

Spatial and seasonal variation of zooplankton assemblages in two tidal control structures in Northeastern Brazil

Variação espacial e sazonal das assembleias do zooplâncton em duas estruturas de controle de marés no Nordeste do Brasil

Variación espacial y estacional de conjuntos de zooplancton en dos estructuras de control de mareas en el Noreste de Brasil

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Abstract

Zooplankton is a group of organisms that can help to understand the quality of aquatic ecosystems, as they are responsible for transforming energy matter, thus making it available to other links, making them important in aquatic trophodynamics. This study analyzed spatial and temporal variations in zooplankton communities found in two tidal control structures on Ilha do Maranhão, northeastern Brazil. Sampling took place from September 2017 to July 2018. Abiotic parameters (temperature, salinity, and transparency) and plankton samples were recorded monthly throughout the study period at each sampling site. The results found for the abiotic parameters showed a well-defined pattern, with a clear division between the dry and rainy periods. Forty taxa represented the zooplankton community of the São Luís tidal control structure, and from São José de Ribamar by 21 taxa, represented mainly by copepods, ichthyoplankton, foraminifera, polychaetes, and mollusks. The analysis of ecological indices of richness, evenness, and diversity showed a difference in the distribution of organisms among the study areas. We identified an important influence of the physicochemical parameters on the zooplankton communities of São Luís and São José de Ribamar, according to the statistical analyzes used in this study.

Keywords: Copepods; Coastal dam; Aquatic communities; Marine plankton.

Resumo

O zooplâncton é um grupo de organismos que podem ajudar a entender a qualidade dos ecossistemas aquáticos, pois são responsáveis por transformar a matéria energética, dessa forma disponibilizar para outros elos, tornando-os importantes na trofodinâmica aquática. Este estudo analisou variações espaciais e temporais nas comunidades zooplânctônicas encontradas em duas estruturas de controle de marés na Ilha do Maranhão, nordeste do Brasil. A amostragem ocorreu durante os meses de setembro de 2017 a julho de 2018. Os parâmetros abióticos (temperatura, salinidade e transparência) e as amostras de plâncton foram registradas mensalmente durante todo o período do estudo em cada local de amostragem. Os resultados encontrados para os parâmetros abióticos mostraram um padrão bem definido, com uma divisão clara entre os períodos seco e chuvoso. A comunidade zooplânctônica da estrutura de controle de marés de São Luís foi representada por 40 táxons, e de São José de Ribamar por 21 táxons, representados principalmente por copépodos, ictioplâncton, foraminíferos, poliquetas e moluscos. A análise dos índices ecológicos de riqueza, equitabilidade e diversidade mostrou que houve uma diferença na distribuição dos organismos entre as áreas de estudo. Identificamos uma influência importante dos parâmetros físico-químicos sobre as comunidades zooplânctônicas de São Luís e São José de Ribamar, de acordo com as análises estatísticas utilizadas neste estudo.

Palavras-chave: Copépodos; Espigão costeiro; Comunidades aquáticas; Plâncton marinho.

Resumen

El zooplancton es un grupo de organismos que pueden ayudar a comprender la calidad de los ecosistemas acuáticos, ya que son los encargados de transformar la materia energética, poniéndolos a disposición de otros enlaces, haciéndolos importantes en la trofodinámica acuática. Este estudio analizó las variaciones espaciales y temporales en las comunidades de zooplancton encontradas en dos estructuras de control de mareas en la Isla del Maranhão, noreste de Brasil. El muestreo se llevó a cabo entre septiembre de 2017 y julio de 2018. Los parámetros abióticos (temperatura, salinidad y transparencia) y las muestras de plancton se registraron mensualmente durante todo el período de estudio en cada sitio de muestreo. Los resultados encontrados para los parámetros abióticos mostraron un patrón bien definido, con una clara división entre los períodos secos y lluviosos. La comunidad de zooplancton de la estructura de control de mareas de São Luís estuvo representada por 40 taxones, y de São José de Ribamar por 21 taxones, representados principalmente por copépodos, ictioplancton, foraminíferos, poliquetos y moluscos. El análisis de los índices ecológicos de riqueza, uniformidad y diversidad mostró que había una diferencia en la distribución de organismos entre las áreas de estudio. Identificamos una influencia importante de los parámetros fisicoquímicos en las comunidades de zooplancton de São Luís y São José de Ribamar, según los análisis estadísticos utilizados en este estudio.

Palabras clave: Copépodos; Estructura de contención costera; Comunidades acuáticas; Plancton marino.

1. Introduction

Marine currents have been causing erosion in Brazilian coastal zones, and tide-control structures are constructed to minimize impacts (Souza, 2009; Paula, 2015). This also occurs due to growing and disorderly real estate speculation in coastal regions that increase pressure on the marine environment (Marcus, 2004; Nunes et al., 2018).

To contain the advance of the sea and protect coastal construction, tide-control structures are built with high or low structural technology (Paula, 2015). These tide-control structures are constructed to contain coastal erosion, which occurs when the sea advances on land, causing erosion and retreat of the coastline (Barra et al., 2018). In some cases, tide control structures are also used as attractions.

These constructions can impair the distribution of aquatic organisms and physical, chemical processes (Ziober & Zanirato, 2014; Webber et al., 2005). Biomonitoring using zooplankton helps to understand these environments better since zooplankton is directly associated with the physical, chemical, and biological characteristics of water, such as nutrient concentrations, pH, salinity, and temperature influence the composition and abundance of zooplankton (Vieira & Dantas, 2015). Considering spatial and seasonal variations and environmental impacts on the trophic web, as well as distribution, life cycle, size, some zooplanktonic organisms can be used as indicators to determine the ecological status and environmental health of a region (Porto Neto et al., 1999; Richardson, 2008; Mackas et al., 2012; Souza, 2019).

There are no previous studies about the impacts of tide-control structures on the marine fauna and flora in the region, making it hard to analyze possible changes. The tide-control structures at São Luís and São José de Ribamar were chosen as study areas because there have been more changes in their coastal environments over the years. At the São Luís tide-control structure, the non-containment zone accumulates a high amount of sand, which can change the region's dynamics and the organisms found. Meanwhile, in São José de Ribamar, there is a high accumulation of organic matter in the substrate of the containment zone.

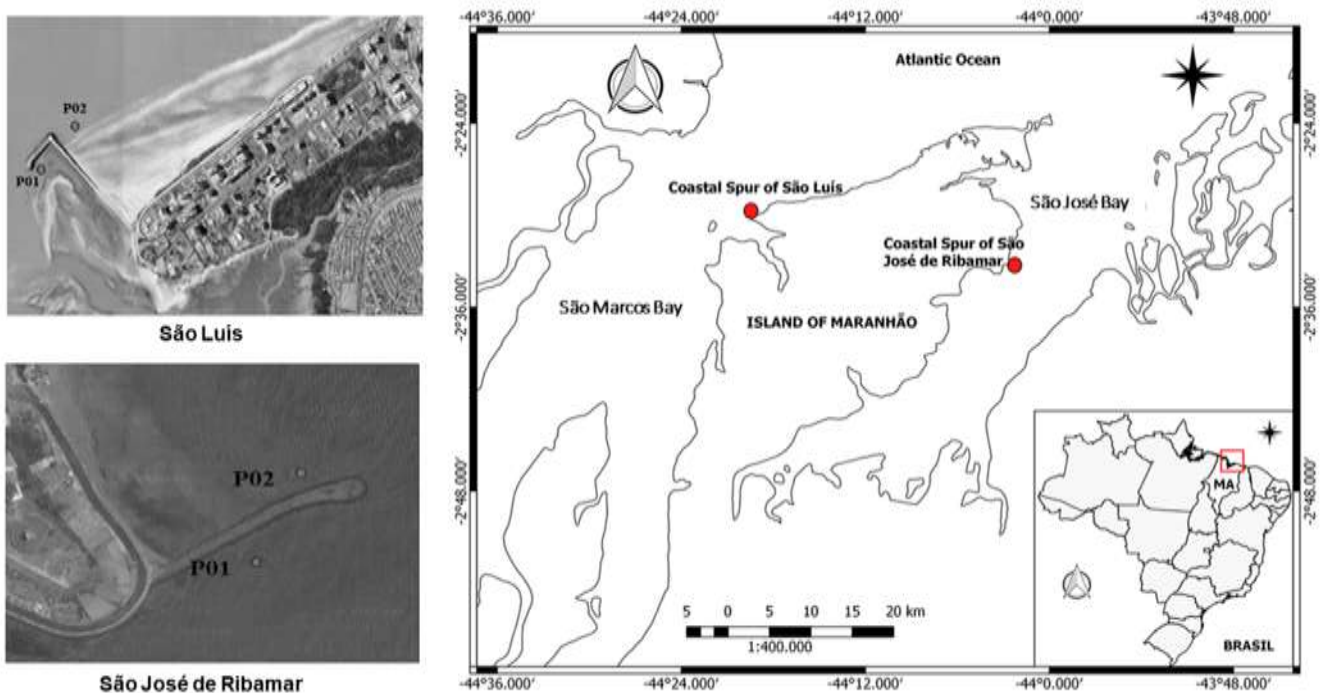
Recognizing that for the marine environment, this information on the relationship between sea containment structures and zooplankton and distribution communities is limited, this study analyzed the distribution spatial and seasonal characterization of zooplankton assemblages at two tide-control structures on Maranhão Island in Northeastern Brazil to increase knowledge about these communities, and verify how these structures can affect the distribution and abundance of these organisms.

2. Methodology

The samples were taken in the tidal containment regions, located in the municipalities of São José de Ribamar (02°27'35" S, 44°13'00" W) and São Luís (2°29'17" S, 44°09'19" W), on Maranhão Island, northeastern Brazil. These structures

were completed in 2014. Each study area had two sampling points, with P01 representing the tidal containment zone and P02 the non-containment region (Figure 1). In the P01 zone, due to the interference caused by the barrier, there is not a great mixture of water, the organisms remaining concentrated in a more closed region. In the P02 zone, because it is open, there is a greater flow dynamic of the organisms, this region being considered without impact. The relief of the Maranhão state reentrances favors a wide range of tides and semi-tides, which vary from 0.0 to 7.2 m, with complex and dynamic oceanographic characteristics (El-Robrini et al., 2015; Masullo, 2016).

Figure 1. Location of the collection points at the São Luís and São José de Ribamar tide-control structure - MA.



Source: Authors.

Abiotic and biological sampling

Monthly campaigns were conducted in the tidal containment zone during the dry season, from September to December 2017, and in the rainy season, from January to July 2018, totaling 22 collections in the two study areas. The physicochemical parameters were recorded monthly with a refractometer, thermometer, and Secchi disk to measure salinity, temperature, and water transparency, respectively. The accumulated rainfall data for 2017 and 2018 were obtained from the National Institute of Meteorology - INMET (<http://www.inmet.gov.br>) database for each collection month.

Plankton samples were collected at the subsurface of the water column using conical-cylindrical plankton nets with two meshes: 120 and 300 μm . The manual drag lasted 10 minutes in each area. Afterward, the samples were fixed with 4% formaldehyde. For each sample, a 6 mL aliquot was collected for the counted subjects using a Sedgewick-Rafter chamber, after which they were taken to a stereoscopic microscope and optical microscope for the lowest possible taxonomic level, following the specialized literature (Boltovskoy, 1999; Bradford et al., 1999; Bonecker, 2006). The organisms were identified with the lowest possible taxonomic level. Protocol 043/2018 of the Ethics Committee on animal use of the State University of Maranhão was respected.

Numerical and statistical treatment

The density analysis was calculated using the formula $D = N / V$, where N is the number of organisms in the subsamples and V is the volume of filtered water. The volume of filtered water (using a flowmeter of water) was obtained with the formula $V = a \times n \times c$, where “ a ” is the area of the mouth of the network, “ n ” is the variation of the number of rotations of the flowmeter and “ c ” is the factor of calibration (0.3). The result was given in org.m^{-3} .

Ecological indices were used to explain the seasonal and spatial behavior of the zooplanktonic organisms in the study regions. Diversity was determined according to Shannon-Wiener (1963), $H' = - \sum p_i \times \log_2 p_i$ (H' = Specific diversity - P_i is the proportion of the species given by n_i/N (Number of individuals (n_i) of taxa by the total number of organisms (N)) to identify how the species varied in the study areas. The specific richness used was that proposed by Margalef (1958) to determine the number of organisms $D = (S-1) / \log N$ (S = total number of species present in the sample; \log = \log in base 2; N = total number of individuals in the sample). The Pielou Equity Indices (1966) were calculated to identify the distribution of individuals among species $J' = J' = H'/H'_{\text{máx}}$ (J' = the equitability index; H' = the calculated diversity index; $H'_{\text{máx}}$ = given by the formula following: $H' / \log 2S$ - S = number of species in each sample).

The constancy indexes used were those described by Dajoz (1983), in which the zooplanktonic organisms were considered “Constant” when registered in more than 50% of the samples, “Accessory” when found in 25 - 50% of the samples, and “Accidental” when recorded in less than 25% of the samples.

The Shapiro-Wilk and Levene test was used to test the normality and homogeneity of the abiotic and biological data variances. We applied a one-way analysis of variance (one-way ANOVA) with the normal data. For variables (were points P1 and P2 grouped to make a comparison between the two periods (seasonal) and between structures (spatial)) that did not meet the one-way ANOVA assumption, the Kruskal-Wallis test was applied, with significant differences considered to be $p < 0.05$. The Principal Components Analysis (PCA) was performed using Pearson’s linear moment-product correlation, revealing and hierarchizing the factors responsible for the data’s variance, including zooplankton occurrence and hydrological parameters. The similarity matrix was based on the Euclidian distance was applied to determine the similarity of the sampling points in relation to the environmental parameters. The Canonical Correspondence Analysis (CCA) was applied to correlate the environmental variables with the abundant groups/species. The statistical analyses were performed with the Past 3.14, STATISTICA 10.0, and PRIMER (version 6.0) software.

3. Results

Physical-chemical parameters

The physical-defined characteristics of the studied variables are summarized in Table 1. The surface temperature (SST) does not present significant differences; however, Secchi, salinity, and rain registered significant differences throughout the study. According to the one-way ANOVA, the sea surface temperature showed no significant seasonal and spatial variation ($p < 0.05$) in either São Luís or São José de Ribamar.

Table 1. Physical-chemical data collected during dry and rainy periods in the tidal containment areas. **Legend:** * Indicates significant stationary and spatial variation of salinity for São Luís and São José de Ribamar ($p < 0.05$ ANOVA one-way); ** Indicates significant stationary and spatial variation of transparency for São Luís and São José de Ribamar ($p < 0.05$ ANOVA one-way).

Parameters	Unit.	Dry season		Rainy season	
		P01	P02	P01	P02
Sea surface temperature	° C	28.2 ± 0.8	28.7 ± 1.4	29 ± 1.1	28.4 ± 0.9
Salinity	-	33.2 ± 1.7*	31.9 ± 3.3*	27.7 ± 4.2*	24.6 ± 3.0*
Secchi	cm	9.8 ± 2.4**	25.5 ± 1.8**	19.3 ± 9.8**	26.9 ± 2.3**
Rainfall	mm	16.4 ± 27.0	16.4 ± 27.0	295.1 ± 162.1	295.1 ± 162.1

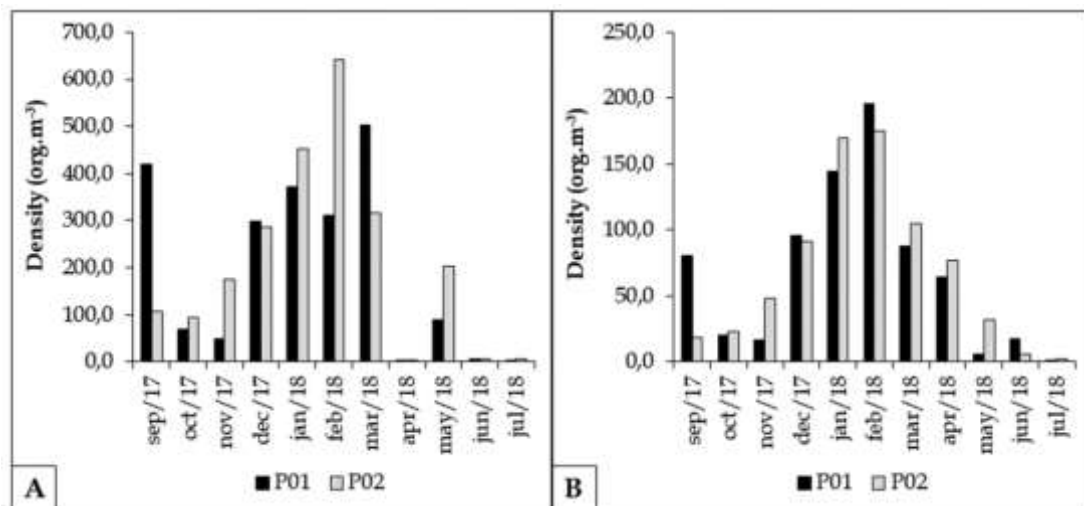
Source: Authors.

Zooplankton assemblage

The zooplankton communities at the tide-control structures were represented by 40 taxa in São Luís and 21 in São José de Ribamar (Table 2), comprised mainly of copepods, ichthyoplankton, foraminifera, Polychaeta, mollusks, and mysids. The organisms of the São Luís tidal containment zone had a significant variation in the constancy indexes (Table 2) between the seasonal periods, with a total of 40 species classified as accidental during the dry season. No constancy between the zooplankton groups was noticed in the rainy season, with 12.5% of the organisms characterized as accessory and 87.5% as accidental. According to the one-way ANOVA ($p < 0.05$), there was no variation in the abundance of organisms between the seasonal periods. During the dry season, the zooplankton organisms at the São José de Ribamar tide-control structure were classified as accessory (81%) and accidental (19%). However, in the rainy season, this changed to 57% accidental, 24% constant, and 19% accessory (Table 2). There was variation in the number of organisms between the seasonal periods ($p < 0.05$, ANOVA one-way).

In terms of density (Figure 2), it was possible to notice that in São José de Ribamar, February had the highest density at P01 with 196.2 org.m⁻³, and at P02, it was calculated at 175.3 org.m⁻³. The density of the zooplanktonic organisms at the São Luís tide-control structure was extremely high in January (point P01) and February (point P02) (372.3 org.m⁻³ with containment and 642.3 org.m⁻³ without containment). The São Luís and São José de Ribamar tide-control structures displayed significant spatial and temporal variations ($p < 0.05$, one-way ANOVA).

Figure 2. Density of zooplanktonic organisms of (A) São Luís and (B) São José de Ribamar. org.m³ - organism per cubic meter.



Source: Authors.

Table 2. Taxonomic synopsis of the zooplankton of the Coastal tide-control of São Luís and São José de Ribamar – MA, between the periods analyzed.

GROUPS and SPECIES	São Luís						São José de Ribamar					
	Dry			Rainy			Dry			Rainy		
	DEN (org.m ⁻³)	TO (%)	CI	DEN (org.m ⁻³)	TO (%)	CI	DEN (org.m ⁻³)	TO (%)	CI	DEN (org.m ⁻³)	TO (%)	CI
FORAMINIFERA												
<i>Ammonia beccarii</i> Linnaeus, 1758	130	5	Ac	288	5.1	Ac	0	0	Ac	0	0	Ac
<i>Ammonia</i> sp. Brünnich, 1771	128	5	Ac	283	4	Ac	0	0	Ac	0	0	Ac
CNIDARIA												
Hydrozoa	6	2.5	Ac	1	0.6	Ac	1	1.8	Ac	0	0	Ac
Hydromedusa	2	1.2	Ac	4	2.3	Ac	6	3.6	Ac	0	0	Ac
MOLLUSKS												
Gastropoda (veliger)	56	3.7	Ac	20	3.4	Ac	1	1.8	Ac	0	0	Ac
Bivalve (veliger)	104	3.7	Ac	309	4.5	Ac	3	1.8	Ac	10	3.0	Ac
COPEPODS												
<i>Acartia lilljeborgi</i> Giesbrecht, 1892	359	5	Ac	348	6.8	A	177	14.5	A	89	12.0	C
<i>Acartia tonsa</i> Giesbrecht, 1892	436	5	Ac	311	6.8	A	75	14.5	A	67	12.0	C
<i>Centropages velificatus</i> Oliveira, 1947	175	5	Ac	44	4	Ac	0	0	Ac	61	8.0	A
<i>Parvocalanus crassirostris</i> Dahl F., 1894	0	0	Ac	0	0	Ac	14	3.6	Ac	229	14.0	C
<i>Paracalanus</i> sp. Giesbrecht, 1893	43	5	Ac	14	2.3	Ac	0	0	Ac	0	0	Ac
<i>Temora turbinata</i> Dana, 1849	59	5	Ac	39	1.7	Ac	0	0	Ac	0	0	Ac
<i>Oithona similes</i> Claus, 1863	12	2.5	Ac	25	4	Ac	0	0	Ac	294	14.0	C
<i>Oithona</i> sp. Baird, 1843	0	0	Ac	0	0	Ac	0	0	Ac	7	6.0	A
<i>Euterpina acutifrons</i> Dana, 1848	259	5	Ac	371	6.8	A	0	0	Ac	141	11.0	C
<i>Euterpina</i> sp. Norman, 1903	0	0	Ac	0	0	Ac	0	0	Ac	10	6.0	A
<i>Corycaeus giesbrechti</i> Dahl, 1894	2	1.2	Ac	2	1.1	Ac	0	0	Ac	0	0	Ac
Copepoda Nauplios	43	5	Ac	178	6.8	A	0	0	Ac	0	0	Ac
MALACOSTRACA												
<i>Belzebub faxoni</i> Borradaile, 1915	12	3.7	Ac	8	1.7	Ac	0	0	Ac	0	0	Ac
Mysids	12	2.5	Ac	19	2.8	Ac	0	0	Ac	0	0	Ac
Brachyura (zoea)	9	3.7	Ac	3	1.7	Ac	354	14.5	A	45	8.0	A

Isopoda	1	0.6	Ac	21	0.6	Ac	0	0	Ac	3	2.0	Ac
Amphipoda	2	1.2	Ac	1	0.6	Ac	0	0	Ac	0	0	Ac
Cumacea	1	0.6	Ac	2	1.1	Ac	0	0	Ac	0	0	Ac
ANNELIDA												
Polychaeta (just)	25	3.7	Ac	36	5.1	Ac	47	14.5	A	1	1.0	Ac
Polychaeta (larvae)	8	1.2	Ac	26	5.1	Ac	0	0	Ac	0	0	Ac
CHAETOGNATHA												
<i>Sagittidae</i> sp. Quoy & Gaimard, 1827	11	5	Ac	30	5.6	A	0	0	Ac	0	0	Ac
APPENDICULARIA												
<i>Oikopleura dioica</i> Fol, 1872	16	0.6	Ac	1	0.6	Ac	0	0	Ac	0	0	Ac
ICHTHYOPLANKTON												
<i>Sardinella brasiliensis</i> Steindachner, 1879	14	2.5	Ac	7	2.3	Ac	29	7.3	Ac	0	0	Ac
<i>Anchoviella lepidentostole</i> Fowler, 1911	5	1.2	Ac	3	1.7	Ac	0	0	Ac	0	0	Ac
<i>Anchovia clupeioides</i> Swainson, 1839	1	0.6	Ac	1	0.6	Ac	0	0	Ac	0	0	Ac
<i>Oligoplites saurus</i> Gill, 1863	12	2.5	Ac	3	1.7	Ac	0	0	Ac	0	0	Ac
<i>Achirus achirus</i> Linnaeus, 1758	3	1.8	Ac	1	0.6	Ac	12	7.3	Ac	0	0	Ac
<i>Achirus</i> sp. Linnaeus, 1758	3	1.2	Ac	4	1.1	Ac	0	0	Ac	0	0	Ac
<i>Chloroscombrus crhysurus</i> Linnaeus, 1766	2	0.6	Ac	0	0	Ac	0	0	Ac	0	0	Ac
<i>Lycengraulis</i> sp. Spix & Agassiz, 1829	2	0.6	Ac	2	1.1	Ac	0	0	Ac	0	0	Ac
<i>Conodon nobilis</i> Linnaeus, 1758	2	0.6	Ac	2	1.1	Ac	0	0	Ac	0	0	Ac
<i>Sphoeroides testudine</i> Linnaeus, 1758	0	0	Ac	1	0.6	Ac	0	0	Ac	0	0	Ac
<i>Elops saurus</i> Linnaeus, 1766	4	0	Ac	4	0.6	Ac	0	0	Ac	0	0	Ac
<i>Lutjanus jocu</i> Bloch & Schneider, 1801	5	0.6	Ac	1	0.6	Ac	0	0	Ac	0	0	Ac
Fish eggs	0	0	Ac	0	0	Ac	6	5.5	Ac	0	0	Ac
OTHERS												
Ostracoda	6	2.5	Ac	6	2.8	Ac	0	0	Ac	2	2.0	Ac
Nematode	4	1.2	Ac	2	0.6	Ac	3	3.6	Ac	1	1.0	Ac
Radiolaria	1	0.6	Ac	0	0	Ac	0	0	Ac	0	0	Ac
Insects	0	0	Ac	0	0	Ac	7	5.5	Ac	0	0	Ac
Total	1971	100	-	2421	100	-	735	100	-	960	100	-

. Legend: DEN – Density (Org.m⁻³ - organism per cubic meter); TO - Total Occurrence; CI - constancy indices (Ac - Accidental; A - accessory; C – constant).Source: Authors.

Ecological Indexes

The ecological indexes show that throughout the study period, the average diversity during the dry season in São Luís was 2.2 ± 0.1 bits ind⁻¹, while in the rainy season, the average was 1.7 ± 0.4 bits ind⁻¹. In contrast, São José de Ribamar had averages of 1.3 ± 0.1 bits ind⁻¹ in the dry season and 1.5 ± 0.2 bits ind⁻¹ in the rainy season (Table 3). According to the one-way ANOVA, the diversity showed significant seasonal and spatial variation ($p < 0.05$) in both study areas.

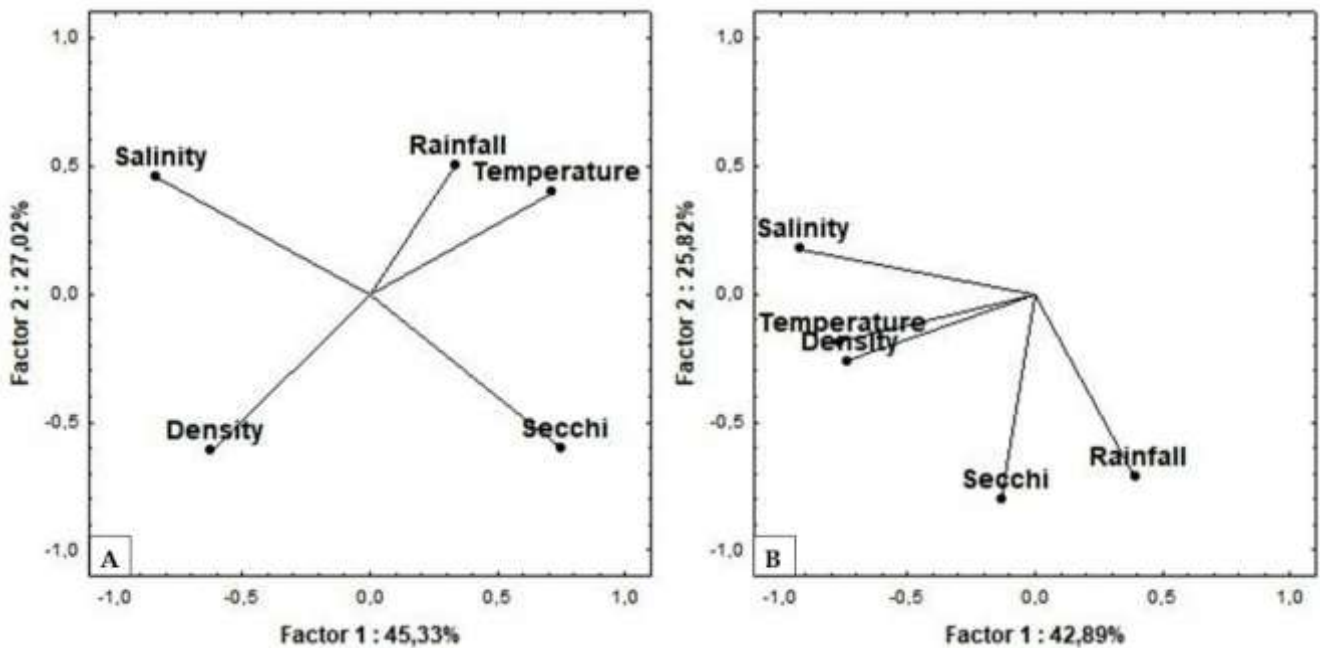
Table 3. Ecological indices of dry and rainy periods in tide-control containment areas.

Ecological indices	Unit.	Dry		Rainy	
		P01	P02	P01	P02
Diversity	Bits ind ⁻¹	2.2±0.1	1.3±0.1	1.7±0.4	1.5±0.2
Richness	Bits ind ⁻¹	1.3±0.2*	1.3±0.2*	1.0±0.2*	1.5±0.4*
Equitability	-	0.7±0.03**	0.7±0.07**	0.7±0.09**	0.8±0.04**

Legend: * Indicates significant stationary and spatial variation of wealth for São Luís and São José de Ribamar ($p < 0.05$ Kruskal-Wallis); ** Indicates significant stationary and spatial variation of equitability for São Luís and São José de Ribamar ($p < 0.05$ ANOVA one-way). Source: Authors.

PCA results explained 68.7% of total variance for the samples taken in São José de Ribamar, with the sum of factors 1 = 42.8% and factor 2 = 25.8% (Figure 3), where the seasonality of the abiotic parameters remained well defined. PCA results explained 72.3% of the total variance for samples from the region of São Luís with the sum of factors 1 = 45.3 and factor 2 = 45.3%.

Figure 3. Analysis of principal components of the zooplankton community and environmental factors from the coastal dam of (A) São Luís and (B) São José de Ribamar.

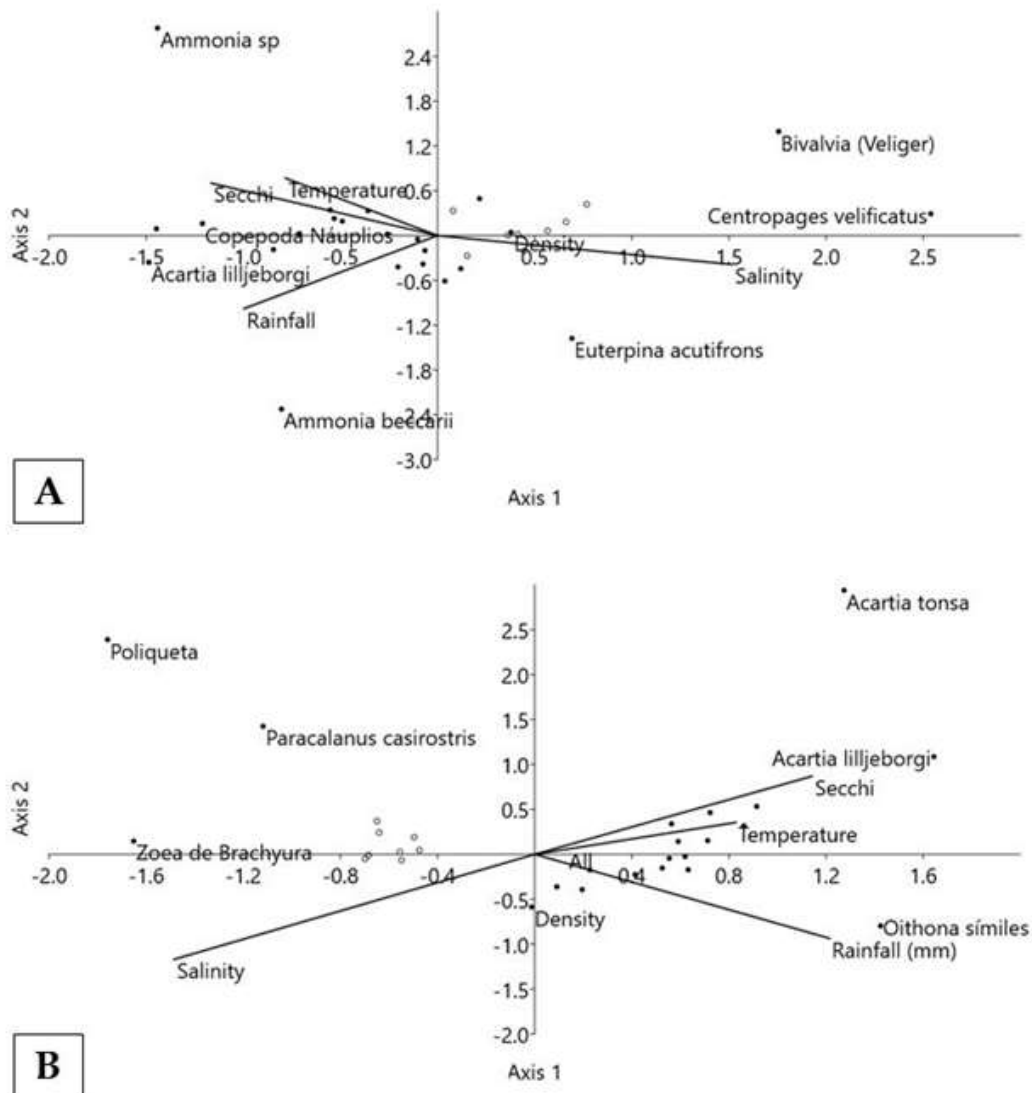


Source: Authors.

In general, the canonical correspondence analysis (CCA) explained 95.8% of the relationship of the environment to the distribution of dominant zooplanktonic groups in the region of São Luís, while in São José de Ribamar, the CCA explained 93.8% of the relationship (Figure 4). In the São Luís coastal dam, it was possible to notice that axis 1 of Figure 4 explained

70.3% of the relation between sea surface temperature, Secchi, and rainfall. All samples from the study area were positively influenced by *Ammonia beccarii*, *Ammonia* sp, *Acartia lilljeborgi*, *Acartia tonsa*, and Nauplius of copepods. For this reason, they are more subject to these environmental factors. Axis 2 of Figure 4 was less representative with 25.4% of the relation; thereby, salinity can influence the spatial and temporal distribution of *Bivalvia*, *Euterpina acutifrons*, and *Centropages velificatus* in the study area. In the region of São José de Ribamar, the spatial-temporal distribution of the species *A. lilljeborgi*, *A. tonsa*, and *O. símiles* were more influenced by the physical-chemical parameters of the sea surface temperature, Secchi and rain, as shown by axis 1, which explained 86.0% of the correlations. Meanwhile, axis 2 explained that 7.8% of the ordinations of the organisms Polychaeta, *Parvocalanus crassirostris*, and Brachyura (zoea) were influenced by the salinity in the environment.

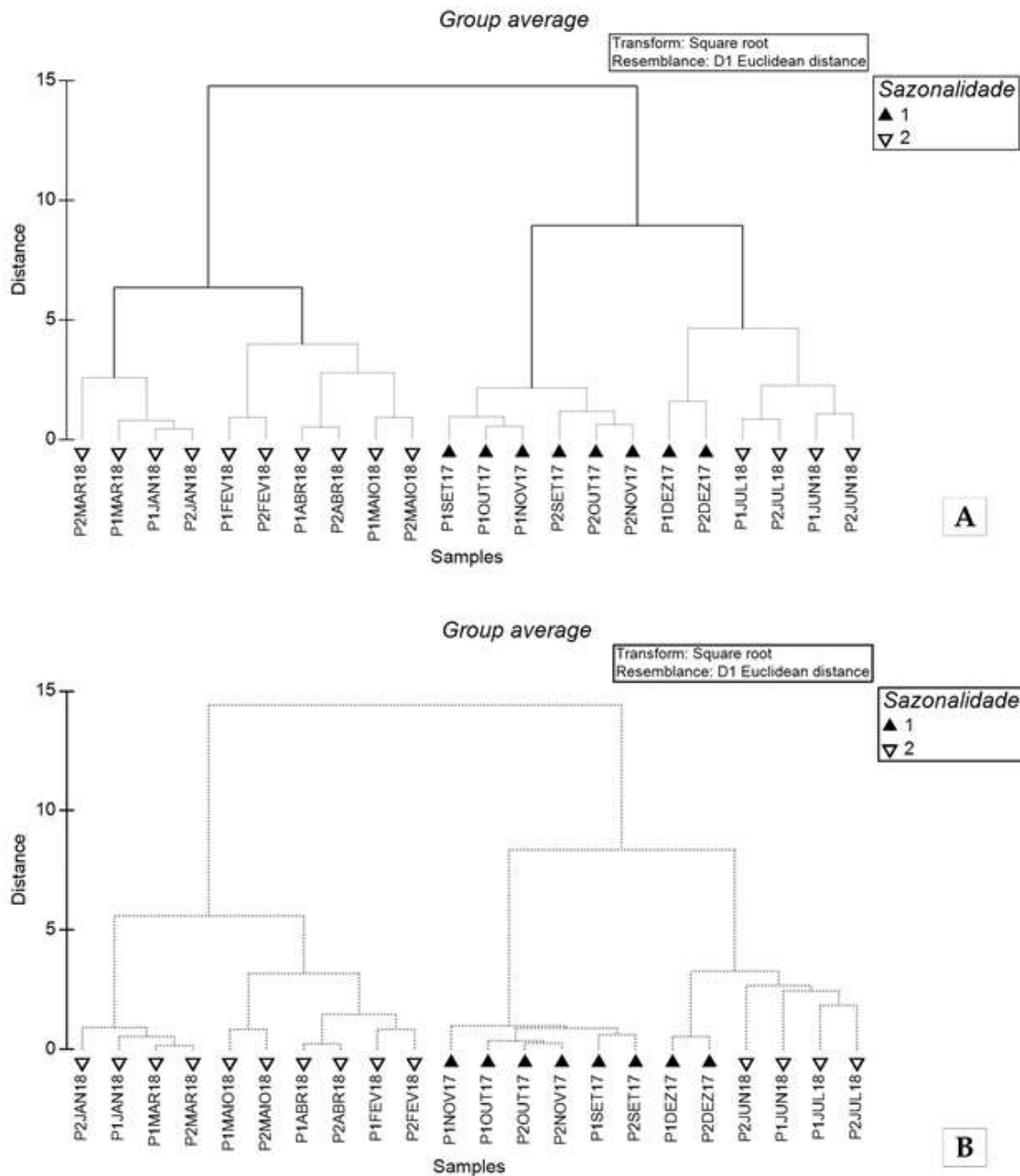
Figure 4. Canonical Correspondence Analysis species of zooplankton and abiotic parameters of the tide-control structures of (A) São Luís and (B) São José de Ribamar. Dry period (open ball) and rainy season (closed ball).



Source: Authors.

The Cluster hierarchical classification method showed that both São Luís and São José de Ribamar had two expressive groupings during the study (Figure 5). At the São José de Ribamar coastal dam, the similarity (Figure 5) between the months studied was well represented by the points P1JAN18 and P2JAN18, which comprised the rainy period, while at the São Luís tide-control structure, the highest similarity was better explained by the rainy season samples from April (P1APR18 and P2APR18).

Figure 5. Cluster hierarchical classification methods: (A) São Luís, (B) São José de Ribamar. (1) Dry period and (2) Rainy season.



Source: Authors.

4. Discussion

Surface water temperature at tidal containment structures followed the expected seasonal and spatial patterns for coastal regions, with constant values and without much variation during drought and precipitation. This reality is best identified on the coast of São José de Ribamar, as shown by Fontes et al. (2016), which identified that the region has relatively constant values. Meanwhile, at São Luís, Azevedo et al. (2008) also found a constant temperature range, mainly seasonally, with an annual average of 27 °C.

Seasonal and spatial variation of salinity was very significant ($p < 0.05$), as expected, since they were probably influenced by rainfall regimes in the regions, considering that the higher the precipitation, the lower the environmental salinity rates tend to be (Santos et al., 2020). It is important to emphasize that the salinity at the sample points ($p < 0.05$ ANOVA one-way) also varied in the region of São Luís and São José de Ribamar, where the tide-control structures may influence not only the organisms but also some abiotic parameters.

It is well known that the island of São Luís has several substantial rivers, mainly in the Bay of São Marcos and Arraial (El-Robrini et al., 2015). Thus, the deposition of organic matter can affect the organisms in the region. It was observed that the cities of São Luís and São José de Ribamar presented two climatic seasons (dry and rainy) through the pluviometric data of the region. According to Azevedo et al. (2008), the rainy season in the Maranhense Gulf extends from January to June, while the dry season is from July to December.

The copepod *A. lilljeborgi* was one of the most abundant organisms in the study, revealing its preference for a set of physical-chemical conditions, such as surface water temperature, transparency, and rainfall. In studies carried out by Resgalla Júnior (2011), he identified that *A. lilljeborgi* has a relationship with temperature and salinity in the coastal region of Santa Catarina. Meanwhile, the *A. tonsa* species was one of the most common organisms during both seasonal periods and study areas. Amaral et al. (2017) and Leite et al. (2009) found a high diversity of this species along the Brazilian coast, indicating it is independent of seasonality since it tends to reproduce whenever it finds favorable oceanographic characteristics. The copepod nauplii identified in the study by Kvilela et al. (2016) were strongly influenced by physical-chemical parameters such as surface water temperature, which corroborates the results found in the São Luís and São José de Ribamar tide-control structures, through canonical correspondence analysis (CCA).

In the region of São José de Ribamar, the Brachyura (zoea) was characterized as representative indicates the dispersion and recruitment of decapod crustaceans, which may be of commercial value to local fishermen. Impacts in this region may cause a deficiency in the recruitment of these individuals in their larval stage, noting that a possible decrease in zooplankton communities may also lead to a decrease in fish stocks, as well as an ecological imbalance in the estuary or adjacent coastal region (Silva-Falcão et al., 2007; Hirose et al., 2015). Finally, trawling can also influence benthic communities in the region (Bernardes et al., 2016).

Salinity influences bivalve mollusks, mainly in the larval stage, when it interferes with their physiological process, determining feeding capacity and survival, as well as the ability to select fixation sites (Moraes et al., 2015). Meanwhile, it can affect reproduction in adulthood since they suffer stress with variations of salinities, which cause organisms to have partial or total spawning.

Boltovscoy (1999) determined in his research that planktonic communities tend to be less dense in estuarine and coastal areas than in oceanic regions, which corroborates with the present study, which found maximum values of 1.8 bits ind⁻¹ at São José de Ribamar and 2.3 bits ind⁻¹ in the region of São Luís. The richness of the zooplankton communities at the tidal control structures was considered low according to Margalef (1995) since they were below 5.0 bits ind⁻¹. These results are considered by Neumann-Leitão et al. (1995) as normal for coastal environments, especially those that are dynamic. The low number of

studies on the composition and ecological indexes of zooplankton in regions with tidal containment makes it impossible to compare our results with other regions with the same problem.

The analysis of the similarity of the São Luís and São José de Ribamar tide-control structures shows that there was homogeneity of the zooplankton, that is, regardless of the influences of the anthropic agents, such as the tidal containment structure itself, the communities are probably able to maintain equilibrium. Finally, this study found zooplanktonic groups like those of Nunes et al. (2020) on the coast of Maranhão.

5. Conclusion

The physical-chemical parameters found at each tide-control structure were found to influence the zooplankton communities at São Luís and São José de Ribamar because the analyses of the ecological indexes and the one-way ANOVA showed that the most significant difference between the study areas was in the distribution patterns of the organisms. The behavior of the environmental parameters was normal for the two coastal regions studied. Finally, it is well known that tidal containment structures can impact biodiversity, and in this study, they were found to affect the distribution, density, and abundance of zooplankton communities at the tide-control structures in São Luís and São José de Ribamar. Based on the research, the waters from rivers can bring nutrients to the coastal zone, making these environments more suitable for the reproduction of fish, for example, in São Luís, where 40 taxa were found, the majority of which are ichthyoplankton. The entry of these rivers could favor this group. This could be the main characteristic that makes the points sampled in São Luís have a greater abundance of zooplankton and are taxonomically richer concerning the points of São José de Ribamar. Finally, this study reinforces the importance of monitoring zooplankton to identify ecological changes in environments.

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