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Bioaccumulation of essential and toxic elements in natural populations of Caiman latirostris: sentinels of pollution in a hypereutrophic urban tropical estuary

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Research Article

Keywords: Trace elements, broad-snouted caiman, urban caimans, Atlantic Forest, mangrove, One Health approach

Posted Date: November 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11545455/v1

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Additional Declarations: No competing interests reported.

Bioaccumulation of essential and toxic elements in natural populations of *Caiman latirostris*: sentinels of pollution in a hypereutrophic urban tropical estuary

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Abstract

The broad-snouted caiman (*Caiman latirostris*) is widely distributed throughout Brazil and, despite being classified as Least Concern, faces increasing anthropogenic pressures. Crocodilians are promising sentinel species for ecotoxicological studies, yet research on free-ranging populations in anthropized tropical estuaries remains scarce. This study investigated caiman ecotoxicology in an Atlantic Forest and mangrove remnant within the eutrophic Capibaribe River estuary (Recife, northeastern Brazil), adopting a One Health approach. Two field surveys during the dry and rainy seasons of 2024 yielded 22 individuals (19 adults and three subadults; 14 males and eight females). Scales, muscle, liver, and kidney samples were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) to quantify 13 essential and potentially toxic trace elements (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Hg, and Pb). Fe, Zn, Al, and Cu had the highest concentrations overall, with the kidney being the primary bioaccumulation organ. Females had higher hepatic Zn and renal Mn concentrations, whereas males had higher muscular Cu, Cd, and Pb concentrations. Subadults had higher hepatic Mn, Zn, Se, and Cd; renal Co, Cu, As, Se, and Cd; and muscular Al, Se, and Hg concentrations. Adults had higher Mn and Zn concentrations in scales. Hepatic melanomacrophages occurred in all individuals, with moderate frequency in 54.5%. Trace-element exposure may threaten caiman health, conservation, estuarine biota, and human populations. These findings support the species' potential as a sentinel for environmental monitoring and for informing biodiversity conservation and environmental management under a One Health framework.

Keywords: Trace elements, broad-snouted caiman, urban caimans, Atlantic Forest, mangrove, One Health approach.

Acknowledgements

We thank the IUCN SSC Crocodile Specialist Group (CSG) for the technical support and funding provided through the Student Research Assistance Scheme.

Introduction

Environmental biomonitoring is an important tool for assessing ecosystem health, particularly through the use of organisms capable of responding to variations in environmental conditions. This information can support the development of measures and legislation aimed at protecting water bodies, aquatic biota, and, consequently, human health (Aragão & Araújo, 2006). In this context, reptiles exhibit characteristics that favor their use in environmental monitoring studies. Although they are considered relatively insensitive to various chemical agents, they are capable of bioaccumulating contaminants, allowing their use as indicators of environmental contamination (Domingues & Bertoletti, 2006). In addition, several species have long life cycles, territorial behavior, and the ability to tolerate environmental changes, characteristics that may contribute to monitoring changes in ecosystem conditions. Since the 1980s, reptiles have been used for the detection and monitoring of contaminated areas, particularly in lentic environments such as lakes, ponds, and reservoirs (Tellez & Merchant, 2015; Schneider et al., 2015; Nilsen et al., 2017a, 2017b).

The broad-snouted caiman, *Caiman latirostris* (Daudin, 1802), is a medium-sized crocodilian. It is a long-lived and opportunistic semi-aquatic predator with a generalist diet (Platt et al., 2006), regulating food webs and facilitating nutrient transport among different habitats (Somaweera et al., 2020). It is found in vegetated habitats and lentic water bodies, such as floodplains, wetlands, mangroves, reservoirs, and estuaries (Verdade & Piña, 2005). Approximately 70% of its global population is concentrated within Brazilian territory, particularly in areas with high human population density (Coutinho et al., 2013). The species is classified as Least Concern (LC) at both the global (IUCN, 2024) and national levels in Brazil (ICMBio, 2024). In Brazil, populations are under intense anthropogenic pressure due to the drainage of water bodies, deforestation, habitat reduction, urban expansion, illegal hunting, pollution, and contamination by pesticides (Verdade, 1997, 2001; Filogônio et al., 2010; Mascarenhas-Junior et al., 2021).

Characteristics such as longevity, prey diversity, and prolonged residence in water bodies (Campbell et al., 2004; Schneider et al., 2012, 2015; Nilsen et al., 2017a, 2017b) make crocodilians vulnerable to the accumulation of contaminants (Verdade & Piña, 2005; Poletta et al., 2008; Stoker, 2011; Schneider et al., 2012, 2015; Nilsen et al., 2017a, 2017b). These animals may be exposed throughout all life stages, either through their diet or through the water and sediments of the habitats they occupy (Poletta et al., 2008; Schneider et al., 2013; Buah-Kwofie et al., 2018), although embryos are considered the most sensitive to contaminants (Poletta et al., 2008). In broad-snouted caimans, alterations in embryogenesis, as well as reduced hatching success and egg mass loss, have already been reported following exposure to organic contaminants, such as herbicides and pesticides (Poletta et al., 2008).

In the Capibaribe River basin, Pernambuco State, northeastern Brazil, bioaccumulation studies have also been conducted on broad-snouted caimans inhabiting lentic environments within the Atlantic Forest (Santos et al., 2021b, 2024). Studies demonstrating the impact of anthropogenic disturbance and contamination by essential and toxic trace elements on broad-snouted caiman populations are important for the implementation of conservation strategies for this species and the biota associated with continental aquatic ecosystems, as well as for providing information on potential health risks to human populations (Aragão & Araújo, 2006) that consume food resources originating from polluted and contaminated water bodies. This issue is particularly relevant in the Capibaribe River, which ranks seventh among the ten most polluted rivers in Brazil (SoCientifica, 2022).

The dynamic of estuarine environments is strongly influenced by hydrodynamic factors, such as salinity, temperature, nutrient availability, and tides (McLusky & Elliott, 2004; Zinardi-Lamardo et al., 2016). The continuous input of organic matter and nutrients creates favorable conditions for the occurrence of various organisms, including caimans, fish, crustaceans, and other organisms that constitute the diet of this crocodilian (Mallin & Paerl, 1994). These environmental characteristics, together with the occurrence of potential prey and the prolonged residence of crocodilians in aquatic environments, may increase opportunities for exposure to contaminants.

The Capibaribe estuary is heavily impacted by urbanization, pollutant discharge, and vegetation removal, while also being used for fishing, tourism, recreation (CPRH, 2020; APAC, 2021), and supplying drinking water to approximately 2 million inhabitants (Silva et al., 2025). In this context, health and conservation actions and policies for this ecosystem are required based on the principles of the One Health approach, which, through transdisciplinary and intersectoral actions, promotes the well-being and health of humans, non-human animals, photosynthetic

organisms, and ecosystems in an interconnected and interdependent manner (Mettenleiter et al., 2023), particularly in anthropogenically impacted aquatic ecosystems, such as rivers and their estuaries (Fonseca et al., 2023).

Accordingly, the objectives of this study in natural populations of broad-snouted caimans were to evaluate the exposure of broad-snouted caimans to environmental contaminants through the quantification and analysis of essential and toxic trace elements, testing the following hypotheses: (a) the liver and kidney bioaccumulate higher concentrations of trace elements; (b) trace element concentrations differ between males and females; and (c) trace element concentrations differ among size classes.

Methodology

Study area

The Capibaribe River is approximately 280 km long, flowing through 42 municipalities in the state of Pernambuco, northeastern Brazil (Figure 1), where it receives large amounts of domestic effluents (lower course), as well as agricultural and industrial effluents (middle and upper courses) (CPRH, 2024). The Capibaribe River supplies potable water to approximately 2 million people (Silva et al., 2025), and is also used for fishing, recreation, and tourism (CPRH, 2024). Currently, the river is the seventh most polluted rivers in Brazil (SoCientifica, 2022).

The study was conducted in the river estuary, in the city of Recife (−8,041761°; −34,920472°), within a stretch of approximately 16 km (Figure 1), encompassing Atlantic Forest and mangrove habitats (CPRH, 2024). The estuary is characterized by strong tidal influence and intense urban activity, with areas of vegetation suppression and discharge of domestic effluents, classified as hypereutrophic (CPRH, 2024).

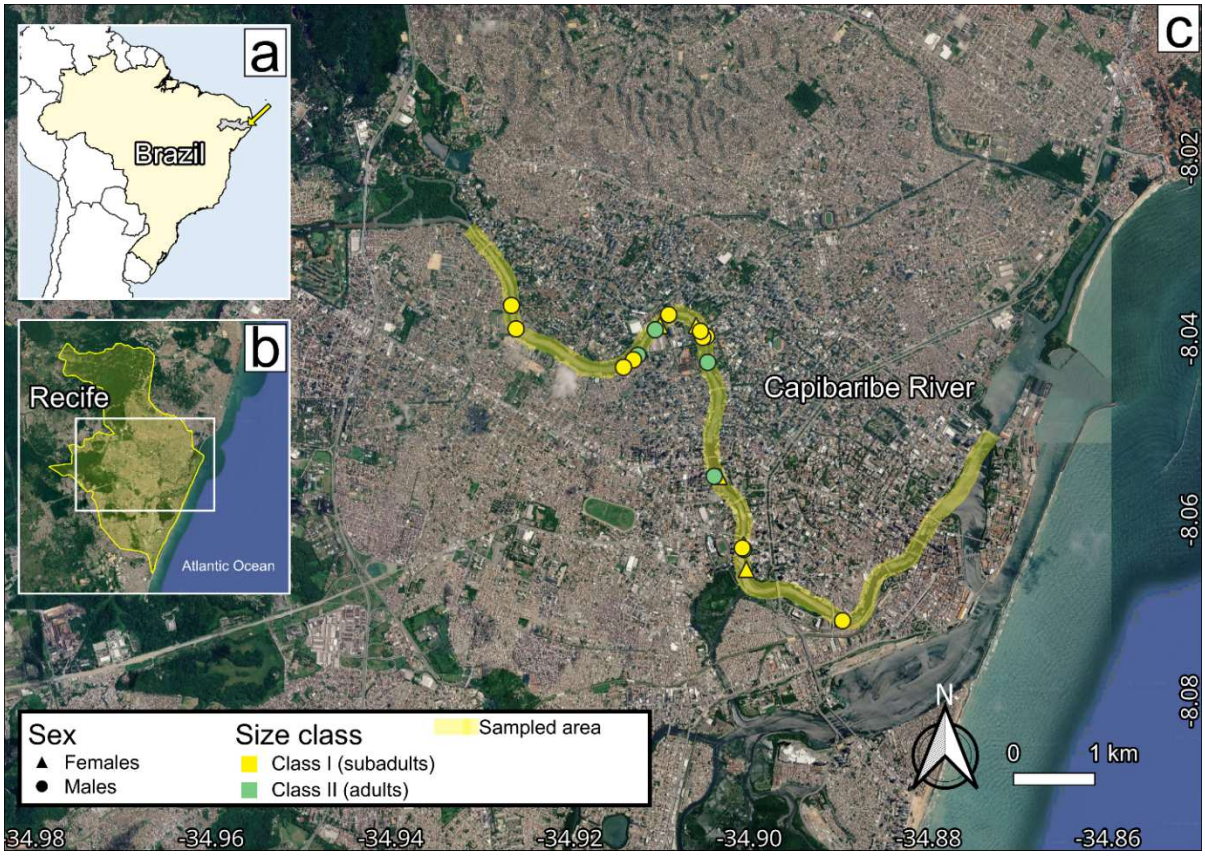


Figure 1. Study area showing the capture sites of broad-snouted caimans (*Caiman latirostris*) in the state of Pernambuco (a), northeastern Brazil. Monitoring was conducted in the urban area of the city of Recife (b), along a 16-km stretch of the Capibaribe River (c).

Capture of caimans and collection and processing of biological samples

This study was authorized by the Biodiversity Authorization and Information System (SISBIO) of the Chico Mendes Institute for Biodiversity Conservation (ICMBio) (SISBIO #63030-11), the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SISGEN #AFOEC7C), and the Animal Use Ethics Committee (CEUA) of the Federal Rural University of Pernambuco (CEUA/UFRPE #860200622).

We captured individuals of broad-snouted caimans in January and October 2024 through active nocturnal surveys using a motorized boat (Bayliss, 1987; Silveira et al., 1997). Caimans were physically restrained for biometric measurements and biological sample collection (Jesus Filho & Freitas-Filho, 2021). We recorded the geographic location of each individual using a handheld GPS receiver. Following capture, we determined caiman sex by cloacal palpation (Webb et al., 1984) and recorded biometric measurements using a measuring tape and calipers. Based on snout–vent length (SVL, cm), individuals were classified into the following size classes, adapted from Leiva et al. (2018): juveniles (< 25 cm); subadults (25–67.9 cm); and adults (> 68 cm). We also recorded body mass using spring scales with a capacity of up to 100 kg.

Subsequently, we euthanized each individual following the recommendations of the National Council for the Control of Animal Experimentation (CONCEA, 2018). We combined xylazine (1 mg/kg) and ketamine (20 mg/kg), and after the individual reached a relaxed state, we administrated a lethal dose of potassium chloride (60 mg/kg) into the occipital sinus (Vieira et al., 2013).

Elemental analysis

We collected tail scales and muscles, liver, and kidney samples for the determination of elemental concentrations of Al, Cr, Fe, Mn, Co, Cu, Zn, As, Se, Cd, Ni, Hg and Pb.

Reagents and standards

All solutions were prepared from concentrated nitric acid (~65% m m-1, Synth, Brazil), which was sub distilled (DST-1000, Savillex, USA). Deionized water (resistivity 18.2 MΩ cm, Master System All, Gehaka,Brazil) was used for all tests and cleaning. For digestion we used: i) digester block (Easy Digest, Analab, Wantzenau, France); ii) For the calibration standard, the solution used were purchased from Perkin Elmer (USA) 10 mg L -1 Hg and Inorganic Venturis (USA) 10 mg L -1 multi-element solution stock 21; iii) The following concentrations of standard calibration solution were used in the preparation of the analytical curves: 50,100, 200, 500, 1000, 2000, 5000 ug. L 1 (Fe, Zn); 0.1, 2,5, 10, 2,50, 100, 200 ug. L 1 (Al, Cr, Mn, Co, Ni, Cu, As, Se, Cd and Pb); 0.1, 0.2, 0.5, 1, 2 ug L 1 (Hg); iv) A solution of Rh and Ge at a concentration of 25 $\mu g \cdot L^{-1}$ was used as an internal standard; v) The certified reference materials SRM 1643f (National Institute of Standards and Technology, USA) and the certified reference materials DORM-4 (National Research Council Canada). Determinations were performed by an inductively coupled plasma mass spectrometer (ICP-MS, Agilent 7900, Hachioji, Japan). The ICP-MS operational conditions are shown in Table 1.

Digester acid block

Scale samples were pre-washed with Milli-Q water in an ultrasonic bath for 5 minutes. All samples (muscle, scale, and kidney tissues) were freeze-dried for 72 hours. Subsequently, the samples were ground and weighed. A mass of up to 200 mg of material (muscle, scale, or kidney) was weighed into 50 mL Falcon tubes, to which 1,000 µL of sub-distilled HNO_3 was added. The tubes were then sealed and taken to a digestion block for organic matter decomposition, following the protocol: (i) pre-digestion for 48 hours at room temperature (25 °C); (ii) manual shaking for homogenization and 1,000 µL of sub-distilled HNO_3 added; (iii) heating at 95 °C for 4 hours. This digestion procedure was adapted from the method proposed by Paniz et al. (2018).

The resulting solutions were diluted to 50 mL with deionized water. Analytical blank solutions, prepared in triplicate, underwent all the same preparation steps, as well as certified reference materials.

All samples were analyzed by ICP-MS under the operating conditions described in Table 1.

Table 1 - Inductively coupled plasma mass spectrometer (ICP-MS) operational conditions for elemental determination.

Apparatus	Condition / Operation
Nebulizer	Mira Mist
Spray chamber	Scott-double pass
Torch	Quartz (1.5mm)
RF Power (W)	1550
Argon (L min^{-1})	Nebulizer: 1.01 Plasma: 15 Auxiliary: 0.28
Collision cell	Helium (purity>99.999%) He at 5ml.min^{-1} or HEHe at 10ml.min^{-1}
Interface	Platinum cones Sampler: 0.9 mm Skimmer: 0.45 mm
Isotopes (mode)	^{27}Al [He], ^{52}Cr [HEHe], ^{55}Mn [HEHe], ^{56}Fe [HEHe], ^{59}Co [He], ^{60}Ni [He], ^{65}Cu [He], ^{66}Zn [He], ^{75}As [HEHe],^{78}Se [HEHe], ^{111}Cd [He], ^{202}Hg [No Gas], ^{208}Pb [No Gas]
Internal Standard	^{103}Rh and ^{72}Ge
Scan Mode	Peak hoping
Integration time (ms)	100 (No gas); 200 (He); 400 (HEHe)
Replicates	3
Sweeps	100
Readings	1
Sampling (mL min^{-1})	1.0

Method validation and evaluation of digestion efficiency

The quality of the calibration curves was assessed using the reference material SRM 1643f, and the efficiency of the method was verified by the recovery rates, which ranged from 92% to 112% (Table 2). The digestion efficiency was also evaluated based on the recovery of the certified reference material DORM-4, which was subjected to the same digestion procedure as the samples. The recovery rates for DORM-4 also ranged from 92% to 112% (Table 2).

The limit of detection (LOD) was calculated based on the mean concentration (MC) and standard deviation (SD) obtained from ten different analytical blanks prepared alongside the samples. The instrumental limit of detection (iLOD) was calculated using the iLOD=MC+3×SD. The instrumental limit of quantification (iLOQ) was calculated as: iLOQ = 3.3 × iLOD, as recommended by Eurachem (2020).

Table 2 - Recovery of reference material.

Elements	Recovery (%)		Limits	
	NIST 1643f	DORM-4	iLOD (ug./L)	iLOQ (ug/L)
Al	99.27	106.63	1.07	3.52
Cr	112.34	100.56	0.01	0.02
Mn	104.84	96.73	0.02	0.05
Fe	111.80	106.99	0.11	0.36
Co	102.53	112.55	0.00	0.01
Ni	99.37	95.42	0.65	2.15
Cu	98.64	110.73	0.10	0.35

Elements	Recovery (%)		Limits	
	NIST 1643f	DORM-4	iLOD (ug./L)	iLOQ (ug/L)
Zn	96.38	98.83	0.24	0.80
As	100.89	92.38	0.05	0.17
Se	97.23	103.91	0.13	0.42
Cd	92.07	97.24	<0.0001	<0.0001
Hg		91.84	0.01	0.03
Pb	93.17		0.01	0.02

Histopathological assessment

Liver samples exhibiting macroscopic alterations were collected and preserved in 10% neutral buffered formalin for subsequent processing using conventional histological techniques. Liver samples were examined microscopically using hematoxylin and eosin (H&E) and Sudan Black B (SB-B) staining. For H&E staining, liver tissue fragments were fixed in 10% buffered formalin for 48 h, trimmed, routinely processed through graded alcohols and xylene, embedded in paraffin, sectioned at 4 µm, and stained.

Statistical analysis

For all quantitative variables, we evaluated the data to determine whether parametric or non-parametric statistical approaches were appropriate. Homogeneity of variances was assessed using Bartlett's test, whereas normality was evaluated using the Shapiro–Wilk test. We assessed differences among group means using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test when the assumption of homogeneity of variances was met. When this assumption was violated, we evaluated differences using the Kruskal–Wallis test followed by Fisher's LSD post hoc test. For comparisons between two groups, we applied a Student's *t*-test when data met the assumption of normality. Otherwise, we used the non-parametric Mann–Whitney test. Thus, we evaluated differences between means or medians according to the distributional assumptions of the data. All statistical tests adopted a significance level of 5%. We performed statistical analyses using R software.

RESULTS

During two expeditions conducted in January and October 2024, we surveyed 15.91 km and 13.01 km, respectively, accounting for 16 hours of sampling effort and resulting in the capture of 22 individuals (11 per expedition). Among these, 19 were classified as adults and three as subadults, comprising 14 males and eight females. The mean body mass was 7,165 ± 6,616 g, and the mean snout–vent length (SVL) was 57.86 ± 14.73 cm.

We analyzed 88 samples of scales (n = 22), kidney (n = 22), muscle (n = 22), and liver (n = 22) for the determination of 13 elements (Al, Cr, Fe, Mn, Co, Cu, Zn, As, Se, Cd, Ni, Hg, and Pb). Nickel (Ni) concentrations were below the detection limit in all samples, making its analysis impossible; therefore, this element was excluded from the statistical analyses.

Overall, Fe, Zn, Al, and Cu exhibited the highest concentrations compared with the other elements across all four analyzed biological matrices. When evaluating the main elements with the highest mean concentrations in these samples, the kidney showed the following pattern: Fe (12.25) > Zn (11.01) > Al (9.84) > Cu (9.15), followed by the liver: Fe (13.05) > Zn (10.72) > Cu (9.93) > Al (9.44), scales: Fe (12.05) > Al (9.87) > Zn (9.81) > Cu (7.55), and muscle: Zn (10.44) > Fe (10.23) > Al (9.24) > Cu (6.67) (Figure 2).

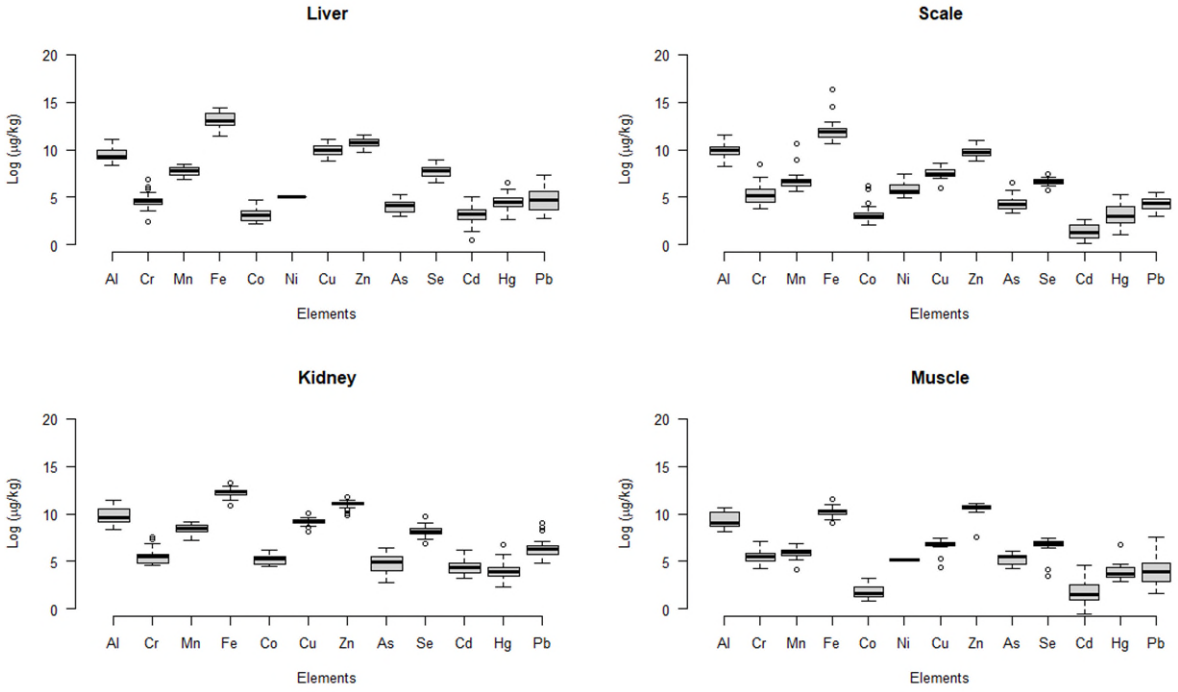


Figure 2. Mean concentrations of the detected elements: aluminum (Al), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), cadmium (Cd), arsenic (As), and zinc (Zn) in liver, kidney, scale, and muscle samples of broad-snouted caimans (*Caiman latirostris)* captured in the urban estuary of the Capibaribe River, Brazil.

We observed significant differences between sexes for specific elements and biological matrices. In the liver matrix, Zn showed higher mean values in females (mean ± SD) (68,685.61 ± 26,314.19 µg/kg) compared to males (41,058.08 ± 17,354.80 µg/kg) (p = 0.0230) (Figure 3A, Table 3 - Appendix). Additionally, in the kidney matrix, females also exhibited higher mean concentrations of Mn (females: 6,105.95 ± 2,139.91 µg/kg; males: 4,015.45 ± 1,706.89 µg/kg) (p = 0.0354) (Figure 3B, Table 4 - Appendix).

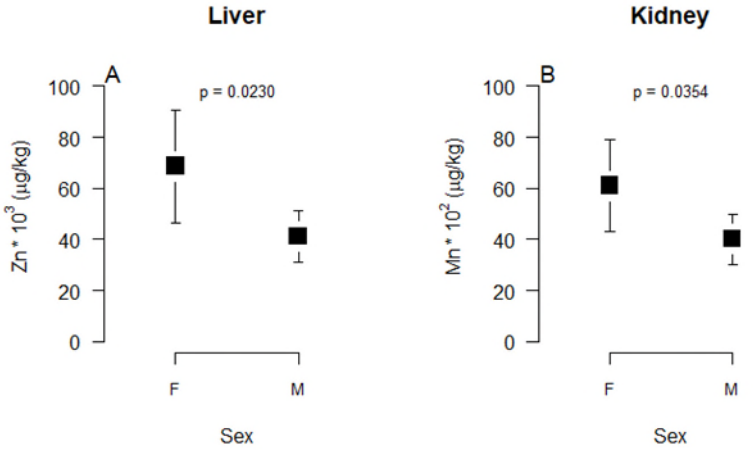


Figure 3. Females exhibited higher mean Zn concentrations (p = 0.0230) in the liver (A) and higher mean Mn concentrations (p = 0.0354) in the kidney (B) of broad-snouted caimans (*Caiman latirostris*) captured in the urban estuary of the Capibaribe River, Brazil.

Conversely, in the muscle matrix, males presented higher concentrations of Cu, Cd, and Pb compared to females. For Cu, median values were 961.30 µg/kg in males and 762.01 µg/kg in females, with mean ± standard deviation values of 1,046.93 ± 448.47 µg/kg and 699.04 ± 214.88 µg/kg, respectively (p = 0.0422). For Cd, median values were 8.24 µg/kg for males and 3.43 µg/kg for females, with mean ± standard deviation values of 21.87 ± 32.14 µg/kg and 3.06 ± 1.95 µg/kg, respectively (p = 0.0292). Finally, for Pb, males presented a median of 111.25 µg/kg and females 18.22 µg/kg, with mean ± standard deviation values of 381.70 ± 614.88 µg/kg and 24.64 ± 19.67 µg/kg,

respectively (p = 0.0038) (Figure 4, Table 5 - Appendix). In the scute matrix, no significant differences in the concentrations of the analyzed elements were found between sexes (Table 6 - Appendix).

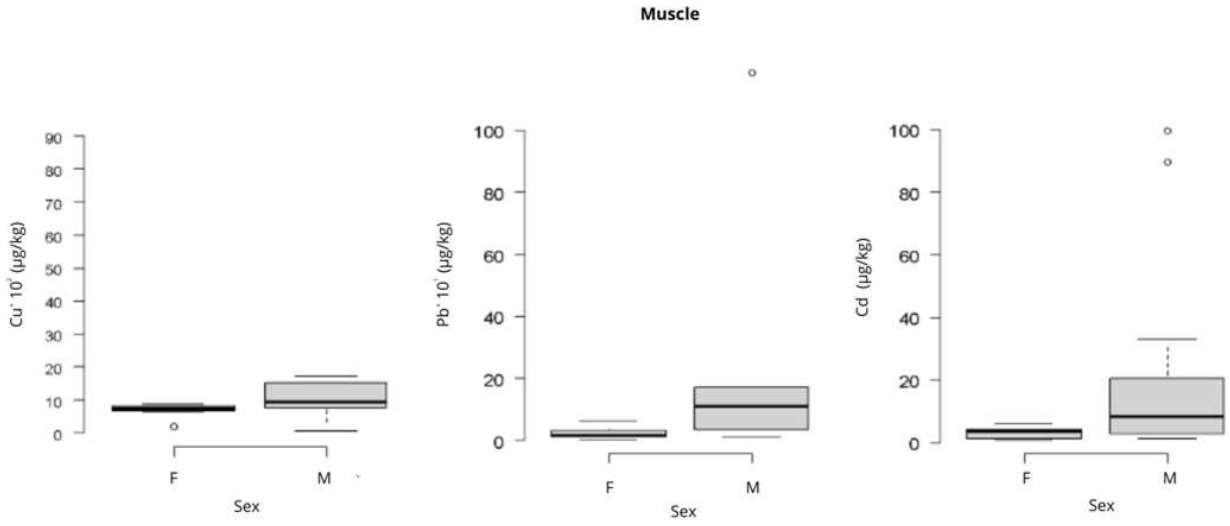


Figure 4. Median concentrations of Cu, Cd, and Pb in the muscle of female and male broad-snouted caimans (*Caiman latirostris*) captured in the urban estuary of the Capibaribe River, Brazil, with males exhibiting higher concentrations (Cu: p = 0.0422; Cd: p = 0.0292; and Pb: p = 0.0038).

Size class

We observed significant differences between size classes. Subadult individuals exhibited higher median concentrations (µg/kg) of Mn (2782.81 vs. 1549.85; p = 0.0098), Zn (59077.39 vs. 35152.06; p = 0.0095), Se (2565.31 vs. 1429.55; p = 0.0184), and Cd (26.95 vs. 14.49; p = 0.0310) in the liver (Figure 5, Table 7 - Appendix). In the kidney, we observed higher median concentrations for Co (201.40 vs. 142.25; p = 0.0093), Cu (11204.90 vs. 9062.71; p = 0.0477), As (159.39 vs. 55.35; p = 0.0583), Se (3711.87 vs. 2773.20; p = 0.0193), and Cd (95.45 vs. 32.56; p = 0.0477) (Figure 6, Table 8 - Appendix). In the muscle, we detected higher median concentrations of Al (9468.42 vs. 5632.24; p = 0.0310), Se (1148.67 vs. 614.70; p = 0.0009) and Hg (62.10 vs 24.26; p= 0,0293) (Figure 7, Table 9 - Appendix).

In contrast, adults exhibited higher median concentrations of Zn (30514.35 vs. 15854.26 µg/kg; p = 0.0246) in the scales (Table 10- Appendix).

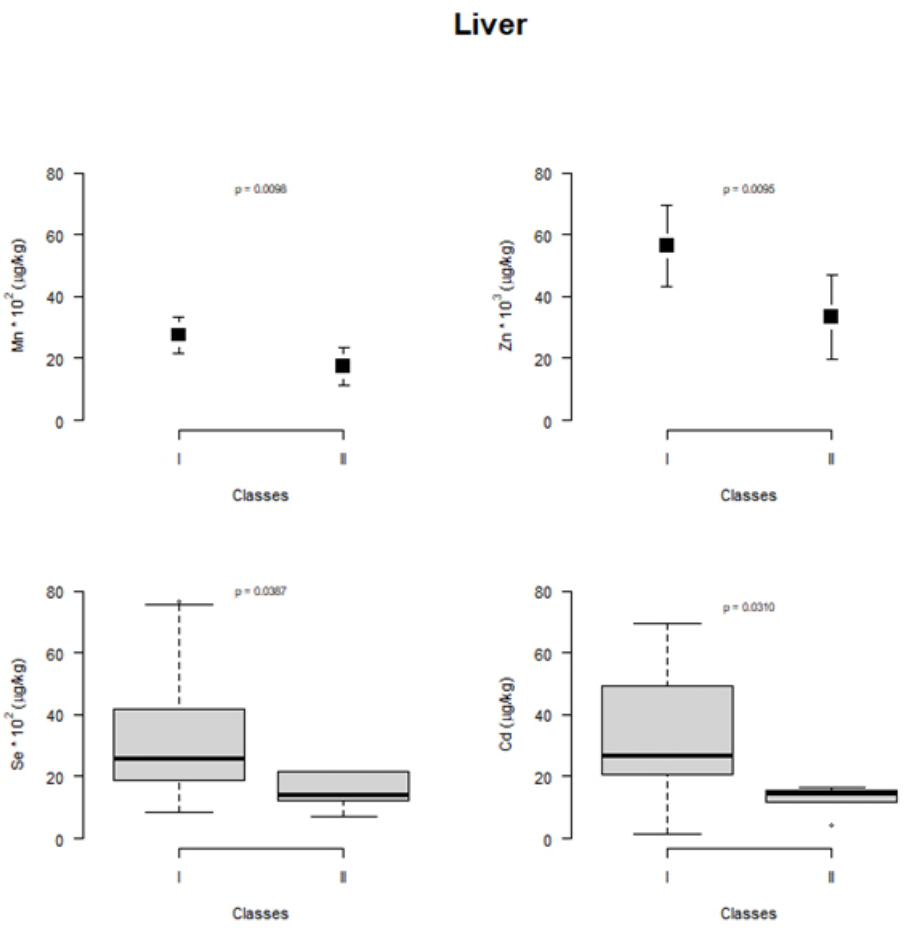


Figure 5. Mean concentrations of Mn and Zn, and median concentrations of Se and Cd in the liver of subadult (Class I) and adult (Class II) broad-snouted caimans (*Caiman latirostris*) captured in the urban estuary of the Capibaribe River, Brazil.

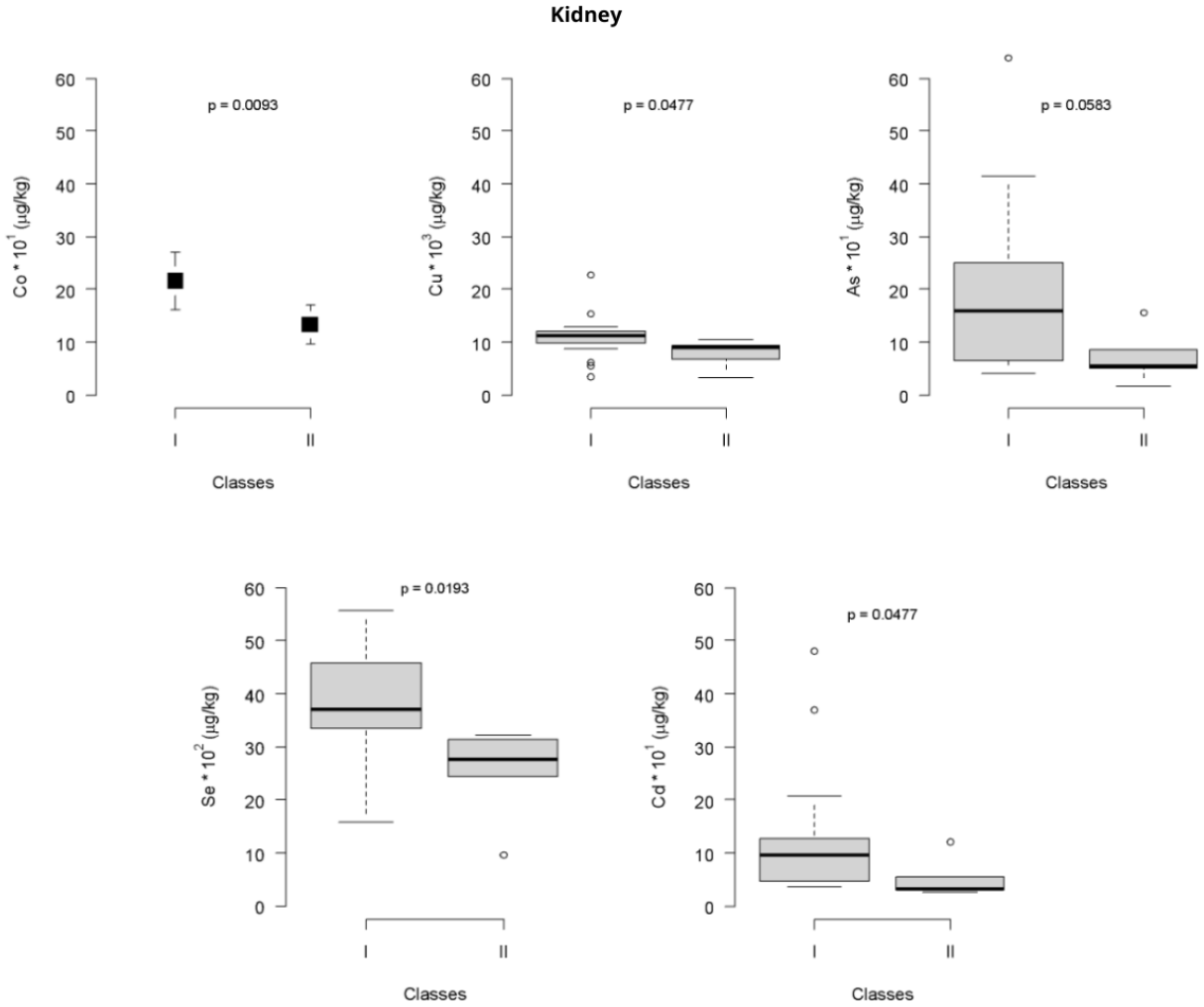


Figure 6. Mean Co concentrations and median Cu, As, Se, and Cd concentrations in the kidney of subadult (Class I) and adult (Class II) broad-snouted caimans (*Caiman latirostris*) captured in the urban estuary of the Capibaribe River, Brazil.

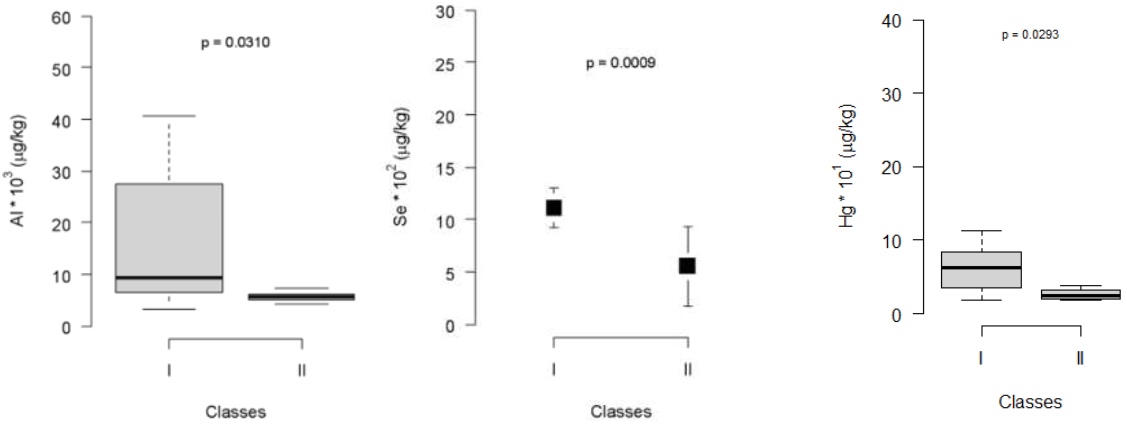


Figure 7. Concentrations of Al, Se, and Hg in subadult (Class I) and adult (Class II) broad-snouted caimans (*Caiman latirostris*) captured in the urban estuary of the Capibaribe River, Brazil.

Some animals exhibited whitish livers (Figure 8). Histopathological analysis of the livers of the 22 animals studied revealed the presence of melanomacrophages, which we classified as moderate (54.5%), mild (27.3%), and severe (18.2%) (Figure 8). In addition, 14 (63.6%) caimans presented moderate (71.4%) or severe (28.6%) hepatic lipidosis (Figure 8).

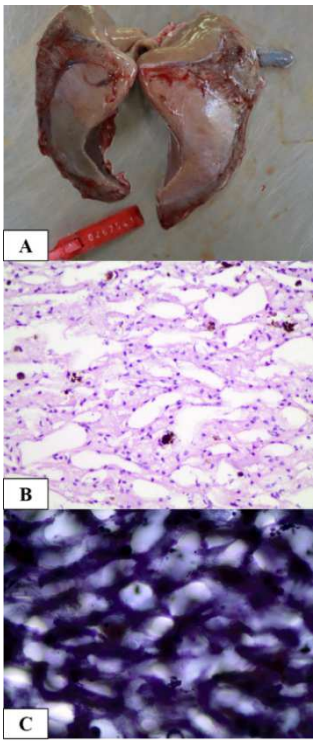


Figure 8. Whitish liver of a broad-snouted caimans (*Caiman latirostris*) individual (A); liver showing a moderate presence of melanomacrophages (B); liver with severe lipidosis (C).

Discussion

The comparative analysis among tissues demonstrated that the kidney and liver presented the highest mean concentrations of microminerals, corroborating their central role in the processes of detoxification and elimination of toxic substances (Cortés, 2016; Siroski et al., 2023). A similar pattern was observed by Buenfil-Rojas et al. (2026) in Morelet's crocodiles (*Crocodylus moreletii*), with greater metal accumulation in these organs. Scales presented intermediate concentrations, reflecting their function as a chronic record of exposure and a secondary detoxification pathway through keratinization (Nilsen et al., 2017a), which justifies their widespread use in ecotoxicological studies with crocodilians (Buenfil-Rojas et al., 2020; Santos et al., 2021a, 2021b; Thirion et al., 2022). In contrast, muscle tissue presented the lowest mean concentrations, in agreement with the results reported by Salazar-Pammo et al. (2021) for Yacare caiman (*Caiman yacare*).

In the present study, we observed differences in trace element concentrations in the tissues between sexes, as expected due to the distinct metabolic and physiological functions of each organ, with females presenting higher concentrations of Zn in the liver and Mn and Cu in the kidney. This pattern may be related to the higher metabolic demand during the reproductive cycle, since the liver plays a central role in the storage and mobilization of metals that are essential prior to oviposition (Jose et al., 2018). Zinc (Zn) is essential for vitellogenesis and embryonic development, making its maternal transfer fundamental for reproductive success (Eisler, 2000; Grillitsch & Schiesari, 2010). The higher Mn concentrations in the kidneys of females may also be associated with its reabsorption and mobilization for eggshell formation (Elejalde-Cadena et al., 2025). In American alligators (*Alligator mississippiensis*), the kidney is recognized as an important site of metal accumulation due to its high vascularization (Nilsen et al., 2017b). In broad-snouted caimans, exposure to metal contaminants has already been associated with alterations in embryogenesis, reduced hatching rates, and egg mass loss (Poletta et al., 2008), demonstrating the potential impact of these elements on the reproductive success of the species.

Subadult individuals presented higher concentrations of Mn, Zn, Se, and Cd in the liver; Co, Cu, As, Se, and Cd in the kidney; and Al, Se, and Hg in the muscle. Similar results were described by Schneider et al. (2013) for American alligators, in which juveniles presented higher concentrations of Zn and Cu compared to adults. This pattern may be explained by the higher metabolic rate and intestinal assimilation efficiency during growth, which favor the absorption of nutrients and trace elements (Schneider et al., 2013; Tracy et al., 2015), in addition to the foraging behavior in shallow waters, where the consumption of benthic macroinvertebrates associated with contaminated sediments may intensify bioaccumulation (Nilsen et al., 2017a, 2017b; Buenfil-Rojas et al., 2020). In contrast, adult individuals presented higher concentrations of Mn and Zn in scales, corroborating the results of Barbosa (2023) for broad-snouted caimans in the Metropolitan Region of Recife. This pattern reinforces that keratinized tissues, such as scales, reflect chronic exposure to contaminants (Nilsen et al., 2017a), whereas the liver and kidney may be more indicative of recent exposure. Thus, the higher concentrations observed in the scales of adult individuals likely reflect their longer lifespan and, consequently, the more prolonged period of exposure to environmental contaminants (Buah-Kwofie et al., 2018; Santos et al., 2021a, 2021b; Barbosa, 2023).

Conclusion

The observed bioaccumulation patterns demonstrate marked differences among the analyzed tissues, with higher concentrations of several elements in the kidney, consistent with the physiological role of this organ in the processes of contaminant storage and elimination. The differences between males and females suggest that physiological factors, possibly related to the reproductive cycle, also influence the accumulation dynamics of certain trace elements. Collectively, these results reinforce the potential of broad-snouted caimans as a sentinel species for biomonitoring trace element contamination in tropical estuaries subjected to urbanization and intense anthropogenic influence.

This study provides baseline information on the accumulation of trace elements in broad-snouted caimans from an estuarine environment impacted by human activity. From the One Health perspective, the results demonstrate a risk to conservation and to the health of humans and the biota associated with this important Neotropical ecosystem.

The absence of trace element analyses in water and sediment limits the direct assessment of environmental exposure. Future studies integrating water, sediment, prey, and caiman tissues, together with biological and

ecological variables, may improve the understanding of exposure pathways and bioaccumulation processes, support biomonitoring and conservation strategies and contributing to the sustainable management of Neotropical estuarine ecosystems and the protection of wildlife and human health.

Author contributions CFRSN assisted with fieldwork, data analyses, and writing. ATOB wrote the original draft of the manuscript. GTND performed the formal analyses, compiled and curated the datasets and prepared the figures and visualizations. CCA, BMF, BLB, LARL and VDAK assisted with lab analysis, validated the results, and critically reviewed and edited the manuscript. RSLB assisted with fieldwork, logistics, data interpretation and writing. PBMS assisted with fieldwork, logistics, data interpretation, writing and prepared the map. JBO and JMSC designed the methodology, assisted with the fieldwork, supervised the research, validated the results and critically reviewed and edited the manuscript.

Funding

This project was funded through the Student Research Assistance Scheme from IUCN SSC Crocodile Specialist Group (CSG).

Data Availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

All authors have read, understood, and have complied as applicable with the statement on "Ethical Responsibilities of Authors" as found in the Instructions for Authors.

Ethics approval and consent to participate The authors declare that they have complied with all ethical responsibilities required by *Environmental Monitoring and Assessment*. All authors have read, understood, and have complied as applicable with the statement on "ethical responsibilities of authors" as found in the instructions for authors. The study did not involve human participants, animals, or biological materials requiring ethical approval or informed consent.

Competing interests

The authors declare no competing interests.

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APPENDIX

Table 3. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, Ni, and Zn in the liver of female and male *Caiman latirostris* captured in the Capibaribe River Basin, Recife, Pernambuco, Brazil. Variables showing statistically significant differences between sexes ($p < 0.05$) are highlighted. Number of individuals analyzed: females (n = 8) and males (n = 14). SD: Standard Deviation.

Liver	Sex	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	Female	4808.38	38896.67	14438.17	8463.15	11617.67	0.0248	0.6642
	Male	4169.25	64693.64	19000.64	12342.82	18085.04	0.0026	
Cr	Female	70.30	926.26	234.1	106.34	293.24	**0.0002**	0.1450
	Male	10.77	437.93	123.09	90.11	111.42	**0.0029**	
Mn	Female	1236.12	4274.31	2727.73	2631.22	942.11	0.9897	0.4951
	Male	923.20	4784.41	2407.70	2234.46	1183.86	0.2377	
Fe	Female	283935.10	1850171.00	802599.4	580248.94	609208.41	**0.0245**	0.2119
	Male	92535.82	1395459.00	546682.52	384076.3	446160.84	**0.0302**	
Co	Female	10.08	46.12	27.97	22.07	13.62	0.1557	0.6163
	Male	8.68	104.83	27.13	23.6	24.27	**0.0001**	
Cu	Female	9390.57	67757.60	32096.58	28583.89	17698.83	0.4529	0.0936
	Male	6770.93	41153.95	19405.83	16588.78	10234.83	0.1641	
Zn	Female	30945.96	100459.71	68685.61	64506.47	26314.19	0.4454	**0.0230**
	Male	16125.97	67539.71	41058.08	41850.09	17354.8	0.4457	
As	Female	21.17	189.36	86.53	75.11	53.12	0.6770	0.1876
	Male	18.86	204.04	64.24	47.1	52.73	0.0019	
Se	Female	1125.92	7567.95	4031.6	3232.05	2398.75	0.3568	0.1100
	Male	699.44	7640.62	2408.3	2162.37	1803.87	0.0040	
Cd	Female	5.71	159.16	47.77	28.53	49.42	0.0170	0.1876
	Male	1.63	52.23	22.58	18.49	16.03	0.3027	
Hg	Female	42.77	341.68	141.81	122.81	99.44	0.2761	0.2973
	Male	14.41	681.67	127.03	83.11	168.89	< 0.0001	
Pb	Female	17.73	953.39	264.04	113.12	331.73	0.0167	0.8676
	Male	16.67	1516.43	248.15	117.15	392.19	< 0.0001	

Table 4. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, Ni, and Zn in the kidney of female and male *Caiman latirostris* captured in the Capibaribe River Basin, Recife, Pernambuco, Brazil. Variables showing statistically significant differences between sexes ($p < 0.05$) are highlighted. Number of individuals analyzed: females (n = 8) and males (n = 14). SD: Standard Deviation.

Kidney	Sex	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	Female	4146.31	91102.91	23085.52	10918.95	29044.54	0.0010	0.1653
	Male	4487.32	92910.48	30695.51	19220.34	25446.47	0.0326	
Cr	Female	113.65	580.98	241.87	202.66	153.84	0.0365	0.8154
	Male	95.49	1940.80	481.21	245.42	580.49	0.0002	
Mn	Female	3309.22	9882.65	6105.95	6549.64	2139.91	0.5946	**0.0354**
	Male	1401.03	7706.04	4015.45	4298.85	1706.89	0.7861	
Fe	Female	101389.00	428833.70	235461.21	227344.71	95859.59	0.5168449	0.9406
	Male	54467.52	577741.70	239292.56	226340.59	141193.78	0.2359734	
Co	Female	88.95	468.91	253.30	241.73	129.48	0.8024	0.1072
	Male	89.60	301.01	165.97	159.30	62.88	0.1893	
Cu	Female	8.00	6059.57	22770.32	12594.38	11672.27	1717.55	0.0936
	Male	14.00	3264.53	12919.48	8915.28	9622.25	823.11	
Zn	Female	41548.88	134373.40	76066.38	71460.05	26553.75	0.0644	0.1360
	Male	19492.19	91565.06	58697.65	61416.72	20395.49	0.2538	
As	Female	52.62	415.10	207.87	233.20	121.22	0.6028	0.1653
	Male	16.26	638.46	144.07	79.61	161.02	0.0003	
Se	Female	2496.49	17355.15	5986.49	4024.07	4909.20	0.0030	0.12660
	Male	962.84	5154.887	3175.29	3359.33	1216.46	0.8156	
Cd	Female	42.28	369.08	122.63	92.14	105.27	0.0040	0.2382
	Male	25.45	480.43	102.24	57.21	119.70	0.0001	
Hg	Female	15.55	319.47	105.18	53.90	109.36	0.0109	0.3301
	Male	10.15	859.22	106.76	44.15	218.82	0.0000	
Pb	Female	235.79	3705.83	837.57	463.13	1165.91	0.0000	0.8154
	Male	121.72	8430.46	1445.66	601.86	2392.67	0.0000	

Table 5. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, Ni, and Zn in the muscle of female and male *Caiman latirostris* captured in the Capibaribe River Basin, Recife, Pernambuco, Brazil. Variables showing statistically significant differences between sexes ($p < 0.05$) are highlighted. Number of individuals analyzed: females (n = 8) and males (n = 14). SD: Standard Deviation.

Muscle	Sex	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	Female	3344.03	27895.85	11897.10	8161.50	9723.87	0.0064	0.8154
	Male	3215.61	40669.03	15488.43	8442.90	13069.03	0.0107	
Cr	Female	169.73	372.54	263.72	259.81	79.82	0.2723	0.6642
	Male	72.55	1163.81	323.05	229.53	307.04	0.0043	
Mn	Female	171.69	540.58	363.07	354.42	117.12	0.9542	0.2653
	Male	59.99	961.06	455.32	365.79	257.93	0.4833	
Fe	Female	12042.97	55734.36	29717.29	28565.18	12613.71	0.3574	1.0000
	Male	8783.40	103774.90	33377.94	29010.68	23367.74	0.0024	
Co	Female	2.29	10.39	4.98	4.17	2.71	0.1340	0.1450
	Male	2.50	24.46	9.74	6.45	7.22	0.0288	
Cu	Female	199.07	871.44	699.04	762.01	214.88	0.0063	**0.0422**
	Male	74.75	1739.65	1046.93	961.30	448.47	0.2769	
Zn	Female	1862.08	50156.18	39232.36	44048.51	15577.81	0.0006	0.2973
	Male	1873.36	66185.42	45125.68	47661.87	17273.85	0.1464	
As	Female	183.92	318.23	251.36	253.65	45.35	0.9080	0.1348
	Male	71.48	443.85	186.38	130.26	115.73	0.5166	
Se	Female	60.95	1782.16	1129.51	1170.29	550.84	0.4685	0.3202
	Male	31.13	1299.52	905.24	949.21	336.20	0.0769	
Cd	Female	0.55	6.12	3.06	3.43	1.95	0.6973	**0.0292**
	Male	1.38	99.78	21.87	8.24	32.14	0.0012	
Hg	Female	37.16	99.62	66.49	66.15	24.03	0.5483	0.1348
	Male	17.67	878.39	106.95	32.30	233.42	0.0000	
Pb	Female	5.05	62.32	24.64	18.22	19.67	0.0889	**0.0038**
	Male	14.83	1876.00	381.70	111.25	614.88	0.0001	

Table 6. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, and Zn in the scales of female and male *Caiman latirostris* captured in the Capibaribe River Basin, Recife, Pernambuco, Brazil. No statistically significant differences were observed between sexes ($p < 0.05$). Number of individuals analyzed: females (n = 8) and males (n = 14). SD: Standard Deviation.

Scales	Sex	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	Female	4802.37	103589.00	40797.62	25235.88	37794.90	0.0293	0.2119
	Male	3703.96	48183.43	19521.56	17444.18	11912.21	0.3934	
Cr	Female	44.91	1161.79	380.69	209.17	402.32	0.0784	0.8676
	Male	53.57	4669.41	495.75	167.78	1205.02	0.0000	
Mn	Female	284.22	7759.58	1620.77	805.07	2506.65	0.0000	0.8676
	Male	303.88	40961.83	3622.87	670.14	10753.33	0.0000	
Fe	Female	44121.75	1962902.00	364425.00	127904.00	651567.60	0.0000	0.9734
	Male	42632.17	12662456.00	1050196.00	139513.90	3343910.00	0.0000	
Co	Female	8.01	78.88	32.17	24.81	24.93	0.2922	0.8154
	Male	11.40	490.73	76.37	19.05	148.93	0.0000	
Cu	Female	398.73	4081.35	2291.99	1913.89	1156.72	0.9810	0.4822
	Male	1102.17	5577.90	2121.20	1715.59	1275.09	0.0005	
Zn	Female	6627.96	46934.72	21612.20	21094.65	12709.74	0.4509	0.7639
	Male	9817.29	58185.04	20850.94	16043.82	13535.45	0.0011	
As	Female	35.89	206.48	105.29	99.43	58.70	0.6993	0.2545
	Male	28.44	660.49	122.31	58.17	171.96	0.0000	
Se	Female	298.27	1640.88	925.75	925.58	395.07	0.9189	0.1266
	Male	483.88	1264.40	738.02	699.22	192.16	0.0426	
Cd	Female	1.13	14.21	6.31	6.76	4.68	0.3790	0.5252
	Male	1.68	14.30	4.51	3.41	3.52	0.0024	
Hg	Female	2.79	77.52	38.74	37.12	24.60	0.9491	0.2973
	Male	7.04	204.58	39.97	17.03	54.75	0.0001	
Pb	Female	19.63	212.15	110.25	88.66	83.27	0.0646	0.9734
	Male	23.07	243.97	93.07	74.37	67.88	0.0135	

Table 7. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, and Zn in the liver of subadult (Class I) and adult (Class II) *Caiman latirostris* individuals captured in the Capibaribe River Basin, Recife, Pernambuco, Brazil. Number of individuals analyzed: Class I (n = 17) and Class II (n = 5). SD: Standard Deviation.

Liver	Age group	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	I	4169.25	64693.64	20069.78	13418.38	17143.93	**0.0048**	0.1196
	II	5009.25	12837.38	8065.62	8002.73	3289.26	0.4602	
Cr	I	44.94	926.26	186.33	102.19	217.94	**< 0.0001**	0.0849
	II	10.77	222.03	85.72	68.30	82.08	0.2867	
Mn	I	923.20	4784.41	2753.19	2782.81	1121.25	0.8038	**0.0098**
	II	1327.30	2442.59	1745.07	1549.85	477.51	0.3233	
Fe	I	92535.82	1850171.22	643969.58	465627.71	530887.54	**0.0079**	0.9396
	II	108359.49	1326386.57	625373.58	432922.03	502080.06	0.5773	
Co	I	9.37	104.83	29.95	23.48	22.70	**0.0005**	0.3587
	II	8.68	26.01	18.90	22.92	7.75	0.2182	
Cu	I	6770.93	67757.60	25658.51	25417.35	15858.30	0.1024	0.1444
	II	12509.84	28787.14	18451.92	17081.91	6123.70	0.1655	
Zn	I	16125.97	100459.71	56309.08	59077.39	25188.75	0.4509	**0.0095**
	II	16420.06	45954.82	33408.71	35152.06	10846.04	0.6917	
As	I	21.17	204.04	82.14	65.74	55.72	**0.0264**	0.0706
	II	18.86	62.15	39.06	32.70	19.93	0.2588	
Se	I	833.67	7640.62	3430.06	2565.31	2242.53	**0.0278**	**0.0184**
	II	699.44	2162.86	1531.59	1429.55	633.60	0.4233	
Cd	I	1.63	159.16	37.42	26.95	36.36	**0.0004**	**0.0310**
	II	4.08	16.32	12.44	14.49	5.00	0.1314	
Hg	I	39.11	681.67	151.06	91.14	160.09	**< 0.0001**	0.3193
	II	14.41	97.50	68.98	87.17	35.67	0.1862	
Pb	I	16.67	1516.43	285.59	97.29	406.43	**< 0.0001**	0.9396
	II	19.02	314.46	146.27	145.14	115.34	0.8518	

555 **Table 8**. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, and Zn in the kidney of subadult (Class I) and adult (Class II) *Caiman latirostris* individuals captured in the Capibaribe
556 River Basin, Recife, Pernambuco, Brazil. Number of individuals analyzed: Class I (n = 17) and Class II (n = 5). SD: Standard Deviation.

Kidney	Age group	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	I	4146.31	92910.48	28965.49	16809.37	28834.26	**0.0015**	0.8795
	II	10485.75	48021.95	24401.59	12710.66	17568.53	0.0705	
Cr	I	95.49	1545.36	342.65	224.44	372.42	**< 0.0001**	0.8201
	II	105.79	1940.80	569.39	260.25	777.83	**0.0082**	
Mn	I	1784.39	9882.65	5122.32	4567.32	2148.46	0.7733	0.1087
	II	1401.03	5105.68	3596.90	3543.25	1527.54	0.5694	
Fe	I	93064.42	428833.71	220009.48	212322.81	97259.57	0.0689	0.4215
	II	54467.52	577741.69	298724.85	254750.17	192530.36	0.8926	
Co	I	88.95	468.91	216.52	201.40	105.39	0.1541	**0.0093**
	II	104.04	172.21	133.83	142.25	29.43	0.3502	
Cu	I	3414.23	22770.32	10969.43	11204.90	4229.01	**0.0450**	**0.0477**
	II	3264.53	10454.80	7817.72	9062.71	2867.15	0.3580	
Zn	I	24275.71	134373.40	68070.77	66343.82	24222.44	0.1126	0.2645
	II	19492.19	75933.85	54619.01	57543.93	21168.60	0.2816	
As	I	39.95	638.46	195.03	159.39	156.51	**0.0109**	**0.0583**
	II	16.26	155.82	72.88	55.35	52.56	0.5816	
Se	I	1578.03	17355.15	4695.14	3711.87	3590.68	**< 0.0001**	**0.0193**
	II	962.84	3214.46	2505.70	2773.20	916.96	0.1296	
Cd	I	35.75	480.43	126.26	95.45	122.24	**0.0001**	**0.0477**
	II	25.45	120.72	53.20	32.56	39.52	**0.0444**	
Hg	I	15.55	859.22	125.67	49.89	205.61	**< 0.0001**	0.3587
	II	10.15	56.06	39.93	48.93	18.29	0.2260	
Pb	I	121.72	8430.46	1422.20	531.62	2267.01	**< 0.0001**	0.5946
	II	248.24	1214.94	552.49	311.88	409.13	0.0918	

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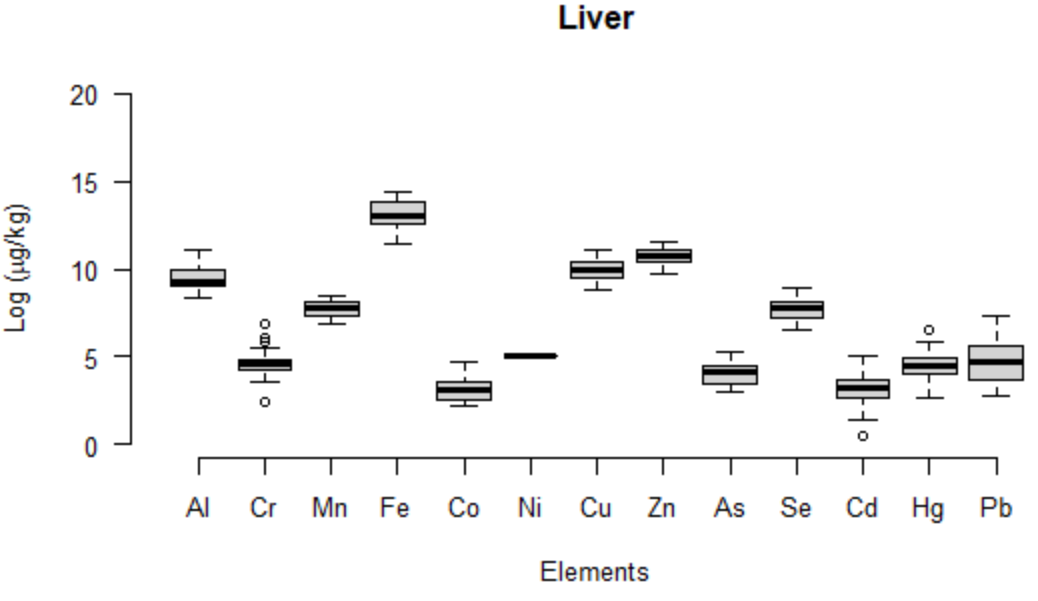
Table 9. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, and Zn in the muscle of subadult (Class I) and adult (Class II) *Caiman latirostris* individuals captured in the Capibaribe River Basin, Recife, Pernambuco, Brazil. Number of individuals analyzed: Class I (n = 17) and Class II (n = 5). SD: Standard Deviation.

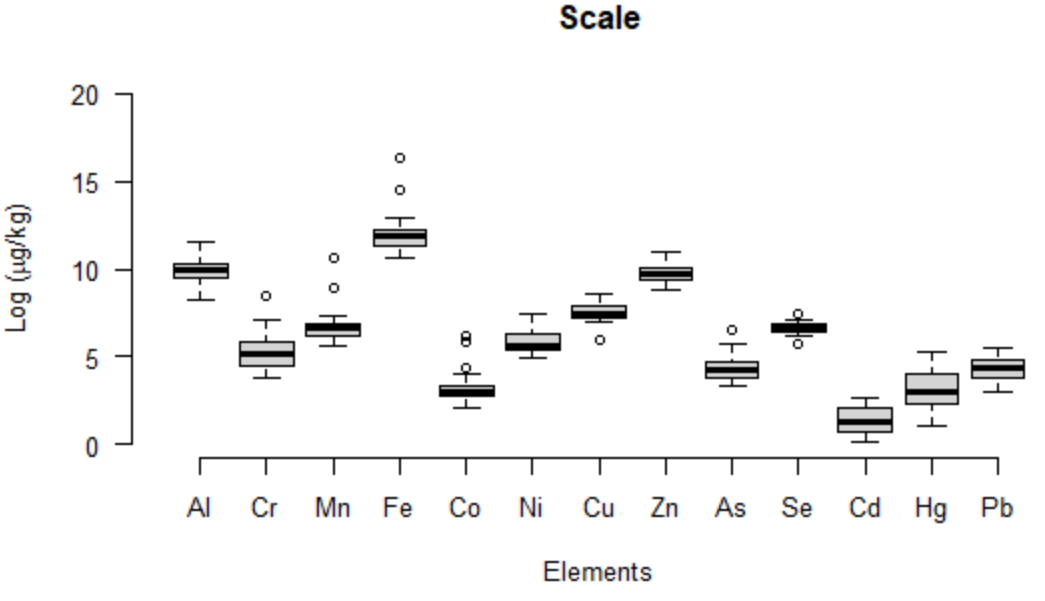
Muscle	Age group	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	I	3215.61	40669.03	16666.11	9468.42	12452.46	**0.0220**	**0.0310**
	II	4302.99	7417.38	5738.18	5632.24	1174.32	0.9824	
Cr	I	72.55	1163.81	337.48	246.34	266.27	**0.0013**	0.1636
	II	74.14	321.25	179.05	106.77	119.06	0.0712	
Mn	I	171.69	961.06	459.24	378.05	222.37	0.0925	0.1047
	II	59.99	489.04	294.41	337.43	164.34	0.9078	
Fe	I	12042.97	103774.85	33948.63	28605.37	21358.34	**0.0005**	0.5426
	II	8783.40	43100.82	25580.57	25038.68	13334.37	0.9892	
Co	I	2.29	24.46	8.52	6.08	6.35	**0.0066**	0.2177
	II	2.50	18.09	6.26	3.10	6.67	**0.0036**	
Cu	I	199.07	1739.65	991.96	8844.32	409.9	0.1002	0.2177
	II	74.75	960.76	677.19	781.87	347.44	**0.0573**	
Zn	I	1862.08	66185.42	42550.74	44522.01	14431.48	0.0700	0.3587
	II	1873.36	61185.84	44451.15	52781.29	24537.07	**0.0347**	
As	I	74.83	443.85	221.93	250.66	101.67	0.3473	0.2679
	II	71.48	244.67	157.92	157.76	89.64	0.1686	
Se	I	60.95	1782.16	1113.25	1148.67	377.61	0.1091	**0.0009**
	II	31.13	781.00	556.84	614.70	304.87	**0.0477**	
Cd	I	0.55	99.78	16.68	3.67	30.56	**< 0.0001**	0.3193
	II	2.20	15.64	9.43	8.94	5.16	0.9408	
Hg	I	17.67	878.39	109.35	62.10	206.97	**< 0.0001**	**0.0293**
	II	19.17	38.46	26.54	24.26	8.63	0.4551	
Pb	I	5.05	1876.00	295.40	35.89	581.66	**< 0.0001**	0.4008
	II	14.83	160.13	103.81	120.33	54.04	0.2992	

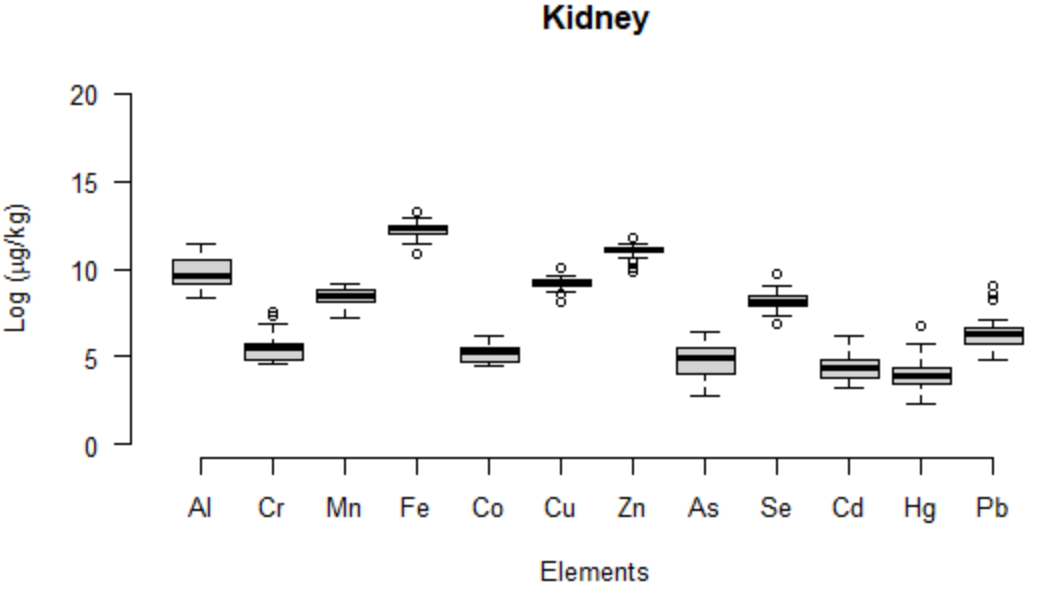
Table 10. Concentrations of Al, Cd, Cr, Mn, Cu, Fe, Pb, and Zn in the scales of subadult (Class I) and adult (Class II) *Caiman latirostris* individuals captured in the Capibaribe River Basin, Recife, Pernambuco, Brazil. Number of individuals analyzed: Class I (n = 17) and Class II (n = 5). SD: Standard Deviation.

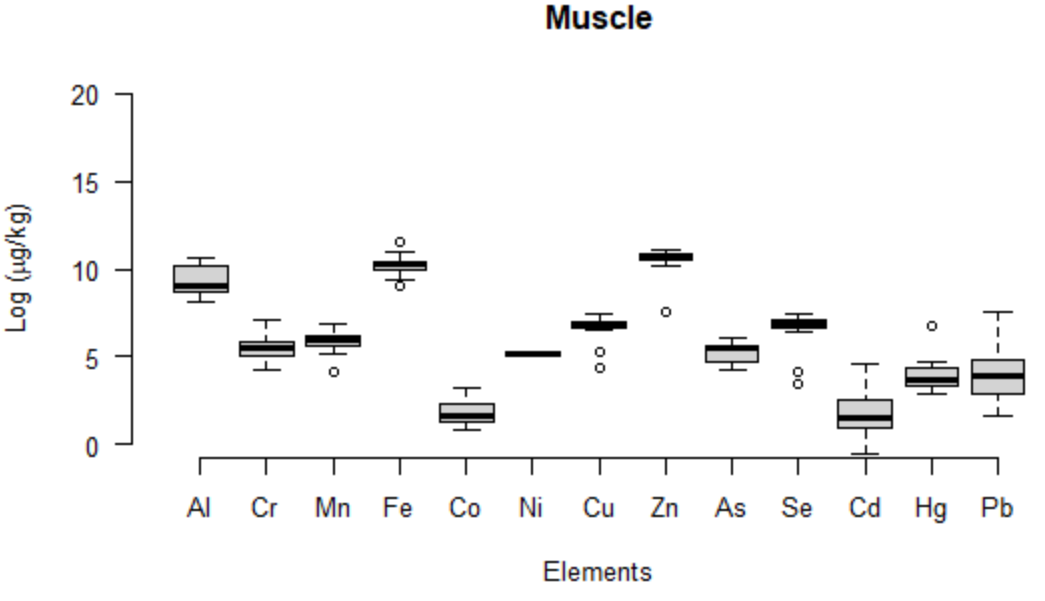
Scales	Age group	Min (µg/kg)	Max (µg/kg)	Average (µg/kg)	Median (µg/kg)	SD (µg/kg)	P1 Value	P2 Value
Al	I	3703.96	103588.96	27501.54	19366.85	28894.79	**0.0001**	0.4929
	II	13382.74	48183.43	26431.35	23740.58	14012.74	0.5021	
Cr	I	44.91	1161.79	258.49	152.55	298.32	**0.0001**	0.1404
	II	162.21	4669.41	1118.31	197.61	1987.27	0.0004	
Mn	I	284.22	7759.58	1129.14	589.94	1745.87	**< 0.0001**	**0.2827**
	II	431.93	40961.83	8898.17	873.26	17928.08	**0.0003**	
Fe	I	42632.17	1962901.82	244337.22	116570.09	451190.15	**0.0001**	0.2488
	II	56110.67	12662456.04	2692881.29	205999.93	5574660.70	**0.0003**	
Co	I	8.01	78.88	24.95	19.20	18.19	**0.0006**	0.2827
	II	11.40	490.73	180.49	28.36	225.76	0.0571	
Cu	I	398.73	4081.35	1969.40	1748.85	890.21	0.6921	0.3384
	II	1360.28	5577.90	2910.58	1708.70	1907.14	0.1122	
Zn	I	6627.96	46934.72	17695.31	15854.26	9563.26	**0.0071**	**0.0246**
	II	16233.39	58185.04	32798.12	30514.35	17108.85	0.5997	
As	I	28.44	206.48	75.82	65.79	47.66	**0.0067**	0.2398
	II	43.63	660.49	247.25	186.01	255.15	0.2174	
Se	I	298.27	1640.88	823.28	760.04	290.56	0.0687	0.6453
	II	483.88	1264.40	748.50	639.58	308.04	0.2010	
Cd	I	1.13	14.21	4.95	3.15	3.81	0.0102	0.6486
	II	1.68	14.30	5.88	4.37	4.88	0.0774	
Hg	I	2.79	77.52	28.82	19.73	21.57	**0.0491**	0.5426
	II	7.04	204.58	75.91	51.35	82.45	0.3054	
Pb	I	19.63	243.97	99.24	67.47	82.07	**0.0022**	0.3587
	II	69.33	127.09	99.59	98.11	23.24	0.8938	

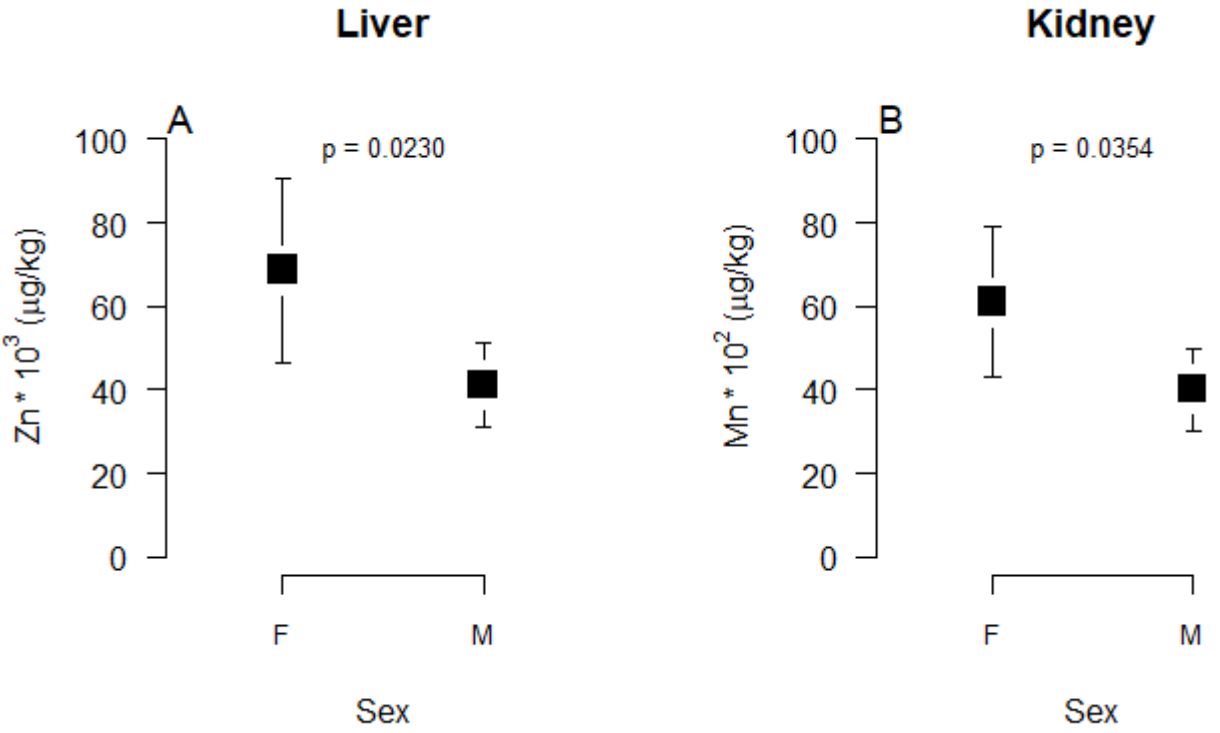

a
Brazil
b
Recife
Atlantic Ocean
c
Capibaribe River
Sex
Females
Males
Size class
Class I (subadults)
Class II (adults)
Sampled area
N
0
1 km
-8.02
-8.04
-8.06
-8.08
-34.98
-34.96
-34.94
-34.92
-34.90
-34.88
-34.86

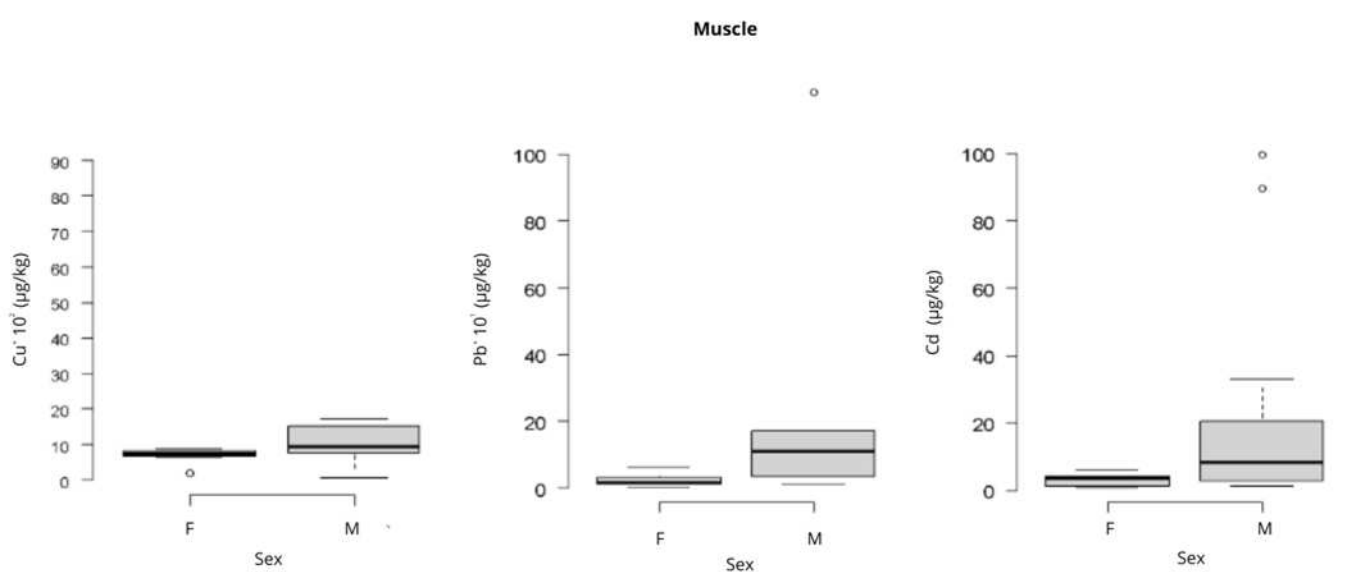

Liver
Log (µg/kg)
20
15
10
5
0
Al Cr Mn Fe Co Ni Cu Zn As Se Cd Hg Pb
Elements


Scale
Log (µg/kg)
20
15
10
5
0
Al Cr Mn Fe Co Ni Cu Zn As Se Cd Hg Pb
Elements

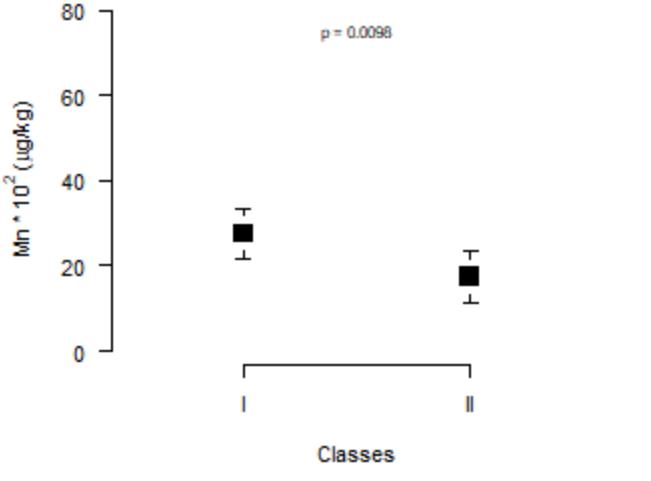

Kidney
Log (µg/kg)
20
15
10
5
0
Al Cr Mn Fe Co Cu Zn As Se Cd Hg Pb
Elements

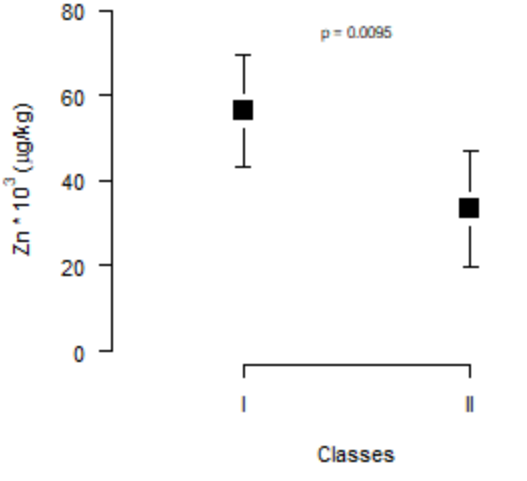

Muscle
Log (µg/kg)
20
15
10
5
0
Al Cr Mn Fe Co Ni Cu Zn As Se Cd Hg Pb
Elements

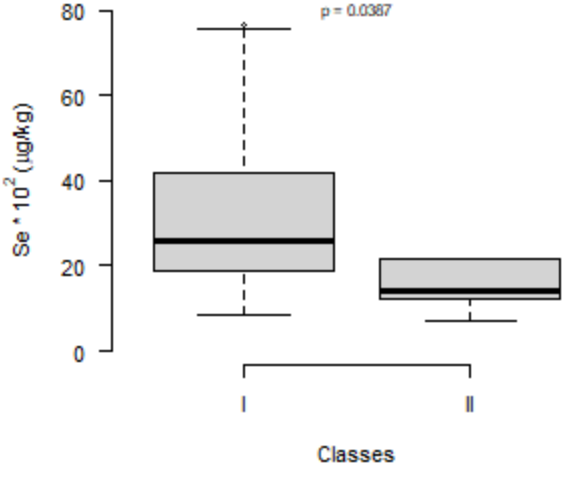

Liver
A
p = 0.0230
100
80
60
40
20
0
Zn * 10^3 (µg/kg)
F
M
Sex
Kidney
B
p = 0.0354
100
80
60
40
20
0
Mn * 10^2 (µg/kg)
F
M
Sex

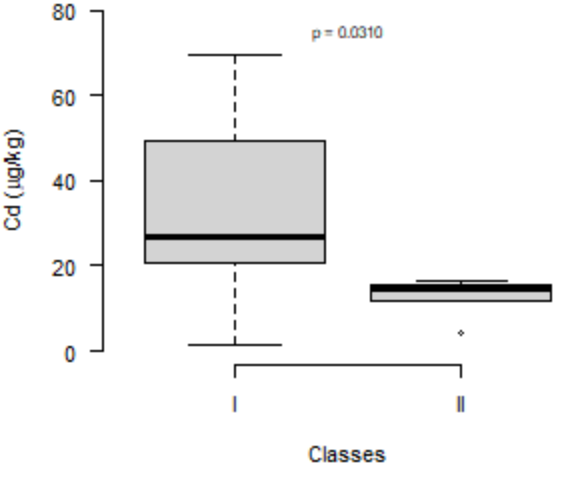

Muscle
Cu * 10² (µg/kg)
90
80
70
60
50
40
30
20
10
0
F
M
Sex
Pb * 10¹ (µg/kg)
100
80
60
40
20
0
F
M
Sex
Cd (µg/kg)
100
80
60
40
20
0
F
M
Sex

Liver

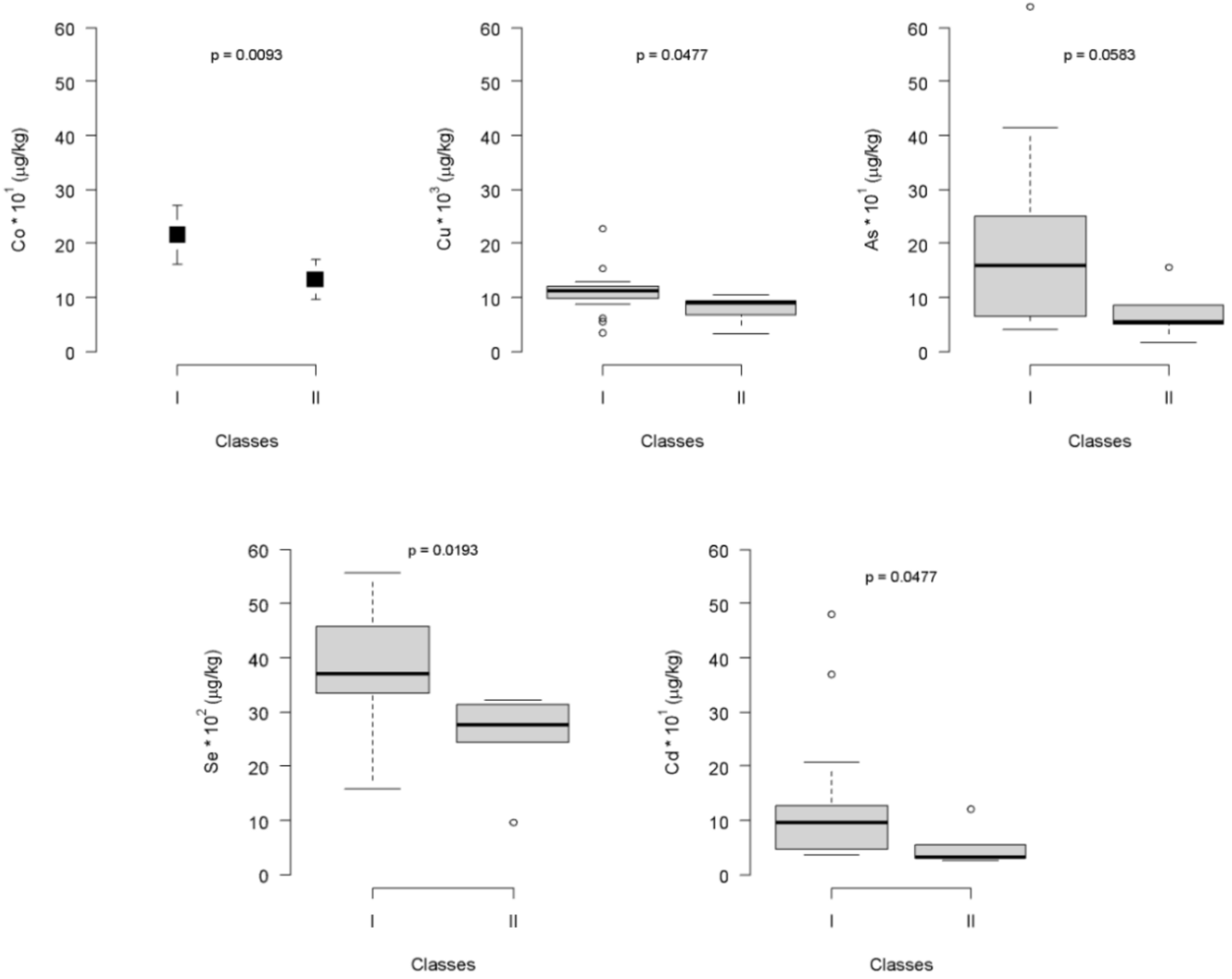

p = 0.0098
Mn * 10^-2 (µg/kg)
80
60
40
20
0
I
II
Classes

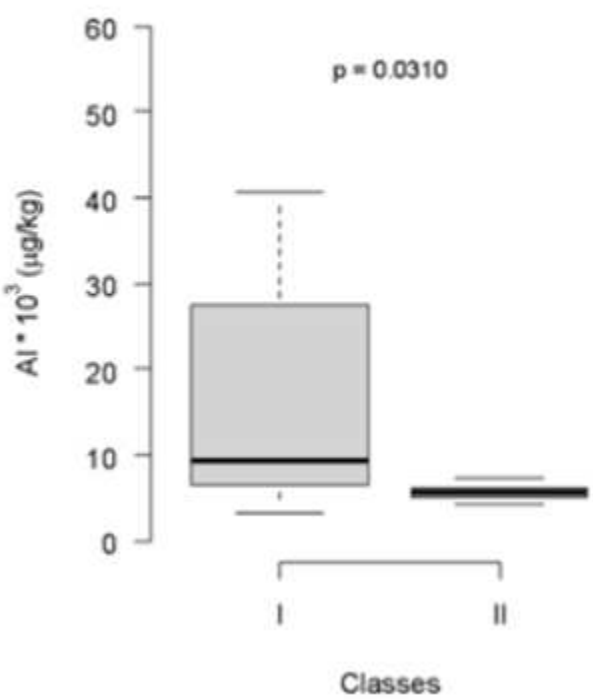

p = 0.0095
Zn * 10^-3 (µg/kg)
80
60
40
20
0
I
II
Classes

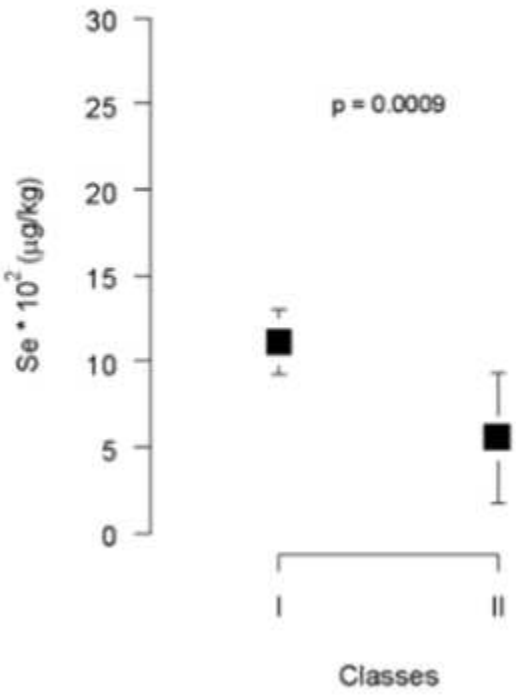

p = 0.0387
Se * 10^-2 (µg/kg)
80
60
40
20
0
I
II
Classes

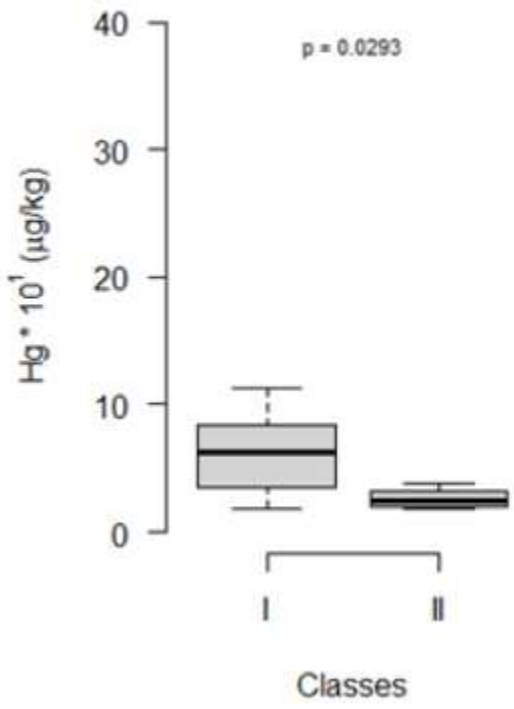

p = 0.0310
Cd (µg/kg)
80
60
40
20
0
I
II
Classes

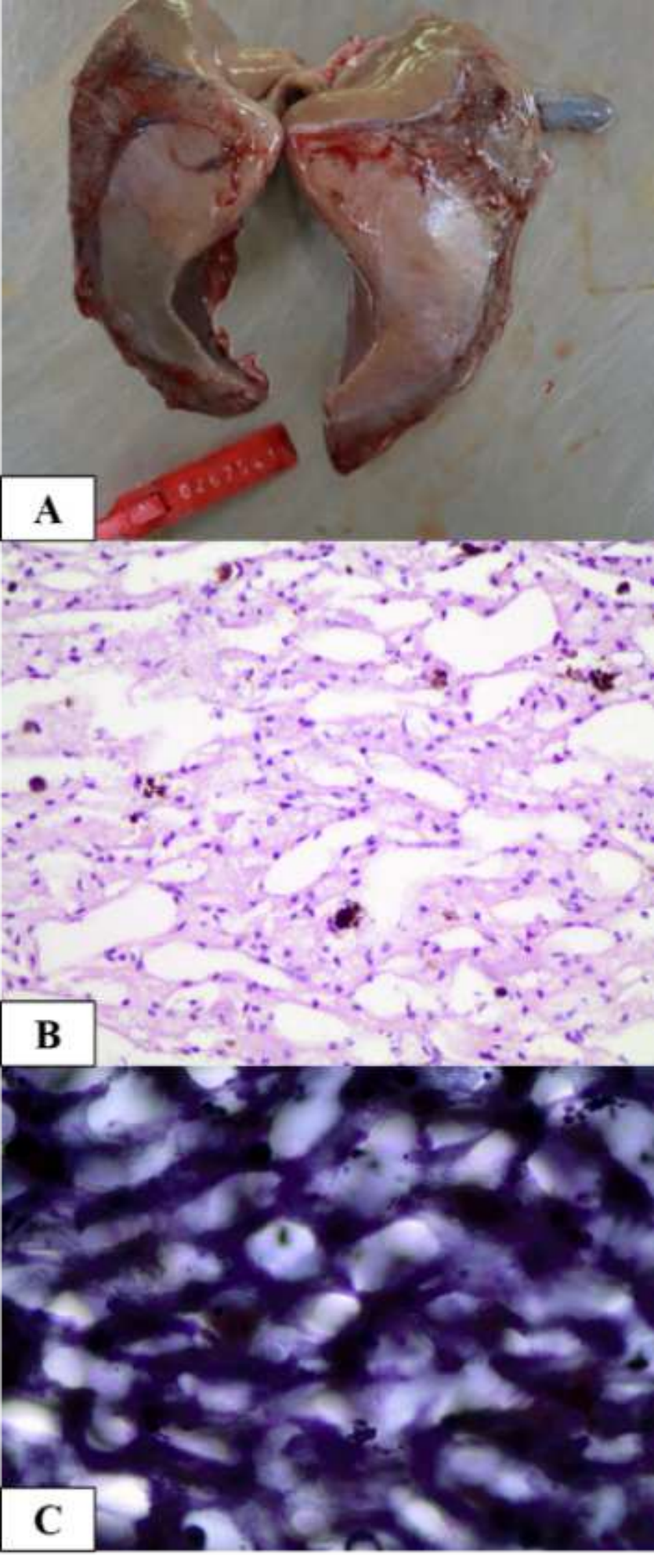
Kidney


p = 0.0093
Co * 10^1 (µg/kg)
p = 0.0477
Cu * 10^3 (µg/kg)
p = 0.0583
As * 10^1 (µg/kg)
p = 0.0193
Se * 10^2 (µg/kg)
p = 0.0477
Cd * 10^1 (µg/kg)
Classes
I
II


p = 0.0310
Al * 10^3 (µg/kg)
60
50
40
30
20
10
0
I
II
Classes


p = 0.0009
Se * 10^2 (µg/kg)
30
25
20
15
10
5
0
I
II
Classes


p = 0.0293
Hg * 10^1 (µg/kg)
40
30
20
10
0
I
II
Classes


A
B
C

Supplementary Files

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

- AppendixSouzaNetoetal.Bioaccumulationofessentialandtoxicelements.pdf