Risk map of human intake of methylmercury through fish consumption in Latin America and the Caribbeans

Elvira Vergara
University of Playa Ancha: Universidad de Playa Ancha
Floria Pancetti
Universidad Católica del Norte: Universidad Catolica del Norte
Liliana Zuñiga
Universidad Católica del Maule: Universidad Catolica del Maule
Paulina Bahamonde (paulina.bahamonde@upla.cl)
Universidad de Playa Ancha https://orcid.org/0000-0002-8880-8463

Research Article

Keywords: health risk, methylmercury, fish, fish consumption, Latin-America and the Caribbean, assessment

Posted Date: October 4th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2026724/v1

Abstract

Methylmercury is a high bioaccumulated pollutant persistent in the aquatic environment, that biomagnifies in the food web reaching concerning levels in predator fish. Mining is one of the most important economic activities of Latin America and the Caribbean, and a relevant global anthropogenic mercury emission. Studies have correlated high fish consumption with higher levels of MeHg in humans along with neurotoxic effects. Latin America occupies one of the top 3 regions with the highest fishery exploitation and aquaculture production, and simultaneously, it has been reported in several Latin American and the Caribbean country's high levels of mercury in marine and freshwater fishes, and in human hair associated with fish consumption. Therefore, this review seeks to assess the risk of mercury exposure and consequently health hazard due to fish consumption in Latin America and the Caribbean. The data of mercury levels in fish and fish consumption rates was searched from all countries in Latin America and the Caribbean. A large data set was created evidencing a concerning presence of methylmercury in fish that are widely consumed. The 6.1% of the total fish species studied were found to have concentrations of MeHg ≥ 1.5 µg g^{-1} dw, independently of the water habitat these were mainly carnivore species, which is recommended to not consume. Furthermore, high risk values (HQ ≥ 1) were estimated in Peru and Venezuela, and even higher-risk values (HQ ≥ 10) were estimated in some fish species inhabiting watersheds in Trinidad. The recommendation is to lower the consumption of this kind of fish species or to avoid mercury pollution.

Introduction

The metallic element mercury (Hg) in its different chemical forms is widely distributed in the environment. It is found in all kinds of ecosystems due to its many natural sources such as volcanic emission, soil and rocks erosion, wildfire, but also due to anthropogenic activities such as fossil fuel burning and mining extraction (Pirrone et al., 2010). Aquatic ecosystems are one of the most relevant for the Hg cycling from the atmosphere due to its methylation carried out by microorganisms in aquatic sediments, giving rise to methylmercury (MeHg), an organic form of Hg with higher toxicity

MeHg is persistent in the environment, reaching between 10–30% of the total Hg (THg) in the aquatic environment(Mason et al. 2000) and its bioaccumulation occurs through the food chain. In fact, more than 85–90% of the Hg in fish is MeHg and its concentration has shown to be correlated with the trophic position, age, and size (Grieb et al. 1990; Southworth et al. 1995). Therefore, humans are susceptible to MeHg´s harmful effects by the intake of MeHg through fish (Rice et al. 2014; Lee et al. 2020; Guzzi et al. 2021), particularly those predator species with the highest trophic position in the food chain (Langeland et al. 2017).

Top predator fish are found to have very high THg levels (EPA's contamination level 0.46 µg g^{-1} wet weight or 1.5 µg g^{-1} dry weight) (Lasut et al. 2010; Esdaile and Chalker 2018). Latin American and the Caribbean produced 18% of global anthropogenic Hg emissions, of which small scale gold mining contributed 70% (340 t out of 2,220 t). In 2015, South America alone accounted for 53% of the estimated

1,220 t of Hg released globally from small scale gold mining to aquatic and terrestrial environments (UN Environment 2019; Canham et al. 2021).

In addition, Latin American and the Caribbean occupies one of the top 3 regions with the highest fishery exploitation and aquaculture production (FAO 2020). Indeed, it has been reported significant mercury concentrations in marine and freshwater fish, and in human hair associated with fish consumption in several Latin American and the Caribbean countries (Langeland et al. 2017; Bravo et al. 2019; Valdelamar-Villegas and Olivero-Verbel 2020).

Neurotoxic and motor skill effects in humans have been related to high MeHg concentration accumulation ($\geq$ 1 µg g^{-1} dry weight; dw) (ATSDR 1999; Guzzi et al. 2021). One of the most well-known cases is the Minamata disaster in the 50's at Minamata Bay in Japan, where there was a high scale poisoning with fish and sea food contaminated with MeHg. This compound was generated as a by-product in reaction chambers for manufacturing acetaldehyde and discharged directly to the bay accumulating in fish and seafood that later was consumed by the local inhabitants. The intake of contaminated marine products produced a syndrome called Minamata Disease, consisting in sensory disturbance in the extremities, ataxia, disequilibrium, bilateral concentric constriction of the visual fields, impairment of gait and speech, muscle weakness, tremor, abnormal eye movement, and hearing impairment. Mental disorder and disturbances of taste and smell are also present occasionally (Eto 2000; Hachiya 2006). Besides this high exposure levels to MeHg, chronic exposure to lower levels can cause hepatic diseases and reproductive toxicity (Tan et al. 2009; Rice et al. 2014). In 2013 the Minamata Convention was created and adopted by 137 countries until today, of which 20 are countries from Latin America and the Caribbean (Hachiya, 2006). Therefore, it is of major importance to implement a risk assessment method that can be applied in decision making and in the generation of environmental regulations in vulnerable countries such as those of Latin-American and the Caribbean. This literature review and meta-analysis seeks to assess the risk of Hg exposure and consequently health hazard due to fish consumption in Latin America and the Caribbean by collecting available data from these countries regarding Hg levels in fish and fish consumption rates in each country.

Methods

Literature review

A literature search on peer-reviewed journal articles and published reports documenting Hg concentrations in fish in Latin America and the Caribbean countries was conducted. Studies published from 2010 until 2022 were selected, with some exceptions of countries where the data were only before 2010. The search was performed in Web of Science and Google Scholar using all combinations of the following keywords: "mercury," "fish" AND "Latin America"; "mercury", "human" AND "Latin America"; "mercury", "fish" AND "country" (every Latin American and the Caribbean country separately)"; and "mercury", "human" AND "country" (every Latin American and the Caribbean country separately)".

Data was classified by country, site (GPS), habitat (marine or freshwater environment) and fish diet (Supplementary Table S1) by fish species. In addition, the Hg species measured (THg and/or MeHg) and the analytical methods used were also considered in the classification.

Mercury risk assessment

The data was filtered by (1) fish species that are consumed by humans, and (2) Hg concentration quantified in muscle that corresponds to the most consumed fish tissue.

Additional data was necessary to determine the level of health risk in the population of each country. Average body weight for adult females (BWF) and males (BWM) from each country was obtained from Eglitis dataset (Eglitis 2021) and average fish consumption per country and per day (FCR) was obtained from the FAO report (FAO 2020) (Supplementary Table S1).

The Target hazard quotient (THQ) is a non-carcinogenic index that assesses the health risk from food consumption by residents and is calculated by equation (Formula 1) (Felix et al. 2022).

$$THQ = \frac{EF \times ED \times FCR \times C_{Hg}}{RfD \times BW \times AT} \times 10^{-3}$$ (Formula 1)

Where EF is the exposure frequency (365 days/year). The factor ED is the total duration of fish consumption (average human life 70 years), FCR is the fish consumption rate (g per day), C_{Hg} is the mercury concentration expressed as (µg g^{-1} wet weight), BW is human body weight (Kg), AT is the average time of food consumption (EF x 70 years), and RfD is the oral reference doses as (0.001 mg per Kg per day) (EPA 2011).

Recommendations for fish consumption (avoid, keep and encourage consuming) were based on the work done by Vieira et al. 2021, and the following equation (Formula 2):

$$MPW = \frac{(RfD \times BW) \times 7 days}{(Fishmealsize(g) \times C_{Hg})/1000}$$ (Formula 2)

For the size of the fish meal the 2015–2020 Dietary Guidelines for Americans who recommend at least 226.8 g of fish per week based on a 2000 cal diet was used (Dietary Guidelines Advisory Committee 2015), and a body weight (BW) was based on the adult population average specific by country and human sex (BWF: female and BWM; male).

Data analysis

The data are presented as MeHg concentration mean ± SD (µg g^{-1} dw). Due to Shapiro-Wilk's test determined a non-normal distribution of the data, non- parametric statistical tests were used to estimate statistical differences (p = 0.05). Kruskal-Wallis and Dwass-Steel-Critchlow-Fligner pairwise comparison tests were employed to determine the mean differences in MeHg concentrations among trophic levels, habitat type (marine or freshwater), and countries (Supplementary Table S2).

A subsample corresponding to the highest quartile of distribution based on the mercury content was used to visualize the frequencies of habitat type (marine or freshwater) and diet preferences (carnivores, detritivores, herbivores, or omnivores) within the fish species. With these classifications a Sankey plot was built (Fig. 1) using the *Sankey Network* function from the *networkD3* R-package (Allaire et al. 2017).

To compare the risk (HQ) differences between human sex (female and male population), a Mann-Whitney test was performed (Supplementary Table S3). To observe the geographic distribution of the Hg exposure risk by fish consumption among inhabitants of Latin America and the Caribbean countries, the obtained risk values for women and men were mapped using the geographic coordinates reported in the respective paper of origin. For this, the rgdal (Bivand et al. 2021) and ggplot2 (Wickam 2016) R-packages (R Core Team 2021) were used.

All plots resulting from the information gathered were created with ggplot2 (Wickam 2016) and R-packages (R version 4.1.2).

Results

Mercury concentration on fish

Studies concerning Hg bioaccumulation in fish consumed by humans were found around 30% of Latin-American and the Caribbean countries including, from north to south: Jamaica, Suriname, Anguilla, Trinidad & Tobago, Cuba, Mexico, Nicaragua, Costa Rica, Venezuela, Colombia, Peru, Brazil, Bolivia, Argentina, and Chile. Brazil and Chile lead in investigation around Hg bioaccumulation in fish. Most of the fish species studied belong to freshwater ecosystems, with no data available for marine fish in Bolivia, Cuba, Peru, and Venezuela. A total of 278 species were analyzed for THg or MeHg in muscle, where 61.2% belong to freshwater ecosystems and 38.8% are from marine ecosystems. Most of the data belong to wild capture fishes.

Freshwater fish MeHg concentrations range goes from 0.02 to 2.1 μg g^{-1}dw; meanwhile marine fish range goes from 0.01 to 10.7 μg g^{-1}dw (Table 1), the tests showed no significant differences between the bioaccumulated MeHg between habitats (p-value = 0.585; Supplementary Table S2). Although marine fishing is an important economic activity, there is less information about mercury pollution on marine fish.

Higher MeHg concentrations (≥ 1.5 μg g^{-1}dw of MeHg) were found in mostly carnivore species, except for *M. acanthogaster* (1.5 μg g^{-1}dw) an herbivore specie from Venezuela. The highest MeHg concentrations are found in the marine species *C. pororus* (11.1 μg g^{-1}dw) and *S. lewini* (6.3 μg g^{-1}dw) from Trinidad. Meanwhile the freshwater species with the highest MeHg levels are the predator *O. mykiss* (2.1 μg g^{-1}dw) from Chungara catchment in Chile and *C. monoculus* (1.8 μg g^{-1}dw) from Brazil (Table 1). These concentrations are considered highly hazardous to health by the FAO regulations (FAO and WHO 1995).

The Sankey plot (Fig. 1) shows a subsample of those fish species from the highest 20% MeHg concentration. This includes 57 fish species with a MeHg concentration ≥ 0.5 $\mu g\ g^{-1}$dw. The remaining 80% is considered to have concentrations that are not harmful and are safe to be consumed in a moderated diet. Various species are repeated in the list because: a) same species were found in different countries, and b) same species were sampled in different sites within the same country. The MeHg concentration is represented by the width of grey ribbons. Dark or light blue bars indicate the distribution between water habitats (marine or freshwater). Food preferences (carnivorous, omnivorous or herbivore are indicated by colored bars to the right. The plot showed that carnivorous species present the largest range and highest concentrations of MeHg (0.01 to 10.7 $\mu g\ g^{-1}$dw), independently of the water habitat. However, one omnivorous (*C. gariepinus, 1.1* $\mu g\ g^{-1}$dw *MeHg*) and one herbivore specie (*M. acanthogaster 1.5* $\mu g\ g^{-1}$dw *MeHg*) also displayed MeHg concentrations that might deserve attention since most of the food intake recommendation are below 1.5 $\mu g\ g^{-1}$dw of Hg.

Health risk of MeHg bioaccumulation in fish from Latin America

The Venn diagram (Fig. 2) summarizes the distribution of MeHg concentration and its interaction with THQ values in the total species assessed in this study. The 93.9% of the total species present MeHg concentrations < 1.5 $\mu g\ g^{-1}$ dw, from which 8.6% contributed to THQ values ≥ 1. The remaining 6.1% of the species with MeHg levels ≥ 1.5 $\mu g\ g^{-1}$ dw contributed in its totally to the THQ values ≥ 1, 1.4% to THQ ≥ 5 and a 0.7% to THQ ≥ 10. This group of fish species with MeHg concentrations above the FDA/EPA recommended levels (≥ 1.5 $\mu g\ g^{-1}$ dw) are found in Trinidad, Colombia, Chile, Brazil and Venezuela, and would not to be recommended for frequent human consumption.

The geolocation of the health risk estimation is presented in Fig. 3. The level of human fish consumption is indicated by color, where high consumption fish are those consumed locally and of highly commercial interest (orange), while the low consumption fish are consumed only locally (green). Additionally, considering that a THQ ≥ 1 is considered hazardous for human health, the frequency plot shows that most studied fish species have no risk for human consumption (85% for female and 86% for male).

In summary, fish species showing MeHg concentrations ≥ 1.5 $\mu g\ g^{-1}$dw and express THQ ≥ 1; are those corresponds to fish species from Anguilla, Brazil, Chile, Colombia, Jamaica, Nicaragua, Paraguay, Peru, Venezuela, and Trinidad. Yet, fishes with lower MeHg concentrations (< 1.5 $\mu g\ g^{-1}$dw) also show to have an HQ ≥ 1 in almost every country (Supplementary Table S1). All species studied from Argentina (20), Bolivia (18), Nicaragua (18), Costa Rica (7), Cuba (7), Ecuador (2) and Mexico (24) show an HQ < 1.

There is a slight trend difference in the risk estimation regarding human female and male population, being the female population the one with the higher THQ values, however no statistical difference between both groups was found (Fig. 3, p-value = 0.268, mean difference 0.07, Supplementary Table S3).

The countries estimated to have the greater health risk were Peru and Venezuela due to more than 50% of the species studied from these countries present a THQ ≥ 1. Fewer species contributed to very high THQ values (THQ < 10) as *C. porosus* (HQF = 32.1; HQM = 29.9) and *S. lewini* (HQF = 18.3; HQM = 17.1).

Discussion

There is a lack of information regarding bioaccumulation of Hg in wildlife and aquaculture fish. Most countries considered in this research do not have an actualized survey of the state of contamination of their fish species. This is a matter of concern since mining is one of the most important economic activities in the history of Latin America (Alimonda 2015) and one of the most relevant Hg contamination sources (Esdaile and Chalker 2018). In spite that most of the global fishery and aquaculture activities are centered in marine species (FAO 2020) there is lack of information of Hg amounts in these species, i.e., 83% of Chilean fishery exports comes from marine fisheries whose main export species are *Trachurus murphyi, Engraulis ringens*, and *Strangomera bentincki and* only one of them is mentioned in the studies (SUBPESCA 2020; OECD 2021)

One of the regions responsible for Hg emissions, east and southeast Asia, also characterize for a high mining and industry economy (UN Environment 2019; Soe et al. 2022) studies from these countries have shown a lower average Hg bioaccumulation in fish that some found in Latin America and the Caribbeans (Hajeb et al. 2009; Park et al. 2011; Jeevanaraj et al. 2019; Shalini et al. 2021; Soe et al. 2022).

The risk index THQ values obtained in this study (HQF = 0.02–32.1; HQM = 0.01–29.9) show to have a wider range and extremely high THQ values compared to other studies such as the one done by Bonsignore et al. (2013) in Augusta Bay in southern Italy (THQ = 0.31–15.8); also, Azore archipelago THQ = 0.1–8.6 and THQ = 0.2–8.5 on the Northwest Portuguese (Felix et al. 2022). The higher MeHg level were dominated by Carnivore species which is consistent with previous studies (Chiang et al. 2021), due to MeHg biomagnification through trophic levels and carnivores are on the top of the trophic web accumulating more MeHg than lower levels. These same species were found to have a significant contribution in the estimation of risk finding a relation between high MeHg concentrations and THQ ≥ 1 value. Nevertheless, in some cases high MeHg levels were not necessarily the cause for high HQ values. This was observed in Peru where all species were found to have safe MeHg concentrations (< 1.5 µg g^{-1}dw), although the THQ values were ≥ 1. Particularly in Peru, they have a high fish consumption rate (68.6 g day^{-1}) of this country due to its gastronomic preferences, compared for example to Argentina a country whose fish species have similar MeHg levels to Peru's, but its fish consumption rate is between the lowest in Latin America and the Caribbeans (15.6 g day^{-1}) therefor Argentina THQ values are safe. Meanwhile, in countries like Trinidad and Jamaica most of their fish species have acceptable MeHg levels, still they have HQ values ≥ 1. This exemplifies that regardless of having safe MeHg concentrations, the fish consumption rates (> 65 g day^{-1}), and body weight (> 76 Kg per females' adult and > 80 kg per male adult) are important factors to determine the safety of fish for human consumption. Therefore, it would be advisable to consider demographics and cultural behavior factors in the design of the regulations and health safety guidelines and not only on the concentrations of Hg found in the fishes' muscle.

For which in Table 2 there is a recommendation chart for those species to avoid consuming, keep consuming with moderation and to encourage their consumption based on their MeHg levels and THQ values obtained during this study. This classification is based on the MPW (meals per week) index, where < 1 MWP is recommended to avoid, 1 > 2 MPW to keep consuming with moderation and < 2 MPW to encourage their consumption, this is specified by country.

Conclusion

As a result of this study, it is possible to conclude from the total species studied in this research 47% are considered safe and non-risky to consume at the same rate that they are being consumed. Likewise, it is recommended to avoid consuming fishes from some genus such as *Thunnus* and *Epinephelus* due to the high MeHg concentrations, and in the case of fishes with concentration below 1.5 μg g^{-1}dw to reduce the consumption of them to minimize the health risk.

As a suggestion, because of the level of mining activity developed in Latin America and the Caribbeans, these countries must improve environmental regulations to help to prevent population health issues. It is not possible to regulate under other countries' standards due to the differences in distribution of Hg emission, population behavior and demographic characteristics.

Declarations

Acknowledgment

The authors would like to thank Dr. Ian Acuña Rodríguez for his support in the representation of this work.

Ethical Approval 'Not applicable'

Consent to Participate 'Not applicable'

Consent to Publish 'Not applicable'

Authors Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by the authors E.V. and L.Z. The first draft of the manuscript was written by E.V. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding

This work was funded by author P.B. grants FONDECYT Initiation Grant # 11180914, ANID Millennium Science Initiative NCN2021_056: Millennium Nucleus of Austral Invasive Salmonids (INVASAL), and Project CHIC ANID/BASAL FB210018. E.V. was funded by ANID Scholarship 21220155.

Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, P.B., upon reasonable request.

References

1. Alimonda H (2015) Mining in Latin America: coloniality and degradation. In: The international handbook of political ecology. Edward Elgar Publishing Limited, pp 149–161
2. Allaire JJ, Ellis P, Gandrud C, et al (2017) Package “networkD3”
3. Arcagni M, Rizzo A, Juncos R, et al (2017) Mercury and selenium in the food web of Lake Nahuel Huapi, Patagonia, Argentina. Chemosphere 166:163–173. https://doi.org/10.1016/j.chemosphere.2016.09.085
4. Arribére MA, Ribeiro Guevara S, Bubach DF, et al (2008) Selenium and mercury in native and introduced fish species of Patagonian Lakes, Argentina. Biol Trace Elem Res 122:42–63. https://doi.org/10.1007/s12011-007-8059-6
5. Ashe K (2012) Elevated mercury concentrations in humans of Madre de Dios, Peru. PLoS One 7: https://doi.org/10.1371/journal.pone.0033305
6. ATSDR (1999) Toxicological profile for mercury: U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Mercury
7. Barbosa AC, Silva SRL, Dórea JG (1998) Concentration of mercury in hair of Indigenous mothers and infants from the Amazon Basin. Arch Environ Contam Toxicol 34:100–105
8. Basu N, Tutino R, Zhang Z, et al (2014) Mercury levels in pregnant women, children, and seafood from Mexico City. Environ Res 135:63–69. https://doi.org/10.1016/j.envres.2014.08.029
9. Benefice E, Luna-Monrroy S, Lopez-Rodriguez R (2010) Fishing activity, health characteristics and mercury exposure of Amerindian women living alongside the Beni River (Amazonian Bolivia). Int J Hyg Environ Health 213:458–464. https://doi.org/10.1016/j.ijheh.2010.08.010
10. Betancourt O, Narváez A, Roulet M (2005) Small-scale gold mining in the Puyango River basin, southern Ecuador: A study of environmental impacts and human exposures. Ecohealth 2:323–332. https://doi.org/10.1007/s10393-005-8462-4

11. Bonsignore M, Salvagio Manta D, Oliveri E, et al (2013) Mercury in fishes from Augusta Bay (southern Italy): Risk assessment and health implication. Food and Chemical Toxicology 56:184–194. https://doi.org/10.1016/j.fct.2013.02.025
12. Bravo MA, Parra S, Quiroz W, Neaman A (2019) Human exposure assessment to mercury through hair analysis in coastal villages of the Valparaiso region (Chile). J. Chil. Chem. Soc, *64*, 2, 4480-4483.
13. Canham R, González-Prieto AM, Elliott JE (2021) Mercury exposure and toxicological consequences in fish and fish-eating wildlife from anthropogenic activity in Latin America. Integr Environ Assess Manag 17:13–26
14. Carrasquero-Durán A (2006) Mercury contamination of workers of gold processing centres at El Callao, Venezuela. J Argent Chem Soc 94(6), 91–100.
15. Chiang G, Kidd KA, Díaz-Jaramillo M, et al (2021) Methylmercury biomagnification in coastal aquatic food webs from western Patagonia and western Antarctic Peninsula. Chemosphere 262:128360. https://doi.org/10.1016/J.chemosphere.2020.128360
16. Corral S, Sáez D, Lam G, et al (2013) Neurological and neuropsychological deterioration in artisanal gold miners from the town of Andacollo, Chile. Toxicol Environ Chem 95:344–358. https://doi.org/10.1080/02772248.2013.766191
17. Cortes S, Fortt A (2007) Mercury content in Chilean fish and estimated intake levels. Food Addit Contam 24:955–959. https://doi.org/10.1080/02652030701278362
18. Dietary Guidelines Advisory Committee (2015) Dietary guidelines for Americans 2015–2020. Government Printing Office, Washington
19. Eglitis L (2021) Average height of men and women worldwide. https://www.worlddata.info/average-bodyheight.php. Accessed 3 Aug 2021
20. Elliott JE, Kirk DA, Elliott KH, et al (2015) Mercury in forage fish from Mexico and Central America: Implications for fish-eating birds. Arch Environ Contam Toxicol 69: https://doi.org/10.1007/s00244-015-0188-x
21. EPA U (2011) Revised Technical Support Document: National-scale assessment of mercury risk to populations with high consumption of self-caught freshwater fish in support of the appropriate and necessary finding for coal-and oil-fired electric generating units
22. Esdaile LJ, Chalker JM (2018) The mercury problem in artisanal and small-scale gold mining. Chemistry - A European Journal 24:6905–6916
23. Eto K (2000) Minamata disease. Neuropathology 20:14–19. https://doi.org/10.1046/J.1440-1789.2000.00295.X
24. FAO (2020) World fisheries and aquaculture: the state of sustainability in action
25. FAO, WHO (1995) Codex Alimentus, International food standards: standard for contaminants and toxins in food and feed. Amended 2019
26. Galvao P, Sus B, Lailson-Brito J, et al (2021) An upwelling area as a hot spot for mercury biomonitoring in a climate change scenario: A case study with large demersal fishes from Southeast

Atlantic (SE-Brazil). Chemosphere 269: https://doi.org/10.1016/j.chemosphere.2020.128718

27. Gammons CH, Slotton DG, Gerbrandt B, et al (2006) Mercury concentrations of fish, river water, and sediment in the Río Ramis-Lake Titicaca watershed, Peru. Sci Total Environ 368:637–648. https://doi.org/10.1016/j.scitotenv.2005.09.076
28. García-Hernández J, Ortega-Vélez MI, Contreras-Paniagua AD, et al (2018) Mercury concentrations in seafood and the associated risk in women with high fish consumption from coastal villages of Sonora, Mexico. Food Chem Toxicol 120:367–377. https://doi.org/10.1016/j.fct.2018.07.029
29. Garcia-Sanchez A, Contreras F, Adams M, Santos F (2008) Mercury contamination of surface water and fish in a gold mining region (Cuyuní river basin, Venezuela). Int. J. Environment and Pollution, *33*(3), 260-274. https://doi.org/10.1504/IJEP.2008.019398
30. Grieb TM, Bowie GL, Driscoll CT, et al (1990) Factors affecting mercury accumulation in fish in the upper Michigan Peninsula. Environ Toxicol Chem 9:919–930. https://doi.org/10.1002/ETC.5620090710
31. Guzzi G, Ronchi A, Pigatto P (2021) Toxic effects of mercury in humans and mammals. Chemosphere 263:127990 https://doi.org/10.1016/j.chemosphere.2020.127990
32. Hachiya N (2006) The history and the present of Minamata Disease-entering the second half a century-investigation of causative agent and spread of the pollution occurrence of Minamata Disease. JMAJ 49.
33. Hacon S de S, Oliveira-Da-costa M, Gama C de S, et al (2020) Mercury exposure through fish consumption in traditional communities in the Brazilian Northern Amazon. Int J Environ Res Public Health 17:1–15. https://doi.org/10.3390/ijerph17155269
34. Hajeb P, Jinap S, Ismail A, et al (2009) Assessment of mercury level in commonly consumed marine fishes in Malaysia. Food Control 20:79–84. https://doi.org/10.1016/J.FOODCONT.2008.02.012
35. Harari R, Harari F, Gerhardsson L, et al (2012) Exposure and toxic effects of elemental mercury in gold-mining activities in Ecuador. Toxicol Lett 213:75–82. https://doi.org/10.1016/j.toxlet.2011.09.006
36. Harris R, Pollman C, Landing W, et al (2012) Mercury in the Gulf of Mexico: Sources to receptors. Environ Res 119:42–52. https://doi.org/10.1016/j.envres.2012.08.001
37. Jeevanaraj P, Hashim Z, Elias SM, Aris AZ (2019) Risk of dietary mercury exposure via marine fish ingestion: Assessment among potential mothers in Malaysia. Exposure and Health 11:227–236. https://doi.org/10.1007/s12403-017-0270-x
38. Lacayo M, Cruz A, Lacayo J, Fomsgaard I (1991) Mercury contamination in Lake Xolotlán (Nicaragua). SIL Proceedings, 1922-2010 24:1174–1177. https://doi.org/10.1080/03680770.1989.11898939
39. Langeland AL, Hardin RD, Neitzel RL (2017) Mercury levels in human hair and farmed fish near artisanal and small-scale gold mining communities in the Madre de Dios River Basin, Peru. Int J Environ Res Public Health 14: 302-302. https://doi.org/10.3390/IJERPH14030302

40. Lasut MT, Yasuda Y, Edinger EN, Pangemanan JM (2010) Distribution and accumulation of mercury derived from gold mining in marine environment and its impact on residents of Buyat bay, north Sulawesi, Indonesia. Water, Air, and Soil Pollution 208:153–164. https://doi.org/10.1007/s11270-009-0155-0
41. Lee S, Cho S-R, Jeong I, et al (2020) Toxics mercury exposure and associations with hyperlipidemia and elevated liver enzymes: A nationwide cross-sectional survey. Toxics 8: https://doi.org/10.3390/toxics8030047
42. Marcovecchio J, Moreno V (1993) Cadmium, zinc, and total mercury levels in the tissues of several fish species from La Plata River estuary, Argentina. Environ Monit Assess 25:119–130
43. Marrugo-Negrete J, Verbel JO, Ceballos EL, Benitez LN (2008) Total mercury and methylmercury concentrations in fish from the Mojana region of Colombia. Environ Geochem Health 30:21–30. https://doi.org/10.1007/s10653-007-9104-2
44. Mason RP, Laporte JM, Andres S (2000) Factors controlling the bioaccumulation of mercury, methylmercury, arsenic, selenium, and cadmium by freshwater invertebrates and fish. Arch Environ Contam Toxicol 38(3):283–297. https://doi.org/10.1007/S002449910038
45. McCrary JK, Castro M, McKaye KR (2006) Mercury in fish from two Nicaraguan lakes: A recommendation for increased monitoring of fish for international commerce. Environ Pollut 141:513–518. https://doi.org/10.1016/j.envpol.2005.08.062
46. Muto EY, Soares LSH, Sarkis JES, et al (2014) Biomagnification of mercury through the food web of the Santos continental shelf, subtropical Brazil. Mar Ecol Prog Ser 512:55–69. https://doi.org/10.3354/meps10892
47. OECD (2021) Fisheries and Aquaculture in United Kingdom January. i:2015–2022
48. Ohlander J, Huber SM, Schomaker M, et al (2013) Risk factors for mercury exposure of children in a rural mining town in northern Chile. PLoS One 8: https://doi.org/10.1371/journal.pone.0079756
49. Olivero-Verbel J, Caballero-Gallardo K, Turizo-Tapia A (2015) Mercury in the gold mining district of San Martin de Loba, South of Bolivar (Colombia). Environ Sci Pollut Res 22:5895–5907. https://doi.org/10.1007/s11356-014-3724-8
50. Olivero-Verbel J, Johnson-Restrepo B, Mendoza-mar C, et al (2004) Mercury in the aquatic environment of the village of Caimitate Mojana region, north of Colombia. Water Air Soil Pollut 159:409–420
51. Páez YC, Betancourt CA, González-Sansón G, et al (2012) Increased mercury and body size and changes in trophic structure of *Gambusia puncticulata* (poeciliidae) along the Almendares River, Cuba. Arch Environ Contam Toxicol 63:523–533. https://doi.org/10.1007/s00244-012-9801-4
52. Park JS, Jung SY, Son YJ, et al (2011) Total mercury, methylmercury and ethylmercury in marine fish and marine fishery products sold in Seoul, Korea. http://dx.doi.org/101080/193932102011638087 4:268–274
53. Pirrone N, Cinnirella, S, Feng, X, et al (2010) Atmospheric chemistry and physics global mercury emissions to the atmosphere from anthropogenic and natural sources. Atmos. Chem. Phys, 10,

5951–5964. https://doi.org/10.5194/acp-10-5951-2010

54. Pouilly M, Rejas D, Pérez T, et al (2013) Trophic structure and mercury biomagnification in tropical fish assemblages, Iténez River, Bolivia. PLoS One 8: https://doi.org/10.1371/journal.pone.0065054
55. Rice K, Walker E, Wu M, et al (2014) Environmental mercury and its toxic effects. Journal of Preventive Medicine & Public Health 47:74–83
56. Ruiz-Guzmán JA, Marrugo-Negrete JL, Díez S (2014) Human exposure to mercury through fish consumption: Risk assessment of riverside inhabitants of the Urrá Reservoir, Colombia. Hum Ecol Risk Assess 20:1151–1163. https://doi.org/10.1080/10807039.2013.862068
57. Shalini R, Jeyasekaran G, Shakila RJ, et al (2021) Dietary intake of trace elements from commercially important fish and shellfish of Thoothukudi along the southeast coast of India and implications for human health risk assessment. Marine Pollution Bulletin 173:113020. https://doi.org/10.1016/j.marpolbul.2021.113020
58. Soares de Campos M, Sarkis JES, Müller RCS, et al (2002) Correlation between mercury and selenium concentrations in Indigenous hair from Rondônia State, Amazon region, Brazil. Sci Total Environ 287:155–161. https://doi.org/10.1016/S0048-9697(01)01002-6
59. Soe PS, Kyaw WT, Arizono K, et al (2022) Mercury pollution from artisanal and small-scale gold mining in Myanmar and Other Southeast Asian Countries. International Journal of Environmental Research and Public Health 19: 6290-6290. https://doi.org/10.3390/IJERPH19106290
60. Southworth GR, Turner RR, Peterson MJ, Bogle MA (1995) Form of mercury in stream fish exposed to high concentrations of dissolved inorganic mercury. Chemosphere 30:779–787. https://doi.org/10.1016/0045-6535(94)00407-L
61. SUBPESCA (2021) Fisheries and Aquaculture Sector Information (Spanish). Department of Sector Analysis
62. Tan SW, Meiller JC, Mahaffey KR (2009) The endocrine effects of mercury in humans and wildlife. http://dx.doi.org/101080/10408440802233259 39:228–269.
63. UN Environment (2019) Global Mercury Assessment 2018. UN Environment Programme Economy Division, Geneva, Switzerland
64. Valdelamar-Villegas J, Olivero-Verbel J (2020) High mercury levels in the indigenous population of the Yaigojé Apaporis National Natural Park, Colombian Amazon. Biological Trace Element Research 194:3–12. https://doi.org/10.1007/s12011-019-01760-0
65. Vieira, H, Ramirez, M et al (2021) Total and Organic Mercury in Fish from Different Geographical Areas in the North Atlantic Ocean and Health Risk Assessment. Exposure and Health, 13(3), 361–373. https://doi.org/10.1007/S12403-021-00388-7/FIGURES/5
66. Webb J, Mainville N, Mergler D, et al (2004) Mercury in Fish-eating Communities of the Andean Amazon, Napo River Valley, Ecuador. Ecohealth 1:SU59–SU71. https://doi.org/10.1007/s10393-004-0063-0
67. Weinhouse C, Ortiz EJ, Berky AJ, et al (2017) Hair mercury level is associated with anemia and micronutrient status in children living near artisanal and small-scale gold mining in the Peruvian

Amazon. Am J Trop Med Hyg 97:1886–1897. https://doi.org/10.4269/ajtmh.17-0269

Tables

Table 1 and 2 are available in the Supplementary Files section.

Figures

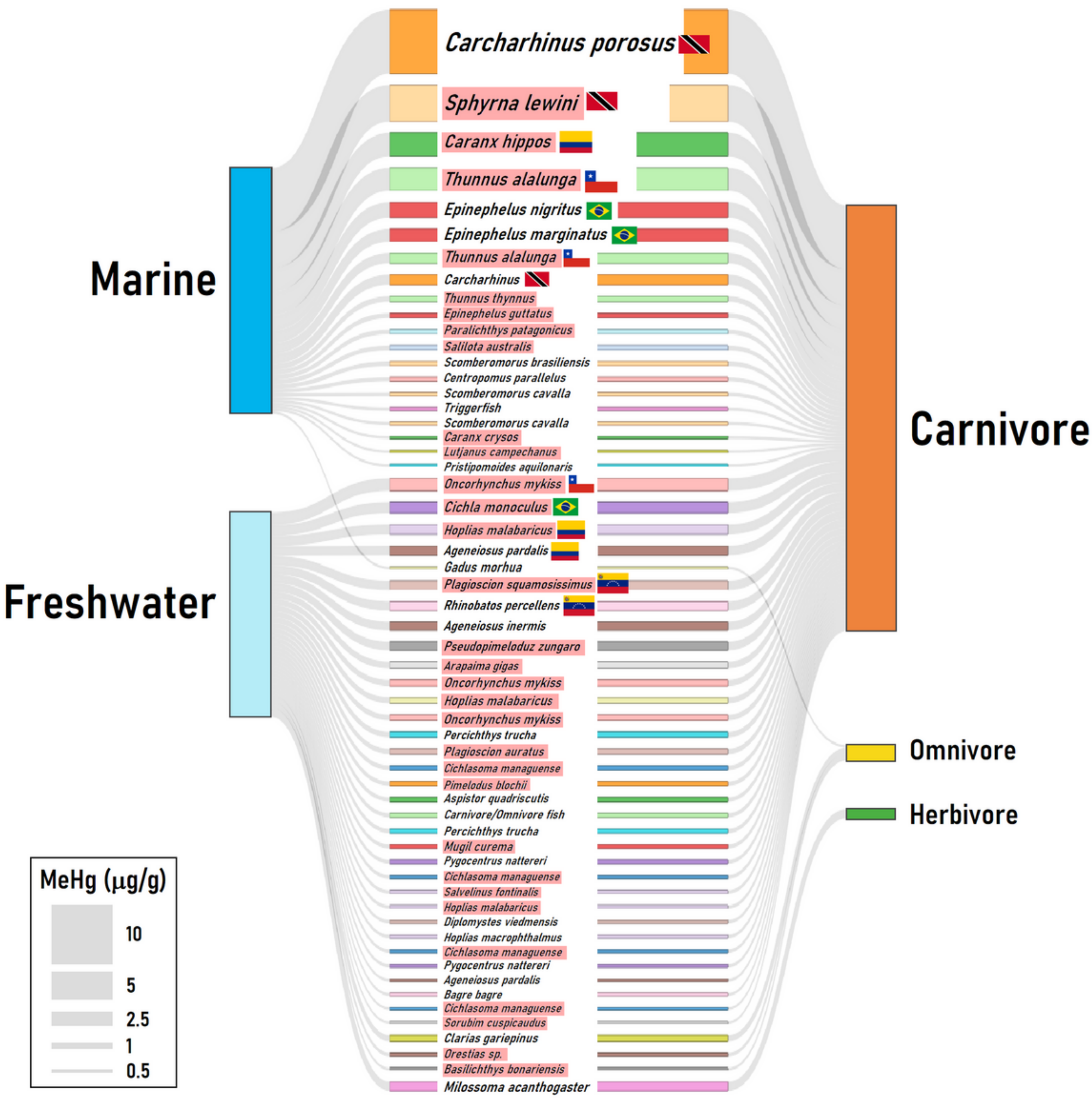

Figure 1

Sankey diagram representing the highest 20% of MeHg levels in fish muscle from Latin-America and the Caribbean. In red are highlighted those species most consumed. Species with MeHg concentrations above the FDA/EPA recommended levels ($\geq$ 1.5 µg g^{-1} dw) are highlighted with the country of origin's flag.

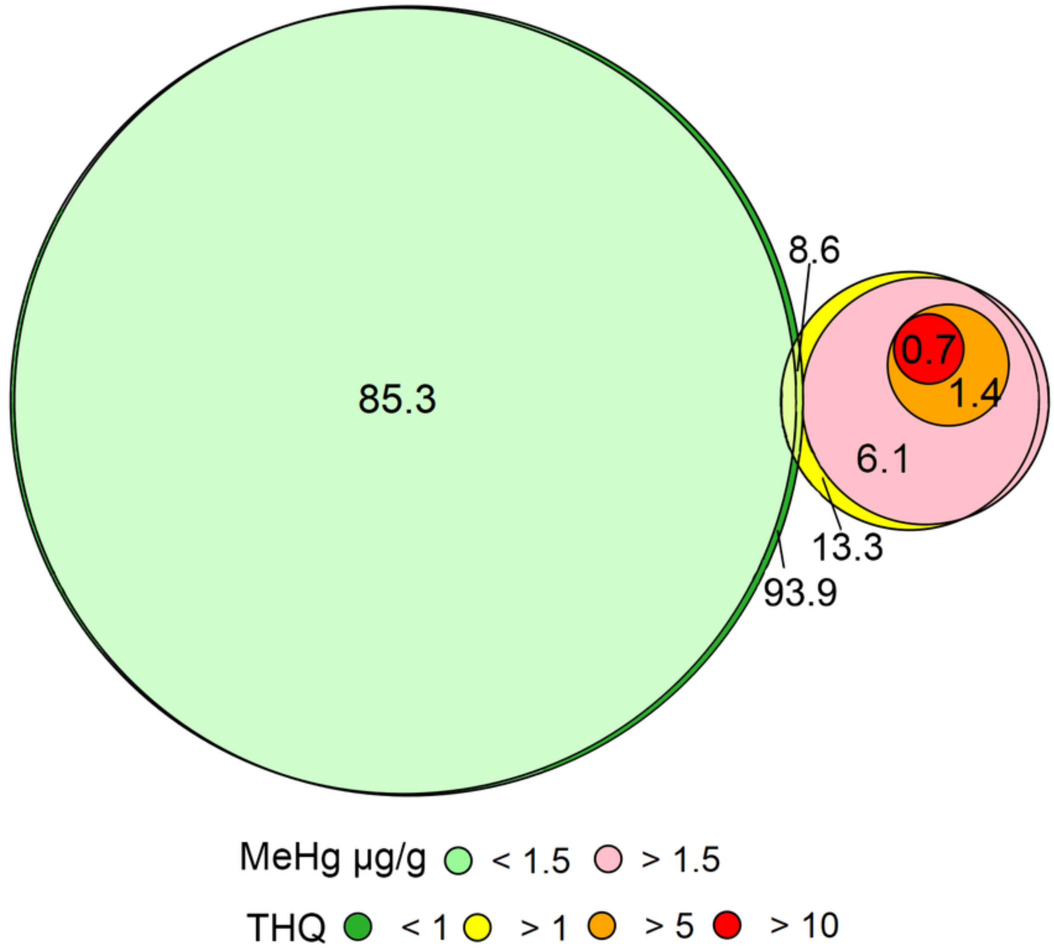

Figure 2

Percentage of MeHg and THQ values, and their association within the species assessed.

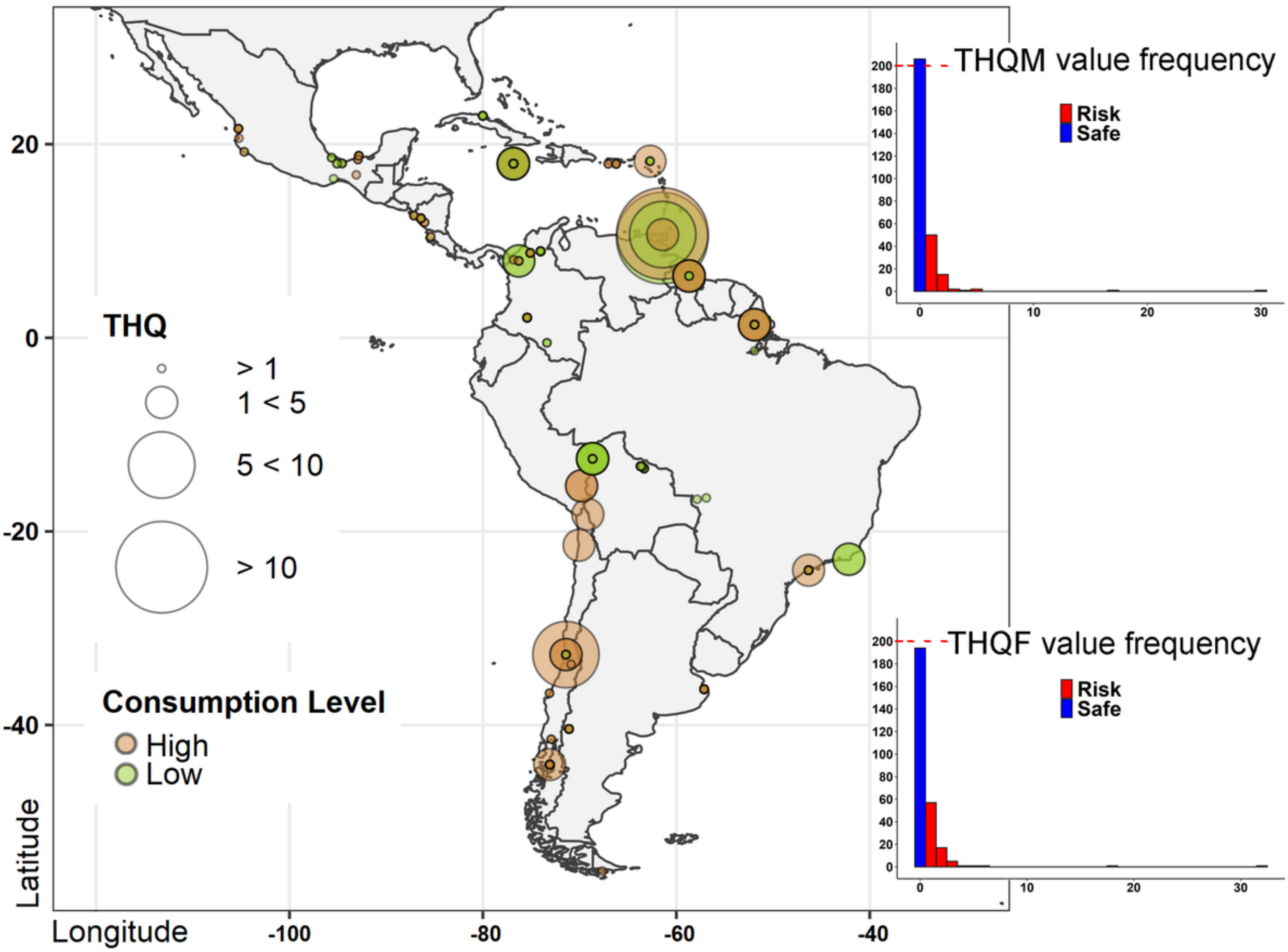

Figure 3

Estimated risk map for human population related to MeHg contaminated fish consumption from Latin American and the Caribbeans. Circles sizes indicate the average THQ value. The color indicates if the specie is highly consumed (orange) or locally consumed (green). The bar graphs illustrate the frequency of THQ for human male population (THQM, up) and female population (THQF, down). Also, THQ > 1 (red bar) and < 1 (blue bar).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Tables.pdf
- Supplementalinformation.pdf