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Characterization and spatiotemporal dynamics of the ichthyofauna of two tidal containment zones on the Brazilian Amazon coast

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ABSTRACT

This study aimed to characterize spatiotemporal variations in the ichthyofauna of two tidal containment zones in Maranhão state, Brazil. Monthly, collections were carried out in the containment zones of São Luís and São José de Ribamar, with samplings performed after the peak of the lowest tide (transition between low tide and high tide). Physicochemical parameters such as water salinity, temperature, transparency, and precipitation were measured monthly. A gill net (25-mm mesh) was used to capture fish. A total of 169 ichthyic individuals were captured and identified in the coastal containment areas of São Luís and São José de Ribamar. The orders Perciformes (41%) and Siluriformes (13.6%) were the most representative in terms of number of species. According to analysis of the t-test, there were significant seasonal and spatial variations in the number of organisms ($p < 0.05$), with the highest catches in rainy and transitional months. It was possible to identify a variation in niches in both study areas, the influence of physicochemical parameters on ichthyofaunal communities of São Luís and São José de Ribamar, and the effects of the containment structures on fish biomass and diversity, mainly in São Luís.

Keywords: Fish; Diversity; Biomass; Physicochemical parameters.

Caracterização e dinâmica espaço-temporal da ictiofauna de duas zonas de contenção de maré na costa amazônica brasileira

RESUMO

Este trabalho teve como objetivo caracterizar a variação espaçotemporal da ictiofauna de duas estruturas de contenção de maré no estado do Maranhão, Brasil. As coletas mensais foram realizadas nas zonas de contenção de São Luís e São José de Ribamar, com coletas realizadas após o pico da maré baixa. Parâmetros físico-químicos como salinidade, temperatura, transparência da água e precipitação foram medidos mensalmente. Uma rede de emalhar (com malha de 25 mm) foi utilizada para capturar os peixes. O total de 169 indivíduos da ictiofauna foram capturados e identificados na área de contenção costeira de São Luís e São José de Ribamar. As ordens Perciformes (41%) e Siluriformes (13,6%) foram as mais representativas em número de espécies. De acordo com o *test-t*, houve variação entre o número de organismos em relação aos períodos sazonal e estacionário nas áreas de estudo ($p<0,05$), com maiores capturas nos meses chuvosos e de transição. Foi possível notar uma variação nos nichos em ambas as áreas de estudo, a influência de parâmetros físico-químicos nas comunidades da ictiofauna de São Luís e São José de Ribamar e o efeito da construção da contenção sobre a biomassa e diversidade de peixes, principalmente em São Luís.

Palavras-chave: Peixes; Diversidade; Biomassa; Parâmetros físico-químicos.

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INTRODUCTION

The Amazon coastal zone, which comprises the Brazilian states of Maranhão, Pará, and Amapá, has several marine fisheries. The high productivity of the region is attributed to the intense biological activity generated by the outflow of rivers transporting organic matter and sediments from the decomposition of mangrove forests. The heterogeneity and dynamics of physicochemical conditions create considerable differences in marine ichthyofauna and the enrichment of the trophic ecology of species in their respective places of existence (Martins-Juras et al., 1987; Barthem and Fabré, 2004; Isaac-Nahum, 2006; Marceniuk et al., 2013). Based on Monteiro-Neto et al. (2008) and Zacardi (2015), tidal and current regimes of coastal ecosystems contribute to the complexity of flow processes, making them dynamic and biologically diverse.

The state of Maranhão has ecological prominence in the national scenario, as it displays a combination of relevant environmental, physical, and geographical characteristics that favor the existence of environments rich in marine species (Piorski et al., 2009). According to Almeida et al. (2011) and Silva Júnior (2012), the environmental conditions found in Maranhão make it one of the leading fish producers in Brazil.

Although the Maranhão coastal region has excellent environmental characteristics and significant ichthyofaunistic diversity, human actions are increasingly interfering with the development of marine ecosystems in the state (Castro et al., 2010). Fishing, tourism, agriculture, aquaculture, and industrial activities are among the main causes of stress in organisms of the marine environment, particularly in fish (Soares et al., 2011).

In addition to these activities, other important sources of environmental impacts are containment structures built to protect the coast from tidal effects, altering the current system, and often the natural supply of sand to beaches (Davenport and Davenport, 2006). Coastal dams are coastal protection structures arranged perpendicularly to the shoreline whose function is to retain the transport of sediments, which can increase the beach area and protect against erosion (Tessler and Goya, 2005; Nascimento and Lavenère-Wanderley, 2006; Palma, 2016). Such structures may also be used for leisure and touristic purposes (Medeiros et al., 2016). However, coastal protection structures can alter the abundance, distribution, and composition of ichthyofaunal communities, potentially eliminating some ichthyofaunistic components (Agostinho et al., 1992; Agostinho et al., 2008; Dala-Corte et al., 2009).

Although the Amazon coastal zone has a combination of great ichthyofaunistic richness and important problems that negatively impact marine environments, few studies have attempted to investigate the fish fauna of the region or assess possible relationships with anthropic actions (Marceniuk et al., 2013; Cardoso et al., 2018). Therefore, this study aimed to characterize spatiotemporal variations in the ichthyofauna of two tidal containment structures in Maranhão state, to assess relationships between physicochemical and biological variables, and to identify possible impacts caused by containment structures on the ichthyic community.

MATERIALS AND METHODS

Study areas

Fish were captured in areas close to the coastal containment zones of the municipalities of São Luís (2°29'17"S 44°09'19"W) and São José de Ribamar (02°27'35"S 44°13'00"W), both located on Maranhão island (Fig. 1). Maranhão island has two climatological periods, a rainy period, from January to June, and a dry period, from July to December (Azevedo et al., 2008).

The São Luís and São José de Ribamar tidal containment zones are directly influenced by the São Marcos and São José bays, respectively. According to Martins-Juras et al. (1987) and Almeida et al. (2016), these bays are characterized by dynamic environments consisting of mangroves delimited by transitional areas between marine and freshwater environments, with numerous estuaries and extensive deposition of organic matter, which favors the development of species with commercial importance in Maranhão state.

Data collection and processing

Monthly, collections were carried out from September 2017 to July 2018 in the tidal containment zones of São Luís (area 1) and São José de Ribamar (area 2). All samples were collected after the peak of the lowest tide, during the transition between low and high tide.

Water salinity, temperature, and transparency were measured using a refractometer, thermometer, and Secchi disk, respectively. Accumulated rainfall data for 2017 and 2018 were obtained from the National Institute of Meteorology (INMET, 2022).

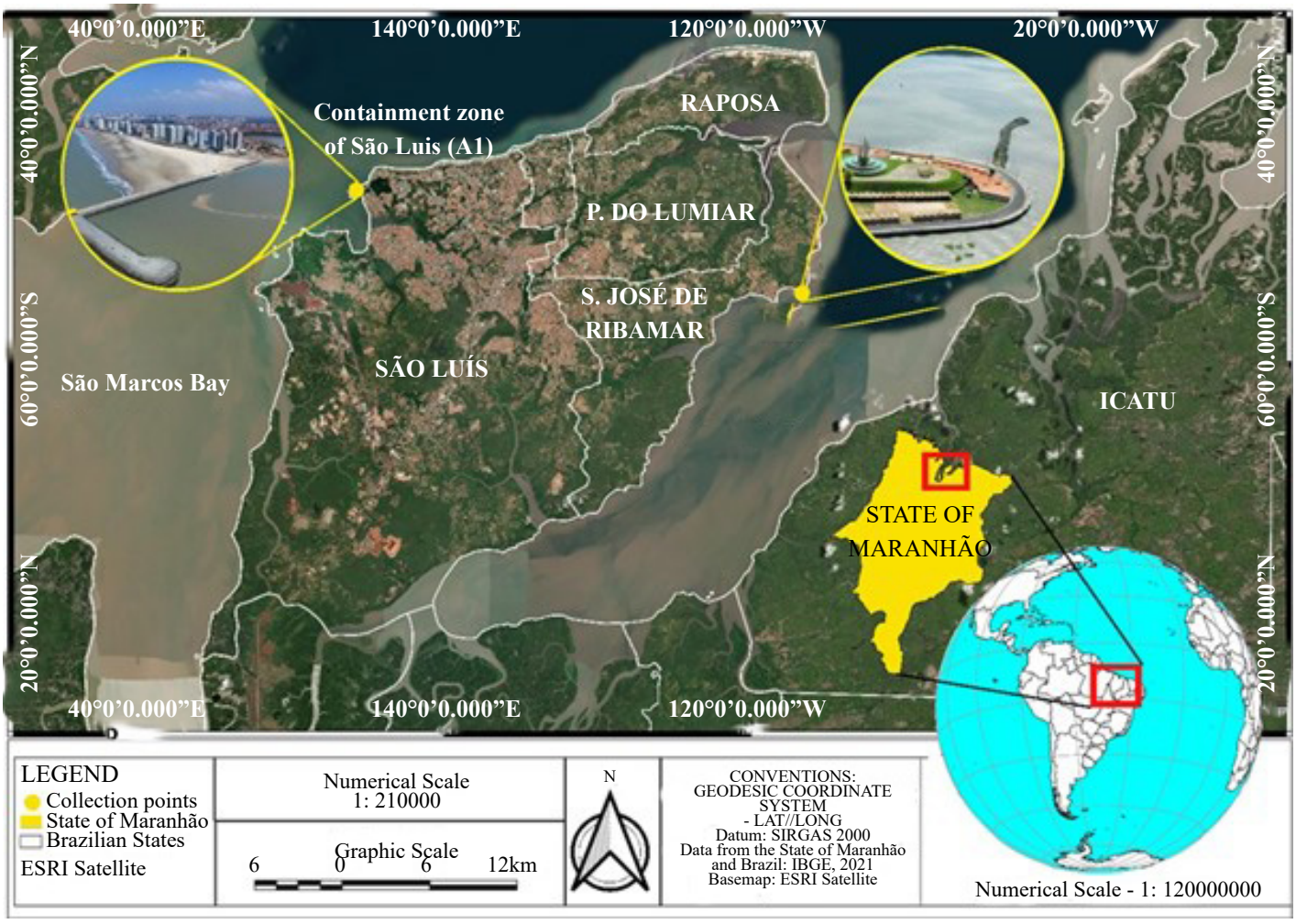


Figure 1. Ichthyofauna collection areas in two tidal containment zones on the Brazilian Amazon coast.

A gill net (25-mm mesh) was used to capture fish for 2 h at each collection site. The net was adapted and operated actively, used for trawls or enclosures at the two collection points. After collection, fish were transported to the Fisheries Biology Laboratory of Universidade Estadual do Maranhão (UEMA), where species were identified by comparison with literature references, such as Figueiredo and Menezes (1978, 1980, 2000), Fischer (1978), Cervigón et al. (1992), Nunes et al. (2001) and Castro (2014). The FishBase.org database was used to update taxonomic names and confirm the biological characteristics of the identified species. Afterwards, the biological material was processed, and the following biometric characteristics were determined: total length (cm) and total weight (g). A millimeter ruler and a scale with an accuracy of 0.01 g were used to measure length and weight, respectively. All procedures were performed based on the ethical principles established by the Ethics Committee on Animal Experimentation (No: 043/2018) of UEMA.

Numerical and statistical treatment

The constancy index was determined according to Dajoz (1983): species were considered constant when they were recorded in more than 50% of samples, accessory when present in 25 to 50% of samples, and accidental when recorded in less than 25% of samples.

Seasonal and spatial variations in the number of individuals (abundance) by biomass were assessed by the method described by Silva (2016). Estimates of catch volume per area and month were obtained by calculating catch per unit area (CPUA) and catch per unit effort (CPUE). In CPUA calculation, the fraction of catches in the effectively swept trajectory (X_1) was considered equal to 1 when the biomass coincided with the CPUA, as given by the Eq. 1:

$$CPUA = (C_w/a) \quad (1)$$

where: C_w: the catch in weight (g); a: the swept area (m).

Catch per unit effort was calculated as the ratio of number of captured individuals (N) to trawl time in hours (t), as expressed by Eq. 2 (Campos and Andrade, 1998; Asano Filho et al., 2003; Petrere Jr. et al., 2010):

$$CPUE = (N/t) \quad (2)$$

Ecological indices for the ichthyological community were calculated using PAST 3 software. Diversity was determined based on Shannon and Weaver (1963) and relative abundance according to Hasle (1978). Species richness was calculated as proposed by Margalef (1958). Evenness was measured using Pielou's index (1966). The indicator value (IndVal) index was used to identify indicator fish species. IndVal was calculated based on the abundance of individuals in collection areas and expressed as specificity and fidelity. Indicator organisms with IndVal>30% were considered potential indicators of ichthyofauna (Dufrêne and Legendre, 1997; Fortunato et al., 2013).

A graphical method of abundance *versus* weight curves expressed by the W statistic was applied to identify possible changes in the ichthyofaunal community structure that could indicate environmental impacts caused by the containment zone. The method described by Warwick (1986) represents an amplification of k-dominance curves (Lambshead et al., 1983), in which the slope of the cumulative curve indicates the level of perturbation and it is correlated with diversity. For determination of the abundance biomass comparison (ABC) index, abundance and biomass (weight) curves were represented in the same graph. Dominance of the abundance curve over the biomass curve indicates that the environment is disturbed, similarity between curves indicates a moderately disturbed habitat, and biomass dominance suggests that the environment is not stressed (Clarke and Warwick, 2001; Magurran, 2004; Yemane et al., 2005; Petesse, 2006; Soares et al., 2011).

The Shapiro-Wilk's test was used to test data normality and homogeneity of variance. When normality and homogeneity assumptions were not met, the data were transformed to log10. Analysis of the t-test was applied to normally distributed data. Significant differences were determined at $p < 0.05$. A similarity matrix (clustering) was constructed using the Bray-Curtis distance. Non-metric multidimensional scaling (nMDS) was applied to determine similarities in species abundance between samplings. For these procedures, the data were transformed to square root. The similarity profile test (SIMPROF) was used to assess the significance of groups. Canonical correspondence analysis (CCA) was used to correlate environmental variables with the dominant species. Statistical analyses were performed using PAST 3.14 and Statistica 10.0 software.

RESULTS

The total of 169 ichthyic individuals were captured and identified in the coastal containment zones of São Luís (61 individuals) and São José de Ribamar (108 individuals) (Table 1). The orders Perciformes (41%) and Siluriformes (13.6%) were the most representative in number of species. The IndVal showed that five species could be considered potential indicators, namely *Cetengraulis edentulus* (40.91%), *Citharichthys spilopterus* (36.36%), *Elops saurus* (40.91%), *Oligoplites palometa* (31.82%), and *Mugil curema* (36.36%). Regarding t-test, there were significant ($p < 0.05$) seasonal and spatial variations in the number of organisms.

Fishing effort (CPUE) varied throughout the study period in the São Luís tidal containment zone, being higher in September (13%), May (17%), June (13%), and July (17%). The fishing effort in São José de Ribamar was higher in February (13%), May (13%), and June (16%). According to t-test, there were significant seasonal and spatial variations in CPUE and CPUA in the studied areas ($p < 0.05$) (Fig. 2).

In São Luís, the mean diversity was significantly higher in the dry season than in the rainy season ($p < 0.05$, t-test). Diversity values were higher in São José de Ribamar than in São Luís in both seasons. Based on t-test, richness and evenness showed significant seasonal and spatial variations ($p < 0.05$) in both areas (Table 2).

Hierarchical clustering revealed three expressive groups: a small cluster associated mainly with the dry season; a second cluster comprising species collected primarily during the rainy season; and a third group composed of sample A11017, possibly very different from the others, regardless of seasonality (Fig. 3). The highest similarity was observed between samplings A11117, A11217, and A10218.

The results for bioindicator species, as selected by using IndVal, were validated by nMDS. The stress level was 0.11, which makes the analysis suitable to define groups according to ichthyofaunal abundance. The indicator species

Table 1. Taxonomic synopsis of the ichthyofauna of São Luís (A1) and São José de Ribamar (A2) containment zones, Maranhão State, Brazil.

Order species	Common name	A1		A2		Dry		Rainy		IndVal
		TO (%)	CI	TO (%)	CI	TO (%)	CI	TO (%)	CI	
BATRACHOIDIFORMES										
Batrachoides surinamensis	Pacamão	2.50	Ac	0.00	Ac	0.00	Ac	1.50	Ac	4.55
CLUPEIFORMES										
Cetengraulis edentulus	Manjuba-Boca-Torta	12.50	Ac	7.00	Ac	10.00	Ac	9.00	A	40.91*
Anchoviella sp.	Sardinha-manjuba	5.00	Ac	0.00	Ac	3.30	Ac	1.50	Ac	9.09
ELOPIFORMES										
Elops saurus	Ubarana	5.00	Ac	12.30	A	6.70	Ac	10.40	A	40.91*
LOPHIIFORMES										
Ogcocephalus vespertilio	Peixe-morcego	7.50	Ac	0.00	Ac	3.30	Ac	3.00	Ac	13.64
MUGILIFORMES										
Mugil curema	Parati	7.50	Ac	8.80	Ac	0.00	Ac	11.90	A	36.36*
PERCIFORMES										
Chaetodipterus faber	Paru-branco	0.00	Ac	7.00	Ac	10.00	Ac	1.50	Ac	18.18
Diapterus auratus	Carapeba-prateada	7.50	Ac	0.00	Ac	0.00	Ac	4.50	Ac	13.64
Genyatremus luteus	Peixe-pedra	2.50	Ac	0.00	Ac	3.30	Ac	0.00	Ac	4.55
Lutjanus jocu	Carapitanga	2.50	Ac	8.80	Ac	3.30	Ac	7.50	Ac	27.27
Macrodon ancylodon	Pescada-gó	5.00	Ac	5.30	Ac	3.30	Ac	6.00	Ac	22.73
Menticirrhus americanus	Boca-de-rato	0.00	Ac	10.50	A	10.00	Ac	4.50	Ac	27.27
Micropogonias furnieri	Cururuca	5.00	Ac	1.80	Ac	0.00	Ac	4.50	Ac	13.64
Oligoplites palometa	Tibiro	5.00	Ac	8.80	Ac	6.70	Ac	7.50	Ac	31.82*
Stellifer naso	Cabeçudo	0.00	Ac	7.00	Ac	6.70	Ac	3.00	Ac	18.18
PLEURONECTIFORMES										
Citharichthys spilopterus	Solha-urumaçara	12.50	Ac	5.30	Ac	20.00	A	3.00	Ac	36.36*
Symphurus jenynsii	Língua-de-vaca	5.00	Ac	1.80	Ac	6.70	Ac	1.50	Ac	13.64
SCORPAENIFORMES										
Prionotus punctatus	Cabrinha	2.50	Ac	0.00	Ac	0.00	Ac	1.50	Ac	4.55
SILURIFORMES										
Cathorops arenatus	Bagre-de-areia	2.50	Ac	0.00	Ac	0.00	Ac	1.50	Ac	13.64
Cathorops spixii	Uriacica-vermelha	2.50	Ac	0.00	Ac	3.30	Ac	0.00	Ac	4.55
Sciades herzbergii	Bagre-guribu	7.50	Ac	5.30	Ac	0.00	Ac	9.00	A	27.27
TETRAODONTIFORMES										
Sphoeroides testudineus	Baiacu-pininga	0.00	Ac	10.50	A	3.30	Ac	7.50	Ac	27.27
TOTAL		100		100		100		100		

TO: total occurrence; CI: constancy index; Ac: accidental; A: accessory; C: constant; IndVal: indicative value; *indicator fish species in this study by IndVal.

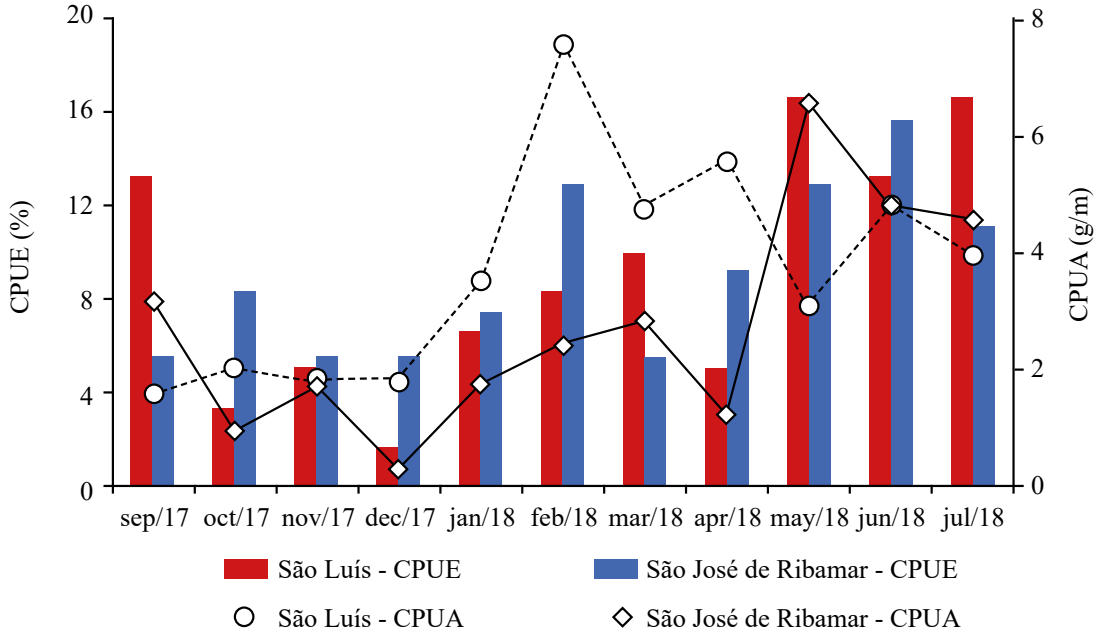


Figure 2. Spatial and temporal variations in catch per unit effort (CPUE) and catch per unit area (CPUA) in São Luís and São José de Ribamar tidal containment zones, Maranhão state, Brazil.

Table 2. Ecological indices of dry and rainy periods in São Luís (A1) and São José de Ribamar (A2) tidal containment zones, Maranhão state, Brazil.

Ecological index	Unit	Dry		Rainy	
		A1	A2	A1	A2
Diversity	bits ind^{-1}	1.33 ± 0.53*	1.44 ± 0.12	0.71 ± 0.41*	1.53 ± 0.47
Richness	bits ind^{-1}	1.83 ± 0.71*	1.70 ± 0.24*	1.07 ± 0.91*	2.10 ± 0.65*
Evenness	-	0.98 ± 0.41*	0.87 ± 0.01*	0.71 ± 0.03*	0.95 ± 0.13*

*Significant seasonal and spatial variations in richness and evenness in São Luís and São José de Ribamar containment zones ($p < 0.05$, t-test).

Menticirrhus americanus (A1), *M. curema*, and *Sphoeroides testudineus* (A2) were found to be well-defined spatially, whereas *C. spilopterus*, *C. edentulus*, *E. saurus*, *Lutjanus jocu*, *Sciades herzbergii*, and *O. palometa* were identified in both study areas (Fig. 4).

Canonical correspondence analysis explained 91.27% of the variation in environmental relationships and ichthyofaunal distribution in both areas (Fig. 5). Axis 1 explained 68.87% of the variation in relationships between abiotic parameters and fish species. Salinity (0.66) positively influenced the distribution of *Chaetodipterus faber* (2.33), *C. spilopterus* (2.29), *Stellifer naso* (1.52), *M. americanus* (0.72), *C. edentulus* (0.56), *O. palometa* (0.13), and *Macrodon ancylodon* (0.09). This finding indicates that these organisms may be more susceptible to changes in population resulting from variations in salinity during stationary periods. Axis 2 was less representative, explaining 22.4% of the variation in relationships. Surface water temperature, Secchi transparency, and rainfall influenced the spatial and temporal distribution of *Micropogonias furnieri* (-1.00), *M. curema* (-0.88), *Sciades herzbergii* (-0.83), *L. jocu* (-0.82), *E. saurus* (-0.55), and *S. testudineus* (-0.17). CCA showed significant variations (eigenvalue = 0.37; $p = 0.012$).

On the basis of ABC analysis, São Luís and São José Ribamar containment zones were classified as disturbed (Fig. 6), since the biomass curve showed dominance over the numerical abundance curve. However, the *W* statistic indicated that the environments were only moderately disturbed ($W_{\text{SãoLuís}} = 0.014$; $W_{\text{SãoJosédeRibamar}} = 0.015$).

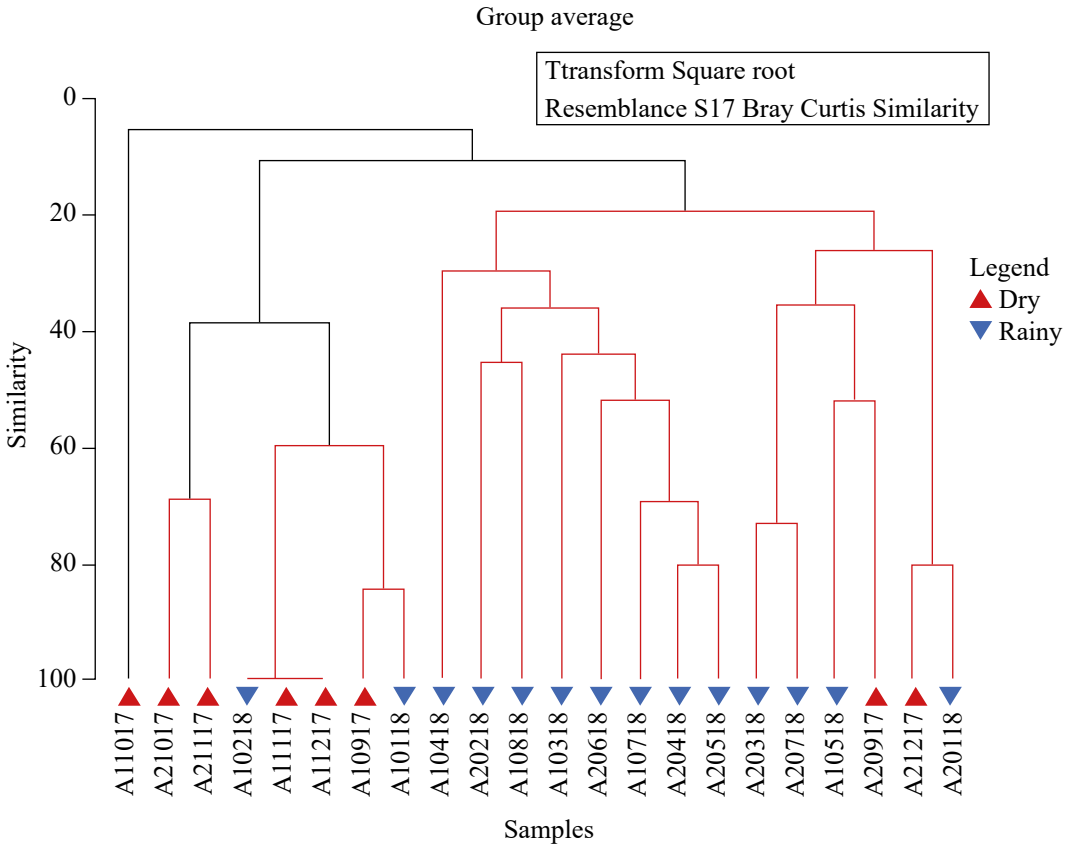


Figure 3. Hierarchical clustering of the ichthyofauna of São Luís (A1) and São José de Ribamar (A2) containment zones, Maranhão state, Brazil, from September 2017 (0917) to July 2018 (0718).

DISCUSSION

The total of 22 fish species were collected in tidal containment zones, more precisely 18 in São Luís and 14 in São José de Ribamar. These species had been recorded in studies on marine ichthyofauna in Maranhão state (Carvalho-Neta and Castro, 2008; Castro et al., 2010). In the estuary of River Paciência, Maranhão state, Silva Júnior et al. (2013) identified 55 individuals, whereas Pinheiro Júnior et al. (2005) identified 43 species on São Luís island, presenting a higher richness than that identified in the containment zones. The number of organisms sampled may differ from other studies due to differences in the sampling effort employed in each work.

Other studies carried out on São Luís island recorded a higher number of species than that observed here. Castro et al. (2010) collected 44 species near an aluminum extraction industry, among which the order Perciformes had the highest frequency (31.3%). Pinheiro Júnior et al. (2005) identified 43 species in the Rio Anil estuary, the majority (63%) of which belonged to the order Siluriformes. Carvalho-Neta and Castro (2008) recorded 32 species on Caranguejos island, Maranhão state, among which 45% belonged to the order Perciformes and 26% to Siluriformes. Teixeira et al. (2017) observed a predominance of fish of the orders Siluriformes and Perciformes in Ceará state, Brazil.

Despite the low number of species sampled in São Luís and São José de Ribamar containment zones, we also observed a predominance of Perciformes and Siluriformes individuals, in agreement with the literature. Fish belonging to these orders have a wide distribution along the northern Brazilian coast, given their tolerance to variations in environmental conditions such as salinity. Tolerance to salinity, for instance, contributes to the distribution of species from the families Sciaenidae and Ariidae in different habitats, including degraded environments (Camargo and Isaac, 2004; Casatti et al., 2009; Helfman et al., 2009; Nelson et al., 2016).

The expressive occurrence of *C. edentulus* in the São Luís containment zone can be explained by the formation of fish shoals, a characteristic that makes the order Clupeiformes more representative in marine environments (Castro, 2001; Barletta et al., 2003). The significant occurrence of *C. spilopterus* in

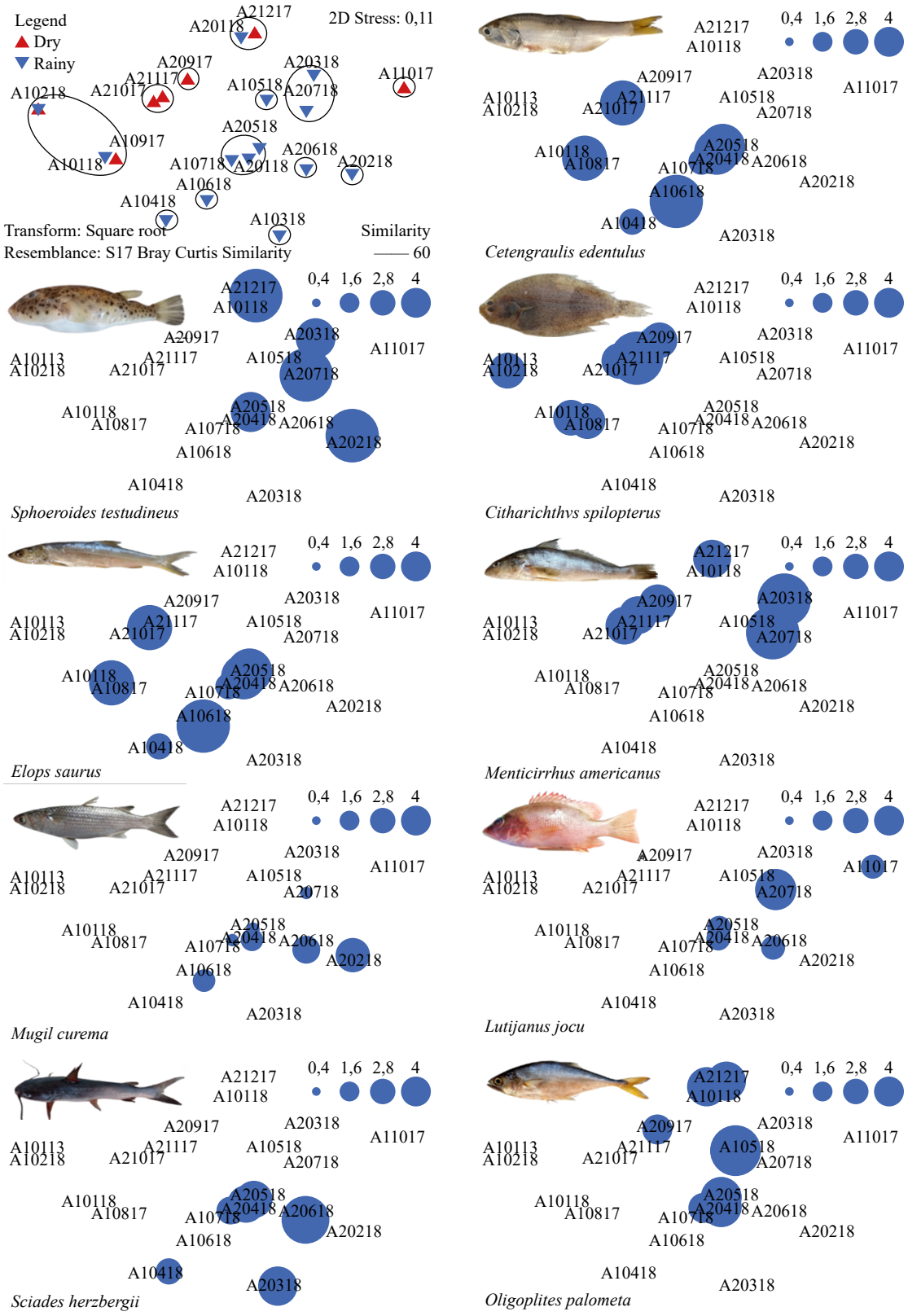
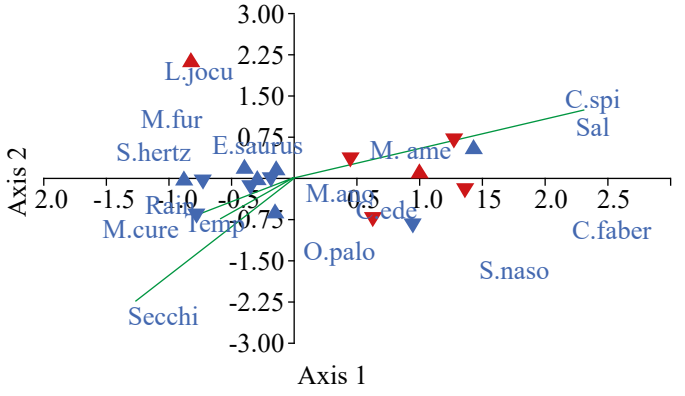


Figure 4. Bubble charts of the main ichthyic species of São Luís (A1) and São José de Ribamar (A2) tidal containment zones, Maranhão state, Brazil, superimposed on the non-metric multidimensional scaling plot. Individuals were captured from September 2017 (0917) to July 2018 (0718).



Temp: temperature; Salt: salinity; Rain: rainfall; Secchi: transparency; C.ede: *Cetengraulis edentulus*; C.spi: *Citharichthys spilopterus*; L.jocu: *Lutjanus jocu*; M.cure: *Mugil curema*; S.herz: *Sciades herzbergii*; O.palo: *Oligoplites palometa*; E.saurus: *Elops saurus*; M.fur: *Micropogonias furnieri*; M.ancy: *Macrodon ancylodon*; S.naso: *Stellifer naso*; C.faber: *Chaetodipterus faber*; S.tes: *Sphoeroides testudineus*; M.ame: *Menticirrhus americanus*; upward triangles: São Luís; downward triangles: São José de Ribamar; red triangles: dry season; blue triangles: rainy season.

Figure 5. Canonical correspondence analysis of the ichthyofaunal community and abiotic parameters of tidal containment zones.

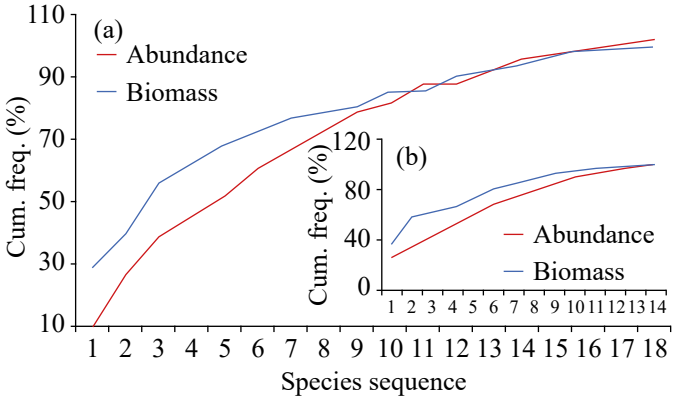


Figure 6. Abundance biomass comparison (ABC) curves of the ichthyofauna of (a) São Luís and (b) São José de Ribamar containment zones, Maranhão state, Brazil.

the region is likely related to the strong connection that the species has with abiotic and biotic factors, such as variation in salinity and food availability, which contribute to its wide distribution (Besyst et al., 1999; Guedes, 2006). The abundance of *C. edentulus* and *C. spilopterus* in the dry season suggests that these species recruit during the period for subsequent development in the rainy season (Soeth et al., 2014).

The higher frequency of *S. testudineus*, *E. saurus*, and *M. americanus* in the São José de Ribamar containment zone might be linked to the peculiarities of each species. The great representativeness of *S. testudineus* in coastal regions is due to the vital link between its life cycle and beach dynamics, characterizing the species as a resident, with wide distribution in estuaries (Felix et al., 2006; Vilar et al., 2011). McBride et al. (2001) state that the presence of *E. saurus* in coastal estuarine environments is strongly influenced by season and temperature gradients, as the species has higher distribution rates at higher temperatures and a significant mortality rate at low temperatures. In this study, this species had a higher occurrence in the rainy season. This result agrees with those of McBride et al. (2001) and Santos et al. (2015), who found a strong relationship between *E. saurus* and the rainy season. The presence of *M. americanus* (family Sciaenidae) is indicative of its preference for shallow waters with sandy or muddy bottoms (Freitas et al., 2011). The family Sciaenidae has high richness, numerical abundance, and biomass and it is very tolerant to variations in water salinity (Carvalho-Neta and Castro, 2008; Zacardi, 2015).

The high catches in terms of biomass and number of individuals in rainy and transitional months in both areas indicate a preference for fish for wet periods, when there is an increase in primary production and food availability (Pessanha et al., 2000; Felix et al., 2006; Spach et al., 2007; Araujo et al., 2008; Ignácio and Spach, 2010).

The São Luís tidal containment zone had higher diversity during the dry season, which, according to Silva Júnior et al. (2013), suggests an association between ichthyofauna and environment heterogeneity and shelter availability as a response to salinity variations.

Araújo et al. (2009) stated that higher diversity during the rainy season indicates a greater number of microhabitats, characterized by better use of available resources due to the rising water levels. This analysis can explain the high species number and expressive diversity during the rainy season in São José de Ribamar, compared to the dry period, even with a lower density than other studies carried out.

There was a significant variation in diversity between collection areas. The São José de Ribamar containment zone had higher diversity than the São Luís zone. According to Carvalho-Neta and Castro (2008), variations in the diversity index are related to several factors, such as environmental stability, biomass accumulation, extension of food chains, and variety and overlapping of niches. It can be inferred, through ABC analysis, that the São José de Ribamar containment zone has greater productivity and environmental stability than the São Luís zone.

The low diversity of area 1 compared with area 2 might be associated with environmental impacts. Pinheiro Júnior et al. (2005) stated that anthropization, together with high sewage

loads released daily in the coastal environment of São Luís island, causes an imbalance in ichthyofauna and a consequent decrease in diversity. According to Shima et al. (2008), the difference in diversity between collection areas lies in that the environments are not seasonally or spatially homogeneous; different interspecies interactions occur parallel to these dimensions.

Margalef (1995) reported that tidal containment systems have low richness (<5 bits ind^{-1}); and it was observed that the tidal containment structures of both areas might also be related to the low richness. This type of system prevents migratory movements, causing changes in the abundance, distribution, and even in the genetic structure of ichthyofauna (Agostinho et al., 2008; Oliveira and Tejerina-Garro, 2010).

The evenness index showed uniformity of species distribution in São Luís and São José de Ribamar containment zones. The evenness index ranges from 0 to 1, and values greater than 0.5 are considered high (Botini et al., 2015). The evenness values of the study areas revealed a good balance in the distribution of organisms and absence of dominant species (Botini et al., 2015).

The ABC method indicated moderate stress in the São Luís tidal containment zone and no stress in the São José de Ribamar tidal containment zone. The results for area 1 corroborate the observations of Soares et al. (2011), who found moderate stress in the ichthyofauna of the Paciência River estuary. According to Warwick (1986) and Petesse (2006), a moderately disturbed community is characterized by the disappearance of large species, thereby resulting in a decrease in differences between dominant species (about weight and number). The results for area 2 are in agreement with the findings of Gonçalves and Braga (2008) for the ichthyofauna of the Upper Paraná River basin, characterized by lack of disturbances. Environments with good stability have a biomass curve above the numerical abundance curve, indicating the dominance of *k*-strategist species, which have larger sizes and longer life cycles (Casatti et al., 2006; Gonçalves and Braga, 2008).

CONCLUSIONS

It was observed a variation in the niches of both study areas, as well as an influence of physicochemical parameters on ichthyofaunal communities of São Luís and São José de Ribamar. Variations in salinity, which tend to be greater during the dry season, directly influenced the distribution of *C. faber*, *C. spilopterus*, *S. naso*, *M. americanus*, *C. edentulus*, *O. palometa*, and *M. ancylodon*, while temperature, precipitation, and transparency, especially in the rainy season, influenced the abundance of *M. furnieri*, *M. curema*, *S. herzbergii*, *L. jocu*, *E. saurus,* and *S. testudineus*. Tidal containment structures might be impacting the ichthyofauna, especially in the São Luís region. The moderate stress revealed by the ABC method may be due to the effects of tidal containment structures, which may cause reduction in the frequency of some species, such as *C. edentulus*, *E. saurus*, and *M. curema* in São Luís, and *E. saurus* and *M. curema* in São José de Ribamar.

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CONFLICT OF INTERESTS

Nothing to declare.

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Data collection: Silva L R, Nunes Y B S; **Formal analysis:** Silva L R; Nunes Y B S; Antonio I C; Figueiredo M B; **Writing – review and editing:** Silva L R; Nunes Y B S; Antonio I C; Figueiredo M B.

DATA AVAILABILITY STATEMENT

Data will be available by upon request.

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