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ORIGINAL ARTICLE

Spatial marine meiofauna variations in areas undergoing different disturbance levels on the Amazon coast

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Abstract
The Brazilian coastal zone comprises several types of environments, including lagoons and beaches, chosen for this study, which evaluate benthic meiofauna spatial distribution patterns in three areas, suffering different disturbance levels, throughout the Brazilian Amazon coast. Sediments from three areas (São Marcos Beach – Low level of disturbance; Calhau Beach – Medium level of disturbance; and Jansen Lagoon – High level of disturbance), in São Luís city (Maranhão, Brazil), were sampled for meiofauna assessments, granulometry and organic matter analyses. A total of 7,254 meiofaunal organisms were identified, 4,371 at São Marcos Beach, 1,856 at Jansen Lagoon, and 1,027 at Calhau Beach. The findings indicate that richness, density, and community structures differed significantly among the sampled areas. Nematoda and Copepoda were the most abundant groups. Copepoda stood out in São Marcos Beach compared to other taxa. Nematoda dominated in Jansen Lagoon. Calhau Beach presented the lowest density and richness values, with Tardigrada as the predominant meiofaunal group. Additionally, the composition of meiofauna was influenced by environmental variables, such as salinity, OM, sediment grain size and nitrate concentration, as well as anthropogenic activities taking place in the sampled areas. Considering the lack of studies in the region with this focus, it is expected that the results presented will contribute to public policies development aimed to conservation of the coastal zone in São Luís.

Introduction

The coastal zone is a complex and ever-changing environment, due to natural processes on wide time scales and increasing human activities (Danovaro and Pusceddu 2007; Defeo et al. 2009; Zho et al. 2018). Lately, there has been growing concern about the environmental impacts in this region (Paoli et al. 2015) as well as the search for solutions to reduce the effects of anthropogenic actions (Pilouk and Koottatep 2017). However, socioeconomic pressures in coastal areas accelerate unplanned urbanization and natural resource degradation, threatening environmental and economic sustainability (Schlacher et al. 2006, 2007; Ariza et al. 2010; McLachlan and Defeo 2017; Bertocci et al. 2019).

In this context, monitoring studies in coastal regions have aided the management of these areas (Ariza et al. 2010; Schlacher and Thompson 2012; Sun et al. 2014; Semprucci et al. 2015a, b; Peña-Alonso et al. 2017), through the use of ecological indicators, such as abundance, density, richness and diversity descriptors, employed to evaluate the *status quo* of coastal environments and plan public policies (Balsamo et al. 2012; Alves et al. 2013). Regularly, the structure of benthic communities is used in environmental studies in order to use the composition of the community as a parameter for environmental quality classification (Weisberg et al. 2008; Ranasinghe et al. 2009).

Because they live in the interstitium, benthic meiofauna have been used as marine ecosystems quality bioindicators

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and are routinely analyzed in environmental stress assessments (Gheskiere et al. 2005; Moreno et al. 2008, 2011; Alves et al. 2013; Zeppilli et al. 2015). Furthermore, due to their short life cycles, the responses of these organisms to the consequences generated by polluting agents are faster, as benthic meiofauna density and diversity are lower in affected environments, with the most sensitive species disappearing and only the most tolerant resisting (Giere 2009; Moreno et al. 2011; Balsamo et al. 2012; Mirto et al. 2012; Alves et al. 2013; Sun et al. 2014; Semprucci et al. 2015b; Zeppilli et al. 2015a; Bertocci et al. 2019).

The coastal zone of Maranhão, in Brazil, presents a mosaic of high environmental relevance ecosystems (Gama et al. 2011). However, the advancing local urban occupation has imposed strong pressures on this area (da Silva et al. 2013; Rêgo et al. 2018; Machado and Rodrigues 2020). Many areas of the state, including the northern coastal region of São Luís city presents significant human population densities, resulting in different needs and interests, and presenting economic and natural potentialities that have been extensively explored, ignoring local environmental laws (Serra and Farias Filho 2019).

With regard to São Luís coastal region, this area has suffered significant environmental degradation due to effluent discharges, solid waste inputs, the removal of coastal dunes, urban constructions in and around the beaches, beach vegetation suppression, real estate speculation, and tourism (Rêgo et al. 2018; Rodrigues et al. 2020; Santos et al. 2021; Guayanaz et al. 2022). And despite all that, coastal management initiatives are practically non-existent (da Silva et al. 2013).

Given this scenario, the present study aimed to evaluate meiofauna spatial distribution patterns between three areas suffering different disturbance levels throughout the Brazilian Amazon coast. A perturbation gradient was postulated in the studied environments and hypothesized that meiofaunal diversity and density decreases as the postulated perturbation gradient increases.

Materials and methods

Study areas

Samples were collected in São Luís city (Maranhão, Brazil), at Calhau (02º28’49.03”S; 44º14’25.79”W) and São Marcos (02º29’11.00”S; 44º18’07.20”W) beaches and Jansen Lagoon (02°29’07’’S; 44°18’02’’W) (Fig. 1). This municipality is one of the four that belong to Maranhão Island, which is inserted in the center of Maranhense Gulf, separating São José Bay to the east and São Marcos Bay to the west (Fernandes et al. 2022). This area is characterized by a macrotidal regime (tidal range up to 6.5 m), with strong currents (up to 1.2 m s^{-1}) and moderate wave heights (Hb) up to 1.1 m, with a period of 3 to 8 s (da Silva et al. 2013; Masullo 2016).

The urban development of São Luís northern coastal area is characterized by building constructions on the dune systems that run parallel to the coastline and cliffs (da Silva et al. 2013). These buildings were constructed without permits or environmental agency controls. Until the 1960s, the coastal zone of São Luís was sparsely inhabited, but

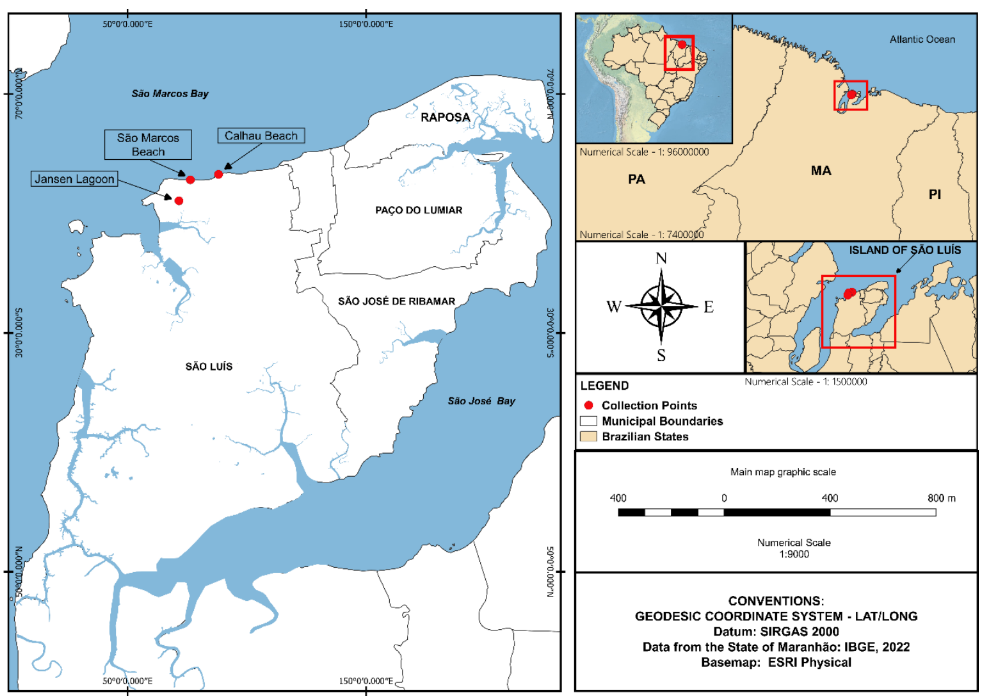

Fig. 1 Map indicating the study areas analyzed in the present study, namely São Marcos Beach, Calhau Beach and Jansen Lagoon

from the beginning of the 1970s, the city underwent a rapid and unregulated territorial expansion, resulting in several impacts (Espírito Santo 2006).

Disturbance level classification

The choice of sampling areas and disturbance level classification considered the bathing quality reports issued by the State Secretary for Environment and Natural Resources of Maranhão (*Secretaria de Estado de Meio Ambiente e Recursos Naturais do Maranhão* - SEMA) from January 2017 to July 2021. These reports were used to identify areas with the highest and lowest incidence of bathing notices. Additionally, other criteria were considered in the selection, as previous studies conducted in the same area and observations, concerning the following parameters, during the sampling campaigns: urbanization/coastal development intensity, domestic effluent discharge, the presence of domestic animals and vehicles, and the intensity of tourism (Adapted from Pereira et al. 2017) (Table 1).

Samplings procedure

Sampling was carried out in November 2021 during low tide. A transect perpendicular to the waterline was drawn in all three areas, from which ten equidistant replicas (10 m) of sediment were collected for meiofauna analyses, totaling 30 samples, using a cylindrical corer with an internal diameter of 2.4 cm to the depth of 20 cm of sediment. Sediment replicas were also collected from each area for particle size and organic matter content analysis. The meiofauna samples were fixed in a 4% formaldehyde solution, still in the field, and physicochemical water variables (pH, salinity, dissolved oxygen, ammonium, and nitrate) were determined *in loco* with the aid of a multiparameter HI9829 HANNA probe.

Laboratory procedures

Meiofauna extraction and identification

The samples were elutriated manually into a 100 mL beaker and poured onto overlapping sieves presenting 0.5 mm and 0.045 mm of apertures. This procedure was repeated three

Table 1 Sampled areas on the state of Maranhão coast (Brazil). Environmental conditions were established based on beach bathing reports, observations during sampling campaigns, and literature data

Area	Location	Disturbance level	% of improper reports between Jan/2018 and Jul/2021	Observed impacts	Impacts described in the literature
São Marcos Beach	02º29’11.00”S 44º18’07.20”W	Low	19%	Intense coastal development. Intense recreational visitation. Domestic effluent discharges from adjacent bars.	Intense and irregular urbanization resulting from real estate speculation (Silva et al. 2009; da Silva et al. 2013; Masullo 2016). Domestic effluent discharges (Silva et al. 2009; da Silva et al. 2013; Masullo 2016; Rêgo et al. 2018; Rodrigues et al. 2020; Santos et al. 2021). Presence of waste in the dunes (da Silva et al. 2013; Rodrigues et al. 2020).
Calhau Beach	02º28’49.03”S 44º14’25.79”W	Medium	84%	Moderate urbanization. Domestic effluent discharges. Presence of vehicles on the beach.	Domestic effluent discharges (Silva et al. 2009; Santos et al. 2021). Sediment compactation (Santos et al. 2021). High concentration of *Enterococcus* (da Silva et al. 2008). Presence of debris on the beach sand (Guayanaz et al. 2022) Recurrent presence of black tongue* (G1 MA 2018, 2019; Estado 2016, 2017, 2020, 2021).
Jansen Lagoon	02°29’07”S 44°18’02”W	High	Not applicable	Intense urbanization. Domestic effluent discharges. Presence of solid waste and animals. Intense foul odor. Chemical products thrown in the water by adjacent residences aiming at reducing the odor.	High total and thermotolerant coliform indices (Pereira et al. 2014; Santos et al. 2014). In natura sewage discharges (Ibañez Rojas et al. 2013; Pereira et al. 2014; Cutrim et al. 2019; Silva 2021). High phosphate values (Ibañez Rojas et al. 2013). Intense fetid odor (Silva 2021). Presence of solid waste (Silva 2021).

*Term used to describe a black residue caused by direct sewage discharge on the beach, from a neighbor malfunctioned Sewage Treatment Station, resulting in the Calhau River pollution and consequent spillover at Calhau Beach.

times for each sample to maximize organism extraction. The material retained on the 0.045 mm sieve was washed with the aid of a beaker and transferred to a Dollfus plate. The meiofauna was then counted and identified to the level of the main taxonomic groups according to Giere (2009) under a stereomicroscope and microscope, and their density was standardized to individuals per 10 cm^{-2}. All extracted organisms were placed in Eppendorfs containing 70% alcohol.

Sediment analysis

The granulometric analysis was performed according to Suguio (1973). The samples were dried in an oven at 60º C and characterized in particle size, combining the wet sieving technique (sieve > 62 µm) and pipetting. The processing was determined according to the Wentworth scale (1922), with nominal sample classifications carried out according to Folk and Ward (1957). Organic matter content was determined following the muffle ignition of 50 g of dry sediment stored in porcelain crucibles and muffled for 12 h at 45 ºC (Walkley and Black 1934). After being removed from the muffle, the sediment was weighed again and the difference in weight meant the amount of organic matter (OM) of each sample volatilized during the ignition process.

Numerical and statistical analyses

The Shapiro-Wilk test (Shapiro and Wilk 1965) and Levene's test (Levene 1960) were used to verify data normality and homogeneity, transformed in log (x + 1). To analyze community structure, density (N), expressed as number of individuals per 10 cm^{-2}, and richness, expressed as number of taxa (S), were calculated. An Analysis of Variance (ANOVA) One-Way was used to verify significant variations in ecological descriptors between sampled areas. Significant variations were compared using Tukey's *a posteriori* test.

Community structure was compared between studied areas using Permutational Multivariate Analysis of Variance (PERMANOVA) with 9999 permutations, based on a Bray-Curtis similarity matrix (Anderson 2014). An nMDS graph was constructed to visualize associations between groups. Relationships between taxa abundance and water and sediment environmental variables were analyzed through a Canonical Correspondence Analysis (CCA) (ter Braak 1986). The Variance Inflation Factor (VIF) was tested to reduce collinearity between variables, but none had to be removed. Finally, CCA significance was tested by an ANOVA test. A significance level of 0.05 was established for all analyses. All multivariate analyses were performed using log (x + 1) transformed data to adjust for the contribution of dominant and rare species (Clarke 1993).

All analyses were performed using the R software (R Core Team 2022) packages car (Fox and Weisberg 2019), ggplot2 (Wickham 2016), lattice (Sarkar 2008), permute (Simpson 2022), and vegan (Oksanen et al. 2022).

Results

Environmental variables

The average salinity was $\bar{X}$ = 14.35 (± 10.58) among the three study areas, with the lowest and highest values registered at Calhau Beach (2.16) and São Marcos Beach (21.2), respectively. Dissolved oxygen (DO) values ranged from 27.40% at the lagoon to 31.70% at São Marcos Beach ($\bar{X}$ = 29.7 ± 2.16). As for pH, values of 6.32, 6.82 and 7.49 were observed for São Marcos Beach, Calhau Beach and Jansen Lagoon, respectively ($\bar{X}$ = 6.87 ± 0.58) (Fig. 2).

Regarding ammonium (NH_4^+), nitrate (NO_3^-), and organic matter (OM) concentrations, the average values for the study areas were 60.13 (± 9.35), 8.8 (± 2.48), 14.6 (± 13.27), respectively, with Jansen Lagoon presenting the highest absolute values for each variable (NH_4^+ = 170.2 µmol L^{-1}; NO_3^- = 23.22 µmol L^{-1}; OM = 30 g dm^{-3}) (Fig. 2).

Granulometry

The sediment in the three study areas was characterized as fine, well sorted or very well sorted sand, corresponding to 97%, 84% and 52% of total sediment at São Marcos and Calhau beaches and Jansen Lagoon, respectively. The second most abundant fraction was coarse sand. Silt and clay fractions were detected only at Jansen Lagoon (Fig. 3).

Meiofauna community

A total of 7,254 meiofaunal organisms were identified, distributed in 10 taxa in the three study areas, 4,371 at São Marcos Beach, 1,856 at Jansen Lagoon and 1,027 at Calhau Beach. The richness detected at São Marcos Beach (10) and Jansen Lagoon (8) were similar, although the faunal composition varied between them, while Calhau Beach presented the lowest value (5) for this descriptor (Table 2).

The total density of individuals was 301.7 ind.10 cm^{-2}, ranging from 125.04 ind.10 cm^{-2} (Copepoda) to 0.04 ind.10 cm^{-2} (Kinorhyncha). Copepod was the taxon with the highest density, at São Marcos Beach (125.04 ind.10 cm^2), meanwhile at Jansen Lagoon, the highest density taxon was Nematoda (73.08 ind.10 cm^{-2}) and at Calhau Beach, Tardigrada (23.83 ind.10 cm^{-2}) (Table 2).

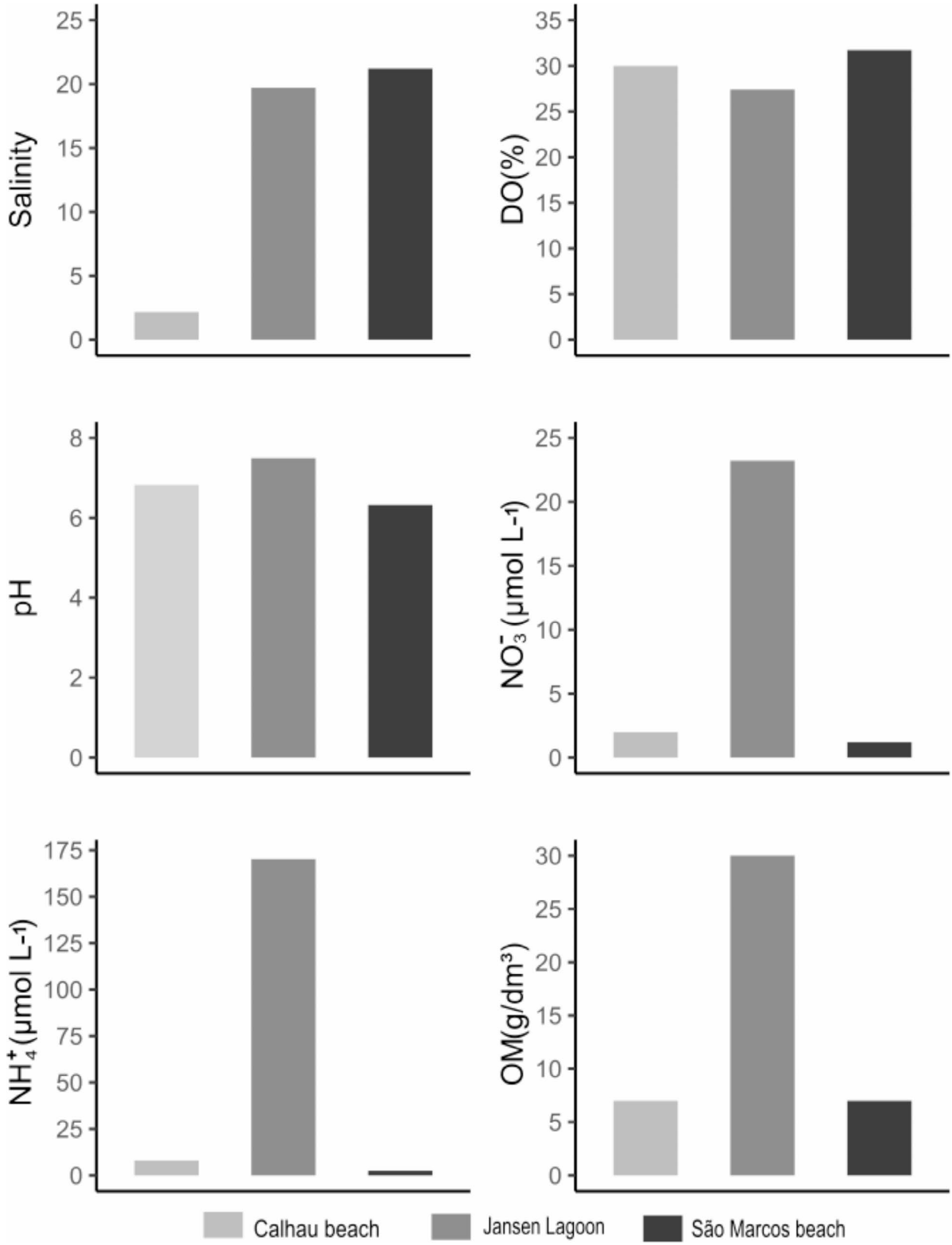

Fig. 2 Environmental variables determined in the three study areas

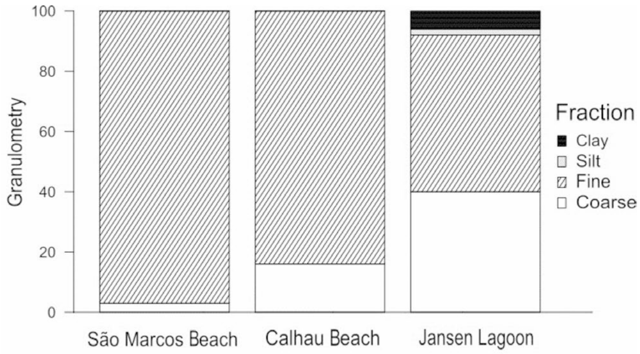

Fig. 3 Sediment sample granulometry at São Marcos and Calhau beaches and Jansen Lagoon

Copepoda was the most abundant group (41.85%), followed by Nematoda (39.21%), representing 81% of all identified organisms. Copepoda Harpacticoida were noteworthy among the other identified taxa at São Marcos Beach, accounting 69% of the relative organismal abundance. Jansen Lagoon was almost totally dominated by Nematoda, which contributed with 95% of the relative abundance in this area. At Calhau Beach, the predominant meiofaunal group was Tardigrada, which made up 56% of the relative organismal abundance (Fig. 4).

The ANOVA results indicate that density and taxa richness differed significantly among the study areas. The PERMANOVA result indicated a dissimilarity in meiofaunal community structure (Table 3). Paired comparisons indicated that density was significantly higher at São Marcos Beach compared to Calhau Beach and Jansen Lagoon, with no significant difference detected between the last two. Richness was significantly lower at Jansen Lagoon compared to São Marcos and Calhau beaches (Fig. 5).

The nMDS analysis demonstrated a clear separation between studied areas in terms of community structure, forming three distinct groups, corroborating PERMANOVA results (Fig. 6).

The CCA was significant ($p = 0.03$) and indicated that 90% of explained data variance associated species density and environmental variables (Axis I: 55.64%; Axis II: 34.36%). Nematoda, Oligochaeta and Bivalvia were positively influenced by OM, pH, NO_3^-, NH_4^+ and fine sand at Jansen Lagoon. At São Marcos beach, Copepoda, Polychaeta, Nemertea, Kinorhyncha and Turbellaria were positively influenced by DO, while Tardigrada were negatively influenced by salinity, at Calhau Beach (Fig. 7).

Table 2 Taxa density in ind. cm^{-2} (D), frequency of occurrence in percentage (Fo) and richness (S) at each study area

Taxa	São Marcos Beach		Jansen Lagoon		Calhau Beach	
	D	**Fo**	**D**	**Fo**	**D**	**Fo**
Nematoda	31.41	100	73.08	100	14.04	100
Copepoda Harpacticoida	125.04	100	0.41	50	1.04	80
Turbellaria	22.29	100	0.29	40	3.83	60
Nemertea	1.87	50	0.20	20	0	0
Tardigrada	0.62	50	0	0	23.83	100
Oligochaeta	0	0	3.08	40	0.04	10
Polychaeta	0.58	50	0	0	0	0
Acari	0.08	20	0.04	10	0	0
Bivalvia	0.16	30	0.20	20	0	0
Kinorhyncha	0.04	10	0	0	0	0
Overall density	**182.09**		**77.3**		**42.78**	
Overall S	10		8		5	

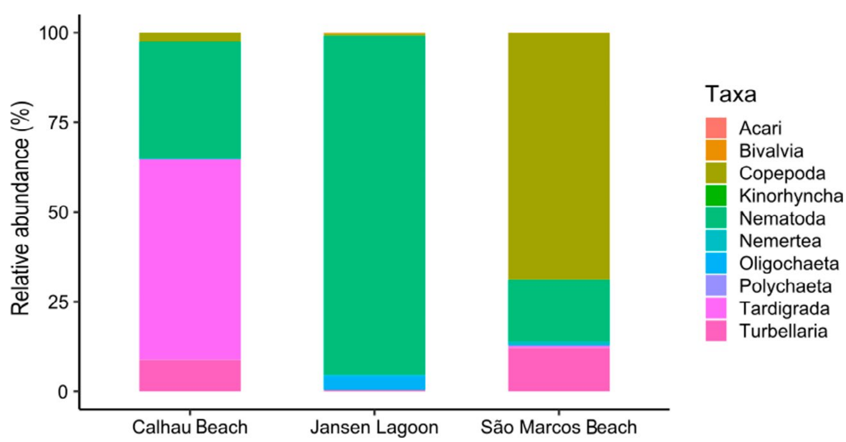

Fig. 4 Relative abundance of each meiofaunal taxa identified at Calhau Beach, São Marcos Beach and Jansen Lagoon

Table 3 Summary of ANOVA density and richness results and PERMANOVA meiofaunal community structure results for Calhau Beach, São Marcos Beach and Jansen Lagoon

Factor	Density				Richness			Community structure		
	df	MS	F	*p*	MS	F	*p*	MS	Pseudo-F	*p*
Areas	2	524.68	6.39	0.005	13.9	9.15	0.0009	0.4	12.17	0.0004
Residuals	27	82.01			1.51			0.52		

df = degrees of freedom; MS = means square; F = F-statistic; *p* = *p* value

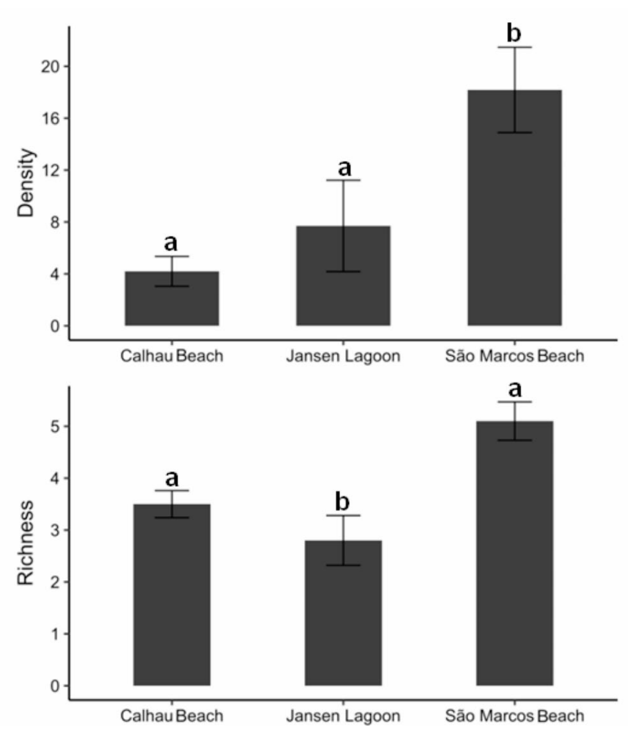

Fig. 5 Average and standard deviations of the analyzed samples density and richness. Different letters indicate statistically significant differences detected by Tukey's test

Discussion

Although meiofaunal communities varied among areas suffering different disturbance degrees, forming three distinct groups according to the nMDS analysis, meiofaunal diversity and density did not decrease according to the postulated disturbance gradient. It was expected that Jansen Lagoon would present the lowest values for the analyzed descriptors, which was, instead, observed for Calhau Beach. São Marcos Beach presented the expected pattern for a less impacted environment, displaying the highest density and richness values. Despite the results, we assume that the richness in the present study is being underestimated due to the low taxonomic resolution used.

Jansen Lagoon exhibited a high density of Nematoda, which tend to increase in contaminated environments (Bouwman et al. 1984; Ferraz et al. 2022), as in this lagoon's case, which receives large loads of surface runoff and pollutants. The overlap of this taxa is explained by its high resistance to osmotic stress (Forster 1998; di Montanara et al. 2022; Jonathan 2022) and ability to use enriched sediment organic content as a potential food source (Bongers and Ferris 1999; Losi et al. 2021; Jonathan 2022; Xu et al. 2022). Furthermore, these worms exhibit a strong relationship with fine sediments (Vanaverbeke et al. 2002; Semprucci et al. 2010, 2015a; Baia and Venekey 2019), such as those found in the lagoon.

Among the three study areas, Jansen Lagoon presented the second highest taxa density and richness, which may be associated to the higher OM in this area compared to others, explaining the correlation between this parameter to this area in the CCA. Meiofauna composition can increase according to sediment OM, and higher OM concentrations are usually associated to higher amounts of organisms (Mouawad et al. 2012). However, although OM from domestic sewage benefits marine meiofauna as a potential food source, negative effects may arise when OM is present in excess, causing anoxic conditions or generating hydrogen sulfide (H_2S) when degraded by anaerobic bacteria (de Oliveira and Soares-Gomes 2003).

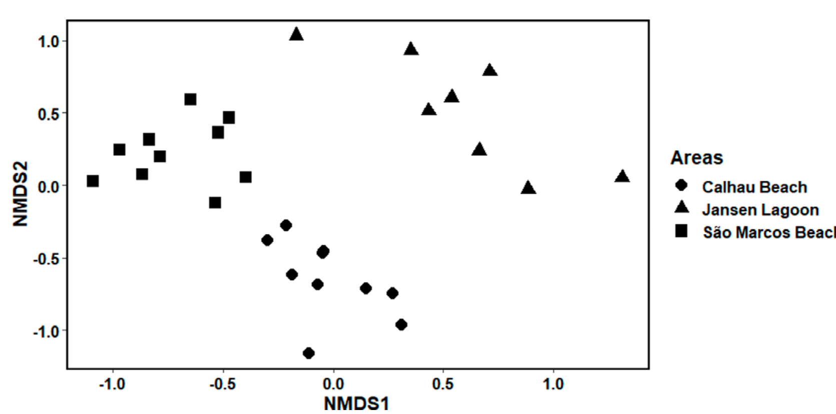

Fig. 6 Similarities between community structure of studied areas according to nMDS analysis

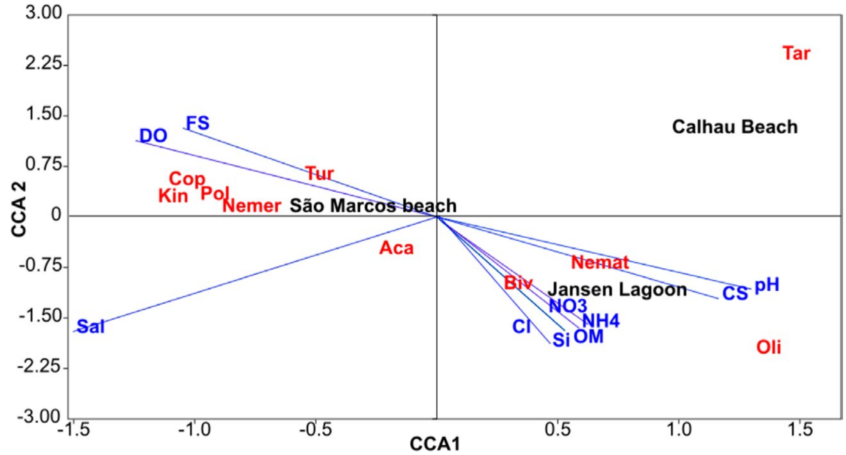

Fig. 7 CCA results concerning meiofauna composition and environmental variables. FS: fine sand. CS: coarse sand. Cl: clay. Si: silt. DO: dissolved oxygen. Sal: salinity. pH: hydrogenic potential. NO3: nitrate. NH4: ammonium. OM: organic matter. Tur: Turbellaria. Cop: Copepoda. Pol: Polychaeta. Kin: Kinorchyncha. Nemer: Nemertea. Aca: Acari. Biv: Bivalvia. Nemat: Nematoda. Oli: Oligochaeta. Tar: Tardigrada

Despite the concentration of ammonium and nitrate, in three study areas, being within the parameters allowed by Brazilian Environmental Legislation for saline and brackish waters (Brasil 2005), the concentration of these parameters was significantly higher in Jansen Lagoon, when compared to the other areas. Ammonium and nitrate occurs in water as a final product of organic nitrogen biological degradation and is generally used as a poor water quality indicator (Mouawad et al. 2012). Moreover, high concentrations of this nitrogenous compound can lead to an excessive microalgae proliferation, with consequent increases in the amount of chlorophyll-a and intense eutrophication events (Penna et al. 2004; Bertocci et al. 2019). Eutrophication can make sediment hypoxic or anoxic (Penna et al. 2004) and benefit opportunistic species (Rabalais et al. 2001; Vanaverbeke et al. 2004a, b; Carriço et al. 2013; Semprucci et al. 2015a). When not associated with oxygen limitation, eutrophic conditions can increase microbial activity and, eventually, meiofauna abundance and diversity (Giere 2009).

Copepoda also presented high density. The CCA correlated the abundance of this taxon at São Marcos Beach to sediment DO. Copepods are more representative in well-oxygenated environments (Coull 1999; Moreno et al. 2006; De Troch et al. 2013; Hure et al. 2020; Medellín-Mora et al. 2021) and exhibit a relatively larger presence compared to Nematoda at tropical beaches (Giere 2009), as observed at São Marcos Beach.

Copepoda stood out in terms of density and relative abundance at São Marcos Beach. This group is considered more sensitive to environmental disturbances than other meiofaunal groups (Raffaelli and Mason 1981; Hicks and Coull 1983; Van Damme et al. 1984; Raffaelli 1987; Gheskiere et al. 2005; Pereira et al. 2017). The dominance of these organisms at São Marcos Beach may be indicative of good environmental quality of this beach, while its near absence at Jansen Lagoon and Calhau Beach may indicate serious disturbances in both areas.

Tardigrada displayed the highest density at Calhau Beach, which is not common, as its density is rarely very high, even in favorable locations (Giere 2009). This result may be related to the low salinity of the study site (Kinchin 1994), corroborating Tilbert et al. (2019), who reported that the highest density values of this group coincided with the low salinity gradient. It is likely that these animals have a wide distribution in brackish water, probably alternating between metabolic activity and inactivity (osmobiosis), according to salinity concentration variations (Kinchin 1994).

Calhau Beach exhibited the lowest richness among the three studied areas, potentially due to OM excess and low salinity, as benthic species usually occur in high salinity and low variability areas (Barroso and Matthews-Cascon 2009; Hourston et al. 2009; La Valle et al. 2021; Laurino and Turra 2021). These factors, in turn, may be related to the presence of Calhau River tributary and nearby a Sewage Pumping Station (SPW). This SPW contributed to the occurrence of the phenomenon known as “Black Tongue” from 2016 to 2021 (G1 MA 2018, 2019, Estado 2016, 2017, 2020, 2021), involving *in natura* SPW sewage releases which, due to malfunctioning, resulted in Calhau River pollution and consequent spillover at Calhau Beach (G1 MA, 2018). Based on these results, it is possible to infer that the conditions on this beach are so adverse that only organisms displaying extreme resilience, such as Tardigrada, are able to survive.

Calhau Beach also suffers from sediment compaction by motor vehicles, some belonging to the municipal government, responsible for waste management (*in loco* observation). Sediment compaction reduces the space between sediment grains and increases resistance to fluid (gas and liquid) displacement, creating a physical barrier that affects air exchanges and hydraulic conductivity between interstices (Schlacher et al. 2008; Giere 2009), affecting benthic fauna severely.

Nematoda and Copepoda are generally considered the most suitable taxa to assess meiofaunal community ecological conditions (Moore and Bett 1989; Cifoni et al. 2021; Cui et al. 2021). However, although other studies have also reported significant meiofauna responses to environmental disturbances when employing higher taxonomic categories (Moreno et al. 2006; Bianchelli et al. 2016a, b; Pereira et al. 2017; Losi et al. 2021), as in the present study, many authors recognize that increased taxonomic resolution is necessary to better understand ecological patterns (Moore and Bett 1989; Balsamo et al. 2012; Zeppilli et al. 2015). Identification at a specific level allows for more accurate assessments regarding community structures and sentinel species ecology assessments, which may be employed to detect anthropogenic impacts (Moreno et al. 2011; Losi et al. 2021; Sahraeian et al. 2020).

Conclusion

Data reported herein indicated decreased density and richness at different patterns than expected, as the most visually polluted area in this study, and considered the most disturbed one, exhibited higher density and richness than the one initially categorized as moderately disturbed. Therefore, the results indicate that Calhau Beach suffers much more significant impact compared to Jansen Lagoon, which exhibited high density of Nematoda, benefited from high OM content. São Marcos Beach showed a high density of Copepoda, indicating a higher environmental quality. In contrast, Calhau Beach presented a high density of Tardigrada, organisms known for their remarkable ability to withstand adverse situations.

Meiofaunal community varied significantly in studied areas and meiofaunal composition was significantly affected by environmental variables such as salinity, OM, sediment grain size and nitrate concentration, corroborating literature data regarding the influence of organic enrichment and sediment contamination on meiobenthic nematodes.

This is the first study to compare spatial meiofauna distribution in areas under marine influence on the Island of Maranhão and suffering environmental disturbances. These findings will contribute to coastal management programs and to the development of public policies aimed at the conservation of São Luís coastal zone, taking into account that this municipality is an important tourist hub in Maranhão state. Future studies are recommended to assess the temporal effects of anthropogenic pressures on the meiofaunal community structure of these areas and increase taxonomic resolution, at least for dominant taxa.

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Declarations

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

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