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Impacts of Port Activities on the Health of Sciades herzbergii in the Amazon, Brazil

Alef Fontinele Teixeira
alef.fontinele@discente.ufma.br

Universidade Federal do Maranhao https://orcid.org/0000-0002-2630-7006
Hetty Salvino Torres
UEMA: Universidade Estadual do Maranhao
Jonatas da Silva Castro
Maranhao State University: Universidade Estadual do Maranhao
Hellon Cunha Viana
Maranhao State University: Universidade Estadual do Maranhao
Luana do Nascimento Dias
Universidade Federal do Maranhão: Universidade Federal do Maranhao
Marina Rocha de Carvalho
Universidade Federal do Maranhão: Universidade Federal do Maranhao
Antonio Carlos Leal de Castro
Universidade Federal do Maranhão: Universidade Federal do Maranhao
Raimunda Nonata Carvalho Neta
UEMA: Universidade Estadual do Maranhao

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Abstract

The harbor area of São Luís hosts the largest cargo complex in the Amazon region and is one of the most important port systems in Latin America. The rapid expansion of port infrastructure and associated activities can generate significant environmental pressures on aquatic ecosystems. However, information on contaminant effects on estuarine fish in Amazonian port areas remains limited. Histopathological biomarkers provide an effective approach for detecting sublethal impacts of environmental contamination in aquatic organisms. This study evaluated gill and hepatic lesions in the estuarine catfish *Sciades herzbergii* to assess the effects of environmental stressors in the harbor area of São Luís, Maranhão, Brazil. A total of 76 individuals were collected in 2018 at two sampling sites: the harbor area (A1) and Crab Island (A2), during both dry and rainy seasons. Gills and livers were processed using standard histological procedures to identify lesions associated with contaminant exposure. Morphometric measurements included total length (Lt), total weight (Wt), and gonad weight (Wg). Gill lesions were more frequent in fish collected at A1, particularly during the rainy season, and occurred in both sexes. Necrosis was especially prevalent in male individuals. In contrast, specimens from A2 showed a lower frequency of gill lesions. Liver analyses revealed a higher occurrence of histopathological alterations in fish from the harbor area during the rainy season, whereas no hepatic lesions were detected in individuals from Crab Island. These results indicate that *S. herzbergii* inhabiting the harbor region are exposed to environmental stressors, especially during the rainy season.

Introduction

The harbour complex is an important economic enterprise to the state of Maranhão (Moreira and Alcântara Jr 2025). The capital city of São Luís, in São Marcos Bay, hosts the largest maritime cargo complex in the country, the Ponta da Madeira maritime terminal, with a total of 223,9 millions tons of cargo in the year of 2024 (ANTAQ 2026). Integrated into this complex is the Port of Itaqui, which occupies a strategic and geographically privileged position, meeting the logistics demand of the Northeast, North and Midwest (EMAP 2019). In 2024, Port of Itaqui had a cargo handling of 33,9 millions tons (ANTAQ 2026).

Recently chemical contamination caused by harbour waste has been a threat to the health of aquatic organisms in the Maranhão port region (Pinheiro-Sousa et al. 2021; Torres et al. 2023). Although the managing body of the port complex of the Port of Itaqui, commit to meet environmental requirements, work carried out in the region demonstrated changes in the physical and behavioral structures of fish and crabs (Carvalho-Neta et al. 2014; Castro et al. 2018; Oliveira et al. 2019).

The use of fish as biomonitors in the aquatic environment has proven to be effective, since they are present in various environments, have wide geographic distribution and participate in different trophic levels of the food chain, being considered excellent biological models of study (Dione et al. 2023). One species that fits these criteria is *Sciades herzbergii* (Perciformes:

Ariidae), known in the region as bagre guribu, which has a history in previous works in the region (Carvalho-Neta et al. 2017; Castro et al. 2019; Pinheiro-Sousa et al. 2021).

Histological biomarkers of gills and livers in fish have been used as indicative of changes in aquatic environments, because the exposure of these organs to xenobiotics can cause histological changes. Gills are in direct contact with pollutants and are the main body surface involved in gas exchange, assisting in osmoregulation, acid-base regulation and excretion of nitrogen substances (Houlihan et al. 1982). The liver is an essential organ for the metabolism and excretion of toxic substances (Popović et al. 2023). In São Marcos Bay, histopathological analyses have demonstrated efficiency in monitoring programs in aquatic environments (Soares et al. 2020; Torres et al. 2023; Macedo et al. 2024b).

In addition to biomarkers, morphometric measurements are effective assessment tools and important to know aspects of fish growth. The weight-length ratio is used both to describe the increase in length and consequent weight gain, and to estimate the condition factor (Vazzoler 1996), which quantitatively indicates the degree of fish hygiene, reflecting recent food conditions and/or reserve spending on cyclical activities. The gonadosomatic index expressed as a percentage the weight of the gonads in relation to the total body weight of the individuals and allows to determine the stages of the reproductive cycle of fish, due to maturation of reproductive cells occur concomitantly with increased gonads weight (Vazzoler 1996).

Chemical contamination compromises aquatic communities and poses risks to the human population that makes use of these resources of economic interest and source of protein for fishing communities. Thus, the present study aims to analyze gill and liver lesions as biomarkers for the evaluation of the degree of stress and the effects of environmental contaminants in the populations of *Sciades herzbergii* of São Marcos Bay, Maranhão.

Methods

Study area

Fish were collected in two areas in São Marcos Bay (Fig. 1). *Sciades herzbergii* is a species of fish estuarine-resident and ecologically established both in protected areas and impacted areas, therefore appropriate for analysis of biomarkers of aquatic contamination. The first area (A1) is located near the Port of Itaqui (568246.00 m E 9713767.00 m S), a region of intense port activity, which also receives effluents of agricultural, industrial and domestic waste (Carvalho-Neta et al. 2012). The second area (A2) is on Crabs Island (557631.00 m E 9692044.00 m S), which is uninhabited and has an area of 345.08 km2 in a perimeter of 165.08 km2, being the largest strip of mangrove of Maranhão (MARANHÃO 2003). Given these characteristics and for integrating an Environmental Protection Area (MARANHÃO 1991), the Crab Island was used as a reference area.

Sampling

To verify if there was seasonal influence on the individuals, two collections were performed, one in March (rainy season) and another in September (dry season), in 2018. The fish were collected in their natural habitats using gill nets and euthanized by transespinal dissection. The material was packed in an isothermal box and transported to the Laboratory of Biomarkers in Aquatic Organisms of State University of Maranhão.

Laboratory analysis

Gill and liver lesions of fish were identified by the usual histological procedure for liver and gills. The fish were dissected and their gills and liver were immediately fixed in 10% formalin, dehydrated in a progressive series of ethanol dilutions and later embedded in paraffin. The sections were stained with hematoxylin and against stained with alcoholic eosin for structural analysis of gills and liver. Four tissue sections of each fish were examined by a Zeiss light microscope.

Data analysis

The histopathological lesions of gills and livers were classified according to the methodology of Bernet et al. (1999), classification of reaction patterns into: 1) circulatory disorders; 2) regressive changes; 3) progressive changes; 4) inflammation and 5) tumor. For each change there is a factor of importance (w), ranging from 1 to 3, where 1 refers to the minimum pathological importance (easily reversible lesion); 2, where the pathological importance is moderate (lesion is reversible in most cases) and 3, where the pathological importance is accentuated (injury is usually irreversible).

In addition to the importance factor is assigned a score value (a) that ranged from 0 to 6 and was assigned by the observer according to the extent of the damage. In this study, the score value was assigned according to the total number of lesions presented by each specimen. Lesions were scored as follows: 0 = no alterations; 1–5 = mild (score 2); 6–10 = moderate (score 4); and > 10 = severe (score 6).

With these data it was possible to calculate the organ index (Iorg) representing the degree of total damage to an organ in the group of individuals, which is obtained from the following expression:

$$I\text{org} = \sum_{rp} \sum_{alt} \left(a_{org\ rp\ alt} \ \text{x} \ w_{org\ rp\ alt} \right)$$

Where org = organ (constant); Rp = reaction pattern; alt = change; a = a score value; w = importance value.

In order to identify possible morphometric variations between sexes and locations, morphometric data of the specimens were collected in the field: total length (Lt), total weight (Wt) and weight of the gonads (Wg). Length data were described in centimeters (cm) and weight in grams (g). The sex of the specimens was macroscopically identified following the

scale proposed by Vazzoler (1996). The total length and total weight data were used in the weight-length ratio and in the definition of the condition factor (K).

The relationship between weight and total length was determined following Lé Cren (1951). The values of the variables were plotted in a scatter plot that showed a tendency to adjust the potential curve represented by the equation:

$$W_t = aL_t^b$$

Where Lt = total length of individuals at time t; Wt = total weight of individuals at time t; a = condition factor and b = constant related to type of growth.

The condition factor was determined from Vazzoler (1996) and aims to quantitatively analyze the reproductive activity of the species, based on the formula:

$$K = \frac{W}{L^b}$$

Where b refers to the angular coefficient of the weight-length ratio for all sampled individuals; W = total weight and L = total length.

The GSI has been used as an indicator of the functional state of the ovaries, since it expresses the percentage that the gonads represent the total weight of the individuals (Vazzoler, 1996), it can be used as an indicator of reproductive periods. Using total weight (Wt) and gonad weight (Wg) was possible to perform the gonadosomatic index (GSI), proposed by Vazzoler (1996), using the following formula:

$$GSI = \frac{Wg}{Wt} \times 100$$

Where GSI = gonadosomatic index, Wg = gonad weight and Wt = total weight.

Sex proportion was evaluated from the chi-square (χ^2) statistic, using the adherence test, assuming a ratio of 1:1 between the sexes. The variables Lt, Wt, K and GSI were also analyzed for sex, using the Student’s t-test, with a significance level of 5%.

Results

A total of 76 individuals were captured, 38 in each season (20 females and 18 males). 332 gill lesions were identified, 314 (94.58%) in fish from the port region and 18 (5.42%) in fish from Crabs Island, divided into four types (Table 1). The results were compared between sexes, locations and periods.

Table 1
Total values of gill lesions in females and males of *Sciades herzbergii* captured in Port of Itaqui (A1) and Crab Island (A2) during rainy and dry seasons

Types of Lesions	Rainy Season				Dry Season			
	Females		Males		Females		Males	
	A1	A2	A1	A2	A1	A2	A1	A2
Aneurysm	90	3	27	3	10	0	10	6
Epithelial Displacement	29	2	17	2	7	0	5	2
Fusion of Primary Lamellae	8	0	42	0	15	0	30	0
Necrosis	0	0	5	0	0	0	19	0
Source: Own Autorship								

Males had 168 lesions (50.6%) and females had 164 lesions (49.4%). Females were more affected during the rainy season (57.89%) and males during the dry season (69.23%). In females, aneurysm was the most common lesion (62.8%), while in males it was fusion of primary lamellae (42.86%).

In the rainy season, a total of 228 lesions were identified, 127 (57.89%) in females and 91 (42.11%) in males. In the port region (A1), the incidence of lesions was observed in all individuals, with aneurysm-type injury being the most frequent in females (70.87%) and primary lamella fusion in males (46.15%). Total lesions in A1 were 2,080% higher than in Crab Island (A2). Necrosis was not observed in females, only in males (5.49%). In the individuals sampled at A2, only 10 lesions were observed.

During the dry season, total lesions were 104, 32 (30.77%) in females and 64 in males (69.23%). In the port region (A1) incidence occurred in 40% of females and 100% of males. Total lesions at sampling point A1 were 1.100% higher than A2. There was a predominance of the primary laminae fusion lesion in females (46.88%) and males (41.67%) and again necrosis only in males. At sampling point A2 lesions were observed only in males (8).

Liver lesions were not observed in the individuals sampled on Crabs Island, while in the port region liver lesions occurred in both periods. A total of 52 cases of lesions were found in the port region (A1), framed in the central type of melanomacrophages and necrosis (Table 2).

Table 2
Total values of liver damage in males and females in the port region (A1) during rainy and dry seasons

Types of Lesions	Rainy Season		Dry Season	
	Females	Males	Females	Males
Melanomacrophage Center	21	3	2	2
Necrosis	4	13	2	5

Source: Own Autorship

During the rainy season, a total of 41 lesions were observed, 25 in females (61%) and 16 in males (39%). In females the majority of lesions were from the center of melanomacrophages (84%) and in males the predominance was of the necrosis type (81.3%).

In the dry season a total of 11 lesions were observed, 4 in females (36%) and 7 in males (64%). In females the amount of lesions by morphological changes was equal and in males the type necrosis predominated (71.4%).

In order to better observe the injury data, the organ index (Iorg) proposed by Bernet et al. (1999) was calculated. Gills and liver showed higher Iorg values in the rainy season. Gill lesions were more frequent in the harbor area (A1), with higher values during the rainy season (96) than in the dry season (62), while low frequencies were observed at A2 in both seasons (8 in the rainy season and 6 in the dry season). Liver lesions were recorded only at A1, with higher values in the rainy season (82) compared to the dry season (24), whereas no liver lesions were observed at A2 in either season.

As for the population structure of *S. herzbergii*, the chi-square test did not show significant differences in the sexual proportion, demonstrating that the population is distributed in a balanced way, regarding sex. Regarding the variation in size and weight, according to seasonality and sex, the t-test showed significant differences (Table 3).

Table 3
Mean values and standard deviation for total length (Lt), total weight (Wt) and weight of gonads (Wg) in females and males of *S. herzbergii* captured in the Port of Itaqui (A1) and Ilha dos Caranguejos (A2) during rainy and dry periods. In bold, where t test indicated differences between locations

Parameters	Rainy Season				Dry Season			
	Females		Males		Females		Males	
A1	A2	A1	A2	A1	A2	A1	A2	
L_t (cm)	**16,93± 4,84**	**23,36± 3,27**	19,12± 6,31	18,53 ± 1,48	**24,08 ± 6,14**	**17,99 ± 1,72**	**26,46 ± 6,77**	**17,5 ± 2,1**
W_t (g)	**109,27 ± 38,26**	**243,98 ± 40,99**	**102,5± 13,91**	**184,38 ± 17,13**	195,67 ± 92,17	180,25 ± 16,69	204,06 ± 112,35	176,19 ± 21,09
W_g (g)	**0,672± 0,628**	**2,8± 0,842**	**0,223 ± 0,486**	**1,29 ± 0,455**	**1.293 ± 1.231***	**1,86 ± 0,171**	**0,128 ± 0,14**	**1.356 ± 0,49**

Source: Own Autorship

The dry season presented fish with higher means of length (21.5 cm) and weight (188.98 g). Females presented higher mean values of Lt and Wt (20.6 cm and 182.29 g). Individuals from the port region showed higher means of length (21.7 cm) and Crab Island higher average weight (197.04 g).

The values for the correlation coefficient (R²), condition factor (K) and gonadosomatic index (GSI) are described in Table 4.

Table 4
Mean values and standard deviation for correlation index (R²), condition factor (K) and gonadosomatic index (GSI) in females and males of *Sciades herzbergii* captured in Porto do Itaqui (A1) and Ilha dos Caranguejos (A2) and during rainy and dry periods

Parameters	Rainy Season				Dry Season			
	Females		Males		Females		Males	
A1	A2	A1	A2	A1	A2	A1	A2	
R²	0,3218	0,5051	0,276	0,8947	0,0044	0,9807	0,9268	0,9999
K	14,2	24,8	12,7	22,2	21,3	22,1	18	22,1
GSI	0,58± 0,52	1,15± 0,27	0,20± 0,43	0,71± 0,26	0,56± 0,08	1,03± 0,02	0,08± 0,09	0,77± 0,28

Source: Own Autorship

The coefficient of determination (R²) showed a good adjustment for males and females during the dry season, especially at sampling site A2.

The condition factor (K) presented the highest values in fish sampled at site A1 in both sexes and periods.

GSI showed significant differences between sites in both periods. GSI values in females were higher in all sites and periods. During the rainy season, females from sampling site A1 showed 98% higher GSI values than in A2 and in the dry season the difference was 83%. In males, during the rainy season the values of A1 were 255% higher than those of A2 and during dry season the value was 862%.

Discussion

The fish of the port region (A1) presented in both periods high number of responses for histological biomarkers in gills and livers, demonstrating that the region has impacts that can cause stress in organisms. Pinheiro-Sousa et al. (2022), Jesus et al. (2020) e Oliveira et al. (2019) observed the presence of trace elements in sediments in the region at levels that exceed the limits set by the CONAMA Resolution nº 344/2004 (BRASIL, 2004) para Al, As, Cd, Fe, Mn, Pb, Ni e Hg. Soares et al. (2020) states that when exposed to contaminants, organisms can have their biological, biochemical, physiological and behavioral vital systems compromised, as it directs energy to detoxification, resulting in gill and liver lesions.

In the rainy season was recorded the highest percentage (68.67%) of total lesions. The calculation of the organ index (Iorg) proposed by Bernet et al. (1999) proved that the individuals of the rainy season were the most affected in both organs, being found values of 54% higher in the case of gills and 241% in the livers when compared to the same organs of individuals collected in the dry season.

Soares et al. (2020), Ribeiro et al. (2023) and Macedo et al. (2024a) performed histological analyses on livers and gills in the same location and species, and also identified a greater number of lesions during the rainy season. Recent studies by Pinheiro-Sousa et al. (2021), Torres et al. (2024) and Macedo et al. (2024b) in the same region evaluating GST, CAT, oxidative stress indicators and histology, showed a greater response in collections during the rainy season, reinforcing the association of area and rainy period, possibly as a result of increased contaminant bioavailability.

During the rainy season, soil leaching occurs, contributing to the remobilization and bioavailability of xenobiotics to the aquatic environment (Duman and Kar 2012; Alfee and Bloor 2025). Koglin et al. (2016) report that the resuspension of sediments in aquatic environments due to characteristics such as rainfall, floods and sediment remobilization due to dredging increases the exposure of fish to contaminants, reflecting in the increase of biomarkers.

The most frequent lesions in the group were aneurysm (44.88%), followed by fusion of primary lamellae (28.61%), epithelial displacement (19.28%) and necrosis (7.23%). Torres et al. (2023) did not identify an aneurysm, but found epithelial displacement (47%), lamellar fusion (15%) and necrosis (5%), as well as hyperplasia (12%) and lamellar narrowing (6%). Castro et al.

(2018) identified aneurysm, primary lamella fusion and necrosis, as well as hyperplasia, capillary dilation, necrosis and epithelial cell proliferation in specimens from the port region of São Marcos Bay.

The aneurysm impairs vascular integrity with the release of large amounts of blood, pushing the lamellar epithelium to the outside, which may result in rupture and consequently hemorrhage (Popović et al. 2023). Epithelial displacement is an initial sign of pathologies in fish, as it can generate disturbances in osmoregulation (Rasmi and Faisal 2024). Lamellar fusion is considered a natural defense mechanism, which protects the direct contact of contaminants with the epithelium of the lamella, but impairing the passage of water, limiting the respiratory function of the organ (Carvalho et al. 2020). Morphological changes in the gills and the loss of their gill functions directly affect the health of fish, due to their role in the animal's respiration, indicating accumulated chemical or physical impacts in the environment, as they are structures with a large contact area and intense interaction with the water (Evans et al. 2005).

Necrosis was observed only in the gills of males in the port region, with no females being identified in any sampling. It was identified that females presented more respiratory problems, while males revealed disturbances in structural levels and even tissue death. This demonstrates that males are being most affected.

As for liver lesions, no changes were identified in the fish collected on Crab Island. In the port region, the rainy season showed most individuals with lesions (78.85%), behavior similar to gills. A similar pattern was found by Viana et al. (2021) in work carried out in São José Bay. Regarding sex, liver lesions had the same pattern as the gills, with females predominating in the rainy season and males in the dry.

The liver lesions found were center-type melanomacrophages (MMC) and necrosis. Females presented more lesions of the MMC type (79.31%) and males of the necrosis type (78.26%). Torres et al. (2023) for the same species and region found these types of lesions, as well as fibrosis and hepatocyte vacuolization.

MMCs in fish liver have the function of destroying, detoxifying or recycling foreign materials, being indicators of environmental conditions (Qualhato et al. 2018). Hepatic necrosis represents an irreversible injury, and many of these changes can lead to organ failure, compromising health and affecting the survival of the organism population (Rabitto et al. 2005). The presence of pathological changes in the liver indicates toxic responses to the absorption of xenobiotics from the environment, since in teleost fish this organ is fundamental in the biotransformation of xenobiotics, elimination of toxic metals, hormonal metabolism and storage of substances (Adeogun et al. 2016; Pedron et al. 2023).

Males play an important role in the reproduction process of *S. herzbergii*, incubating fertilized eggs in their mouths. This causes a reduction in their feeding, as they allocate a large part of their energy to reproduction (Figueiredo and Menezes 1980; Queiroga et al. 2012). Therefore,

impaired health in males of this species, makes the population more susceptible to depletion of stocks. Carvalho-Neta et al. (2017) in work carried out in the same locations and species, observed male catfish incubating eggs in the mouth, only on Crab Island, indicating a behavioral response of organisms related to anthropogenic impact and which may have harmed recruitment.

Currently, few studies investigate differences in responses to environmental stressors between genders. Figueiredo-Fernandes et al. (2006) found that the activities of the antioxidant enzymes SOD and GST were higher in males exposed to paraquat, while GR enzyme activity was significantly higher only in females, indicating a gender-dependent enzymatic response.

There is a need to incorporate enzymatic analyses (GST, CAT, SOD) and measure contaminant loads (metals, PCBs) by gender in the future, in addition to mapping the microspatial investigation by sex, in order to determine whether the observed differences result from exposure or physiological/endogenous differences.

Regarding mean fish length and weight, individuals captured in the port region exhibited higher mean lengths but smaller mean weights. This may indicate that exposure to contaminants interferes with fish growth, as demonstrated by Torres et al. (2023). The highest length and weight values were found during the dry season. Females had higher values.

Exposure to contaminants can cause damage to biological systems and increase the energy demand for detoxification processes, which explains the lower weight values observed in the port region (Klátyik et al. 2024). Montes et al. (2023) state that the reduction in fish size in the region may be related to high turbidity levels, in addition to the presence of contaminants.

The condition factor (K) always presented higher values for fish sampled in the reference area, as the region's streams are the main sites used by *S. herzbergii* for feeding, growth, and reproduction (Pinheiro-Sousa et al. 2021). In contaminated regions, such as the port region, the K value is usually lower due to higher energy consumption. Average K values were higher during the dry season, with females presenting higher values than males.

GSI values in the port area were low, whereas at Ilha dos Caranguejos they exhibited higher values, in line with the results found by Carvalho-Neta et al. (2017) for the same species and region. This suggests greater reproductive activity at island, as higher GSI values indicate adequate gonad maturation (Vazzoler 1996). Males presented the lowest GSI values, establishing a direct relationship with elevated values for gill and liver lesions. A similar result was found by Macedo et al. (2024b) at the same site and species. Socha et al. (2024) argue that xenobiotics affect the endocrine and reproductive systems of fish, compromising processes such as gonad development, oocyte maturation, steroidogenesis, and gamete formation.

The specimens captured in the port region are not with adequate gonadal development. Individuals had lower gonads weight in all comparisons, even when the average weight and length were higher. Reduced values of gonads in large fish signals that the species does not reproduce properly, which can lead to slow replenishment of stocks (Marshall et al. 2021).

According Woo, Sin and Wong (1993), organisms living in contaminated regions are exposed to high concentrations of pollutants, exerting physiological influence and compromising stages of the reproductive process, inducing them to reserve energies for the detoxification process. Yamamoto et al. (2023) state that under these conditions of exposure to xenobiotics, the fish's metabolic reserves are reallocated to detoxification mechanisms, depleting the reserves originally intended for growth, resulting in individuals with smaller lengths and weights.

Conclusion

Histological analysis of gills and livers and morphometric analysis enabled the identification of changes in *Sciades herzbergii* in the port region of Maranhão. Regardless of the period and sex, the fish presented compromised health, possibly due to exposure to contaminants present in the region.

During the rainy season the worst histological and morphometric indexes occurred, which can be explained due to the xenobiotics available in the water column after sediment leaching, which implies greater energy expenditure to detoxify possible contaminants. This pattern is consistent with observations made in estuaries under port influence, where rainfall events increase the load of suspended pollutants.

Studies with Ariidae rarely address differences in impact by sex, and the occurrence in this study of higher values in males for liver necrosis and the exclusivity of this type of lesion in gills suggests greater vulnerability in this population. This may be linked to reproductive behavior (mouthbrooding), which reduces feeding and energy for defense to physiological differences, such as lower detoxification capacity or greater accumulation of contaminants or to the occupation of more polluted microhabitats. The scarcity of detailed sexual analyses in *S. herzbergii* and the Ariidae family reinforces the originality and relevance of this finding.

The average values of weight, length, gonads, GSI and K, indicated that the fish of the port region have deficient gonadal development. The condition factor (K) demonstrated reserve expenditures in cyclic activities, indicating that the specimens are using energy to deal with the xenobiotics present in the region and not in the reproductive process. Morphometric measurements were efficient in understanding the histological analysis.

Males showed great correlation in their populations, being more suitable for biomarker analysis. Low incidence of gill lesions and absence of liver lesions in fish from Crab Island indicate the area as a good reference area.

The identification of histopathological lesions in *S. herzbergii* in the port reinforces the need to integrate ecological and social approaches, as impairments to fish health may directly affect food security and the sustainability of artisanal fisheries. There is a clear need for integrated policies that simultaneously address the health of aquatic ecosystems and the strengthening of fisheries governance.

Declarations

Ethics Approval and Consent to Participate

This study was approved by the Animal Ethics Committee of the Centro de Ciências Agrárias, Universidade Estadual do Maranhão (provisional accreditation by CONCEA/MCT; process no. 01200.002200/2015-06; protocol no. 25/2016). All data and samples were collected in accordance with relevant institutional guidelines and standard scientific protocols. Moreover, all the applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Consent for Publication

All authors have approved the manuscript for submission.

Competing interests

The authors declare that they have no competing interests.

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Author Contributions

AFT Conceptualization, Methodology, Investigation, Data curation and Writing – Original Draft; HST Data curation and Formal analysis; JSC Data curation and Validation; HCV Data curation and Investigation; LND Software and Visualization; MRC Visualization; ACLC Writing – Review & Editing; RNFCN Conceptualization, Supervision, Project administration, Funding acquisition and Writing – Review & Editing.

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Data Availability

All data generated or analyzed during this study are included in this article.

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Figures

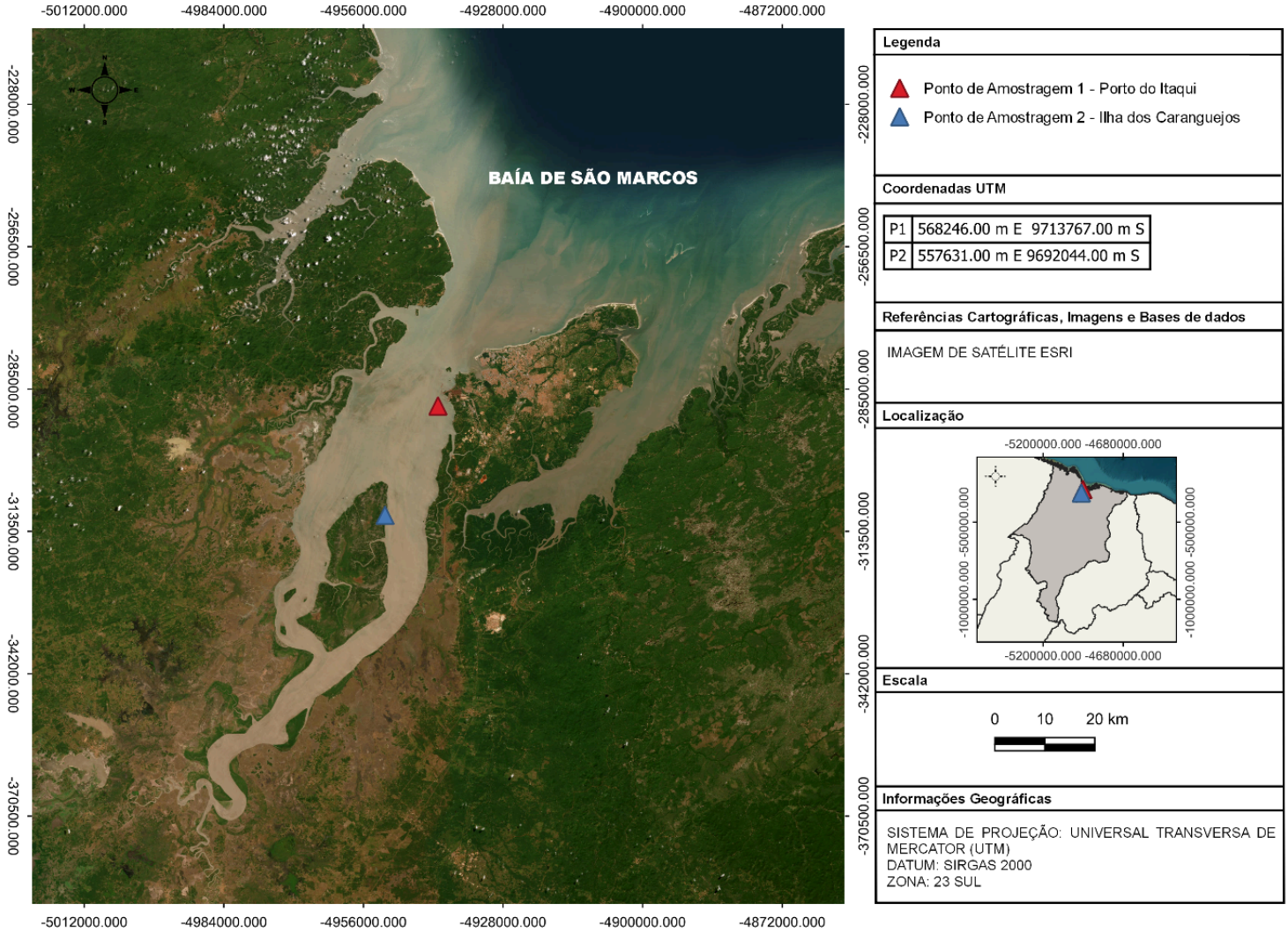


Figure 1

Capture location of *S. herzbergii* , in the Port of Itaqui (A1) and Crab Island (A2). **Source:**Own Autorship