



Assessment of crabs from Trindade, a Brazilian remote island: Support to marine studies

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ABSTRACT

Trindade is a remote island far from 1170 km of the Brazilian coast in the Atlantic Ocean, between South America and South Africa. The island has great biodiversity and scientific studies on the fauna and flora of Trindade are still scarce. Accordingly, since crustacean species of the island are also little known, this research features an unprecedented data set, which provides information on the level of potential toxic elements in two crab species: the *Grapsus grapsus* (herbivore) and the endemic species *Gecarcinus lagostoma* (omnivorous) which is in threatened status. Although Trindade has experienced contamination from human activities, mainly plastic debris, the element levels found in the samples suggest that there are no relevant inorganic sources into the island. Since minor and trace elements accumulated by marine invertebrates does not present a pattern behavior, our results can support other studies focused on the impact of global warming to the marine ecosystem.

1. Introduction

Human pressure on natural systems remains as a global challenge. The scenario becomes even more worrying, since extreme weather events have already been experienced, and prospects are not enthusiastic (IPCC, 2021). Environmental degradation goes far beyond physical damage; it comprises a tangle of problems that also involve economic and social issues (IPCC, 2021).

The increase of temperature affects all stages of the water cycle: evaporation, condensation, precipitation, infiltration, and transpiration – which significantly impairs its availability. Some estimates indicated that the stress levels will continue to increase as demand for water grows and the effects of climate change intensify (UNESCO, 2019). For 2050, water demand is expected to increase by up to 30 %, compared to current needs. More than two billion people already suffer from high water stress and approximately four billion people are affected by severe water shortages for at least one month a year (UNESCO, 2019).

In order to seek an ecologically balanced development pattern, in which environmental and social issues are contemplated, the 2030

Agenda for Sustainable Development of the United Nations, of which Brazil is a signatory, was created in a participatory manner. The 2030 Agenda is the result of the nations, which have accumulated experiences, based on the “Our Common Future” Report (Burton, 1987).

The 2030 Agenda comprises 17 Sustainable Development Goals (SDGs), which meet specific purposes, but which are interconnected, especially in matters related to its main goal: the eradication of poverty, protection of the planet and the improvement of the quality of life of all living beings (UN-Habitat, 2016).

With regard to the SDG 14 - *conserve and sustainably use the oceans, seas, and marine resources* - it is important to highlight that oceans play an important role to the global systems, since they make our planet habitable for humankind. In this sense, rainwater, drinking water, weather, climate, coastlines, much of our food, and even the oxygen in the air we breathe, are all ultimately provided and regulated by the sea (UN-Habitat, 2016).

In social terms, according to the Organization for Economic Cooperation and Development (OECD), the oceans provided about 31 million of direct full-time jobs in 2010, mainly those linked to fisheries

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activities, as well as 350 million jobs related to artisanal fishing, tourism, and research (OECD, 2016).

Therefore, careful management of the oceans as a vital global resource is a key feature for a sustainable future. Nevertheless, at the current time, the deterioration of coastal waters owing to pollution, and ocean acidification has been continuous, which result in adverse effects on the functioning of the sea ecosystems, its biodiversity, with negative consequences for socioeconomic issues (UNCTAD, 2014).

Although islands make up around 5 % of the Earth's land surface, they are recognized as pivotal ocean places to favor and protect endemic species; i. e., they work for the conservation of global biodiversity (Horton and Barnes, 2020). Special focus has been given on oceanic islands that, due to their geographical isolation, present singular fauna, and flora as a result of long periods apart from external interferences (Frankham, 1997; Walter, 2004; Andrades et al., 2018; Monteiro et al., 2020). Hence, oceanic islands present well-defined borders which allow the development of studies focused on ecological processes (Matthews et al., 2019).

Furthermore, the dynamic of climate changes and global warming has intensified the coverage of marine contamination; i. e., the consequences of human pressures on ecosystems will tend to be more harmful on vulnerable areas, such as the oceanic islands (MEA, 2005; UNCTAD, 2014; OECD, 2016; Horton and Barnes, 2020). These places are home to a larger number of endemic and sensitive species which give access to seasonal food for a major proportion of global higher marine predators (Horton and Barnes, 2020).

Previous studies reported that anthropic activities have been affecting island ecosystems heavily (Millennium Ecosystem Assessment [MEA], 2005; Petersen et al., 2016; Monteiro et al., 2020). Among the several kinds of contaminants, oceans are being flooded with two main types of pollution: chemical - inorganic and organic substances - and marine litter (Petersen et al., 2016; Andrades et al., 2018; Trevizani et al., 2018; Landrigan et al., 2020).

However, in the specific case of oceanic islands, the research is scarce, and it have been focused on plastic debris (Petersen et al., 2016;

Monteiro et al., 2020; Schofield et al., 2020). Therefore, there are still opportunities to scientific investigations regarding the assessment on endemic organisms in oceanic island which may be used as indicators of environmental quality.

Among the methods commonly used to assess the impacts of human activities across the sea, is the biological monitoring. (Gupta et al., 2014; Saher and Siddiqui, 2019). Several marine organisms may function as sentinel to indicate the magnitude of those activities and their potential adverse effects for the aquatic ecosystems. Therefore, organisms have been used as suitable biomonitor to determine the available of potential toxic substances in the sea, such as the case of elements (Císař et al., 2018; Trevizani et al., 2018; Saher and Siddiqui, 2019).

Suitable element biomonitors must have the ability to accumulate the element in its tissues, in a way that the accumulation reflects a positive relation with the amount of the elements (Saadati et al., 2020). Furthermore, they must: (i) be non-migratory, (ii) live in a specific habitat, (iii) be easily identifiable, (iv) have long life and abundance over the years and (v) have adequate living tissues for sampling (Císař et al., 2018).

In this sense, the main objective of this study was to quantify minor and trace elements, essential and non-essential, such as Cu and Cd, respectively, in biological samples of crustaceans – different species of crabs – to contribute to a database and examine the environmental quality of Trindade, a Brazilian oceanic island. With regard to its environmental importance, scientific studies have reported the native end endemic fauna and flora, highlighting the role of Trindade to the breeding and feeding of various marine and terrestrial species, such crustaceans, birds, and turtles (Martins and Alves, 2007; Clemente et al., 2009; Camacho-Montealegre et al., 2019).

The oceanic island is the furthest from the coast of Brazil; therefore, the access to the site is complex and requires the mobilization of the armed forces - the Brazilian Navy - for the logistical support and protection of researchers.

Accordingly, as crustacean species of the Trindade Island are also little known, this research features a novel data set, which provides

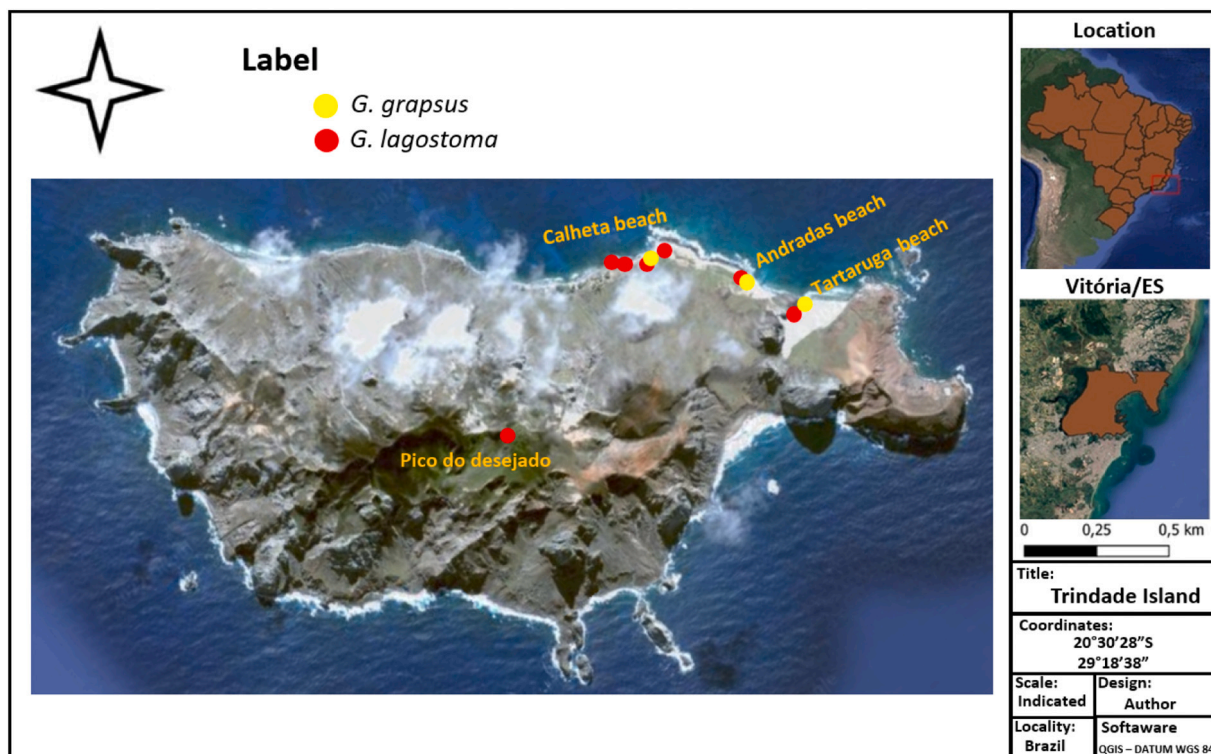


Fig. 1. Local sites for collection of crabs in the oceanic island of Trindade, Vitória-ES, Brazil.

information that could support futures marine studies on the effects of climate changes and global warming and the practical actions to reach the 2030 Agenda, mainly, the SDG 14.

2. Materials and methods

2.1. Study area – collection – sample preparation

Trindade is located at 620 nautical miles (approximately 1170 km) off the coast of Vitória, Espírito Santo State (ES), Brazil at the eastern end of the Vitória-Trindade underwater chain, lying between the parallels 20°29' and 20°32'S and meridians 29°17' and 29°21'W (Bongiolo et al., 2015; PROTRINDADE, 2015).

Trindade island has about 10 km² of area and is characterized by a steep relief, the highest points have 600 m, approximately, of altitude in relation to sea level (Castro, 2010; Alves, 1998). The island has a tropical oceanic climate, the annual average temperature is 25 °C. February has the warmer average temperatures and August has the cooler average ones (Comando do 1° Distrito Naval, 2014).

The occupation of oceanic islands began soon after the arrival of the Portuguese in Brazil at the XVI century. However, only Fernando de Noronha archipelago and Trindade Island presented conditions for perennial occupation (Soto, 2009). Before being officially part of Brazilian territory, in 1882, Trindade Island was occupied by Azorean, who introduced pigs and sheep herds into the island. The animals were abandoned, and they were reproducing freely. As a consequence, over twelve years - more than a thousand individuals - caused deep degradation on the natural landscape of the island. (Martins and Alves, 2007).

For the Brazilian Navy point of view, as other oceanic islands, Trindade is considered a strategic area, due to its great political importance. As an Exclusive Economic Zone (EEZ), the region that starts from the coastline and extends for 200 nautical miles. Within the EEZ, the country has the right to explore, conserve and manage all living and non-living resources and, normally, the country may also support scientific studies in these areas (Leitão and Carvalho, 2005; Marliere, 2006).

However, Brazilian Navy poses restrict access to Trindade Island; as a result, ecological studies focused on the impacts of anthropic activities on the local biodiversity is still minimal (Petersen et al., 2016; Andrades et al., 2018; Santos-Silva et al., 2018; Camacho-Montealegre et al., 2019) in comparison to other studies that have been conducted over the sea and next to the coastal zone (Burger et al., 2002; Eça et al., 2013; Hong et al., 2014; Lavradas et al., 2014; Baki et al., 2018; Saadati et al., 2020).

Gecarcinus lagostoma (or *Johngarthia lagostoma*), so called Yellow crab, occurs in great abundance, from beach areas to the top of the island, and feeds on a substantial number of different items, such as leaves and seeds from almond trees, animal remains, eggs and baby turtles, among others. Another crab species studied here is the *Grapsus grapsus*, also as Sally lightfoot crab, which disperses through planktonic larvae, depending mostly on surface currents to reach the oceanic islands (Freire et al., 2021). In Trindade, the Sally lightfoot crab is more abundant on intertidal zone (Oliveira, 1951).

The crustaceans, such as crabs, do not have an advanced metabolism system and can be exposed to chemical substances due to significant contact with sediments, i. e., they may accumulate potential toxic elements into their body. Therefore, they have been used to determine the availability of metals in aquatic ecosystems (Baki et al., 2018). For this reason, Yellow crab and Sally lightfoot crab were chosen as possible biomonitors and for determination of their elemental composition to reach the main goal of this research.

Fig. 1 shows the geographic localization of Trindade Island, with the points where crabs were collected. Focus was given on the study of crabs. In this case, two collections were made on Trindade Island, the first during the fall, late March to May 2011, and the second during spring and summer, from November 2011 to February 2012. During

Table 1
Analytical control for the experimental data.

Element	CRM	Certified value (mg kg ⁻¹)	Experimental (mg kg ⁻¹)*	SRD (%)	Error (%)
Al	SRM-2976	134.0 ± 34.0	113 ± 15	14	16
As	SRM-2976	13.3 ± 1.8	13.4 ± 0.2	1.9	0.6
Cd	SRM-2976	0.8 ± 0.1	0.70 ± 0.04	5.5	9.3
Cu	SRM-2976	4.0 ± 0.3	4.3 ± 0.2	5.6	8.1
Fe	SRM-2976	171.0 ± 4.9	139.9 ± 3.0	2.1	18
Mn	SRM-2976	33.2 ± 2.0	31.7 ± 1.0	3.3	4.0
Ni	SRM-2976	0.9 ± 0.1	0.8 ± 0.2	21	7.1
Pb	SRM-2976	1.2 ± 0.2	1.20 ± 0.06	5.1	0.6
Se	SRM-2976	1.8 ± 0.1	2.1 ± 0.3	17	18
Zn	SRM-2976	137.0 ± 13.0	133.2 ± 3.0	2.3	2.7
Hg	DORM-2	4.64 ± 0.26	4.5 ± 0.2	4.6	2.3

* n = 8.

these periods 60 individuals of the species *G. lagostoma* and 56 individuals of the species *G. grapsus* were collected, at different sites of the Island (Fig. 1). *G. lagostoma* is an endemic specie that, with the negative consequences anthropic activities, has been considered vulnerable to extinction (Pinheiro et al., 2016). This crab is essentially herbivore (Barth, 1958) and is found in the whole island, even in the highest sites, such as “Pico do Desejo” (Fig. 1). *G. grapsus* lives among the rocks at turbulent, windy shores, just above the limit of the sea spray. This crab feeds primarily on algae and, occasionally, sampling plants and dead animals (Barth, 1958). The crabs were collected with the help of a net and for minor and trace elements quantification the muscles of leg and cheliped were used. All samples were lyophilized, macerated, and stored properly before being subjected to chemical methods.

2.2. Chemical analyses

For the quantification of the minor and trace elements: Al, As, Cd, Cu, Fe, Mn, Ni, Pb, Se and Zn, an acid digestion method was used. In this method 0.35 g of leg and claw crab muscle sample was added to a tube with 4 mL of concentrated HNO₃. The tubes were left overnight, this time, 1 mL of 30 % (v/v) H₂O₂ was added, and the tubes were taken to the heating block at 90 °C for 03 h. This procedure was based on the method used by Moreira (2010), but it was adapted, the detailed description of the method used is available in Theophilo (2013). Quantifications were performed by Inductively Coupled Plasma Optic Emission Spectrometry (ICP OES).

For Hg quantification, the acid digestion performed was based on the 7471B method (US EPA, 2007). This method was developed, at the beginning for the digestion of sediment, soil, sludge and solid or semi-solid residues, however, modifications were applied to the method. So that it could be applied to organisms and obtain satisfactory results (Theophilo, 2013). In this method, 0.6 g of crab leg and claw muscle sample was added to a tube with 1.7 mL of reagent water and 1.7 mL of aqua regia (a mixture of HCL and HNO₃ at a ratio of 3:1). The tubes were heated in a water bath for 2 min at 90 °C. After reaching room temperature, 4.9 mL of potassium permanganate and 16.4 mL of deionized water were added, and this solution was again taken to a water bath at 90 °C for 30 min. After cooling, 2.0 mL of hydroxylamine hydrochloride was added, the samples were then filtered and made up to 40 mL with deionized water.

After the digestion, the quantification of Hg was performed using the

Table 2

Wavelengths, method quantification limits (MQL) and method detection limits (MDL) for quantified elements by ICP OES.

Element	Wavelength (nm)	MQL (mg kg ⁻¹)	MDL (mg kg ⁻¹)
Al	396.152	1.94	0.64
As	188.980	2.96	0.98
Cd	214.439	0.38	0.13
Cu	327.395	0.42	0.14
Fe	238.204	1.43	0.48
Mn	257.610	0.45	0.15
Ni	231.604	0.31	0.10
Pb	220.353	0.80	0.27
Se	196.026	4.65	1.55
Zn	213.857	0.93	0.31
Hg	194.164	17.7 ^a	5.9 ^a

^a In µg kg⁻¹.**Table 3**Elemental contents in muscle crab samples, in mg kg⁻¹, collected in Trindade Island, Brazil.

	<i>G. grapsus</i>			<i>G. lagostoma</i>		
	$\bar{X} \pm SD$	Min–Max	n	$\bar{X} \pm SD$	Min–Max	n
Al	31.7 ± 14.4	13.7–70.1	52	42.0 ± 18.3	15.4–86.7	58
As	18.4 ± 8.8	6.3–39.3	53	19.3 ± 19.1	3.1–69.7	37
Cd	<0.42	–	–	0.5 ± 0.1	0.4–1.1	24
Cu	36.1 ± 10.3	15.5–62.6	54	59.2 ± 12.9	30.2–83.4	58
Fe	47.8 ± 35.3	12.6–142.5	53	47.6 ± 21.1	15.7–109.7	57
Hg	<17.7 ^a	–	–	<17.7 ^a	–	–
Mn	1.5 ± 0.7	0.5–3.7	56	1.9 ± 0.6	0.7–3.3	57
Ni	0.7 ± 0.3	0.3–1.4	54	0.5 ± 0.1	0.3–0.9	49
Pb	<0.80	–	–	<0.80	–	–
Se	<4.65	–	–	<4.65	–	–
Zn	110.3 ± 23.3	65.3–170.1	56	238.6 ± 28.0	195.4–299.4	60

n = number of samples (n is different for the elements because outliers and values lower than MQL were disregarded).

^a Hg results are in µg kg⁻¹.

Vapor Generation Accessory (VGA) technique coupled to the ICP OES.

2.3. Analytical control and statistical treatment of the results

Aliquots of certified reference materials (CRM) were digested with the crab muscle samples for analytical control of the data. The CRMs used during this study were NIST SRM-2976 (National Institute of Standards and Technology, mussel tissue), in which were quantified: Al,

Table 4Comparison of minor and trace elements levels (mg kg⁻¹) in different crab species, according to previous works.

Study	Local	Species	Al	As	Cd	Cu	Fe	Mn	Ni	Pb	Se	Zn
Present study	Trindade Island, Brazil	<i>G. grapsus</i>	31.7 ± 14	18 ± 9	<0.42	36 ± 10	48 ± 35	1.4 ± 0.6	0.7 ± 0.3	<0.80	<4.65	110.3 ± 23.3
Present study	Trindade Island, Brazil	<i>G. lagostoma</i>	41 ± 18	19.3 ± 19.1	0.5 ± 0.1	59 ± 13	47 ± 21	1.9 ± 0.6	0.5 ± 0.1	<0.80	<4.65	238.6 ± 27.0
de Jesus et al., 2021	Crab Island, Brazil	<i>Ucides cordatus</i>	–	0.4	<0.1	4.02	–	–	0.19	–	–	53.56
Yogeshwaran et al., 2020	Punnakayal, India	<i>Scylla serrata</i>	–	–	0.13 ± 0.001	0.41 ± 0.05	–	–	–	0.09 ± 0.01	–	39.92 ± 1.20
Çoğun et al., 2017	Mersin Bay, Turkey	<i>Callinectes sapidus</i> ^a	–	–	0.4 ± 0.2	4.5 ± 0.13	–	–	–	1.2 ± 0.11	–	15.8 ± 1.15
Çoğun et al., 2017	Mersin Bay, Turkey	<i>Callinectes sapidus</i> ^b	–	–	1.5 ± 0.25	4.7 ± 0.22	–	–	–	1.8 ± 0.51	–	15.1 ± 2.27
Lavradas et al., 2014	Ilha Grande Bay, Rio de Janeiro, Brazil	<i>Callinectes</i> sp. (females)	–	–	0.15 ± 0.07	46.26 ± 8.86	–	–	–	0.14 ± 0.03	–	116.34 ± 19.50
Lavradas et al., 2014	Ilha Grande Bay, Rio de Janeiro, Brazil	<i>Callinectes</i> sp. (males)	–	–	0.22 ± 0.09	59.08 ± 5.37	–	–	–	0.11 ± 0.03	–	131.25 ± 32.17
Miao et al., 2001	Oahu Island - Hawaii	<i>Grapsus tenuicrustatus</i>	–	27.4	1.9	49.7	–	–	–	0.2	8.3	–

^a Collected in spring.^b Collected in autumn.

As, Cd, Cu, Fe, Mn, Ni, Pb, Se and Zn, and NRCC DORM-2 (National Research Council Canada, *Squalus acanthias* muscle tissue) for the quantification of Hg. The minor and trace elements in the CRMs results are showed in Table 1 and indicated the suitability of the methods for the quantification of studied elements.

The method detection limit (MDL), and the method quantification limit (MQL) were calculated and are presented in Table 2, along with the wavelengths used in this study for the quantification of each minor and trace elements.

For the results obtained from the analyses performed on the crab muscle, box-plots of the quantified elements in each species were first performed. The means, standard deviations, maximum and minimum values were calculated with the samples from the first and second sampling, without outlier values and values below the limit of quantification of the methods (MQL).

After the descriptive part, two-way analysis of variance (ANOVA) was performed, but before the analysis, the Shapiro-Wilk test for normality and the Levene test for homoscedasticity were applied. For each species of crab, two ANOVA tests were performed, in the first one, gender and the elements were used as factors and in the second one, seasons and elements. Tukey's Honestly Significant Difference (HSD) test was performed when significant differences between the results analyzed were observed, after applied ANOVA.

Finally, the correlation between biomass and element concentrations and the length of the individuals with the concentrations were performed to check any relationship. All statistical analysis were performed in Statistica 12.0 software.

3. Results and discussion

The elemental contents are summarized in Table 3, where the results are presented as: average, standard deviation, and their concentration range. The average concentration for both species - *G. grapsus* and *G. lagostoma* - are in the same order of magnitude, except for Al, Cu and Zn that are higher in *G. lagostoma*. The results for Pb, Se and Hg were lower than MQL, as well as Cd for *G. grapsus*.

As mentioned above, this study features an unprecedented data set for *G. grapsus* and *G. lagostoma*; i.e., it was not found any study in the literature with these crab species that would allow the comparison of minor and trace elements contents with the results here obtained. Although some researchers have suggested inputs in the island of crude oil from ships and petroleum platforms (Camacho-Montealegre et al., 2019), the main source of contamination comes from plastic fragments and other debris dispersed on the sea across long distances (Petersen

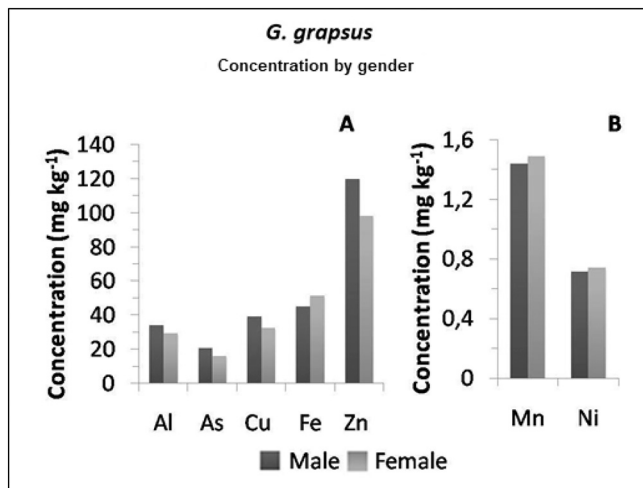


Fig. 2. Elemental concentrations, considering the gender for *G. grapsus*.

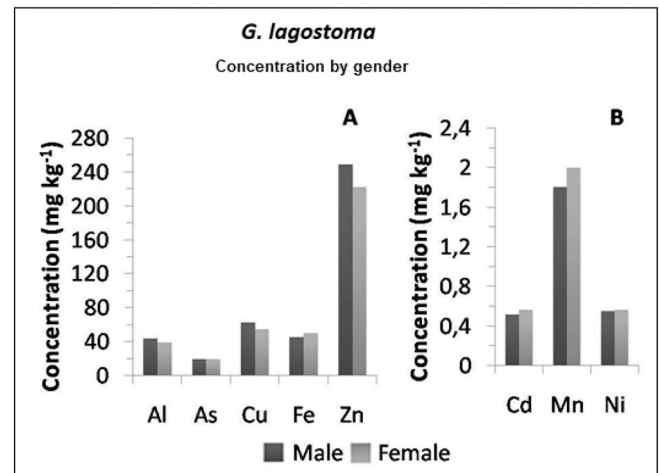


Fig. 3. Elemental concentrations, considering the gender for *G. lagostoma*.

et al., 2016; Andrades et al., 2018). Therefore, since Trindade is a remote area, we assume that, for now, there is no relevant anthropic source of toxic and potential toxic elements to the island. Accordingly, for comparison purposes, Table 4 presents some studies on minor and trace elements in other crab species sampled from control sites.

The comparison of our results with previous works, considering areas with none or low anthropic influence, indicated the same order of magnitude for most studies. The biggest discrepancies were observed in the study of de Jesus et al. (2021), since they analyzed *U. cordatus* sampled inside of an Environmental Protection Area in Baixada Maranhense - Brazil, previous studies performed by the research group have shown that there is no impact in the local site, because the area has been a natural reserve since 1991.

The results reported by Yogeshwaran et al. (2020), indicated the lowest concentrations of Cu, for *S. serrata*. The crabs were bred in situ culture by local fish farmers of Punnakayal. This region, in Tuticorin, Southeast Coast of India, was considered a low polluted environment due to limited anthropogenic activity. Likewise, the levels of Cu reported by Çoğun et al. (2017) were below 5 mg kg⁻¹. The authors conducted two sampling – spring and autumn -, in an unpolluted site of Mersin Bay, one of the largest bays of northeastern Mediterranean Sea, in Turkey.

According to Lavradas et al. (2014), Ilha Grande Bay, located in Rio de Janeiro, Brazil, has been reported as a control site to metal studies, because it presents low levels of metals in water, biota, and sediments. However, the authors emphasized the presence of an oil terminal, a shipyard and two nuclear power plants, potential pollution sources.

The values found by Miao et al. (2001) for As were similar to the crabs from Trindade. The control site of the study was Oahu Island – Hawaii; the authors analyzed samples of *G. tenuicrustatus*. The levels of As may be associated with the fact that both Oahu and Trindade Island are influenced, or in the past were influenced, by volcanic processes, which are sources of As.

Table 4 is useful to observe the levels of minor and trace elements in crabs collected in clean areas. However, it is important to highlight that the absorption rate of a minor and trace elements - by several marine invertebrates - is run by the physicochemical conditions of the environment, which controls the concentration equilibrium of the free metal ion and the binding of the specific metal ion to a type of organic ligand (Rainbow, 1985). Along a dilution gradient, considering the kind of the environment - sea, estuaries, and fresh water - the physiology of the invertebrate itself, in each species, will lead to different rates of absorption of trace elements (Rainbow, 1985). Thus, this behavior of each invertebrate species is one of the parameters that could explain the differences between the concentrations observed in Table 4.

Furthermore, since the planet has been experimented accumulation

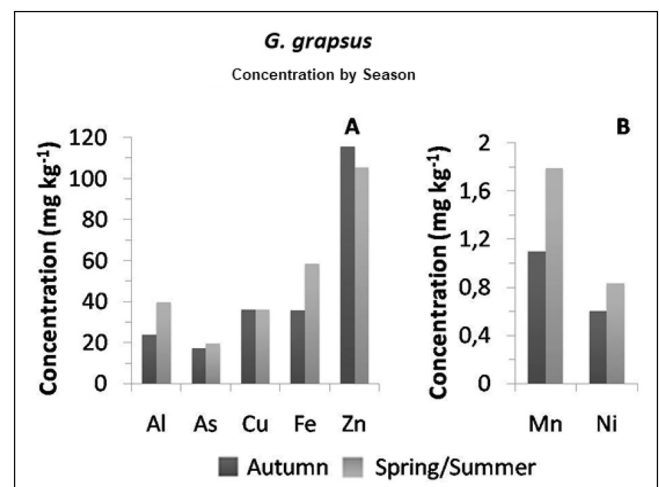


Fig. 4. Elemental concentrations, considering the seasons for *G. grapsus*.

of greenhouse gases in the atmosphere that has resulted in warmer sea surface temperatures, which leads to water acidity, several physiological process of the organisms can be affected and put in risk the marine ecosystems (Schmidtke et al., 2017; Camp et al., 2018).

Therefore, focusing on the environmental conditions observed in Trindade, the elemental contents, considering the gender of each crab species, are presented in Fig. 2 (A and B) for *G. grapsus*, whereas Fig. 3 (A and B) present these results for *G. lagostoma*. After statistical treatments, only for the Zn data, the concentrations values were considered statistically different ($p < 0.05$), for both species.

The average Zn concentrations for males, 120 ± 20 mg kg⁻¹ in *G. grapsus* and 249 ± 27 mg kg⁻¹ in *G. lagostoma* were higher than females, in which average Zn values of 98 ± 21 mg kg⁻¹ in *G. grapsus* and 222 ± 27 mg kg⁻¹ in *G. lagostoma* were found.

Previous studies based on gender also indicated no significant differences in minor and trace elements levels. For instance, Beltrame et al. (2010) analyzed the hepatopancreas of *Neohelice granulata* and did not observe significant differences in the Cd, Cr and Mn concentrations between males and females. Turoczy et al. (2001) analyzed Cd, Cu, Hg and Zn in leg, chela, muscle, hepatopancreas and gills of *Pseudocarcinus gigas* from the sea of Southeastern Australia. The authors reported no significant differences in any of the analyzed tissues.

Regarding the season, the first sampling was conducted, in 2011, at the end of the March up to the end of May, i.e., throughout the autumn.

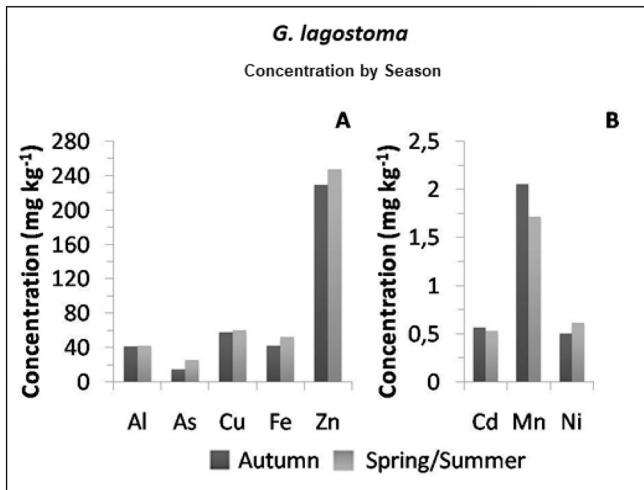


Fig. 5. Elemental concentrations, considering the seasons for *G. lagostoma*.

The second sampling began at the end of November (2011) until February (2012); i.e., it was conducted from part of springer to the summer. Focusing on the period of the collection, the ANOVA indicated significant differences between concentrations and the seasons ($p < 0.05$), for both species. According to the a posteriori test of Tukey, for *G. grapsus*, the Fe contents were statistically different (Fig. 4 – A and B). In the case of *G. lagostoma*, the Zn contents were different (Fig. 5 – A and B). For both Fe and Zn, concentrations were higher for samples collected during springer/summer.

The Fe average concentrations for *G. grapsus* (Fig. 4) were $31.3 \pm 23.0 \text{ mg kg}^{-1}$ (autumn) and $49 \pm 19 \text{ mg kg}^{-1}$ (spring/summer). The Zn average concentrations varied from $229 \pm 22 \text{ mg kg}^{-1}$ (autumn) to $247 \pm 29 \text{ mg kg}^{-1}$, in the spring/summer (Fig. 5).

The highest levels of minor and trace elements also were found in the spring and summer for *Neohelice granulata*. According to the authors, in these seasons the biological activity is higher (Beltrame et al., 2010); therefore, it is observed relevant changes in other physicochemical environment parameters that can lead to higher uptake of nutrients by the crabs, such trace elements (Rainbow, 1985). It is also important to consider the potential of current sub-optimal crab environments to function as potential refugia under changing environmental conditions.

Correlations analysis were also carried out. For such purpose, elemental contents were related with weight and length of the crab species.

According to Fig. 6 (A), Cu presented a very low correlation with weight ($r = 0.35$) and also with length ($r = 0.36$), whereas Zn correlation was higher (Fig. 6 B), with r values equal 0.67 for weight and 0.71 for length.

In the case of *G. lagostoma* (Fig. 7 A), the Mn data showed a low negative correlation of concentration with weight ($r = -0.34$) and also with length ($r = -0.32$). For Zn (Fig. 7 B), it was observed a positive correlation with weight ($r = 0.40$) and with length ($r = 0.26$).

Bjerregaard and Depledge (2002) analyzed Fe, Zn, Cu, Cd, Mn, and Co in different tissues of *Carcinus maenas* from southwest Funem, Denmark. Likewise, in this study, the correlation between Zn concentrations and size, for both species, was positive. Furthermore, the authors also observed negative correlations for Cu, Cd, Mn, and Co. Here, it was observed negative correlations for Mn in the *G. lagostoma*, whereas, for Cu in *G. grapsus* a low and positive correlation was found. Once again, it may be suggested that the availability of minor and trace elements plays the key role to the organism accumulate these elements. According to Rainbow (1985), the accumulation of Zn and Cu by *C. maenas* could be explained in terms of the regulation of body concentrations of these essential metals up to a threshold of dissolved metal exposure.

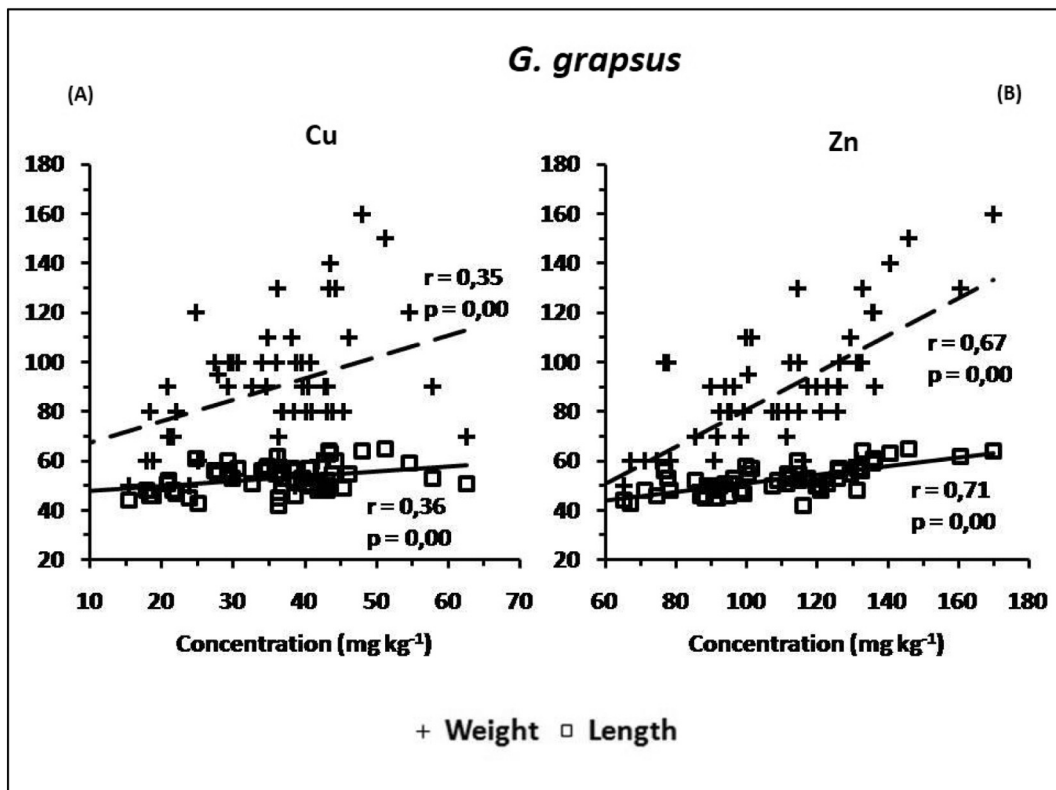


Fig. 6. Correlation analysis among concentrations versus weight (g) and concentration versus length (mm): (A) Cu and (B) Zn for *G. grapsus*.

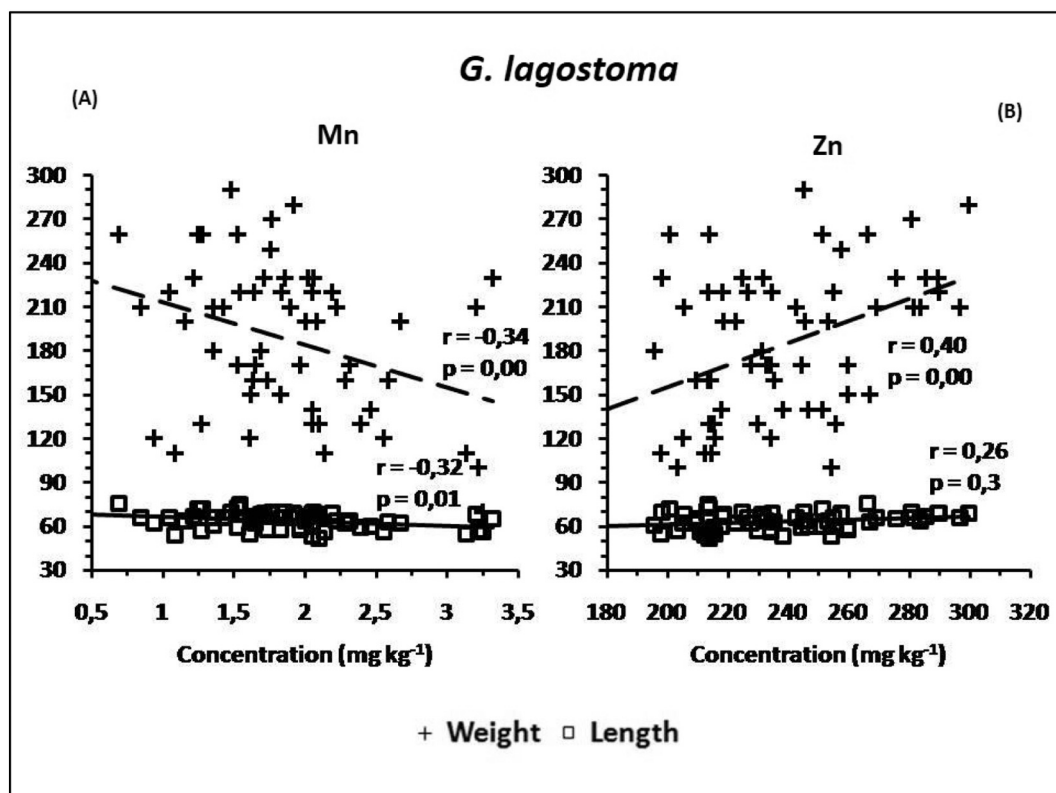


Fig. 7. Correlation analysis among concentrations versus weight (g) and concentration versus length (mm): (A) Mn and (B) Zn for *G. lagostoma*.

4. Conclusions

The minor and trace elements concentrations determined in both crab species were not statistically different, except for Zn, which presented values in the *G. lagostoma* were higher than in the *G. grapsus*. The differences may be associated with availability of Zn in the environment and the eating habits. Nevertheless, these levels do not allow to associate the Zn with any anthropic source, since the other metals, such as Cd, Cu and Pb, also associated to human negative impacts, were similar in both species. The assessment of metal concentrations with gender, size and weight also agreed with previous studies on other crab species.

Finally, we highlight that this is the first study that presents baseline data for minor and trace elements for the crabs from Trindade Island. Special attention must be given to the *G. lagostoma*, an endemic species from the Brazilian oceanic islands, which has been vulnerable due to human activities. Furthermore, it is relevant to indicate the necessity of studies focused on biomonitoring of negative impacts of global warming to the marine ecosystem and the impacts of natural processes or anthropogenic contributions. In this sense, both crab species could be used as bioindicators of the environmental quality of the Brazilian oceanic islands.

CRedit authorship contribution statement

All authors contributed to the study conception and design:

CYST: was responsible for the sampling strategy;

CYST, APR, THT: performed the chemical analysis;

CYST, APM, EGM, CSCA, FR: performed some statistical analysis;

CYST, APR, RCM, RCLF: performed some statistical analysis;

CYST, APR, EGM, RCLF: wrote the first draft of the manuscript.

All authors commented the evaluation given by the reviewers. All authors read and approved the revise version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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