the barnacle *T. milleporosa* collected from the Academy Bay and South Plaza sites. Residual plots of the data were examined to ensure linear regression and that *t*-test assumptions were met, along with the Shapiro–Wilk test for normality and Levene’s test for homogeneity of variance.

For converting our crab leg muscle Hg values from dry weight (dw) to wet weight (ww), we used the estimated moisture content of the crab muscle of 75%. This is a common value for shrimp [25], and it is also close to the average value of 75.1% that was used for the blue crabs *Callinectes sapidus* collected from the Northeast Atlantic coast of North America. [24]. We used the following equation for converting the Hg dw concentration to Hg ww concentration [25]:

$$\text{Hg}_{\text{mg kg}^{-1}(\text{ww})} = \frac{100 - 75}{100} \times \text{Hg}_{\text{mg kg}^{-1}(\text{dw})}$$

Note that the values of mg kg^{-1} used in this study are the same as ppm or $\mu\text{g g}^{-1}$ used in other studies. For consistency, all the values discussed in this paper (and citations from the literature) are referred to as mg kg^{-1} .

3. Results

Mean mercury values ($\text{mg kg}^{-1} \text{ dw}$) for *G. grapsis* varied considerably between sites, ranging from a low of 0.06 at Isabella protected to a high of 2.04 at San Cristóbal (Table 2). For comparison with other studies (and for dietary recommendations), we converted the mercury levels in the crab leg muscle to wet weight (ww). The converted wet weight values ranged from a low of 0.01 at the Isabela protected site to 0.88 mg kg^{-1} for the highest value at San Cristóbal. Mean and median values, respectively, ranged from 0.014 and 0.015 at Isabela protected to 0.51 and 0.44 mg kg^{-1} at San Cristóbal (Table 2).

Table 2. Summary of mercury levels found in *G. Grapsus* at the study sites in the Galápagos Archipelago. The dry weight values were obtained in the laboratory, and wet weight values were converted based on an estimated water content of 75% in crab muscle.

Site	n	Mercury Level mg kg^{-1} Dry Weight			Mercury Level mg kg^{-1} Wet Weight		
		Mean	Median	Range	Mean	Median	Range
San Cristóbal	10	2.04 ± 0.69	1.78	1.34–3.53	0.51 ± 0.1716	0.44	0.34–0.88
South Plaza	10	1.19 ± 0.60	1.16	0.44–2.50	0.2981 ± 0.1501	0.29	0.11–0.63
Academy Bay	12	0.56 ± 0.34	0.50	0.09–1.06	0.1404 ± 0.0859	0.13	0.023–0.26
Isabela U	10	0.18 ± 0.15	0.13	0.082–0.57	0.0442 ± 0.0364	0.03	0.020–0.14
Isabela P	10	0.06 ± 0.02	0.06	0.04–0.08	0.0144 ± 0.0038	0.01	0.01–0.02

Both total mercury ($\text{mg kg}^{-1} \text{ dw}$) and carapace width (mm) were log-transformed to meet assumptions for the linear regression model. The regression model was statistically significant ($F_{(5,46)} = 59.02, p \leq 0.0001$), indicating that site and carapace width accounted for 85% of the total variation in total mercury. However, the covariate of carapace width was not a significant predictor in the model, suggesting that its effect on total mercury was similar across sites ($p > 0.05$). Conversely, site was a significant predictor of total mercury, with all the sites being different from one another ($p < 0.0001$, see Figure 2, Table 2). To make it easier to compare total mercury levels between sites, the log coefficients were converted back to their original scale. When using Isabela protected as the reference site, on average, the expected total mercury level at San Cristóbal was approximately 30.5 times higher than Isabela protected. Similarly, total mercury levels at South Plaza and Academy Bay were around 16.3 times and 7.6 times higher, respectively. Isabela urban had the closest values to Isabela protected and was, on average, approximately 2.4 times higher (see Figure 2, Table 3).

Table 3. Linear regression model results of site and log carapace width (mm) on log total mercury (mg kg^{-1}).

	Coefficient	Std. Error	t-Value	p-Value
Intercept	−5.79	2.50	−2.32	0.025 *
Log Carapace Width	0.73	0.63	1.16	0.251
Site: South Plaza	2.809	0.27	10.18	<0.001 ***
Site: San Cristóbal	3.42	0.27	12.86	<0.001 ***
Site: Isabela Urban	0.89	0.25	3.62	0.001 ***
Site: Academy Bay	2.03	0.23	8.67	<0.001 ***
Multiple R-squared = 0.87				
Adjusted R-squared = 0.85				

* $p \leq 0.05$, *** $p \leq 0.001$.

Due to unequal variances in the total mercury levels of the barnacle samples collected at South Plaza and Academy Bay, Welch's *t*-test for unequal variances was performed. The *t*-test revealed that the total mercury levels (mg kg^{-1}) in the barnacles at South Plaza (0.1212 ± 0.0116) were, on average, 2.7 times higher than at Academy Bay (0.0449 ± 0.1159) ($t_{(10.49)} = 5.773, p < 0.001$) (Figure 3).

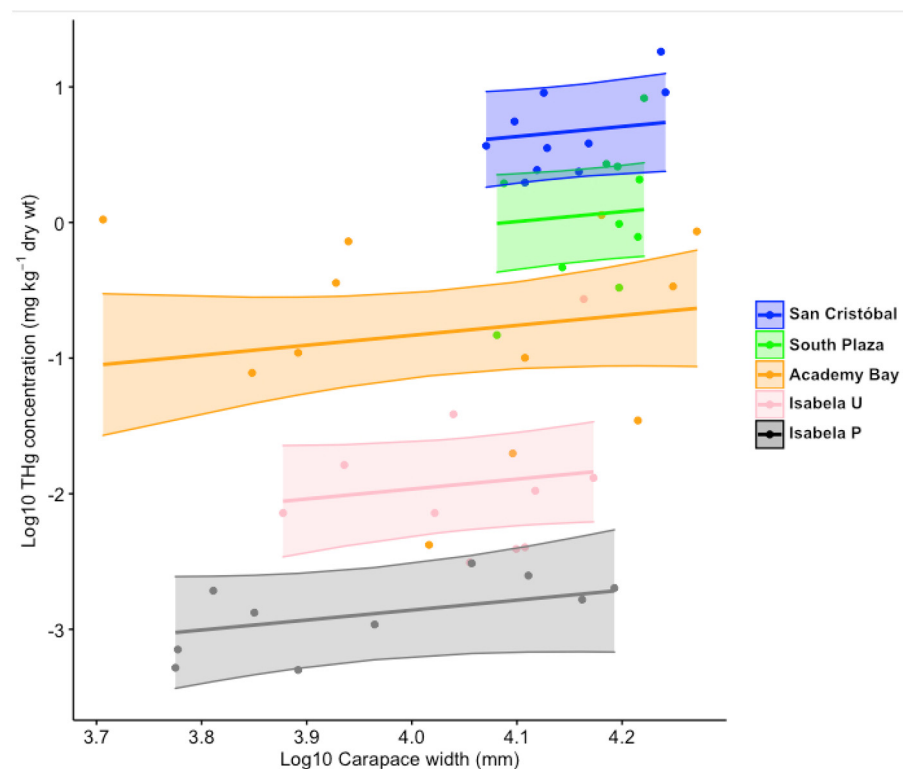


Figure 2. Relationship between log10 total mercury (THg) concentrations in dry weight of leg muscle and log10 carapace width for individuals of *Grapsus grapsus* for each of the sampling sites in the Galápagos Island. Isabela U = Isabela urban site, Isabela P = Isabela protected site.

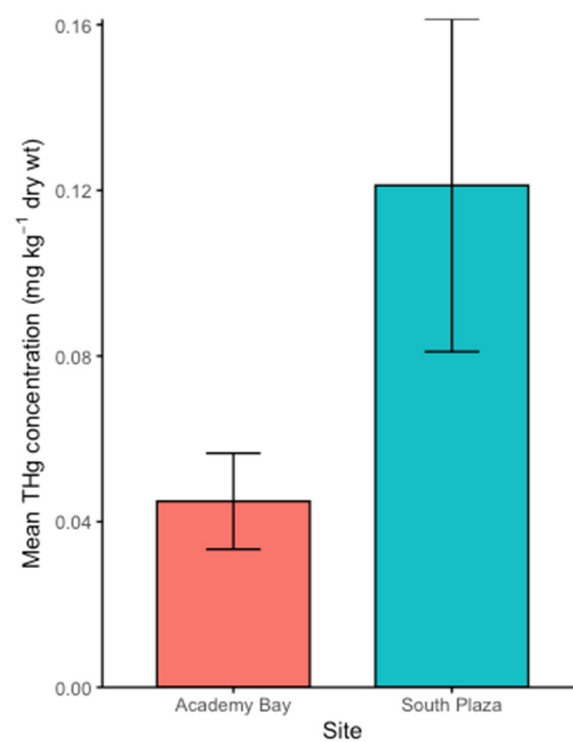


Figure 3. Relationship between mean total mercury concentration (THg) (mg kg⁻¹ dry weight) in the tissue of the barnacle *Tetraclita milleporosa* from sites at Academy Bay, Santa Cruz Island, and South Plaza Island in the Galápagos archipelago.

The oysters collected from the mangrove inlet at Academy Bay ranged from 0.03 to 0.14 mg kg⁻¹ dw, with a mean of 0.07 ± SD 0.03. The one oyster collected at South Plaza near the boat landing had a higher mercury level of 0.2284 mg kg⁻¹ dw.

4. Discussion

The results of this study on the mercury levels in *G. grapsus* (as high as 1–2 mg kg⁻¹ dw) muscle from the Galápagos Archipelago were surprising. Not only was there a marked variability in crab mercury content between and within all the sites, but there were also higher levels of mercury than anticipated, despite the lack of any obvious anthropogenic sources of mercury and the remoteness of the archipelago. Moreover, we expected these higher mercury values to be associated with areas of greater human impact. However, this was not the case. The higher human impact sites of Isabela urban and Academy Bay had low and moderate levels, respectively, while the more pristine site of South Plaza and the human-impacted site, San Cristóbal, both had exceptionally high mercury values. The extremes in mercury values identified at the different sites make it difficult to identify any logical patterns resulting in mercury accumulation in these marine intertidal organisms. The previous work conducted on commercial fish species in the Galápagos region [23] also found significant mercury levels in some species, and it was suggested that due to the lack of Industry on the Galápagos Islands, the mercury contamination in fish could likely have resulted from volcanism. However, the localized high levels of mercury (such as in San Cristóbal harbor) warrant further investigation as to whether human input could be a potential factor.

A further contributing factor in the variation in mercury levels, particularly in *G. grapsus*, could be related to diet. In some regions, the crabs may be scavenging on higher trophic food sources such as birds, fish, and sealion carcasses and placentas. For example, there are a number of nesting birds on South Plaza. Furthermore, San Cristóbal has one of the largest colonies of the Galápagos sea lion *Zalophus wolfebaeki*, with 13% of the population living on San Cristóbal, and the largest colony in Wreck Bay just off Puerto Baquerizo Moreno [26], where the crabs were collected in this study. Both birds and pinnipeds have been shown to have elevated mercury levels, in the Galápagos region [27,28]. In contrast, in the locations where crabs had lower mercury level, they may be mostly grazing on algae and feeding at lower trophic levels. Further examination incorporating stable isotope analysis (e.g., [29,30]) would be helpful in determining if the crabs are feeding at different trophic levels at different sites.

Although the levels of mercury in barnacles and oysters were lower compared to crabs, we did find a similar pattern between Academy Bay and South Plaza. The mercury levels in the crabs and barnacles, respectively, were approximately 2× and 3.3× greater at South Plaza compared to Academy Bay. Moreover, the single mercury value for the oyster collected at South Plaza was approximately 2.7× the mean value for the oysters in the mangrove inlet at Academy Bay. It is noteworthy that we obtained relatively similar increased mercury levels in these three different organisms (crabs—grazers/scavengers, barnacles and oysters—filter feeders) at South Plaza compared to Academy Bay. This suggests that the mercury levels are also elevated in the pelagic ecosystem and not just in the littoral benthic feeding community. Furthermore, the variation in mercury levels could be related to the degree of bioavailability of mercury at the different sites. There are a number of factors that can influence mercury methylation [31], and different sites may have different properties that affect the degree of mercury methylation and thus bioavailability. The reasons behind these fluctuating levels in mercury are still unknown and worthy of further research.

In recent years, San Cristóbal has been subjected to two fuel spills. This includes approximately 570,000 L of diesel fuel in 2001 (<https://www.theguardian.com/environment/2001/jan/22/oilspills.endangeredspecies> (accessed on 20 March 2024)) and over 2200 L of oil in 2019 (<https://whc.unesco.org/en/news/2073> (accessed on 20 March 2024)). While there is the potential for mercury to be present in oil products [32], it is uncertain if these

spills could have been a source as mercury levels depend on where the oil was refined. Gasoline and diesel fuel in California are not seen as significant contributors of mercury [33]. Shipwrecks can also be sources of mercury contamination in the environment, including in crabs [34]. Spanish galleons that carried mercury for gold mining and have sunk in centuries past have also been shown to be potential sources of mercury contamination [35].

The second-highest levels of mercury reported at South Plaza are hard to explain as the island has very minimal human impact. The current airport on Baltra Island, approximately 17 km northwest of South Plaza, was also the site of a large military base during WWII. After the war, the military base was dismantled and the equipment dumped in the ocean, including the infrastructure, vehicles, machinery, and tanks <https://www.youtube.com/watch?v=nYPibVzbPwA> (accessed on 20 March 2024). It is currently uncertain whether this dumping may be responsible for the elevated mercury at South Plaza but deserves further investigation.

The site of the greatest human impact and potential for the greatest levels of pollution was at Academy Bay on Santa Cruz Island, due to this site having the largest population, the biggest marina and ferry terminal, and the most prominent tourist destination, Puerto Ayora. However, this site had relatively low levels of mercury in the crab muscle, which were lower than both the San Cristóbal and South Plaza crabs, but higher than the crabs at the Isabela sites. The mercury levels at Isabela were the lowest among all the sites. However, we could detect a significant difference in mercury levels when comparing the urban region near the landing jetty and the protected location several kilometers along the coast. The levels at the urban site were still around 2.4 times higher than the protected location. This difference between the urban and protected sites suggests that there is an anthropogenic component which is a potential source of mercury in the more populated region of the coast of Isabela. This could potentially be due to pollution, or perhaps crabs are scavenging fishing discards at the urban site.

Crabs have been found to have variable mercury levels in the vicinity of chlor-alkali plants. In Portugal, levels in the *Carcinus maenas* ranged from 0.03 to 0.63 mg kg⁻¹ ww, with a large number of crabs having values >0.5 mg kg⁻¹ ww [30]. Similarly, values in crabs (*Callinectes sapidus* and *C. bocourti*) along the Caribbean coastline of Columbia, including a site near an abandoned chlor-alkali plant, had mean values all below 0.4 mg kg⁻¹ ww, with only two values greater than 0.5 mg kg⁻¹ ww. [36]. In Norway, populations of the brown crab *Cancer pagurus* were found to have relatively low mercury levels <0.1 mg kg⁻¹ ww, although these crabs had alarmingly high values of cadmium [37].

For mercury levels reported in seafood (and in many studies), mercury concentration is usually reported as wet weight (ww). For the purposes of comparison, we used our converted ww values (Table 2) to compare to the values discussed in other studies, which are all in ww. Considerable work has been carried out on the blue crab *Callinectes sapidus* on the USA Atlantic coast. The highest mean values for *C. sapidus* ranged from 0.083 to 0.792 mg kg⁻¹ in Narragansett Bay in Southern New England [24]. Furthermore, in a review of the mercury levels in *C. sapidus* at 11 sites along the USA Atlantic seaboard, mean muscle mercury levels ranged from 0.042 to 0.445 mg kg⁻¹ [24]. Snow crabs *Chionoecetes japonicus* in Japanese waters were found to have 0.3–0.56 kg⁻¹ levels of mercury, with a mean of 0.21 [38].

High levels of mercury in seafood can be toxic and negatively affect human health. Some of the levels found in this study are concerning. Mercury is particularly dangerous when it is methylated and forms methyl mercury. This form of mercury is many times more toxic to aquatic organisms than inorganic mercury [31]. Methylmercury accounts for over 95% of mercury in fish tissue [39] and is the only form that bioaccumulates in wildlife, crosses the blood–brain barrier in humans, and accumulates in neurological tissues [1]. It can also readily pass across the placenta to the fetus and the fetus brain [40]. Previous analysis found that methylmercury accounts for 98–100% of the total mercury in blue crab *Callinectes sapidus* muscle and 93–97% in whole crabs [41], and 77–99% in red snow

crab *Chionoecetes japonicus* muscle [38]. It is expected that methylmercury will also be the predominant form found in *G. grapsus* in the Galápagos Archipelago.

Government agencies have set various maximum levels of allowable mercury for the consumption of seafood. The EU has set a maximum level of 0.5 mg kg^{-1} [30,37]. In the US, the EPA has set a threshold of avoiding seafood with mercury levels above 0.3 mg kg^{-1} , [24,40]. For the *G. grapsus* populations sampled in the Galápagos Archipelago, two of the collecting sites had crabs exceeding the US EPA threshold limit. All the crabs collected at San Cristóbal and 50% of the crabs collected at South Plaza exceed the US EPA limit (Table 2). Moreover, we also compared our mean crab muscle mercury levels to selected species in the US FDA/EPA advice for seafood consumption of women of childbearing age, pregnant women, and for children aged 1–11 years (Table 4). The mean mercury value recorded for a variety of crab species in the US report is relatively low at 0.065 mg kg^{-1} . In contrast, for the South Plaza crabs, the mean of 0.3 mg kg^{-1} sits right on the threshold, with some of the individuals collected being in the range recommended to avoid. The San Cristóbal crabs, with a mean value of 0.51 mg kg^{-1} , sit between the marlin and orange roughy, both of which are in the range of mercury levels to be avoided by pregnant women, those who might become pregnant, and children aged 1–11 years. Even though *G. grapsus* is not a commercial species, future harvesting may occur. We suggest that the ingestion of crabs from San Cristóbal and South Plaza pose a potentially serious health risk, especially for women of childbearing age and for young children, and therefore should be avoided. Local island communities should be warned about the risks and potential effects of mercury ingestion vis *G. grapsus* in order to protect the health of the local population.

Table 4. Seafood mercury levels reported by the US FDA with San Cristóbal and South Plaza crab mercury values converted to wet weight for comparison. The FDA diet advice is for women who might become or are pregnant or breastfeeding, and children aged 1–11 years *. ND = no data.

Species	Mean Mercury Level (ppm/mg kg ⁻¹) Wet Weight	Range	Comments and, FDA Advice
Crab	0.065	ND–0.61	From blue, king and snow crab
South Plaza crab	0.3	0.11–0.63	Higher range in avoid level
Marlin	0.485	0.1–0.92	Avoid
San Cristóbal crab	0.51	0.34–0.88	Falls in level to avoid
Orange roughy	0.571	0.23–1.12	Avoid
Tuna	0.69	0.13–1.82	Fresh/frozen bigeye, Avoid
King mackerel	0.73	0.23–1.67	Avoid
Shark	0.98	ND–4.54	Avoid
Swordfish	1.0	ND–3.22	Avoid

* <https://www.fda.gov/food/consumers/advice-about-eating-fish#choice> (accessed on 20 March 2024).

Recently, mercury levels were also documented in five demersal and four pelagic fish species from Galápagos waters [23]. This study also found elevated levels of mercury in a number of the species with all the species having a median muscle mercury concentration $> 0.3 \text{ mg kg}^{-1}$, except for *Thunnus albacares* which had a value of 0.28 mg kg^{-1} . Three of the species had exceptionally high values, namely the Wahoo *Acanthocybium solandri*, Mottled Scorpionfish *Pontinus clemensi*, and Misty grouper *Hyporthodus mystacinus*, which had median mercury levels of 0.65, 0.65, 1.26 mg kg^{-1} , respectively. These species were deemed not suitable for ingestion or commercial exploitation and could pose a risk to human health. It was suggested that these mercury levels could have come from volcanism [23].

5. Conclusions

The source of mercury, particularly the concerning high levels at San Cristóbal and South Plaza, deserves further research. While we agree that volcanism may be a significant source of mercury in the Galápagos archipelago, the fact that our study found such variable levels of mercury contamination at different sites suggests that there may be other significant sources of mercury apart from volcanism. We suggest that further research

should be conducted on a variety of species from different habitats and locations around the Galápagos archipelago to better assess mercury levels within the biota and the potential health risks this might pose to people of the Galápagos ingesting seafood. It would be particularly useful to examine the trophic level that the crabs are feeding at among the different sites by using stable isotopes to see if there might be significant differences in crab diet among the different sites.

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