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Metal(loid) concentrations in shark meat commercialized in Brazil: Implications for human health and biological conservation

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Abstract

Metal(loid) concentrations were assessed in samples of shark meat commercialized in Brazil. Samples were from sharks caught in Brazil (15%) or imported (85%) from Taiwan, Portugal, China, Spain, Uruguay, and Peru. Among the imported samples, 68% were labeled as blue shark (*Prionace glauca*). In addition, molecular identification performed in 226 samples (94.2%) indicated that all of them were of blue shark. Regarding metal(loid)s, Al, As, Cr, Cu, Fe, Hg, Mn, Ni, and Zn were quantified in all samples. Cd and Pb were quantified in 97.9% and 98.3% of the analyzed samples, respectively. For most of the analyzed metal(loid)s, concentration values observed were excessive when compared to those reported by the other studies with *P. glauca* or those permissible by different regulations from several regions around the world. This finding points to a potential risk for human health associated with the long-term dietary exposure to the excessive concentrations of metal(loid)s present in the analyzed samples. Our findings underscore the critical need to avoid consuming shark meat, not only to protect human health from the long-term risks posed by high metal(loid) concentrations but also to support global efforts in the biological conservation of shark populations.

Keywords: arsenic; blue shark; conservation; contamination; fish meat; metals.

Practical Application: Findings support public policies on human health and biological conservation.

1 INTRODUCTION

Sharks have faced irreversible population declines in recent years, highlighting the need for immediate conservation actions (Pacoureau et al., 2021). This decline is largely driven by human activities such as overfishing and habitat degradation, which critically endanger these apex predators vital for marine ecosystem stability (Dulvy et al., 2021; Prasky et al., 2023). Their k-strategist life history traits – slow growth, late maturity, few pups, and long gestational periods—further hinder rapid population recovery and make them particularly vulnerable to anthropogenic impacts (Dulvy et al., 2014). As a result, these biological constraints, combined with habitat loss and climate change, elevate the risk of extinction, particularly in heavily fished regions (Dulvy et al. 2021).

Fishing represents the most significant threat to shark populations, primarily driven by high consumer demand and advancements in fishing technology that enable increased fishing effort and often lead to unregulated activities. Such practices result in overfishing and the imminent risk of population collapse (Barreto et al., 2017; Pacoureau et al., 2021). Current estimates reveal that approximately 36% of the nearly 1,200 known species of sharks, rays, and chimaeras are threatened with extinction (International Union for Conservation of Nature [IUCN], 2021). Since the 1970s, populations of oceanic sharks and rays have experienced a staggering decline of 71% due to increased fishing pressure (Pacoureau et al., 2021). However, more recent analyses demonstrate that shark mortality has continued to rise despite global finning bans, largely due to the growing demand for shark meat (Hammerschlag & Sims, 2024). This shift underscores the urgent need for regulations that directly limit overall shark mortality, rather than focusing solely on processing practices such as finning.

The most well-known practice associated with the harvesting of shark species is the global fin trade, which poses severe threats to shark populations worldwide (Dent & Clarke, 2015;

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Van Houtan et al., 2020). In the last decade, efforts have been made to enhance shark conservation by adopting policies that prohibit "naturally attached fins." Such policies, implemented in countries like India, Brazil, and Taiwan, aim to combat the cruel practice of finning, wherein only the fins are removed from the sharks, often while the animals are still alive, and their bodies are discarded back into the ocean (Martins et al., 2018). This practice not only results in tremendous animal suffering but also contributes to a drastic decline in shark populations (Dent & Clarke, 2015). While these regulatory measures indicate progress in shark conservation, this practice has led to increased consumption of shark meat, particularly in developing countries, allowing the fin trade to continue (Barreto et al., 2017; Dent & Clarke, 2015; Niedermüeller et al., 2021). It is estimated that approximately 100 million sharks are killed globally each year, primarily for their fins and meat (Van Houtan et al., 2020). This heavy exploitation has caused alarming declines in various shark populations (Queiroz et al., 2019). Moreover, even in areas with expanding Marine Protected Areas (MPAs), many critical habitats for sharks remain insufficiently protected, with less than 8% of Important Shark and Ray Areas (ISRAs) falling under no-take zones (Mouton et al., 2025).

Brazil stands out as the world's largest importer of shark meat and ranks ninth among the top ten nations that kill the most sharks (Dent & Clarke, 2015; Niedermüeller et al., 2021). This growing shark meat trade can be attributed in part to attractive prices and widespread consumer unawareness, since Brazil does not require accurate species-level labeling for sharks (Bornatowski et al., 2018). Consequently, many critically endangered species such as hammerhead (Sphyrnidae) and angel sharks (Squatiniformes) are traded freely without oversight, including imported species labeled only as "dogfish" (Alvarenga et al., 2021; Cruz et al., 2021; Souza-Araujo et al., 2021). Due to this, Brazil has increasingly been identified as a significant hub for the shark trade, often referred to as a "shark laundry" because of the complex dynamics between legal fishing activities and illegal harvesting practices. Furthermore, the widespread mislabeling of shark products under generic terms like "cação" obscures species identification and facilitates illegal trade (Almerón-Souza et al., 2018; Cruz et al., 2021). Deoxyribonucleic Acid (DNA) barcoding is now routinely used to monitor the shark trade, revealing that a substantial portion of meat sold in markets originates from vulnerable or endangered species (Alvarenga et al., 2024; Cruz et al., 2021). Despite legal protections, enforcement remains weak amid ongoing demand for shark products both locally and internationally, creating a gap between conservation policies and market realities. Currently, Brazilian regulation (Brazil, 2020) mandates accurate species-level labeling only for imported fish of the Salmonidae (salmon and trout) and Gadidae (cod) families. This regulatory gap not only undermines conservation but also obscures potential health risks to consumers, since shark meat frequently contains elevated levels of toxic contaminants (Peixoto-Rodrigues et al., 2025).

In addition to the biological conservation concerns associated with shark fishing, the consumption of shark meat may pose potential health risks to humans. Several studies have demonstrated that shark meat contains elevated levels of metal(loid)s across various species and sizes (Amorim-Lopes et al., 2020; Hauser-Davis et al., 2024; Silva et al., 2025; Souza-Araujo et al., 2021). This is because these animals occupy a high trophic level in the food web and, consequently, accumulate significant amounts of dietary metal(loid)s from their prey over their lifetime (Amorim-Lopes et al., 2020; Souza-Araujo et al., 2021). However, information regarding the risk to human health from consuming contaminated shark meat is not provided on packaging or communicated to consumers. Despite the growing global consumption of shark meat—surpassing the trade in fins in quantity and value (Niedermüeller et al., 2021)—little attention has been paid to the potential health risks associated with this trade. Recent toxicological reviews reinforce that elasmobranchs are particularly vulnerable to pollutant accumulation due to their life-history traits, and that their consumption can represent a significant ecotoxicological and public health concern (Peixoto-Rodrigues et al., 2025).

In the present study, we accessed the concentrations of metal(loid)s in shark meat samples collected from several markets in Southeastern and Southern Brazil. Additionally, we considered information on the imported and sold shark species, complemented by molecular identification of a random subset of samples. For each analyzed metal(loid), results were compared to data reported in other studies involving the blue shark "*P. glauca*" and to the maximum permissible concentrations established by regulations from different regions worldwide, including Brazil. By integrating conservation and public health perspectives, this study aims to provide updated evidence on the dual risks posed by the shark meat trade, highlighting the urgent need for stronger regulatory frameworks that simultaneously safeguard biodiversity and human health.

1.1 Relevance of the work

Findings reported in the present study point to a potential risk to human health associated with long-term dietary exposure to the high levels of several essential and non-essential metal(loid)s present in the blue shark meat commercialized in Brazil. Furthermore, they highlight the concern about the current fishing pressure on populations of the blue shark *Prionace glauca*. Therefore, findings reported here are evidence of the need for establishing public policies aiming at the continuous evaluation and monitoring of the levels of contaminants in commercialized shark meat, as well as the improvement of the conservation status of blue shark populations.

2 MATERIALS AND METHODS

2.1 Sample collection and analysis

Samples of shark meat sold in markets in the states of Paraná (Southern Brazil), São Paulo, and Rio de Janeiro (Southeastern Brazil) were randomly collected between December 03, 2021, and May 26, 2022. The collected samples were divided into two aliquots: one for genetic identification of the shark species and the other for determination of the metal(loid) concentrations. Samples for genetic analysis were stored in plastic tubes containing 96% ethanol. Total DNA was extracted from muscle tissues according to the protocol established by Ivanova et al. (2006). Partial sequences of the approximately 650 bp of the COI gene were obtained by Polymerase Chain Reaction (PCR) amplifications using primers described by Ward et al. (2005). Details on the analytical procedure (PCR amplification and sequencing) are described in Cruz et al. (2021). DNA sequences were edited and aligned using Geneious Pro 4.8.5 software (Kearse et al. 2012). The edited sequences were compared with those deposited in the National Center for Biotechnology Information (NCBI) GenBank. The BLASTn tool was used to identify the shark species employing DNA barcoding (Cruz et al., 2021).

For analysis of the metal(loid) concentrations, meat samples were stored in plastic tubes and kept frozen (−20 °C) until analysis. Aliquots (0.20–0.25 g) of muscle samples were dried in an oven (60 °C) and then completely digested with 1 mL of 65% nitric acid (HNO_3; SupraPur®; Merck, Darmstadt, Germany) for 24 h in an oven (60 °C). Digested samples were 10-fold diluted with ultrapure water (resistivity of 18.2 MΩ cm) (Aquapur Evolution AQ3000, Permution, Curitiba, PR, Brazil). Determination of metal(loid) concentrations (Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn) was performed by inductively coupled plasma mass spectrometry (ICP-MS, Plasma Quant MS Q, Analytik Jena, Jena, Germany), following the procedures described by the EPA 6020 Guidelines. The ICP-MS parameters were set as follows: radiofrequency (RF) power—1300 W; plasma flow (argon)—15 L/min; auxiliary flow—1.2 L/min; nebulizer argon flow—0.42 L/min; replicate readings—5; dwell time—50 ms; and detector operating mode—dual mode. Yttrium-89 ($89Y^+$) was used as the internal standard. Concentrations were determined based on calibration curves built for each analyte, using a serial dilution of a multielement standard (1 g L^{-1}) solution (Merck, Darmstadt, Germany). Data on metal(loid) concentrations were expressed as mg kg^{-1} wet weight.

The instrumental quantification limit (limit of detection; LOD) was determined by the 10/1 signal-to-noise ratio. The limit of quantification (LOQ) was determined using the LOD, extracted sample mass (g), concentration unit used to express the results, and the extract dilution factor. The LOD and LOQ values are shown in Table 1. The quality control assurance procedures were performed using high-purity reagents, new and/or contamination-free consumables, instrument and method blank analyses for each batch of 50 samples, analytical curves built with a certified standard solution, and semiannual analyses of fish protein certified reference material (Dogfish Muscle Reference Material [DORM-5]; Environment Canada, Ottawa, Canada). The recovery rates from the certified reference material corresponded to 95.98, 86.96, 91.26, 81.27, 88.32, 90.54, 85.36, 84.05, 83.39, and 86.13% for Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn, respectively. All determinations performed on the equipment and method blanks showed values below the LOQ, indicating that there was no contamination during the sample preparation and analysis.

2.2 Data presentation and statistical analysis

Data on metal(loid) concentrations were expressed as minimum, maximum, median, and mean (± standard error) values. For each metal(loid), comparison with the respective maximum concentration permissible by regulations of several regions around the world, including Brazil, was performed based on the lower and upper quartiles of the dataset. Metal(loid)s with lower (75% of data) or upper (25% of data) quartile values higher than those permissible by the more restrictive regulation for each analyzed element were considered as posing risk to human consumption in the long term.

3 RESULTS AND DISCUSSION

A total of 240 shark meat samples were obtained and analyzed. Among these, 36 samples (15%) were of sharks caught in Brazil, while 204 samples (85%) were of sharks imported from six different countries (Taiwan 39.2%; Portugal 17.5%; Spain 10.8%; China 8.8%; Uruguay 8.3%; and Peru 0.4%). Of all samples, 226 (94.2%) were genetically identified as blue sharks (*Prionace glauca*). All samples were analyzed and quantified for Al, As, Cr, Cu, Fe, Hg, Mn, Ni, and Zn. Cd and Pb were quantified in 97.9 and 98.3% of the samples, respectively (Table 1). The metal(loid) concentrations found were compared with data from other studies on *P. glauca*, as long as they were expressed on a wet weight basis (Table 2). Results were also compared with the maximum concentration permissible for each metal(loid) by

Table 1. Descriptive statistics of metal(loid) concentrations (mg kg^{-1} wet weight) in shark meat samples commercialized in markets of Southeastern and Southern Brazil.

Metal(loid)	Minimum	Maximum	Mean	SEM	Median	LOD	LOQ
Al	0.163	97.56	10.11	0.910	5.150	0.0227	0.068
As	0.023	0.944	0.288	0.012	0.241	0.0017	0.005
Cd	0.004	101.0	2.624	1.050	0.022	0.0013	0.004
Cr	0.064	12.02	1.330	0.075	1.044	0.0013	0.004
Cu	0.219	50.65	4.145	0.455	1.478	0.0167	0.050
Fe	0.209	122.9	16.57	1.235	10.41	0.0333	0.100
Hg	0.052	0.499	0.247	0.008	0.228	0.0010	0.003
Mn	0.159	23.66	2.111	0.172	1.310	0.0167	0.050
Ni	0.079	6.021	1.173	0.053	0.961	0.0188	0.057
Pb	0.014	101.0	1.886	0.860	0.152	0.0017	0.005
Zn	2.302	198.5	38.45	2.106	27.85	0.0033	0.010

SEM: standard error of mean; LOD: limit of detection; LOQ: limit of quantification.

Table 2. Concentrations of metal(loid)s in muscle of blue sharks (*Prionace glauca*) from different regions around the world. Data are expressed as mean values or range of values.

Source	**Metal(loid) concentration (mg kg^{-1} wet weight)**										
	Al	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
This study	10.1	0.29	2.62	1.33	0.46	16.6	0.25	2.11	1.17	1.89	38.5
All sources	1.70–30.1	0.29–104.9	0.01–2.62	0.1–2.58	0.142–22.7	2.5–445.3	0.01–2.5	0.033–7.35	0.02–2.58	< 0.02–2.89	2.9–169.2
(1)	30.1	8.9		0.1	0.20	2.5	1.9	0.05	0.02	0.7	2.9
(2)	—	—	0.04	—	—	—	0.78	—	—	—	—
(3)	—	104.9	0.76	2.1	22.7	445.3	0.36	7.35	2.14	2.89	169.2
(4)	—	—	—	—	—	—	1.88	—	—	—	—
(5)	—	—	0.01–0.04	—	—	—	0.09–0.50	—	—	0.04–0.25	—
(6)	1.70	—	—	0.14	0.98	—	—	—	—	—	5.38
(7)	—	—	—	—	—	—	0.5	—	—	—	—
(8)	23.8	78.19	0.01	2.58	1.15	28.21	1.36	0.63	0.34	0.12	24.61
(9)	—	—	—	—	—	—	2.3	—	—	—	—
(10)	6.81	7.23	0.02	< 2.0	0.22	—	0.77	0.07	< 0.2	<0.1	5.20
(11)	—	—	—	—	—	—	2.25	—	—	—	—
(12)	—	—	—	—	—	—	1.1	—	—	—	—
(13)	—	—	—	—	—	—	0.01	—	—	2.24	—
(14)	—	—	—	—	0.142	—	—	0.033	—	—	1.952
(15)	—	6.66	0.20	—	1.64	27.39	1.03	—	—	< 0.074	6.10
(16)	—	—	—	—	—	—	1.96	—	—	—	—
(17)	—	—	—	—	—	—	1.39	—	—	—	—
(18)	—	—	—	—	—	—	0.22–2.5	—	—	—	—
(19)	—	—	—	—	—	—	0.398	—	—	—	—
Source	**Metal(loid)**										
	Al	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
(20)	—	—	—	—	—	—	0.16–1.84	—	—	—	—
(21)	—	—	—	—	—	—	0.38	—	—	—	—
(22)	—	—	—	—	—	—	0.27–1.20	—	—	—	—
(23)	—	—	0.45	—	0.24	6.34	—	1.55	2.58	< 0.02	—
(24)	—	—	< 0.05	—	4.4	—	—	—	—	< 0.20	35.00

Source: (1) Alves et al. (2023); (2) Castro-Rendón et al. (2022); (3) Álvaro-Berlanga et al. (2021); (4) Maurice et al. (2021); (5) Reátegui-Quispe and Pariona-Velarde (2019); (6) Vignatti et al. (2018); (7) Biton-Porsmoguer et al. (2018); (8) Alves et al. (2016); (9) Kim et al. (2016); (10) Machado (2016); (11) Matos et al. (2015); (12) Carvalho et al. (2014); (13) Lopez et al. (2013); (14) Olmedo et al. (2013); (15) Barrera-García et al. (2012); (16) Maz-Courrau et al. (2012); (17) Escobar-Sánchez et al. (2011); (18) Branco et al. (2007); (19) Mársico et al. (2007); (20) Branco et al. (2004); (21) Storelli et al. (2001); (22) Davenport (1995); (23) Vas (1991); (24) Stevens and Brown (1974).

regulations of several regions around the world. Unfortunately, no regulation was found for Mn. In this case, a relevant article on this topic was adopted (Table 3).

Comparisons indicated that the muscle samples of blue sharks evaluated in the present study exhibited the lowest As concentration and the highest Cd concentration ever reported in studies of the blue shark over the last five decades (1974–2025). Concentrations of the other analyzed metal(loid)s were well within the ranges found in previous studies (Table 2). In this context, it is worth noting the high risk to human health associated with ingestion of shark meat contaminated with the high concentration of Cd observed here. Long-term exposure to dietary Cd can pose significant risks by impacting the kidneys and bones, and potentially increasing the risk of certain types of cancer (United Kingdom, 2024). Recent toxicological assessments reinforce that elasmobranchs tend to accumulate pollutants at higher levels than teleost fishes due to their long lifespan and trophic position, aggravating risks for frequent consumers (Peixoto-Rodrigues et al., 2025).

For all the analyzed metal(loid)s, except Cd, Pb, and Zn, the upper quartile concentration values (comprising 25% of the analyzed samples) observed in the present study exceeded those permissible by the more restrictive regulations considered here. The same finding is observed for most elements analyzed (Al, As, Cr, Fe, Hg, Ni, and Zn) when considering the lower quartile concentration values (comprising 75% of the analyzed samples) (Table 3). Therefore, the risk of long-term consumption of the shark meat analyzed in the present study is not only associated with the observed high levels of Cd compared to those reported in other studies. It is also related to the excessive concentrations of several essential (Cr, Cu, Fe, Ni, and Zn) and other non-essential (Al, As, and Hg) elements, considering the maximum concentrations permissible by the more restrictive regulations employed here. As mentioned above for Cd (United Kingdom, 2024), excessive intake of other non-essential and essential metal(loid)s can cause harmful effects on human health (Zaynab et al., 2022). This highlights a paradox where sharks are simultaneously targeted for human consumption and conservation concern,

Table 3. Lower and upper quartile values for the concentrations of metal(loid)s in shark meat samples analyzed in the present study and those permissible in muscle of predator fishes by different regulatory agencies around the world.

Source	**Metal(loid) concentration (mg kg^{-1} wet weight)**										
	Al	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
LQ	1.40	0.151	0.015	0.642	0.963	3.75	0.158	0.808	0.680	0.102	18.06
UQ	11.98	0.403	0.032	1.763	3.029	22.60	0.320	2.325	1.358	0.212	48.81
All sources	0.1	0.1–75	0.05–5.5	1.0–50	10–100	100	0.1–1.6	1.0	0.5–80	0.3–10.0	30–1000
(1)	—	1.0	0.05	—	—	—	1.0	—	—	0.3	—
(2)	—	3.5	—	—	—	—	—	—	—	0.5	—
(3)	—	—	0.05	—	—	—	1.0	—	—	0.3	—
(4)	—	—	0.1	2.0	—	—	—	—	—	0.5	—
(5)	—	0.1–6.0	0.05–5.5	1.0	10–100	—	0.1–1.0	—	—	0.5–10.0	30–1000
(6)	—	75	3.0	12	—	—	1.0	—	80	1.5	—
(7)	—	—	—	—	—	—	—	—	—	0.3	—
(8)	—	—	0.05	—	—	—	0.5	—	—	0.3	—
(9)	—	—	—	—	—	—	1.0	—	—	0.5	—
(10)	—	—	1.0	50	30	100	—	1.0	0.5-1.0	2.0	100
(11)	—	—	0.05	—	—	—	1.0	—	—	0.2	—
(12)	—	—	0.05	—	—	—	1.0	—	—	0.3	—
(13)	0.1	—	—	—	—	—	—	—	—	—	—
(14)	—	—	—	—	—	—	0.4/0.3	—	—	—	—
(15)	—	—	—	—	—	—	—	—	—	—	50
(16)	—	—	—	—	20	—	—	—	—	—	—

LQ: lower quartile value; UQ: upper quartile value.

Source: (1) Brazil (2022); (2) Canada (2024); (3) European Union (2023); (4) China (2014); (5) Nauen (1983); (6) India (2011); (7) Food and Agriculture Organization of the United Nations and World Health Organization (2025); (8) Turkey (2023); (9) Australia (2022); (10) World Health Organization (1989); (11) Eritrea (2003); (12) Saudi Arabia (2025); (13) Ranau et al. (2001); (14) Japan (2001); (15) United Kingdom (1953); (16) United Kingdom (1956).

amplifying the "double jeopardy" for biodiversity and public health (Hammerschlag & Sims, 2024).

Finally, it is worth noting that the blue shark *P. glauca* is considered as "Near Threatened" in The The International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Furthermore, its populations in the North and South Atlantic are considered as "Endangered" and "Vulnerable," respectively (Rigby et al., 2019). In this context, it is important to note that all samples genetically identified and analyzed here were from the blue shark *P. glauca*. Therefore, in addition to the risk posed to human health as pointed out above, our findings highlight the need for the establishment of public policies aiming to improve the conservation status of blue shark populations, especially those from the North and South Atlantic. Considering that less than 8% of ISRAs overlap with strict no-take zones (Mouton et al., 2025), enforcement of spatial protections is urgently required to complement fishery regulations and mitigate overexploitation of blue shark stocks.

4 CONCLUSIONS

Our study report excessive concentrations of several essential and non-essential metal(loid)s in the blue shark meat commercialized in Brazil. Therefore, findings reported here indicate a potential risk to human health associated with long-term dietary exposure to the high levels of these food contaminants. Additionally, they draw attention to the current fishing pressure on populations of the blue shark *Prionace glauca*.

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