Iheringia
Série Zoologia

e-ISSN 1678-4766
www.scielo.br/isz

Museu de Ciências Naturais

Article

Does dredging activity exert an influence on benthic macrofauna in tropical estuaries? Case study on the northern coast of Brazil

Lorena K. S. Sousa[1], Marco V. J. Cutrim[1],
Miodeli Nogueira Júnior[3] & Verônica M. de Oliveira[2]

1. Programa de Pós-Graduação em Oceanografia, Universidade Federal do Maranhão, Av. dos Portugueses, s/n, Cidade Universitária Dom Delgado, 65080-805 São Luís, Maranhão, Brasil. (lorenakarine.ss@gmail.com; marco.cutrim@ufma.br)
2. Programa de Pós-Graduação em Recursos Aquáticos e Pesca, Universidade Estadual do Maranhão, Cidade Universitária Paulo VI, Tirirical, 65055-970 São Luís, MA, Brasil. (oliveira.veronica@gmail.com)
3. Departamento de Sistemática e Ecologia, Universidade Federal da Paraíba, João Pessoa, PB, Brasil. (miodeli@gmail.com)

Received 4 October 2022
Accepted 16 March 2023
Published 15 May 2023
DOI 10.1590/1678-4766e2023009

ABSTRACT. The aim of the present study was to investigate the effect of dredging activities on the structure of the macrobenthic community of a port complex in São Luís do Maranhão (2°S, Brazil). Sampling was performed on four occasions: pre-dredging, dredging 1 (25% of the material dredged), dredging 2 (75% of the material dredged) and post-dredging. Total mean density was 430.8 ± 55.0 ind/m², with 147.76 ± 280.82 ind/m² at pre-dredging, 161.90 ± 285.67 ind/m² at dredging 1, 53.83 ± 72.15 ind/m² at dredging 2 and 67.29 ± 72.58 ind/m² after dredging, revealing a reduction during dredging 2. The most representative groups were Polychaeta, Oligochaeta, Crustacea and Mollusca. *Lumbrineris* sp. (Polychaeta) was present in all sampling periods and was the dominant species. Richness and Shannon diversity of the species were higher in the pre-dredging and post-dredging periods, with reductions during the dredging activities (dredging 1 and 2). Principal component analysis revealed a correlation with granulometry and heavy metals in the sediment. The dredging activities led to a reduction in the macrobenthic community. Moreover, post-dredging recovery was insufficient for the recovery of the community.

KEYWORDS. São Marcos Bay; microbenthic fauna; port complex.

Coastal ecosystems have high ecological, social and economic value, but have been undergoing changes due mainly to the excessive exploitation of natural resources as well as disorderly land use and occupation (Gruber *et al.*, 2003). Among the different impacts to which coastal environments are subjected, the expansion of port activities is considered one of the factors posing the greatest environmental risk (Bolam, 2012). The operational and expansion activities of a port complex exert a considerable impact on the ecosystem (Castro & Almeida, 2012). Moreover, periodic dredging for the maintenance of navigation channels (Cruz-Motta & Collins, 2004) causes impacts in the form of changes to the water and sediment, such as an increase in the turbidity of the water column, pollution by toxic substances as well as changes in the structure and dynamics of macrobenthic communities (Lewis *et al.*, 2001; Bolam, 2012).

Benthic communities are important to the secondary production of aquatic ecosystems, playing key roles in the stability of the sediment, the cycling of organic matter and as an important food source for larger organisms, many of which have economic value (Thrush & Dayton, 2002; Bolam, 2014). The occurrence, abundance and structure of the benthic macrofauna are influenced by the predominant environmental characteristics, especially those related to the sediment, availability of food sources and environmental stability (Almeida & Vivan, 2011; Zalmon *et al.*, 2013). Environmental factors, such as the homogeneity of the sediment and organic enrichment, are also determinants in the reduction of the benthic macrofauna, making environments with a high degree of disturbance azoic (Pires-Vanin *et al.*, 2011). Dredging activities cause short- and long-term effects on benthic communities, such as reducing the number of species and abundances, altering the properties of sediments, nutrients and organic matter (Newell *et al.*, 1998; Wilber *et al.*, 2007; Ponti *et al.*, 2009).

Due to their errant or sedentary lifestyle and relatively long lifecycles, benthic organisms offer a precise reflection of environmental conditions prior to the time of sampling (Sola & Paiva, 2001; Khedhri, 2016), making them excellent indicators for evaluation of environmental changes (Netto & Lana, 1994; Sandrini-Neto *et al.*, 2016). The rapid deterioration of estuarine ecosystems due to urbanization and industrialization throughout the world has been widely discussed. One such issue is the recovery of dredged environments, where the loss of taxonomic and functional characteristics has hindered evaluations in tropical regions

(Mulik *et al*., 2017), which are generally studied less. This is particularly true for the channels that connect estuaries to the ocean in port areas. Recurrent dredging activities affect the depth, re-suspension and composition of the sediment, resulting in changes in local communities, which are often unable to attach themselves in these environments, leading to their sporadic occurrence (Cruz-Motta & Collins, 2004).

The impact of dredging on macrobenthic communities has been worrying, because this group plays an important role in nutrient recycling, secondary production and is efficient as an indicator of environmental disturbances (McLusky & Elliot, 2004; Gray & Elliott, 2009; Rehitha *et al*., 2017). Studies have shown that macrofaunal communities of stressed habitats are typically more resilient in comparison to those in more stable environments; moreover, the recovery of the original community may take nine months in less stressed environments, but up to four or five years in more disturbed environments (Bolam & Rees, 2003; Froján *et al*., 2011). Thus, regions under the influence of port and industrial activities are extremely susceptible to pollution and contamination.

The São Luís Port Complex in the state of Maranhão is one of the main ports of Brazil (Amaral & Alfredini, 2010) and has considerable economic importance due to intensive exportation activities, particularly grains, iron and aluminum. Dredging activities have been performed when needed for the circulation of ship traffic in the region since 1856 (Viveiros, 1954). The frequent dredging for the maintenance of navigation channels underscores the need to evaluate the impact on biological communities in this tropical estuarine ecosystem. It has potentially high diversity, but has been sparsely studied, especially in terms of benthic macrofauna, which are drastically exposed to disturbances of the sediment. The few studies on the benthic macrofauna of the Maranhão coast have mainly been conducted around São Marcos, which is near the port complex, as well as in mangroves and on beaches (Oliveira & Mochel, 1999; Fernandes, 2003; Barros, 2008; Feres *et al*., 2008; Neves & Valentin, 2011; Ribeiro & Almeida, 2014; Cutrim *et al*., 2018).

Considering the results of previously conducted studies, one may expect significant reductions in the abundance, diversity and richness of the benthic macrofauna during dredging activities as well as the subsequent recovery of these organisms in the dredged area. Therefore, the objective of the present study was to evaluate the impact of dredging, environmental variables and the recovery time of organisms in the studied area.

MATERIALS AND METHODS

Study area. The São Luís Port Complex is located in São Marcos Bay (02º 30'0"S 44º37'0"W) to the southeast of São Luís Island (Fig. 1). It is considered one of the largest ports on the Brazilian coast and the second largest port in Latin America in terms of cargo movement (Amaral & Alfredini, 2010). The tidal pattern of the port areas is semi-diurnal macrotides (~7 m in range; Diniz *et al*., 2014). Mean currents range from 0.6 to 6.3 knots during the low and high tide, respectively (Garcia & Alfredini, 2005). The region is dominated by mangroves and characterized by a warm, semi-humid climate with two well-defined seasons (a rainy season from January to June and a dry season from July to December), with total annual precipitation around 2000 mm (Azevedo & Cutrim, 2007).

Sampling and analysis. Sampling was performed on four occasions: prior to dredging (January 27, 2014), dredging 1 with 25% of the material dredged (February 2, 2015), dredging 2 with the remaining 75% of the material dredged (March 9, 2015) and 120 days after the conclusion of the dredging activities (June 16, 2015). Eight points (P1-8) were sampled in each period. P3 and P5 were areas of the discarding of the dredged material; P4 and P6 were located near the mangrove; P1 and P2 were in the mooring area; and P7 and P8 were in the navigation canal.

The area was dredged by Cutter and Suction Dredge, which has equipment for the fragmentation of hard material and a self-transporting dredge as secondary dredging equipment, totaling 580,343 m³ of dredged material in the two campaigns.

Samples were collected from each sampling point with the aid of a 20-l stainless steel van Veen sampler for the analysis of the macrofauna, granulometric characterization and the determination of heavy metals. Immediately after collection, one of the samples at each point was placed in a plastic bag and fixed with 4% formalin. The material was transported to the laboratory for sorting with a sieve (0.5-mm mesh) and the organisms were identified with the aid of specialized literature (Rios, 1994; Amaral & Nonato, 1996). The other sediment samples were stored in plastic bags and transported to the laboratory for the determination of the textural characteristics of the sediment through sifting (ABNT NBR norm 7181/84) and the determination of heavy metal concentrations following recommendations by American Public Health Association - APHA (2012). Additionally, sub-surface water (-50 cm) was collected from each point with a Nansen bottle for the determination of temperature, pH, dissolved oxygen and salinity, which were measured using a multi-parameter probe (Hanna HI 9828). The water was then stored and sent to the laboratory for the determination of total heavy metals (dissolved Mn, Fe, Zn and Fe) according to APHA (2012). Heavy metal concentrations in both the water and sediment were compared to the limits established by Brazilian environmental legislation (CONAMA Resolutions 357/2005 and 454/2012, respectively).

Margalef richness, Shannon-Weaver diversity and Pielou evenness were calculated using the PRIMER 6.0 software program. Two-way analysis of variance (ANOVA)

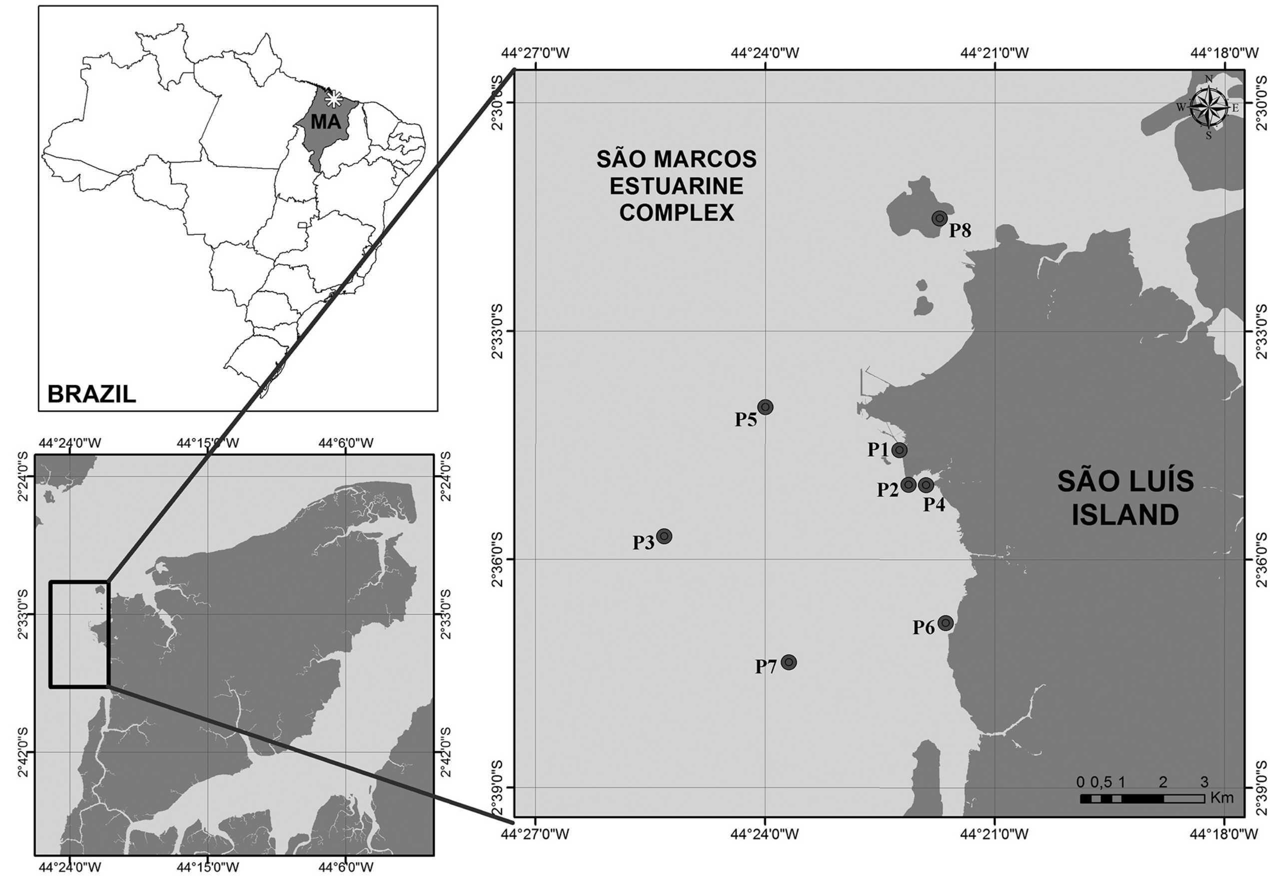

Fig. 1. Map of the location of Port Complex of São Luís, Maranhão, Brazil, indicating the eight sampling points.

was used to test significant differences ($p < 0.05$) of ecological indexes, total and main species density between periods and sampling points. Kolmogorov-Smirnov test was run in order to test the normality of the data (Zar, 2010), with the aid of the Statistic 6 program. Agglomerative hierarchical clustering analysis was performed to identify spatial distribution patterns in the structure of the associations (Bray-Curtis similarity index) based on abundance data from the sampling points calculated using the PRIMER 6.0 program. Principal component analysis (PCA) was performed using the software PAST - Palaeontological Statistics, version 1.81 (Hammer *et al.*, 2008) to analyze the influence of environmental variables on the distribution of the benthic fauna. Pearson's correlation matrix was used for the selection of the most significant environmental variables for these analyses.

RESULTS

Physicochemical characteristics of water. All abiotic water variables differed among the sampling campaigns, but differed relatively little among the sampling points (Figs 2A – D). Salinity was lowest in the post-dredging (25 to 29.5) and pre-dredging (28 to 29) periods, with values > 29 during dredging 1 and 2, reaching as high as > 33 in the latter period (Fig. 2A). Temperature varied little (27.5 to 29.7°C), generally with values < 28°C during dredging 1 and > 28.5°C during the other sampling campaigns (Fig. 2B). Dissolved oxygen ranged from 3.3 to 6.6 mg L^{-1} (Fig. 2C), with large spatial variations in the pre-dredging period, but not during the other campaigns; the highest dissolved oxygen values were found during dredging 1. PH remained around 8 for all campaigns, except during dredging 1, when pH was ~8.5 (Fig. 2D).

Granulometric composition. The sediment was generally dominated by sand in all periods, except at points 2, 4 and 6, which had a large silt content. Dredging 2 was the period that most stood out from the rest, with a reduction in the sand content at all points, except points 2 and 4, at which the sand content increased and the silt content decreased, and point 6, at which the clay content increased (Fig. 3).

Heavy metals in water and sediment. The largest concentrations of total iron in the water (~6 to 10 mg kg^{-1}) occurred in the pre-dredging period at points 3, 4, 6 and 7, always remaining less than 4 mg kg^{-1} in the other samples (Fig. 4A). The concentration of dissolved iron was always < 0.07 mg kg^{-1}, except at point 4 in the pre-dredging period

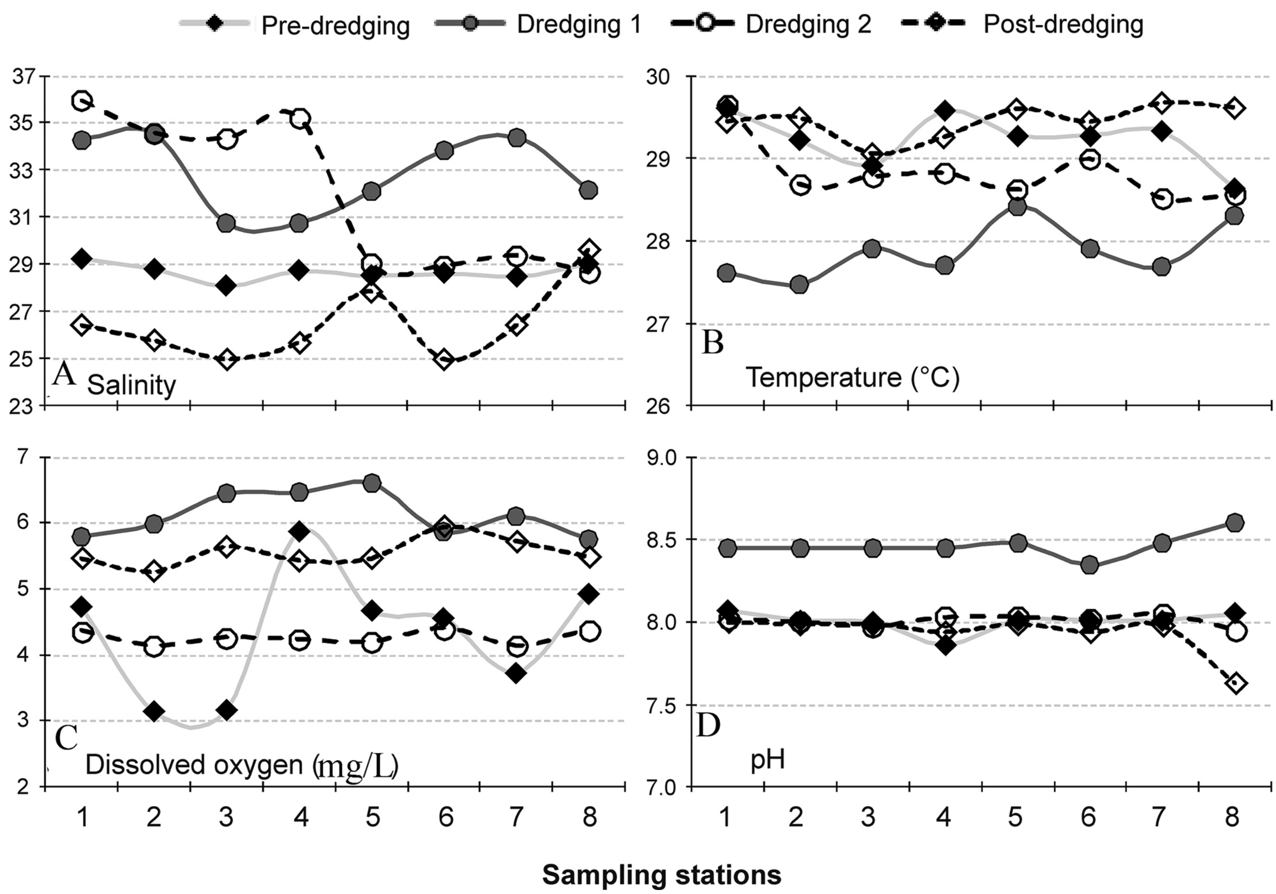

Fig. 2. Temporal and spatial variation of sub superficial salinity (A), temperature (B), dissolved oxygen (C) and pH (D) at São Luís Harbor, Maranhão, Brazil.

(Fig. 4B). Manganese concentrations were generally < 0.1 mg kg^{-1} during dredging 1 and 2 and generally > 0.15 mg kg^{-1} in the pre-dredging and post-dredging periods (Fig. 4C). Zinc concentrations were always < 0.1 mg kg^{-1}, except at point 4 in the post-dredging period (~0.5 mg kg^{-1}) and a peak of 5.0 mg kg^{-1} at point 6 in during dredging 1 (Fig. 4D).

In the soil, highest concentrations of lead (Fig. 5A), nickel (Fig. 5D) and zinc (Fig. 5E) were found in the pre-dredging period, especially at points 2, 4 and 6. The highest concentrations of copper (Fig. 5B) were found during dredging 1 at points 2 and 4. The highest concentrations of chromium (Fig. 5C) were found at point 2 during dredging 1 as well as at point 4 in the pre-dredging and dredging 1 periods. No large differences in arsenic concentrations (Fig. 5F) were found among the different periods.

Macrofauna. Macrofauna was present in 75% of the samples, always with a small number of species as well as low density and diversity (Figs 6AD). Nine taxonomic Phylum were found, among which we identified 21 species of polychaetes, five mollusks, four crustaceans and one ophiuroid. The other groups were rare and not identified on lower taxonomic levels (Tab. I). The vast majority of individuals did not show high density and this was not commom to all sampling campaigns. A total of 46 different taxa belonging to nine major taxonomic Phylum were collected, these 40 taxa occurred in only one or two samples (Tab. I). The dominant organisms were *Lumbrineris* sp. and Oligochaeta, accounting for 28.5 and 16.2% of the total macrofauna, respectively, but even these organisms were found in only 15.5% of the samples (Tab. I).

The number of species in each sample never surpassed seven, with higher values in the pre-dredging period and the lowest during dredging 2, when the number of species never surpassed three. Spatially, the number of species was consistently lower at points 3 and 5 in all periods (Fig. 6A). Density of organisms was generally low – typically < 100 individuals in all periods, with peaks of 35 to 55 individuals at points 2 and 4 in the pre-dredging and dredging 1 periods (Fig. 6B). Shannon's diversity index was always < 2, with particularly low values during dredging 1 and 2 (typically lower than 1 and 0.7, respectively) (Fig. 6C).

Despite a certain tendency toward reductions in density, the number of species and the Shannon diversity during the dredging periods, with a subsequent increase in the number of species and Shannon index in the post-dredging period, no significant differences were found due to the considerable variability among sampling points (Tab. II).

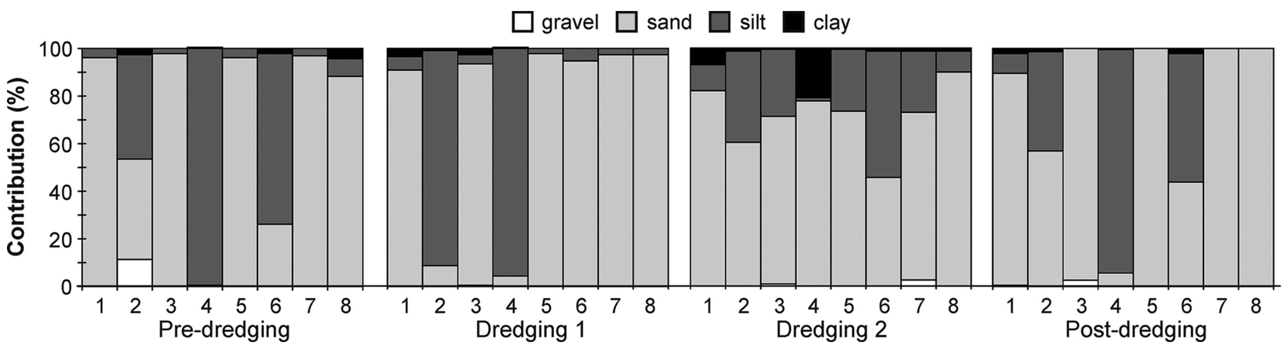

Fig. 3. Temporal and spatial variation of different granulometric size fractions contribution (%) to the sediment total weight at São Luís Harbor, Maranhão, Brazil. The number below the x-axis indicate the sampling stations.

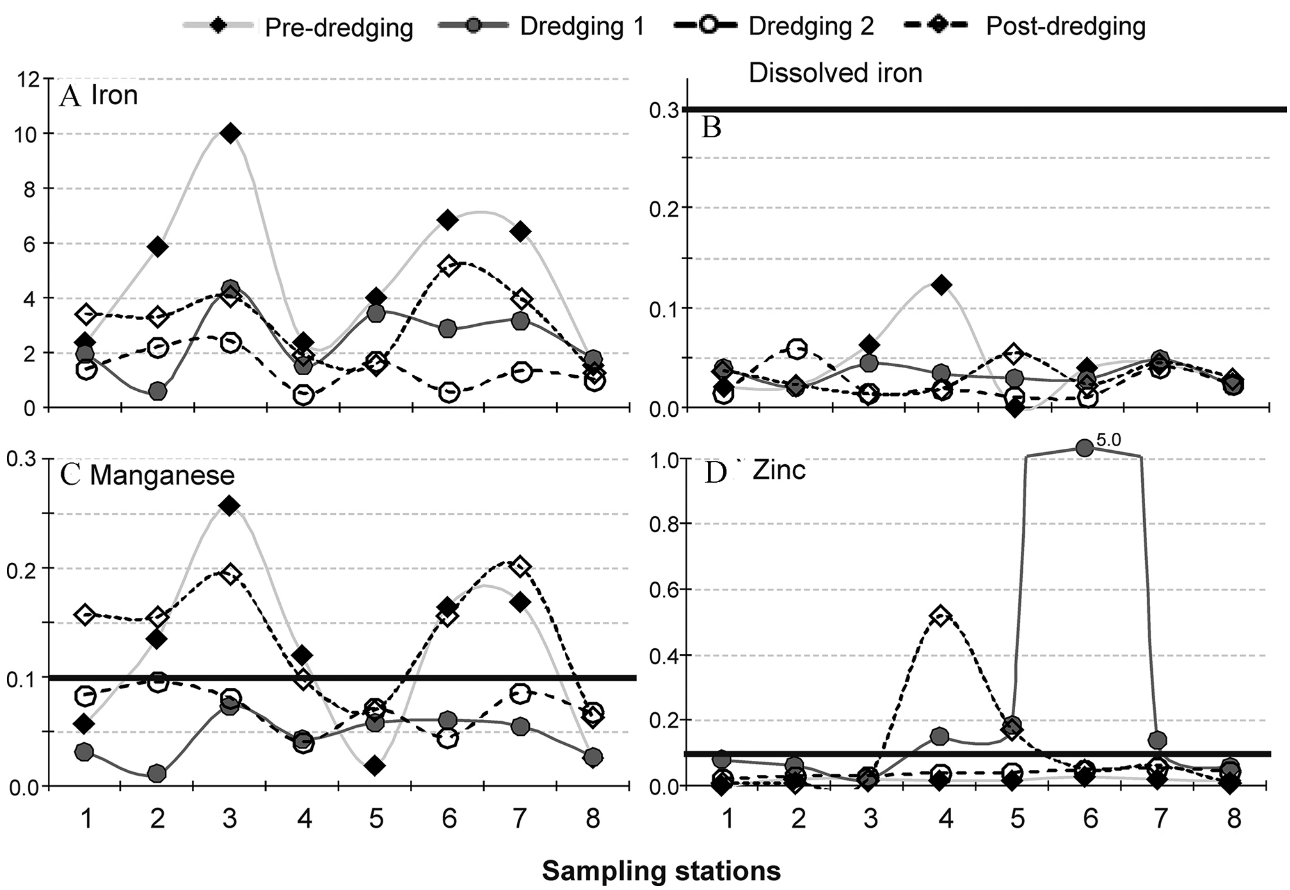

Fig. 4. Temporal and spatial variation of total iron (A), dissolved iron (B), manganese (C) and zinc (D) concentrations (mg kg-1) in the sub superficial water at São Luís Harbor, Maranhão, Brazil. The thick black bar indicates the maximum allowed by resolution 357/05.

With the increase in dredging activities, a decrease occurred in the density of the organism: 147.76 ± 280.82 ind/m² in the pre-dredging period; 161.90 ± 285.67 ind/m² during dredging 1; 53.83 ± 72.15 ind/m² during dredging 2; and 67.29 ± 78.58 ind/m² in the post-dredging period (Tab. I). The highest density values were found for polychaetes, especially *Lumbrineris* sp. Decapods and *Monocorophium* sp. stood out among the other crustaceans, whereas *Graptacme perlonga* stood out among the mollusks (Tab. I).

The highest density of organisms was found at point 4 during all periods except the post-dredging period, when point 8 had the highest abundance. Point 2 stood out in the pre-dredging and dredging 1 periods, whereas point 6 stood out in the dredging 2 and post-dredging periods. At points 3 and 5, which were used for the discarding of the dredged material, density was low, especially during the dredging activities, when no organisms were found at these sites (Fig.6B). No significant differences in density were found

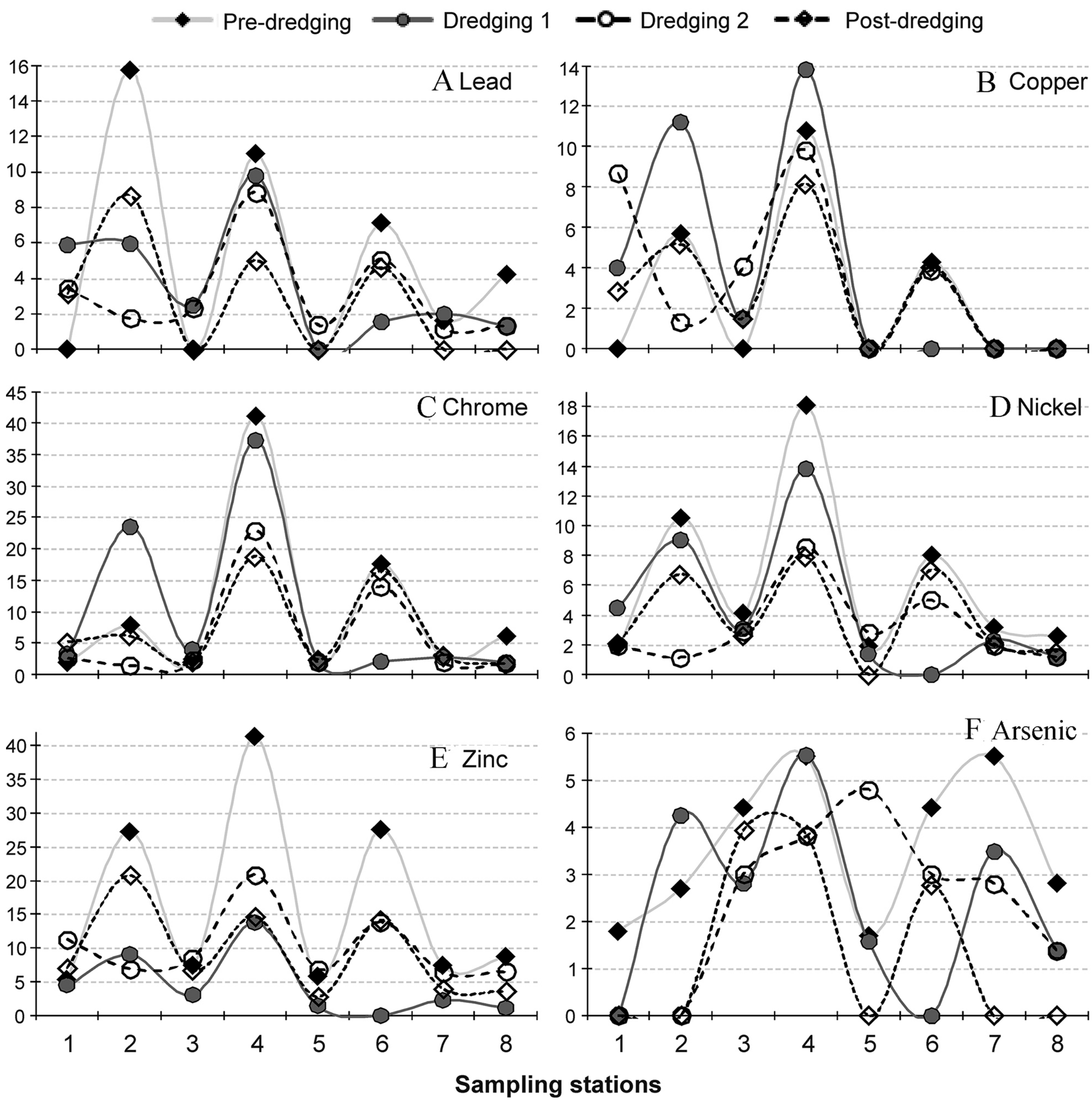

Fig 5. Temporal and spatial variation of metals and semimetals concentrations (mg kg^{-1}) in the sediment at São Luís Harbor, Maranhão, Brazil: (A) Lead, (B) Copper, (C) Chrome, (D) Nickel, (E) Zinc and (F) Arsenic.

among the sampling periods (df= 3; F = 1.0; p = 0.392) (Tab. II). Point 4, which was located near the mangroves of the estuary, was dominated by Polychaeta, Oligochaeta and Nematoda, with the polychaete *Lumbrineris* sp. the dominant species in the area sampled. In contrast, Bryozoa, Cnidaria and Echinodermata had few representatives and occurred at points 3, 5 and 7, which were the most disturbed. Point 3 and 5 were the discarding sites and point 7 was located in the navigation channel, which has high hydrodynamics.

The dendogram shows that points 6 and 8 were the most similar (73.9%), followed by points 3 and 7 (73.4%) and points 2 and 4 (70%). Above 40%, we may consider the formation of two large groups (Fig. 7)

The PCA explained 64.24% of the variation among the samples (Factor1 = 39.24% and Factor 2 = 25.00%). Silt and heavy metals in the sediment (copper, chromium, nickel and zinc) were positively correlated with the dredging 2 period. Sand was negatively correlated with these metals in the sediment during the pre-dredging period. Manganese in the water was positively correlated with iron and pH was negatively correlated with temperature (Tab. III; Fig. 8).

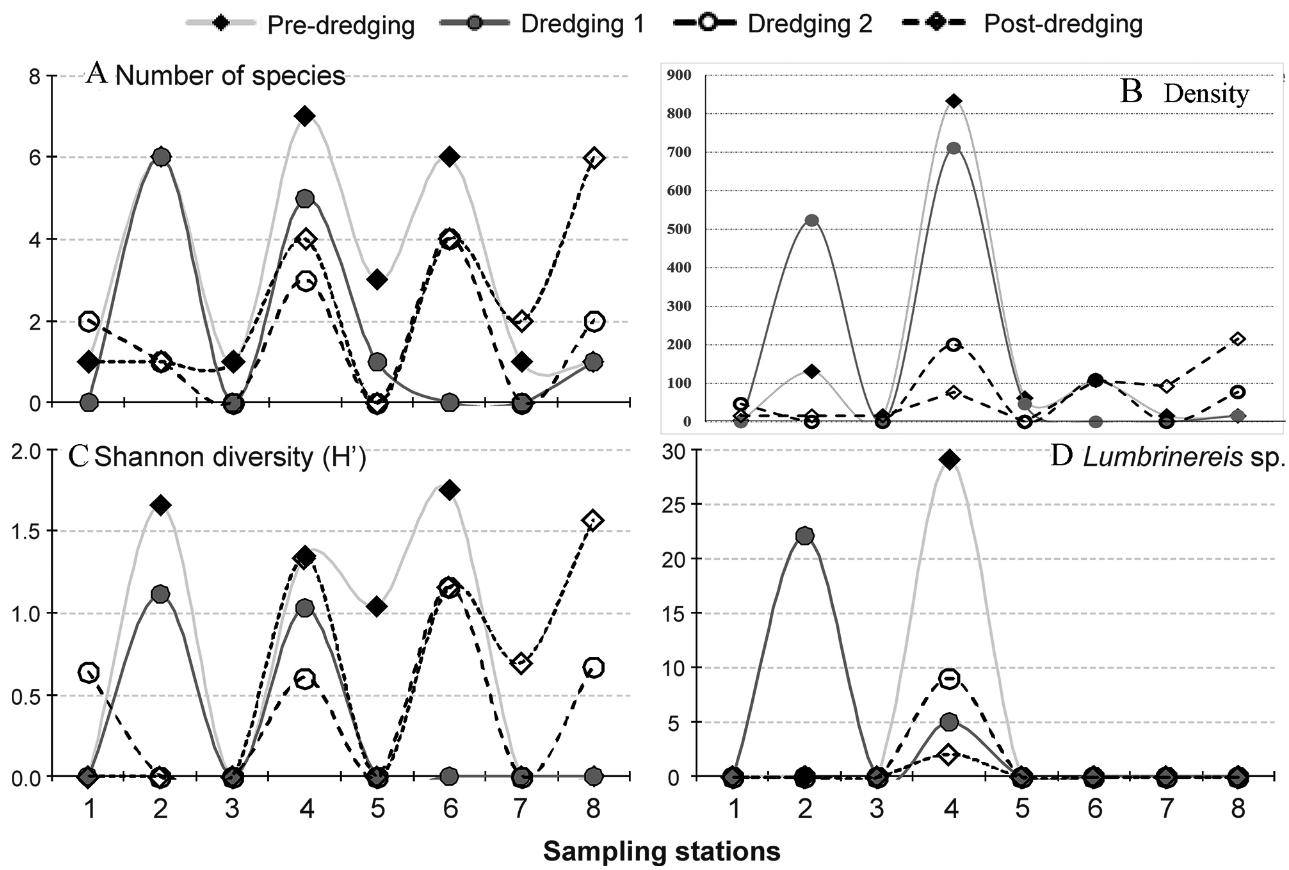

Fig. 6. Number of species, density and diversity of Shannon of the benthic macrofauna found in the Port Complex of São Luís, Maranhão, Brazil: (A) Number of species, (B) Density, (C) Shannon diversity and (D) *Lumbrineris* sp.

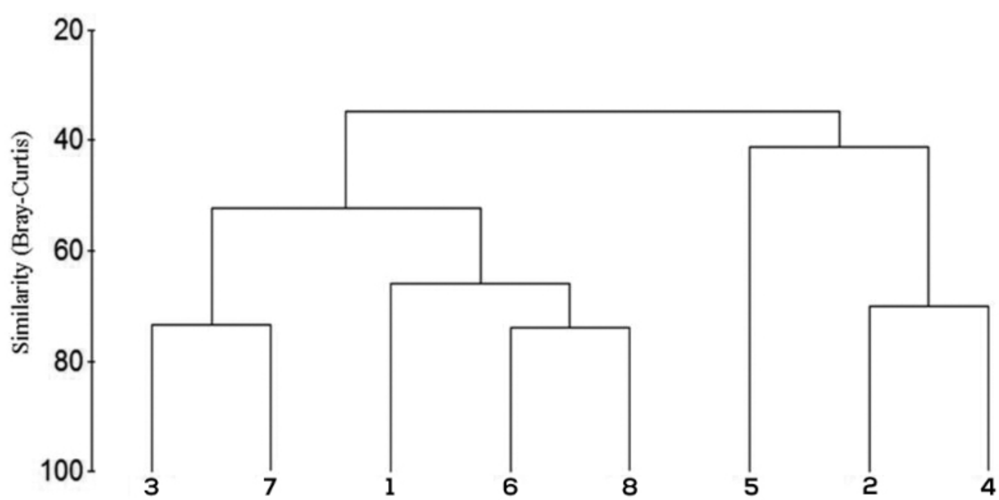

Fig. 7. Dendrogram of Bray-Curtis similarity between the points sampled in the Port Complex of São Luís, Maranhão, Brazil.

Tab. I. Average density (ind/m²) of macrofaunal species and their frequency of capture (%; FC) in the São Luís Port Complex, Brazil.

Species	Pre-dredging		Dredging 1		Dredging 2		Post-dredging		Total	
	Dens	FC	Dens	FC	Dens	FC	Dens	FC	Dens	FC
Oligochaeta	1.9±5.4	12.5	69.2±155.6	37.5	1.9±5.4	12.5	0	0	18.3±79.8	15.6
Polychaeta										
Armandia hossfeldi	0	0	1.9±5.4	12.5	0	0	0	0	0.5±2.7	3.1
Capitella sp.	3.8±10.9	12.5	0	0	0	0	0	0	1.0±5.4	3.1
Cossura sp. nov.	0	0	5.8±16.3	0	1.9±5.4	0	1.9±5.4	0	2.4±8.8	9.4
Dorvileia sp.	0	0	0	0	0	0	1.9±5.5	12.5	0.5±2.7	3.1
Eulalia sp.nov.	3.8±10.9	12.5	0	0	0	0	0	0	1.0±5.4	3.1
Exogone sp.	9.6±21.7	25	0	0	0	0	0	0	2.4±11.1	6.3
Eusyssllis sp.	1.9±5.4	12.5	0	0	0	0	0	0	0,.5±2.7	3.1
Glycinde multidens	0	0	0	0	3.8±10.9	12.5	0	0	1.0±5.4	3.1
Isolda pulchella	21.1±59.83	12.5	0	0	0	0	0	0	5.3±29.9	3.1
Lumbrineris sp.	55.8±157.7	12.5	51.9±118.9	25	17.3±48.9	12.5	3.8±10.9	12.5	32.2±99.4	15.6
Magelona papillicornis	0	0	0	0	1.9±5.4	12.5	0	0	0.5±2.7	3.1
Micronephtys sp.	19.2±54.4	12.5	0	0	0	0	0	0	4.8±27.1	3.1
Nematonereis sp.	0	0	0	0	7.7±14.2	25	0	0	1.9±7.6	6.3
Onuphis sp.	0	0	0	0	7.7±16.4	25	0	0	1.9±8.5	6.3
Prionospio sp.	0	0	1.9±5.4	0	0	12.5	0	0	0.5±2.7	3.1
Sabellaria wilsoni	0	0	0	0	0	0	7.7±21.7	12.5	1.9±10.9	3.1
Scoloplos sp.	0	0	1.9±5.4	12.5	1.9±5.4	12.5	7.7±16.4	25	2.9±9.1	12.5
Sigambra grubei	0	0	1.9±5.4	12.5	0	0	0	0	0.5±2.7	3.1
Sternaspis sp.	0	0	0	0	0	0	13.5±38.1	12.5	3.4±19.0	3.1
Syllis sp. nov.	0	0	0	0	0	0	1.9±5.4	12.5	0.5±2.7	3.1
Terebellides sp.	0	0	1.9±5.4	12.5	0	0	0	0	0.5±2.7	3.1
Crustacea										
Aegla sp.	0	0	0	0	0	0	1.9±5.4	12.5	0.5±2.7	3.1
Amphipoda	1.9±5.4	12.5	0	0	0	0	0	0	0.5±2.7	3.1

Tab. I. Cont.

Species	Pre-dredging		Dredging 1		Dredging 2		Post-dredging		Total	
	Dens	FC	Dens	FC	Dens	FC	Dens	FC	Dens	FC
Decapoda	0	0	0	0	7.7±21.7	12.5	0	0	1.9±10.9	3.1
Gammaridae	1.9±5.4	12.5	0	0	0	0	0	0	0.5±2.7	3.1
Megalopa	0	0	0	0	0	0	3.8±7.1	25	1.0±3.8	6.3
Monocorophiuma cherusicum	7.7±21.7	12.5	0	0	0	0	0	0	1.9±10.9	3.1
Mysidacea	1.9±5.4	12.5	0	0	0	0	0	0	0.5±2.7	3.1
Ogyrides sp.	0	0	0	0	0	0	1.9±5.4	12.5	0.5±2.7	3.1
Peracarida	1.9±5.4	12.5	0	0	0	0	0	0	0.5±2.7	3.1
Tanaidacea	1.9±5.4	12.5	0	0	0	0	0	0	0.5±2.7	3.1
Upogebia vasquezi	5.8±16.3	12.5	0	0	0	0	0	0	1.4±8.1	3.1
Insecta										
Chironomidae	3.8±10.9	12.5	0	0	0	0	0	0	1.0±5.4	3.1
Echinodermata										
Ophiactis lymani	1.9±5.4	12.5	0	0	0	0	1.9±5.4	12.5	1.0±3.8	6.3
Mollusca										
Parvanachis obesa	0	0	0	0	0	0	3.8±10.9	12.5	1.0±5.4	3.1
Crepidula protea	0	0	0	0	0	0	1.9±5.4	12.5	0.5±2.7	3.1
Graptacme perlonga	9.6±18.3	25	5.8±16.3	12.5	0	0	1.9±5.4	12.5	4.3±12.5	12.5
Nuculana concentrica	3.8±10.9	12.5	0	0	0	0	1.9±5.43	12.5	1.4±6.0	6.3
Tectonatica pusilla	1.9±5.4	12.5	0	0	0	0	0	0	0.5±2.7	3.1
Nematoda	0	0	19.2±54.4	12.5	1.9±5.4	12.5	0	0	5.3±27.2	6.3
Nemertea	1.9±5.4	12.5	0	0	0	0	0	0	0.5±2.7	3.1
Sipuncula	3.8±7.1	25	0	0	0	0	0	0	0.9±3.8	6.3
Total density	147.7±289.0	100	161.5±284.9	50	53.8±61.0	62.5	67.3±92.3	87.5	113.0±206.9	75
N° spp.	3.2±2.6		1.6±2.4		1.5±1.5		2.4±2.1		2.2±2.2	

Tab. II. Summary of the ANOVA testing for differences in the number of species, Shannon diversity, total density and the dominant species abundance (ind/m²) considering the temporal (4 levels) and spatial (8 levels) factors in the São Luís Port Complex, Brazil. Differences are considered significant if p<0.05. DF = degree of freedom; SS = sum of squares; MS = mean squares; F = parameter of the ANOVA; p = probability associated to the test.

Maturity stage	Factors	DF	SS	MS	F	p
Number of species	Intercept	1	153.1	153.1	48.8	<0.001
	Temporal	3	15.6	5.2	1.7	0.206
	Spatial	7	71.4	10.2	3.2	0.017
	Error	21	65.9	3.1		
Shannon diversity	Intercept	1	7.7	7.7	26.4	<0.001
	Temporal	3	1.0	0.3	1.1	0.352
	Spatial	7	4.7	0.7	2.3	0.068
	Error	21	6.1	0.3		
Total density	Intercept	1	408468.9	408468.9	14.4	0.001
	Temporal	3	8838.8	29612.9	1.0	0.392
	Spatial	7	645081.4	92154.5	3.3	0.017
	Error	21	593232.2	28249.2		
Lumbrinereis sp.	Intercept	1	33202.7	33202.7	3.9	0.059
	Temporal	3	15761.8	5253.9	0.6	0.604
	Spatial	7	115258.9	16465.5	2.0	0.108
	Error	21	175421.6	8353.4		

Tab. III. Analysis of Principal Components among environmental parameters, density of organisms and dredging campaigns. *(W): water and (S): sediment

Variables	PC1	PC2	PC3	PC4
Temperature (W)	0.013	0.444	0.235	-0.369
Salinity (W)	-0.050	-0.465	0.241	0.069
Dissolved oxygen (W)	0.060	0.168	-0.527	-0.449
pH (W)	-0.038	-0.374	-0.347	0.351
Fe (W)	-0.050	0.359	-0.016	0.612
Mn (W)	0.005	0.462	0.074	0.345
Cu (S)	0.397	-0.120	0.115	0.020
Cr (S)	0.396	-0.049	-0.030	-0.009
Ni (S)	0.398	0.029	0.023	0.135
Zn (S)	0.343	0.163	0.229	0.017
Sand (%)	-0.384	0.018	0.072	-0.059
Silt (%)	0.373	-0.005	-0.150	0.059
Clay (%)	0.057	-0.159	0.609	-0.100
Density of organisms	0.359	-0.060	-0.119	-0.048

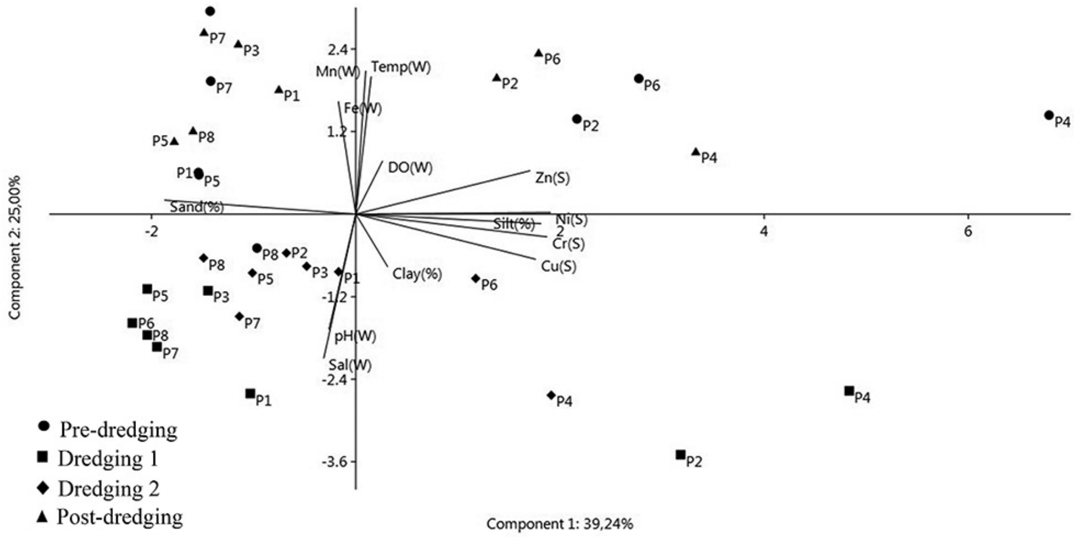

Fig. 8. Diagram of Principal Component Analysis during collection periods [Temp(W), water temperature; Sal(W), water salinity; OD(W), water dissolved oxygen; pH(W), pH of water; Fe(W), water iron; Mn(W), water manganese; Cu(S), copper from sediment; Cr(S), chromium from sediment; Ni(S), nickel from sediment; Zn(S), zinc from sediment].

DISCUSSION

Significant differences in environmental variables among the dredging periods do not correspond to the causal agents of changes in microbenthic communities. However, the removal of sediment generally leads to a reduction in the abundance and diversity of organisms, exerting an influence on the structure of the communities (Ceia *et al.*, 2013).

An increase in silt occurred during the dredging periods at nearly all sampling points. A reduction in the size of the sediment particles can alter the composition of the community, exerting a direct effect on species with requirements that are specific to the sediment type (Ceia *et al.*, 2013). This is a general pattern in several regions throughout the world (Schettini *et al.*, 2002; Xu, 2014; Rehitha *et al.*, 2017).

After dredging, the characteristics of the sediment were similar to those found in the pre-dredging period, demonstrating that depositional environments achieve a balance with the governing environmental conditions of these locations before 120 days after the last dredging period. This factor plays an important role in the dynamics of the sediment (Bellotto *et al.*, 2009), despite the high hydrodynamics of the region.

Among the heavy metals found in the water, manganese in the pre-dredging and post-dredging periods and zinc at point 4 in the post-dredging period were above the limits permitted by Brazilian legislation (CONAMA Resolution 357/05). The high concentrations of manganese at the sampling points may be related to the port cargo, as this mineral is the main product that circulates in the loading activities of the São Luís Port Complex (Amaral & Alfredini, 2010).

The higher concentrations of heavy metals at points 2, 4 and 6 are related to the granulometric composition. These sites are near mangroves and consequently have larger amounts of silts, suggesting the greater adsorption of these metals (Faraco & Lana, 2003) and the consequent reduction in the benthic fauna, as metals are determinant factors to the reproductive success and mortality of invertebrates (Ellis *et al.*, 2017). The force of the tides and velocity of the currents are low in these locations. This probably favors the deposition of fine sediments and organic matter, which have greater capacity for the adsorption of heavy metals (Siqueira & Aprile, 2012). Despite the presence of these metals in the study area, the concentrations were within the limits permitted by CONAMA Resolution 454/2012.

A significant reduction in organisms was found in the dredging 2 period. Dredging activities are generally accompanied by reductions in the number of species, population density and the biomass of benthic organisms (Froján *et al.*, 2011; Ceia *et al.*, 2013; Katsiaras, 2015). However, there are records of increases in Polychaeta and Crustacea (Bemvenuti *et al.*, 2005; Vivan, 2009).

The highest densities of organisms were also recorded at points 2 and 4. Environments with fine particles are favorable to the establishment of benthic populations (McLachlan & Brown, 2006). This type of substrate offers larger proportions of organic matter and facilitates the locomotion of organisms (Knox, 2001; Levinton, 2001).

The reduction or absence of organisms at points 3 and 5 during the dredging activities is probably due to the fact that these points are discard sites, leading to the burying of organisms and subsequent death by asphyxiation (Schratzberger *et al*., 2000). Previous studies have reported the immediate effect of the dumping of dredged material on benthic assemblages, with a reduction in the total abundance of individuals (Cruz-Motta & Collins, 2004; Powilleit *et al*., 2005; Witt *et al*., 2004).

However, the recovery time of affected areas depends on the magnitude and frequency of disturbance events (Lundquist *et al*., 2010). As the communities inhabit fine sediments, they generally recover faster than reef communities of sand, gravel or coral, which are more prone to the migration of opportunistic species (Newell *et al*., 1998).

The largest number of species was found in the pre-dredging and post-dredging periods, which explains the higher Margalef and Shannon-Weaver indices in these periods. The recovery of the benthic macrofauna in the post-dredging period has previously been recorded in terms of density and diversity. Nonetheless, dredging leads to the decline of more sensitive species and their replacement by more tolerant species (Cruz-Mota & Collins, 2004; Ceia *et al*., 2013).

The study area has extremely high hydrodynamics that can form dunes up to four meters in height that are subsequently displaced to other locations (Amaral *et al*., 2003). The disturbance caused by dredging and the high hydrodynamics hinder the migration and settlement of microbenthic juveniles in this location. The recovery of benthic communities in disturbed environments is associated with the migration of opportunistic species, juveniles and larval recruitment (Faraco & Lana, 2003; Egres *et al*., 2012; Gern & Lana, 2013; Sandrini-Neto & Lana, 2014).

The cluster analysis showed that points 6 and 8 had the greatest similarity. This finding apparently is directly related to the equal abundance and distribution of individuals in the sampling periods. These points are located closer to land and are consequently more protected, with low hydrodynamics and composed of finer sediments, which favors the establishment of benthic populations (Paiva *et al*., 2005). In contrast, points 3 and 7 had the smallest number of individuals and greater heterogeneity among the species. These points are in the central area of the channel and are consequently more prone to local disturbances. A similar situation has been reported near the navigation channel and mooring of the ships, with the occurrence of greater sedimentation suppressing the local fauna (Lana *et al*., 2001).

The PCA suggested/indicated a positive correlation between silt and heavy metals in the sediment. A similar situation has been described along the coast of the state of Rio de Janeiro, where positive correlations were found between a reduction in grain size and the occurrence of Pb, Cr, Ni, Cu and Co (Cabrini *et al*., 2016). It is likely that this correlation is related to fine sediment, in which *Lumbrineris* sp., *I. pulchella* and *Micronephtys* sp. are generally more abundant; this type of substrate also favors the fixation of metals (Faraco & Lana, 2003). *Lumbrineris* sp. and *I. pulchella* are surface deposit-eating species, whereas *Micronephtys* spp. are carnivorous and highly mobile (Fauchald & Jumars, 1979; Jumars *et al*., 2015).

Dredging activities altered the structure of the benthic assemblages, leading to reductions in the density and diversity of the organisms, followed by their recovery after the cessation of the dredging activities. Despite this recovery, the species were not all found throughout the pre-dredging to the post-dredging period, occurring sporadically in all campaigns, with the exception of *Lumbrineris* sp. This study could serve as the basis for future studies on the dredging area, considering the importance of the location as the second largest port with a natural depth in the world, where the maintenance of large cargo ships and navigation through the port area cause considerable changes to the composition and functioning of the local benthic communities.

Acknowledgments. The authors are grateful to the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES [Coordination for the Advancement of Higher Education Personnel]) for awarding a study grant, the Federal University of Maranhão, the undergraduate student of oceanography James Jordan Marques Corrêa for assistance with the statistical analyses and all those who contributed to the drafting of the article.

REFERENCES

Almeida, T. C. M. & Vivan, J. M. 2011. Macrobenthic associations in a South Atlantic Brazilian enclosed bay: The historical influence of shrimp trawling. **Marine Pollution Bulletin 62**(10):2190-2198.

Amaral, A. C. Z.; Denadai, M. R.; Turra, A. & Rizzo, A. E. 2003. Intertidal macrofauna in Brazilian subtropical tidedominated sandy beaches. **Journal of Coastal Research 35**:446-455.

Amaral, R. F. & Alfredini, P. 2010. Modelação Hidrossedimentológica no Canal de Acesso do Complexo Portuário do Maranhão. **Revista Brasileira de Recursos Hídricos 15**(2):5-14.

Amaral, A. C. Z. & Nonato, E. F. 1996. **Annelida, Polychaeta – Características, glossário e chaves para famílias e gêneros da costa brasileira**. Campinas, Ed. Unicamp. 124p.

Azevedo, A. C. G. & Cutrim, M. V. J. 2007. Fitoplâncton costeiro das porções norte-nordeste da ilha de São Luís, MA, Brasil. *In*: Silva, A.C. & Fortes, J. L. O. orgs. **Diversidade biológica, uso e conservação de recursos naturais do Maranhão**. São Luís, Universidade Estadual do Maranhão, p. 67-92.

Barros, F.; Hatje, V.; Figueiredo, M. B.; Magalhães, W. F.; Dórea, H. S. & Emídio, E. S. 2008. The structure of the benthic macrofaunal assemblages and sediments characteristics of the Paraguaçu estuarine system, NE, Brazil. **Estuarine**, **Coastal** and **Shelf Science 78**:753-762.

Bellotto, V. R.; Kuroshima, K. N. & Cecanho, F. 2009. Poluentes no ambiente estuarino e efeitos da atividade de dragagem. *In*: Lunardon-Branco, M. J. & Bellotto, V. R org. **Estuário do Rio Itajaí-Açú, Santa Catarina: caracterização ambiental e alterações antrópicas**. Itajaí, Editora UNIVALI, p. 105-126.

Bemvenuti, C. E.; Angonesi, L. G. & Gandra, M. S. 2005. Effects of dredging operations on soft bottom macrofauna in a harbor in the Patos Lagoon estuarine region of southern Brazil. **Brazilian Journal of Biology 65**(4):573-581.

Bolam, S. G. 2012. Impacts of dredged material disposal on macrobenthic invertebrate communities: A comparison of structural and functional (secondary production) changes at disposal sites around England and Wales. **Marine Pollution Bulletin 64**(10):2199-2210.

Bolam, S. G. 2014. Macrofaunal recovery following the intertidal recharge of dredgedmaterial: A comparison of structural and functional approaches. **Marine Environmental Research 97**:15-29.

Bolam, S. G. & Rees, H. L. 2003. Minimizing Impacts of Maintenance Dredged Material Disposal in the Coastal Environment: A Habitat Approach. **Environmental Management** 32(2):171-188.

Cabrini, T. M. B.; Barboza, C. A. M.; Skinner, V. B.; Hauser-Davis, R. A.; Rocha, R. C.; Saint'Pierre, T. D.; Valentin, J. L. & Cardoso, R. S. 2016. Heavy metal contamination in sandy beach macrofauna communities from the Rio de Janeiro coast, Southeastern Brazil. **Environmental Pollution 221**:116-129.

Castro, S. M. & Almeida, J. R. 2012. Dragagem e conflitos ambientais em portos clássicos e modernos: uma revisão. **Sociedade & Natureza 24**(3):519-534.

Ceia, F. R.; Patrício, J.; Franco, J.; Pinto, R.; Fernández-Boo, S.; Losi, V.; Marques, J. C. & Neto, J. M. 2013. Assessment of estuarine macrobenthic assemblages and ecological quality status at a dredging site in a southern Europe estuary. **Ocean & Coastal Management 72**:80-92.

Cruz-Motta, J. J. & Collins, J. 2004. Impacts of dredged material disposal on a tropical soft-bottom benthic assemblage. **Marine Pollution Bulletin 48**(3-4):270-280.

Cutrim, A. S. T.; Sousa, L. K. S.; Ribeiro, R. P.; Oliveira, V. M. & Almeira, Z. S. 2018. Structure of a Polychaete Community in a Mangrove in the Northern Coast of Brazil. **Acta Biol**ógica **Colombiana** 23(3):286-294.

Diniz, L. G. R.; Jesus, M. S.; Dominguez, L. A. E.; Fillmann, G.; Vieira, E. M.; Franco, T. C. R. S. 2014. First Appraisal of Water Contamination by Antifouling Booster Biocide of 3rd Generation at Itaqui Harbor (São Luiz - Maranhão – Brazil. **Journal of the Brazilian Chemical Society 25**(2):380-388.

Egres, A. G.; Martins, C. C.; Oliveira, V. M. & Lana, P. C. 2012. Effects of an experimental in situ diesel oil spill on the benthic community of unvegetated tidal flats in a subtropical estuary (Paranaguá Bay, Brazil). **Marine Pollution Bulletin 64**(12):2681-2691.

Ellis, J. I.; Clark, D.; Atalah, J.; Jiang, W.; Taiapa, C.; Patterson, M.; Sinner, J. & Hewitt, J. 2017. Multiple stressor e ects on marine infauna: responses of estuarine taxa and functional traits to sedimentation, nutrient and metal loading. **Scientific Reports 7**:1-16.

Faraco, L. F. D. & Lana, P. C. 2003. Response of polychaetes to oil spills in natural and defaunated subtropical mangrove sediments from Paranaguá bay (SE Brazil). **Hydrobiologia 496**:321-328.

Fauchald, K. & Jumars, P. A. 1979. The diet of worms: a study of Polychaete feeding guilds. **Oceanography and Marine Biology 17**:193-284.

Feres, S. J. C.; Santos, L. A. & Tagori-Martins, R. M. C. 2008. Família Nereidae (Polychaeta) como bioindicadora de poluição orgânica em praias de São Luís, Maranhão –Brasil. **Boletim do Laboratório de Hidrobiologia 21**(1):95-98.

Fernandes, M. E. B. 2003. **Os manguezais da costa norte brasileira**. Maranhão, Fundação Rio Bacanga. 132p.

Froján, C. R. S. B.; Cooper, K. M.; Bremner, J.; Defew, E. C.; Wan Hussin, W. M. R. & Paterson, D. M. 2011. Assessing the recovery of functional diversity after sustained sediment screening at an aggregate dredging site in the North Sea. **Estuarine**, **Coastal** and **Shelf Science 92**(3):358-366.

Garcia, P. D. & Alfredini, P. 2005. Caracterização hidrodinâmica das correntes de maré na área portuária do Maranhão. **Revista Pesquisa Naval 18**:39-44.

Gern, F. R. & Lana, P. C. 2013. Reciprocal experimental transplantations to assess effects of organic enrichment on the recolonization of benthic macrofauna in a subtropical estuary. **Marine Pollution Bulletin 67**(1-2):107-120.

Gray, J. S.; Elliot, M. 2009. Ecology of Marine Sediments. 2 edition. Oxford University Press.

Gruber, N. L. S.; Barboza, E. G. & Nicolodi, J. L. 2003. Geografia dos Sistemas Costeiros e Oceanográficos: Subsídios para Gestão Integrada da Zona Costeira. **Gravel 1**:81-89.

Hammer, O.; Harper, D. & Ryan, P. (SF). 2008. **PAST: Paquete de Programas de estadística paleontológica para enseñanza y análisis de datos.** Available at <http://palaeo-electronica.org/2001_1/past/spain.htm>. Accessed on 12 April 2014.

Jumars, P. A.; Dorgan, K. M. & Lindsay, S. M. 2015. Diet of Worms Emended: An Update of Polychaete Feeding Guilds. **Annual Review of Marine Science 7**:497-520.

Katsiaras, N.; Simboura, N.; Tsangaris, C.; Hatzianestis, I.; Pavlidou, A. & Kapsimalis, V. 2015. Impacts of dredged-material disposal on the coastal soft-bottom macrofauna, Saronikos Gulf, Greece. **Science of the Total Environment 508**:320-330.

Khedhri, I.; Atouia, A.; Ibrahima, M.; Aflia, A. & Aleyab, A. 2016. Assessment of surface sediment dynamics and response of benthic macrofauna assemblages in Boughrara Lagoon (SW Mediterranean Sea). **Ecological Indicators 70**:77-88.

Knox., G. A. 2001. **The Ecology of Seashores.** Boca Raton, CRC Press. 557p.

Lana, P. C.; Marone, E.; Lopes, R. M. & Machado, E. C. 2001. The subtropical estuarine complex of Paranagua Bay, Brazil. **Ecological Research 144**:131-145.

Levinton, J. S. 2001. **Marine Biology: Function, Biodiversity, Ecology**. Oxford, Oxford University Press. 420p.

Lewis, M. A.; Weber, D. E.; Stanley, R. S. & Moore, J. C. 2001. Dredging impact on an urbanized Florida bayou: effects on benthos and algal-periphyton. **Environmental Pollution 115**(2):161-171.

Lundquist, C. J.; Thrush, S. F.; Coco, G. & Hewitt, J. E. 2010. Interactions between disturbance and dispersal reduce persistence thresholds in a benthic community. **Marine Ecology Progress Series 413**:217-228.

McLachlan, A. & Brown, A. 2006. **The Ecology of Sandy Shores**. 2ed. Cambridge, Academic Press. 373p.

McLusky, D. S. & Elliott, M. 2004. **The estuarine ecosystem: ecology, threats and management**. 3ed. Oxford, Oxford University Press. 223p.

Mulik, J.; Sukumaran, S.; Srinivas. & Vijapure, T. 2017. Comparative efficacy of benthic biotic indices in assessing the Ecological Quality Status (EcoQS) of the stressed Ulhas estuary, India. **Marine Pollution Bulletin 120**(1-2):192-202.

Netto, S. A. & Lana, P. C. 1994. Effects of sediment disturbance on the structure of **Marine Ecology Progress Series 106**: 239-247.

Neves, R. A. F. & Valentin, J. L. 2011. Revisão bibliográfica sobre a macrofauna bentônica de fundos não-consolidados, em áreas costeiras prioritárias para conservação no Brasil. **Arquivos de Ciências do Mar 44**(3):59-80.

Newell, R. C.; Seiderer, L. J. & Hitchcock, D. R. 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. **Oceanography and Marine Biology 36**:127-178.

Oliveira, V. M. & Mochel, F. R. 1999. Macroendofauna bêntica de substratos móveis de um manguezal sob impacto das atividades humanas no sudoeste as ilha de São Luís, Maranhão, Brasil. **Boletim do Laboratório de Hidrobiologia 12**(1):75-93.

Paiva, A. C. G.; Coelho, P. A. & Torres, M. F. A. 2005. Influência dos fatores abióticos sobre a macrofauna de substratos inconsolidados da zona entre-marés no canal de Santa Cruz, Pernambuco, Brasil. **Arquivos de Ciências do Mar 38**(1-2):85-92.

Pires-Vanin, M. A. S.; Muniz, P. & De Leo, F. C. 2011. Benthic macrofauna structure in the northeast area of Todos os Santos Bay, Bahia State, Brazil: patterns of spatial and seasonal distribution. **Brazilian Journal of Oceanography 59**(1):27-42.

Ponti, M.; Pasteris, A.; Guerra, R. & Abbiati, M. 2009. Impacts of maintenance channel dredging in a northern Adriatic coastal lagoon. II: Effects on macrobenthic assemblages in channels and ponds. **Estuarine, Coastal and Shelf Science 85**(1):143-150.

Powilleit, M.; Kleine, J. & Leuchs, H. 2005. Impacts of experimental dredged material disposal on a shallow, sublittoral macrofauna community in Mecklenburg Bay (Western Baltic Sea). **Marine Pollution Bulletin 52**(4):386-396.

Rehitha, T. V.; Ullas, N.; Vineetha, G.; Benny, P. Y.; Madhu, N. V. & Revichandran, C. 2017. Impact of maintenance dredging on macrobenthic community structure of a tropical estuary. **Ocean** & **Coastal Management 144**:71-82.

Ribeiro, R. P. & Almeida, Z. F. 2014. Anelídeos Poliquetas do estado do Maranhão, Brasil: síntese do conhecimento. **Bioikos 28**(1):45-55.

Rios, E. C. 1994. **Seashells of Brazil**. Rio Grande, Museu Oceanográfico da Fundação Universidade de Rio Grande. 331p.

Sandrini-Neto, L. & Lana, P. C. 2014. Does mollusc shell debris determine patterns of macrofaunal recolonisation on a tidal flat? Experimental evidence from reciprocal transplantations. **Journal of Experimental Marine Biology and Ecology 452**:9-21.

Sandrini-Neto, L.; Martins, C. C. & Lana, P. C. 2016. Are intertidal soft sediment assemblages affected by repeated oil spill events? A field-based experimental approach. **Environmental Pollution 213**:151-159.

Schettini, C. A. F.; Santos, M. I. F. & Abreu, J. G. N. 2002. Observação dos sedimentos de fundo de uma plataforma abrigada sob influência de atividade de dragagem: Saco dos Limões, Florianópolis, SC. **Notas Técnicas FACIMAR 6**(1):165-175.

Schratzberger, M.; Rees, H. L. & Boyd, S. E. 2000. Effects of simulated deposition of dredged material on structure of nematode assemblages-the role of burial. **Marine Biology 136**:519-530.

Siqueira, G. W. & Aprile, F. M. 2012. Distribuição de mercúrio total em sedimentos da Plataforma Continental Amazônica – Brasil. **Acta Amazônica 42**(2):259-268.

Sola, M. C. R. & Paiva, P. C. 2001. Variação temporal da macrofauna bentônica sublitoral da praia da Urca (RJ) após a ocorrência de ressacas. **Revista Brasileira de Oceanografia 49**(1-2):137-142.

Thrush, S. F &, Dayton, P. K. 2002. Disturbance to marine benthic habitats by trawling and dredging: Implications for marine biodiversity. **Annual Review of Ecology, Evolution, and Systematics 33**:449-473.

Vivan, J. M.; Di Domenico, M. & Almeida, T. C. M. 2009. Effects of dredged material disposal on benthic macrofauna near Itajaí Harbour (Santa Catarina, South Brazil). **Ecological Engineering 35**:1435-1443.

Viveiros, J. 1954. História do comércio do Maranhão 1612-1895. Volume 1. São Luís, Associação Comercial do Maranhão. 360p.

Wilber, D. H.; Clarke, D. G. & Rees, S. I. 2007. Responses of benthic macroinvertebrates to thin-layer disposal of dredged material in Mississississippi Sound, USA. **Marine Pollution Bulletin 54**(1):42-52.

Witt, J.; Schroeder, A.; Knust, R. & Arntz, W. E. 2004. The impact of harbour sludge disposal on benthic macrofauna communities in the Weser Estuary. **Helgoland Marine Research 58**:117-128.

Xu, K.; Sanger, D.; Riekerk, G.; Crowe, S.; Dolah, R. F. V.; Wren, P. A. & Ma, Y. 2014. Seabed texture and compositin changes offshore of Port Royal Sound, South Carolina before and after the dredging for beach nourishment. **Estuarine, Coastal and Shelf Science 149**:57-67.

Zalmon, I. R.; Macedo, I. M.; Rezende, C. E.; Falcão, A. P. C. & Almeida, T. C. 2013. The distribution of macrofauna on the inner continental shelf of southeastern Brazil: The major influence of an estuarine system. **Estuarine, Coastal and Shelf Science 130**:169-178.

Zar, J.H. 2010. **Biostatistical Analysis**. 5ed. Upper Saddle River, Prentice Hall. 944p.