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SPATIAL-TEMPORAL DISTRIBUTION OF POLYCHAETA IN URBANIZED SANDY BEACHES OF NORTHEASTERN BRAZIL: TOOLS FOR ENVIRONMENTAL ASSESSMENT

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Abstract: In the last years, the use of Polychaeta as indicators of marine pollution has intensified, due to the sensitivity of these organisms to environmental variations and their significant presence in quantitative and qualitative terms when compared to other benthic fauna organisms. We aimed to analyze the Polychaeta assemblage of two urbanized beaches in São Luís – Maranhão (Brazil), focusing on spatial-temporal distribution and look for the relation of the species sampled and possible contamination to indicate if they are suitable for environmental assessment. Sediment collection was carried out in the intertidal zone of both beaches in dry (September and November/2015) and rainy periods (March and May/2016). The samples were screened for extraction of the species, which were classified at the lowest possible taxonomic level. The samples revealed the following taxa: Lumbrineridae (*Scoletoma tetraura*), Nereididae (*Laeonereis culveri*) and Spionidae (*Scolelepis* sp.). The diversity and abundance of Polychaeta were greater on Caolho Beach. On these beaches, organic enrichment is not the determining variable in the structure of the Polychaeta assembly. Other studies are needed to improve the knowledge on other macrofauna species of the studied areas, comparing the richness among microhabitats and seasons, and thus elaborate conservation strategies for these ecosystems; and to test the hypothesis of the influence of tourism on this assemblage.

Keywords: benthos; bioindicators; marine pollution.

INTRODUCTION

Environmental changes of anthropic origin can have significant effects on the biodiversity and functioning of beaches (Veloso *et al.* 2008). Benthic organisms besides being dominant in these environments are sensitive to disturbances and, therefore, are useful tools for monitoring the state of conservation of those areas (Veloso *et al.* 1997, Yong & Lim 2009). Because of the relatively low mobility, they are representative of the area in which they are collected (Queirós *et* *al.* 2013). These organisms have a relatively short life cycle, are closely associated with sediments, have high biological diversity, and are important components of aquatic ecosystems (Schratzberger & Ingels 2018).

In the last years, the number of studies using benthic communities for environmental assessments have increased (Amaral *et al.* 1998, Gesteira & Dauvin 2000, Blankensteyn 2006, Mangion *et al.* 2017, Bonanno & Orlando-Bonaca 2018, Santos & Ferreira 2019). Aside from the sensitivity to environmental disturbances, the use of Polychaeta as indicators of marine pollution has intensified, due to their significant presence in quantitative (e.g. abundance) and qualitative terms (e.g. functional traits), when compared to other benthic fauna organisms, like crustaceans (Amaral *et al.* 1998, Feres *et al.* 2008). Besides, the collection can be made using low-cost tools, not requiring very sophisticated technical instruments (Maia *et al.* 2001).

Some Polychaeta species are highly tolerant to pollution and low oxygen stress, such as presented during the organic enrichment process (Reish 1986, Amaral *et al.* 1998, Elias *et al.* 2004, 2005, Dean 2008). Besides, they present physiological and behavioral adaptations to benefit from the increased food supply and reduced competition (Rocha *et al.* 2013), as the ability to feed on deposits (Fauchald & Jumars 1979). Other species, however, do not tolerate the hypoxic and/or anoxic conditions created by the enhanced decomposition activity, generated by the increased organic input, or the high concentrations of hydrogen sulfide produced by anaerobic bacterial activity (Amaral *et al.* 1998). So, assessing the structure of the Polychaeta assemblage and its spatio-temporal patterns are important for monitoring the environmental quality of coastal ecosystems.

Sandy beaches have been suffering increasing modifications and degradation due to the disorderly occupation of coastal areas and tourism. In Brazil, in particular, there is no adequate environmental planning, and besides the intense real estate speculation in coastal regions, investments in infrastructure for basic sanitation are scarce (Oliveira & Nicolodi 2012, Scherer 2013, Klumb-Oliveira & Souto 2015, Obraczka *et al.* 2017, Seixas *et al.* 2018). Coastal management in Brazil is still incipient and concentrates, in the vast majority of cases, on the implementation of protected areas devoid of participatory management, especially in the south and southeast regions of the country (Seixas *et al.* 2018). The localization of beaches is also important, because dilution factors in coves and bays are much lower than those observed in open coastal regions. The decrease in water renewal rates in these regions favors the concentration of pollutants, thus limiting the dilution capacity of the receiving environment (Amaral *et al.* 1998, Feres *et al.* 2008, Fistarol *et al.* 2015).

On the coast of São Luís municipality (Maranhão) the water quality is compromised, as there are no adequate sewage collection and treatment systems. Marine waters receive domestic and industrial organic effluents unduly discharged into rivers and streams, transporting them to the sea (Santos et al. 2005). Considering the importance of benthic fauna for the biomonitoring of marine environments and for coastal management, this study evaluated the Polychaeta assembly on two urbanized beaches, with research focused on space-time distribution, effect of environmental variability on the assembly (including organic content as a proxy for nutrient load), and individual taxon.

MATERIAL AND METHODS

Study Area

The Island of São Luís (02º23’00”; 02º47’00” S and 44º00’29”; 44º24’29” W), located in the center of the Golfão Maranhense and north coast of the state of Maranhão, Northeast Brazil (Figure 1), includes an area of 1.453 km²; separates the bays of São José to the east (which receives the Itapecuru and Munim rivers) and São Marcos to the west (which receives the Mearim, Pindaré and Grajaú rivers) (Rios 2001). São Marcos (02º29’01” S; 44º16’74” W) and Caolho beaches (02º29’03” S; 44º15’11” W) were selected on Island of São Luís, located in the northern coastal area of the city of São Luis and are about 6.7 km away from each other (Figure 1). In both beaches there are tides of the semidiurnal type; with an average amplitude of 4.6 m, reaching the climax of 7 m during spring tides. These are dissipative beaches with an intertidal width of 300 m.

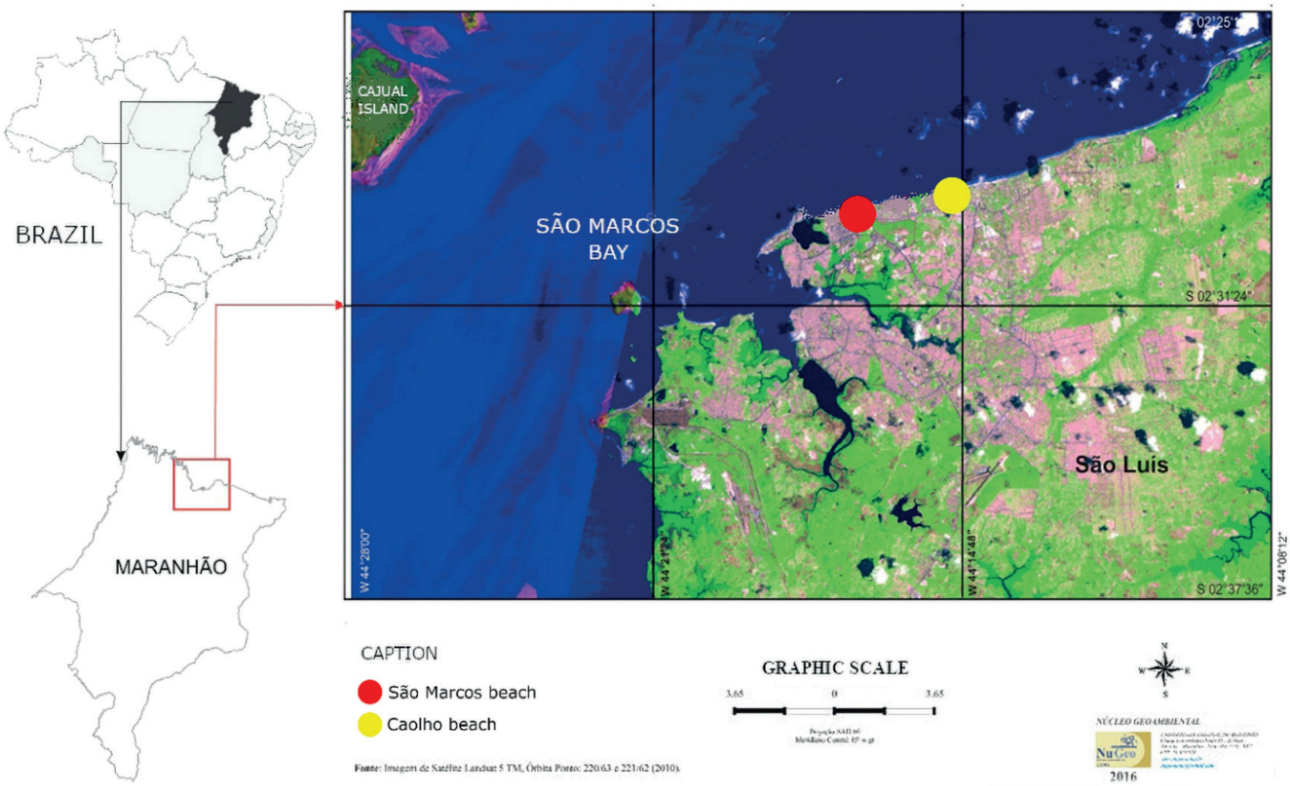

Figure 1. Study area: São Marcos and Caolho beaches, São Luís, Maranhão state, Northeast Brazil.

The two beaches are urbanized and located in areas without basic sanitation programs, thus subject to contamination due to domestic and industrial effluents. Solid waste is disposed of near the beach huts, and effluent from houses and pubs and are continuously dumped on the shore (Masullo 2016, Maranhão 2020). Still, they are tourist points of great importance for the capital of Maranhão (Costa 2017).

Data collection

The collections were made in the intertidal area of each beach during September and November 2015 (dry season) and March and May 2016 (rainy season), during the low spring tides, according to the Tide Table (DHN 2015, 2016). To obtain the samples, three zones (50 m away) perpendicular to the beach line were delimited: A (upper mesolittoral), B (intermediate mesolittoral) and C (lower mesolittoral). In each zone, three samples of sediment (10 m distance) were collected using a PVC collecting cylinder (10 cm diameter × 20 cm depth), totaling nine samples per beach.

Temperature, salinity, and pH of the interstitial water were measured *in situ*, with a HANNA HI-9828 multiparameter probe, from one randomly chosen replicate per zone during the four months of sampling in each beach. One sediment sample, for particle size and organic matter content analysis, was collected per zone in each beach and month of sampling and analyzed at the Laboratory for Geological Oceanography Studies, Federal University of Maranhão (LEOG/UFMA) according to Walkley and Black (1934) and Suguio (1973).

The samples for biological data analysis were screened in the field with a 0.5 mm diameter per pore sieve; the organisms found were packed in plastic jars, labeled, anesthetized with 7 % magnesium chloride, fixed in a 4 % formaldehyde solution, and transferred to 70 % alcohol to be preserved. In the Plant and Marine Biology Laboratory of the State University of Maranhão (UEMA), all the collected Polychaeta were observed on a stereomicroscope and identified to the lowest taxonomic level possible. For the identifications, specialized literature was adopted (Fauchald 1977, Uebelacker & Johnson 1984, Amaral & Nonato 1996). The collected material was deposited in the biological collection of the above-mentioned laboratory. The collections were authorized by the Authorization and Information in Biodiversity System (SISBio/ICMBio), license number 23716/2015.

Data analysis

The data were tested for normality, using the Shapiro-Wilk test, and for homoscedasticity, using the Levene's test, to check validity of the assumptions for parametric tests, which were met. The environmental variables of interstitial water were statistically compared by Two-way Analysis of Variance, considering additive and interation effects of season (dry and rainy) and local (Caolho and São Marcos beaches). The assemblage structure was statistically compared by Two-way PERMANOVA (beaches and seasonal periods), considering the total density values (ind/m²) of the organisms. The probability value of PERMANOVA was obtained through the Monte Carlo randomization method, based on 9,999 permutations. To analyze the influence of environmental variables on the occurrence and distribution of Polychaeta, the Canonical Correspondence Analysis (CCA) was performed with the same number of replicates for environmental (interstitial and sedimentary) and biological samples. Environmental variables whose values were equal to zero or almost zero were discarded. The data used were log-transformed (x+1).

The univariate and multivariate analyses mentioned above were performed as proposed by Clarke and Ainsworth (1993), Clarke and Warwick (1994) and Anderson *et al.* (2008). Paleontological Statistics Software Package for Education and Data Analysis (PAST v.4.02, Hammer *et al.* 2020) and Plymouth Routines in Multivariate Ecological Research (PRIMER v.6, Clarke *et al.* 2014) were used to perform the statistical analysis.

RESULTS

Environmental variables

During the four months of collection, salinity varied from 22 to 34 (= 29.75 ± 5.43); temperature varied from 27 to 32 ºC (= 29.25 ºC ± 2.21) and pH varied from 7.45 to 8.85 (= 8.22 ± 0.62) (Figure 2). There was no significant variation in any of the environmental variables between beaches, seasons, or in the interaction between factors (Table 1). The substrate was predominantly characterized as fine sand with high organic matter content (Table 2).

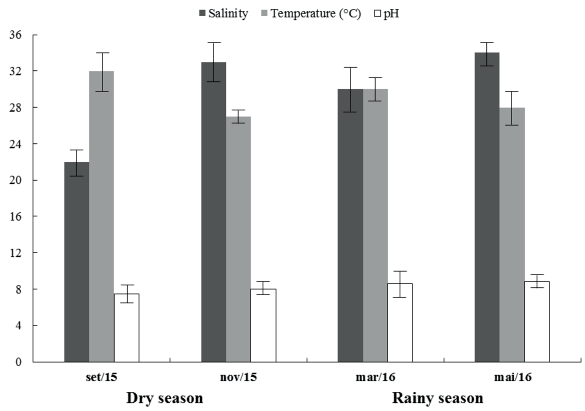

Figure 2. Average and standard deviations of interstitial water variables during the dry and rainy periods, at São Luís - MA beaches.

Biological data

During the study period, 91 individuals were sampled, 38 in the dry season and 53 in the rainy season. A total of 24 specimens, all belonging to the same species (Nereididae – *Laeonereis culveri* Webster 1879) were collected at São Marcos Beach. At Caolho Beach, 67 specimens were collected, distributed in three different families, each one with a single species (Lumbrineridae – *Scoletema tetraura* Schmarda 1861; Nereididae – *L. culveri*; Spionidae – *Scolelepis* sp.). In both beaches, only the upper mesolittoral (Zona A) presented Polychaeta (Table 3). PERMANOVA showed significant variation only in composition between beaches (Table 4).

In the Canonical Correspondence Analysis, the Axis 1 explained almost 22.7 % of the variation due to the predominance of the fraction of fine sand, which created a strong gradient in the axis. *Scolelepis* sp. had greater relation with organic matter and negative association with temperature. *S. tetraura* was positively related with pH, salinity and medium sand in Caolho beach, while *L. culveri* was positively related with fine sand and temperature and negatively with salinity (in both beaches) and organic matter (Figure 3).

DISCUSSION

The results point localizations with high organic matter content and low density and richness of lumbrinerid, nereidid, and spionid Polychaeta, comparing with other beaches in the region (Coelho-Costa 2007, Feres *et al.* 2008, Cutrim 2017, Tavares-Cutrim *et al.* 2018). The degree of sediment

Table 1. Analysis of variance (ANOVA) Two-way results for interstitial water variables sampled between locations (Caolho and São Marcos beaches) and seasons (dry and rainy season).

Source	df	Salinity			Temperature			pH		
		Ms	F	p	Ms	F	p	Ms	F	p
Beaches	1	2	0.1	0.76	2	0.38	0.57	0.005	0.04	0.83
Seasons	1	32	1.7	0.26	0.5	0.09	0.77	0.29	2.49	0.18
Interaction	1	0.5	0.02	0.87	2	0.38	0.57	0.01	0.14	0.72
Residual	4	18.75			5.25			0.11		
Total	7									

Table 2. Granulometry classification of the Caolho and São Marcos beaches during the dry and rainy seasons, based on Wentworth (1992) classification and in the degree of selection from Folk and Ward (1957).

	Caolho Beach		São Marcos Beach	
	Dry season	Rainy season	Dry season	Rainy season
Sediment	Fine sand	Fine sand	Fine sand	Fine sand
Selection	Well-selected	Well-selected	Moderately selected	Well-selected
Fine sand (%)	90.42	96.29	95.05	92.92
Medium sand (%)	6.8	3.14	4.7	6.76
Coarse sand (%)	0.98	0	0.25	0.32
Clay (%)	0	0	0	0
Silt (%)	1.8	0.57	0	0
Organic matter (%)	28	30	33	32

selection is an important factor in the abundance and distribution of benthic organisms. At our sampling sites, the sediment was classified as moderately to well-selected (more homogeneous), which may influence the structure of the local Polychaeta assemblage, since poor or very poor selected sediments harbor a greater diversity of species, the increase in heterogeneity is probably caused by the creation of several microhabitats (Omena & Amaral 1997, Capitoli & Bemvenuti 2004, Zalmon *et al.* 2013). Moreover, the low sampling effort, when compared to the studies mentioned above, may have influenced the low values of density and richness.

The high percentages of organic matter in Caolho and São Marcos beaches are strongly related to the organic enrichment, probably as a result of the expressive urbanization in São Luís shore, the non-existence of basic sanitation and deficient seawater quality. The low quality of water is shown by the presence of unsuitable points for bathing since 2015, when the State Secretary of Environment started monitoring the beaches of São Luís (Maranhão 2020). This enrichment process has already been reported for São Marcos beach (Masullo 2016, Silva *et al.* 2009, 2013, Trindade *et al.* 2011) and has also been observed in other beaches of São Luís (Feres *et al.* 2008, Silva

Table 3. Absolute abundance (Ab.Ab.), relative abundance (Ab.Rel.), abundance in the dry season (Ab. Ds.) and abundance in the rainy season (Ab.Rs.) of Polychaeta species sampled at São Marcos and Caolho beaches, São Luís – MA.

	Family	Species	Ab.Ab.	Ab.Rel.(%)	Ab.Ds.	Ab.Rs.
São Marcos Beach	Nereididae	*Laeonereis culveri*	24	26.37	9	15
	Lumbrineridae	*Scoletoma tetraura*	16	17.58	11	5
Caolho Beach	Nereididae	*Laeonereis culveri*	48	52.74	18	30
	Spionidae	*Scolelepis* sp.	3	3.29	0	3

Table 4. PERMANOVA results for differences in Polychaeta assemblage structure between locations (Caolho and São Marcos beaches) and stations (dry and rainy season). Significant values in bold.

Source	df	Mean square	Pseudo-F	p-value
Beaches	1	0.22	0.85	**0.04**
Seasons	1	0.03	0.14	0.87
Interaction	1	0.02	0.08	0.95
Residual	20	0.27		
Total	23			

et al. 2008, Serra & Farias Filho 2019, Rodrigues *et al.* 2020).

Besides the anthropic contribution of organic matter, the fact that those beaches are close to estuarine environments, with the presence of mangroves on their edges, stands out. This type of environment carries fine and particulate material, rich in organic matter, to the interstitial system, which, in very high quantities, may lead to an enrichment process, that can harm the fauna due to the oxygen depletion (Gray & Pearson 1982, Rosenberg *et al.* 1992). Rainer and Fitzhardinge (1981) found that low oxygen levels are one of the most important factors in limiting species in sites with extreme conditions when compared with other factors such as temperatures and salinities. Periods of oxygen deficiency can negatively affect the abundance, distribution, and biomass of species in many coastal environments (Rosenberg & Loo 1988, Desprez *et al.* 1992).

The species *L. culveri* was correlated positively with temperature and negatively with salinity and organic matter. The wide distribution of this organism is related to high tolerance to temperature and salinity variations, being abundant in environments with wide salinity ranges (Pettibone 1971). Using the organic matter content as proxy of enrichment, the CCA shows a negative correlation between *L. culveri* and this variable. This implies that the increase in organic matter is limiting the growth of the population of this species, which would not be expected from an indicator of contamination.

The results observed for *L. culveri* differ from those found in other studies with this species. High population densities of Nereididae individuals were observed by Amaral *et al.* (1998) on beaches from São Paulo with different degrees of organic pollution, mainly on beaches classified by the Companhia Ambiental do Estado de São Paulo

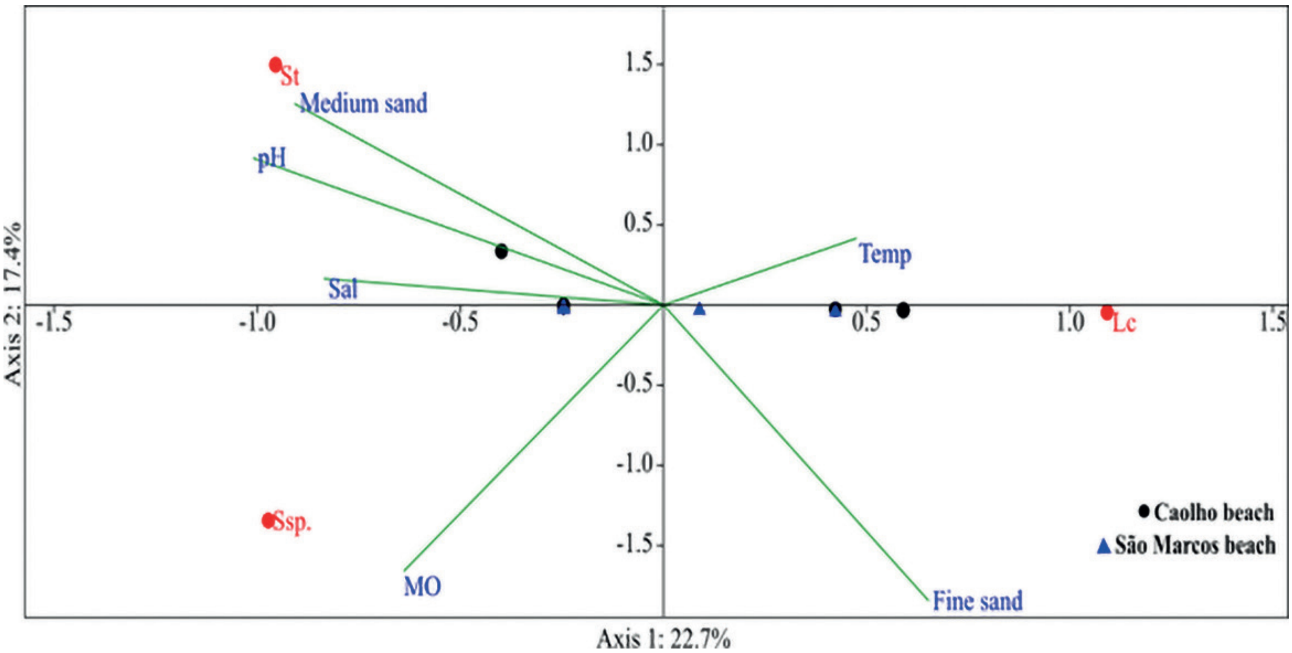

Figure 3. Canonical Correspondence Analysis between environmental variables, rate density and sampled beaches. St – *Scoletoma tetraura*; Lc – *Laeonereis culveri*; Ssp. – *Scolelepis* sp.; Sal – Salinity; Temp – Temperature; MO – Organic matter.

(CETESB) as inappropriate (São Paulo, 2020). Feres *et al.* (2008), studying Polychaeta families as bioindicators of organic pollution in Ponta d'Areia and Araçagy beaches, both in São Luís, verified that the Nereididae family was the most abundant species at the assemblage. However, in the studies cited, the authors could not identify all the taxa at the species level.

The genus *Scolelepis* is composed of deposit-feeding species (Fauchaud & Jumars 1979, Jumars *et al.* 2015), which are associated with organically enriched sites unsuitable for bathing (Amaral *et al.* 1998, Vieira *et al.* 2012), and with many species that occur in beach environments (Bolívar & Lana 1986, Santos *et al.* 2009). Pearson and Rosenberg (1978) revealed, in studies about the distribution of benthic macrofauna, according to organic enrichment gradients (different levels of pollution) that, the high occurrence of Spionidae species, with emphasis on the genus *Scolelepis*, has benefited due to this pollution, by the increasing availability of nutrients. But this was not observed in this study. Although the CCA has shown a positive correlation between *Scolelepis* sp. and organic matter, the total abundance of this species (three individuals) is very low for a pollution indicator. Likely, the low abundance of this taxon at Caolho beach and the absence at São Marcos beach are related to the trampling by visitors (Machado *et al.* 2017), which is even more intense at the latter beach. However, further studies are needed to confirm this.

The species *S. tetraura* (formerly called *Lumbrineris tetraura*) can be found in several types of substrates: sand, muddy, broken shells, gravel, and mixed bottoms, between zoster and algae, in rocky puddles, in *Laminaria* seaweed supports and oyster beds, from the intertidal zone to abyssal depths, being typical of circumtropical regions, in warm temperate and tropical waters (Camargo & Lana 1995). Many species belonging to Lumbrineridae family are associated with resistance to pollution, like domestic wastewater (Del Pilar Ruso *et al.* 2008). For example, it was detected that Polychaeta from the genus *Lumbrineris* are resistant to pollution (Gray *et al.* 1990), and oil contamination (Raz-Guzmán, 2000). This could explain why, in this study, a clear correlation between *S. tetraura* and organic matter was not observed.

Polychaeta occurred only in upper mesolittoral, where the traffic of vehicles is less (and consequently the sediment is less compacted) compared to others (Serra & Farias Filho 2019). The sediment compaction causes a decline in the benthic communities infaunal, due to the decrease in the size of pores, which in turn, decreases the humidity and oxygen supply (Santos & Ferreira 2019). Temporally, there was greater abundance in the rainy season. The benthic macrofauna of beaches, in general, presents high densities in this period, when the risk or desiccation decreases due to the more frequent precipitations (Viana *et al.* 2005).

In the present study, the low diversity and abundance of Polychaeta seems to be associated with other factors than organic enrichment. As these beaches are urbanized, low abundance and diversity can be related to the trampling and other tourism related impacts rather than organic enrichment. Among the impacts of tourism that affect the benthic macrofauna and that occur on these beaches: alteration of the natural landscape, increase of waste volume produced, removal of debris of natural or anthropic origin, naturally deposited by the tide in the supralittoral portion (which can reduce the amount of organic matter, macrofauna biomass, microbial production and alter water quality), and trampling, due to the high density of people on the beaches (Santos & Ferreira 2019, Silva Reis & Santos 2020).

Macrofauna studies on these beaches are still incipient, and this is one of the few researches done so far. For this reason, more studies are needed to improve the knowledge of other groups of benthic macrofauna at the studied areas, comparing the richness between the several microhabitats and the seasonality, and so elaborate conservation strategies for these ecosystems; in addition to further studies investigating the effects of the other impacts cited (e.g. trampling). Therefore, we conclude that, the real urbanization effect is the change in composition and abundance of species, rather than an enrichment effect. It is emphasized that the impact of tourism was not tested in this paper, and is only a hypothesis to be tested further, in future studies.

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