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Taxonomic composition and spatio-temporal distribution of ichthyoplankton in São Marcos Bay, Maranhão, Brazil

Composição taxonômica e distribuição espaço-temporal do ictioplâncton na Baía de São Marcos, Maranhão, Brasil

Composición taxonómica y distribución espacio-temporal del ictioplancton en la Bahía de São Marcos, Maranhão, Brasil

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ABSTRACT
This study aims to verify the taxonomic composition and ecological diversity of ichthyoplankton in São Marcos Bay (SMB), a region on the Brazilian Amazon coast with vast ecological and socioeconomic importance. Samples of fish larvae were collected in four biannual campaigns at different points throughout the bay, during the rainy and dry seasons. In the field, physicochemical parameters (water temperature, salinity, pH, dissolved oxygen and turbidity) and meteorological conditions were recorded. The biological samples were morphologically identified according to the identification keys. A total of 8,231 fish larvae were identified belonging to 15 orders, 22 families, 25 genera and 31 species, with greater abundance of species during the dry season. The results obtained reveal that the ichthyoplankton present in São Marcos Bay is mainly composed of species from the families Engraulidae, Clupeidae and Sciaenidae, with greater occurrence during the dry season. It also shows that the structure and composition of aquatic biota is mainly determined by the variation in salinity and rainfall.

Keywords: Brazilian Coast, Fish Larvae, Tropical Estuary, Rainfall, Port Area, Engraulidae.

RESUMO
Este estudo tem como objetivo verificar a composição taxonômica e a diversidade ecológica do ictioplâncton na Baía de São Marcos (SMB), região da costa amazônica

brasileira de vasta importância ecológica e socioeconômica. Amostras de larvas de peixes foram coletadas em quatro campanhas semestrais em diferentes pontos da baía, durante as estações chuvosa e seca. Em campo foram registrados parâmetros físico-químicos (temperatura da água, salinidade, pH, oxigênio dissolvido e turbidez) e condições meteorológicas. As amostras biológicas foram identificadas morfologicamente de acordo com as chaves de identificação. Foram identificadas 8.231 larvas de peixes pertencentes a 15 ordens, 22 famílias, 25 gêneros e 31 espécies, com maior abundância de espécies no período de seca. Os resultados obtidos revelam que o ictioplâncton presente na Baía de São Marcos é composto principalmente por espécies das famílias Engraulidae, Clupeidae e Sciaenidae, com maior ocorrência no período seco. Mostra também que a estrutura e a composição da biota aquática são determinadas principalmente pela variação da salinidade e da pluviosidade.

Palavras-chave: Costa Brasileira, Larvas de Peixes, Estuário Tropical, Precipitação, Zona Portuária, Engraulidae.

RESUMEN

Este estudio tiene como objetivo verificar la composición taxonómica y la diversidad ecológica del ictioplancton en la Bahía de São Marcos (SMB), una región de la costa amazónica brasileña con gran importancia ecológica y socioeconómica. Se recolectaron muestras de larvas de peces en cuatro campañas bianuales en diferentes puntos de la bahía, durante las estaciones lluviosa y seca. En campo se registraron parámetros fisicoquímicos (temperatura del agua, salinidad, pH, oxígeno disuelto y turbidez) y condiciones meteorológicas. Las muestras biológicas fueron identificadas morfológicamente según las claves de identificación. Se identificaron un total de 8,231 larvas de peces pertenecientes a 15 órdenes, 22 familias, 25 géneros y 31 especies, con mayor abundancia de especies durante la época seca. Los resultados obtenidos revelan que el ictioplancton presente en la Bahía de São Marcos está compuesto principalmente por especies de las familias Engraulidae, Clupeidae y Sciaenidae, con mayor ocurrencia durante la estación seca. También muestra que la estructura y composición de la biota acuática está determinada principalmente por la variación de la salinidad y las precipitaciones.

Palabras clave: Costa Brasileña, Larvas de Peces, Estuario Tropical, Precipitaciones, Zona Portuaria, Engraulidae.

1 INTRODUCTION

Ichthyoplankton consists of the eggs and larvae of fish that drift in the water column and has an important role in aquatic ecosystems, since these organisms are essential in the recruitment and variation of the spatio-temporal distribution of fish populations (Zhang et al., 2020; Giraldo et al., 2024). During their development, they use a wide variety of habitats, from the continental shelf to coastal lagoons, bays and estuaries (Hoss and Thayer, 1993). The study of these organisms promotes knowledge on biology and systematics, related to several fields of study like taxonomy, repopulation, identification of new stocks and analysis of those already studied, providing better understanding of the ecology of fishes (Stratoudakis et al., 2006; Dourado et al., 2017).

The ichthyoplankton community exhibits different types of distribution, with spatial and temporal patterns (Kipper et al., 2011). The formation of larval fish communities is strongly determined by the mode, location, time and duration of adult reproduction, which depend on adequate conditions to ensure the survival of a sufficient number of individuals. In addition, due to their lack of ability to swim against factors such as currents, tides, winds and water stratification, these organisms are directly affected by the dynamics of the environment in which they find themselves (Bialetzki et al., 2005; Kipper, 2011; Mota, 2014).

São Marcos Bay (SMB) is the main estuarine system of the Gulf of Maranhão, situated along the central section of Maranhão's coast. It is characterized by a vast estuarine area, widely exposed on the internal continental shelf, with tides that can reach amplitudes of up to 7.2 m, averaging around 6.6 m (Amaral and Alfredini, 2010; Carvalho-Neta et al., 2012; Caroli et al., 2017). Waves are often considered one of the key factors influencing the dynamics of coastal regions, both in constructive and destructive processes, affecting the generation of currents (Gonzalez et al., 2004).

The bay is characterized by intense industrial activity, with a high level of human interference, where the main cargo and mineral maritime terminals are located (Castro et al., 2019, Queiroz et al., 2022, Macedo et al., 2024). This area is considered to be of high ecological relevance, due to the mosaic formed by estuaries, islands and mangroves that serve as nursery areas for many resident and migratory fish species (Blaber and Barletta, 2016). In addition, it constitutes an important fishing site where estuarine species contribute substantially to the composition of fish assemblages (Carvalho-Neta et al., 2012; Lima and Piorski, 2016; Santana et al., 2025).

Studies carried out in different locations of the Gulf of Maranhão show that the region has several nursery areas for different species of fish. Soares et al. (2020) found marine, estuarine and freshwater ichthyoplankton species present on Caranguejos Island, located in SMB, which shows that this region is an important reproductive area for species that are commercially exploited in the region. Cardoso et al. (2021) observed that the fishing zones on the beaches of Gulf of Maranhão are also spawning grounds for several fish species. Given the ecological importance of this region, as well as the port area, which is one of the largest cargo handling port complexes in the world (Amaral and Alfredini, 2010), this study aims to verify the taxonomic composition, spatio-temporal distribution and diversity of ichthyoplankton in São Marcos Bay.

2 MATERIAL AND METHODS

2.1 STUDY AREA

The Maranhão coast is the second largest in Brazil with approximately 640 km, extending from the mouth of Gurupi River in the western portion to the Parnaíba delta in the eastern portion (Machado and Souza 2019). The region has a humid tropical climate, with temperatures ranging between 28°C and 34°C throughout the year and and has two distinct seasons: the rainy season (from January to June) and the dry season (from July to December), with annual rainfall varying between 1.600 mm and 2.000 mm (IMESC, 2021). The central part of the Maranhão coast is distinguished by the presence of mangroves and many rivers that flow into the bays of São Marcos, São José, Curupu, and Arraial, making this area a large estuarine complex (El-Robrini et al., 2015).

São Marcos Bay is the largest bay in Brazil, with an area of approximately 1,800,000 km², characterized as an active estuary in the Maranhão coastal zone, where the rivers Pindaré and Mearim converge (Fachi et al., 2017; Silva et al., 2023). The bay has approximately 3,000.00 m² ranging from the division of the Mearim River, in Caranguejo Island, to the continental shelf (Silva et al., 2023). The average depth of the region is 10 m, which can vary to depths greater than 50 m. SMB has great economic

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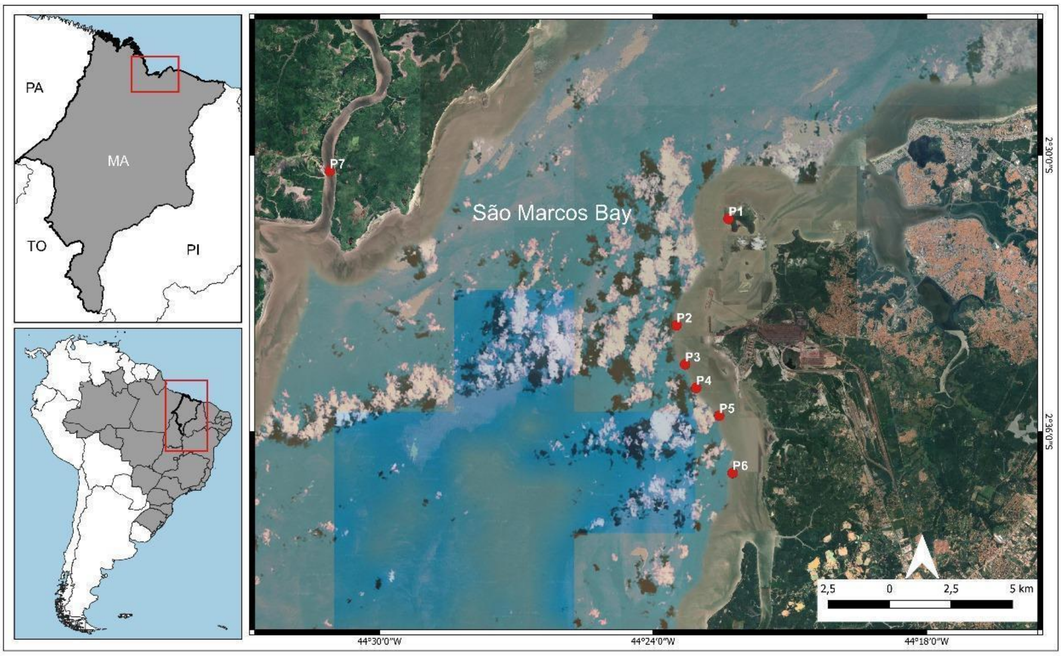
importance for the State of Maranhão. It has suitable width and depths for the operation of large-tonnage ships. Due to this, the region contains one of the largest port complexes in cargo and mineral handling in the world, with three large shipping terminals: Itaqui, Ponta da Madeira and Alumar (Amaral and Alfredini, 2010; Fachi et al., 2017; Queiroz et al., 2022).

2.2 SAMPLING

The collections were carried out between May 2018 and December 2023 at seven sites in the São Marcos Bay during the dry and rainy periods (Figure 1).

Figure 1. Location of the ichthyoplankton sampling sites in São Marcos Bay, coast of the state of Maranhão, northern Brazil.



Source: Prepared by the authors

To determine ichthyoplankton, active trawls were carried out with an average duration of five minutes, using a net with a 300 µm mesh and a mouth opening of 60 cm. The arch of the net was equipped with a previously calibrated mechanical flow meter (Sea-Gear Corporation), through which it was possible to calculate the volume of water filtered during horizontal trawls in the water column subsurface with the aid of a vessel. After collection, the samples were fixed in 4% formalin solution and placed in properly labeled polyethylene bottles. The abiotic conditions (water temperature, salinity, pH, dissolved oxygen and turbidity) were measured in the field using a multiparameter (Horiba U-51).

2.3 FREQUENCY AND DENSITY ANALYSIS

The samples were screened in the laboratory using a stereoscopic microscope on a Bogorov plate to separate the larvae and eggs from the rest of the plankton. Larvae were quantified and identified by the lowest possible taxonomic group based on morphological, meristic and morphometric characteristics (Silva et al., 2010; Zacardi and Bittencourt, 2017).

The frequency of occurrence of the collected organisms was calculated using: Fo = Ta. 100/TA (Fo = occurrence frequency; Ta = number of samples in which the family occurred; TA = total number of samples). The results will be given as a percentage using the classification criteria described by Omori and Ikeda (1984): (>75%) dominant; (<75% - 50%) constant;(<50% - 25%) infrequent; (<25%) rare.

The density (Larvae/100 m^3) was obtained from the quotient between the total number of larvae in each sample (N) and the volume of filtered water (V), using the formula: N/100 m^3 = (N/V) * 100. The calculation of the volume of filtered water by the net was carried out using the following formula: V = a.n.c, where: V = volume of filtered water (m^3); a = area of the net mouth (m^2), n = number of flow meter rotations during dragging (rot), and c = flow meter measurement factor ($m.rot^{-1}$).

2.4 STATISTICAL ANALYZES

Abiotic statistical analyzes were carried out using the R 4.3.3 software, where the mean and standard deviation of environmental variables (dissolved oxygen, salinity, pH, turbidity, transparency and water temperature) were calculated. To determine the significant difference ($p<0.05$) in environmental data between seasonal periods and months of collection, the parametric One-Way ANOVA and the non-parametric Kruskal-Wallis tests were used, and the homogeneity of variables was determined using Levene's test.

Two-way PERMANOVA test was used to verify significant differences in the community structure, in terms of time and space, the Non-metric Multidimensional Scaling (NMDS) to compare the composition over the months, and the Redundancy Analysis (RDA) to evaluate the effect of environmental variables on the composition of fish larvae, were also used.

3 RESULTS

The water surface temperature showed a substantial difference between the seasons and months of collection. The lowest temperature recorded was 27.44 ºC and the highest was 29.74 ºC. The rainy season has the highest average of 29.23±0.29. Even though there are significant differences, the values presented are within the limits established by CONAMA Resolution No. 357/2005.

Salinity showed significant variations between seasons and months of collection with an average value of 26.84±3.85 in the rainy period, and an average of 31.90±2.08 in the dry season. The pH showed stability during both seasons, presenting values above 7.5 throughout the period of collection, and the medium was considered alkaline.

The dissolved oxygen values were heterogeneous with fluctuations in the measured data, with the lowest value recorded (4.47 $mg.L^{-1}$) and the highest (7.68 $mg.L^{-1}$) in the rainy period. In some months and in both seasons, the DO presented values below those established by CONAMA Resolution No. 357/2005 for brackish waters, which states that the amount of dissolved oxygen cannot be less than 5 mg/L.

A total of 8,231 fish larvae and 155 eggs were collected. The larvae were classified into 15 orders, distributed in 22 families, 25 genera and 31 species. One hundred larvae were not identified because they had damaged structures or were at a very early stage of development, leaving these larvae grouped in the unidentified category. Among the 155 teleost eggs collected, 52 belong to the family Engraulidae and 103 were not identified.

The order Clupeiformes was predominant with 7,597 fish larvae, corresponding to 92.33% of the total. The majority of these individuals were representative of the family Engraulidae, with 7,167 individuals (87.04% of the total), followed by the family Clupeidae with 428 (5.20%) and Sciaenidae with 369 specimens (4.48%) (Table 1).

Table 1. Frequency of occurrence of fish larvae families.* Fo(occurrence frequency); NI (not identified).

Order	Family	Total	Fo%*
Acanthuriformes	Sciaenidae	369	44.10%
Anguilliformes	Ophichthidae	2	1.24%
Atheriniformes	Atherinopsidae	2	0.62%
Beloniformes	Belonidae	4	1.86%
	Hemiramphidae	20	9.94%
Blenniiformes	Dactyloscopidae	1	0.62%
Clupeiformes	Clupeidae	428	34.16%
	Engraulidae	7167	96.27%
	Pristigasteridae	2	1.24%
Elopiformes	Elopidae	65	21.12%
Gobiiformes	Gobiidae	8	3.10%
Moroniformes	Ephippidae	1	0.62%
Mugiliformes	Mugilidae	20	7.45%
Perciformes	Carangidae	6	3.11%
	Centropomidae	5	2.48%
	Haemulidae	7	2.48%
Pleuronectiformes	Achiridae	2	1.24%
	Paralichthyidae	3	1.24%
Scombriformes	Trichiuridae	2	1.24%
Siluriformes	Ariidae	1	0.62%
	Aspredinidae	1	0.62%
Tetraodontiformes	Tetraodontidae	15	6.83%
Order NI*	NI	100	26.07%
	TOTAL	**8231**	

Source: Prepared by the authors

The family Engraulidae has the highest occurrence (96.27%) and was classified as the only dominant family (>75%). The family Sciaenidae (44.10%) was the second in occurrence, followed by the Clupeidae (34.16%), and both families were considered constants in the present study. All other families found were considered rare (<25%).

The dry period had the highest occurrence with 4,407 organisms collected, comprising 18 genera and 23 species, while in the rainy period 3,624 individuals were collected, within 17 genera and 20 species. Twelve species were recorded in both periods:

Anchoa sp., *Anchoviella* sp., *Anchoviella lepidentostole* (Fowler, 1911), *Centropomus* sp., *Elops smithi* (McBride, Rocha, Ruiz-Carus & Bowen, 2010), *Hyporhamphus* sp., *Hyporhamphus roberti* (Valenciennes, 1847), *Mugil curema* (Valenciennes, 1836), *Rhinosardinia amazonica* (Steindachner, 1879), *Stellifer rastrifer* (Jordan, 1889), *Sphoeroides psittacus* (Bloch & Schneider, 1801) and *Strongylura timucu* (Walbaum, 1792) (Table 2).

Table 2. Taxa found in the sampled seasonal periods.

Order	Family	Taxa	Rainy season	Dry season
Acanthuriformes	Sciaenidae	*Menticirrhus martinicensis* (Cuvier, 1830)	0	72
		Micropogonias furnieri (Desmarest, 1823)	15	0
		Scianidae sp.	57	86
		Stellifer sp.	0	11
		Stellifer rastrifer (Jordan, 1889)	64	47
		Plagiosion sp.	0	17
Anguilliformes	Ophichthidae	Ophichthidae sp.	2	0
Atheriniformes	Atherinopsidae	*Atherinella brasiliensis* (Quoy & Gaimard, 1825)	0	2
Beloniformes	Belonidae	*Strongylura* sp.	1	0
		Strongylura timucu (Walbaum, 1792)	2	1
	Hemiramphidae	*Hyporhamphus roberti* (Valenciennes, 1847)	4	7
		Hyporhamphus sp.	3	6
Blenniiformes	Dactyloscopidae	*Dactyloscopus sp.*	1	0
Clupeiformes	Clupeidae	Clupeidae sp.	21	98
		Rhinosardinia amazonica (Steindachner, 1879)	278	31
	Engraulidae	*Anchoa* sp.	51	161
		Anchoviella sp.	360	2.225
		Anchoviella lepidentostole (Fowler, 1911)	2123	332
		Engraulidae sp.	705	532
		Lycengraulis grossidens (Spix & Agassiz, 1829)	0	678
	Pristigasteridae	*Odontognathus mucronatus* (Lacepède, 1800)	0	2
Elopiformes	Elopidae	*Elops smithi* (McBride, Rocha, Ruiz-Carus & Bowen, 2010)	15	50
Gobiiformes	Gobiidae	Gobiidae sp.	2	5
		Gobionellus oceanicus (Pallas, 1770)	0	1

Moroniformes	Ephippidae	*Chaetodipterus faber* (Broussonet, 1782)	0	1
Mugiliformes	Mugilidae	*Mugil* sp.	0	12
		Mugil curema (Valenciennes, 1836)	1	7
Perciformes	Carangidae	Carangidae sp.	0	1
		Oligoplites saurus (Bloch & Schneider, 1801)	5	0
	Centropomidae	*Centropomus* sp.	2	3
	Haemulidae	Haemulidae sp.	0	7
Pleuronectiformes	Achiridae	*Trinectes paulistanus* (Miranda Ribeiro, 1915)	2	0
	Paralichthyidae	*Citharichthys spilopterus* (Günther, 1862)	0	3
Scombriformes	Trichuridae	*Trichiurus lepturus* (Linnaeus, 1758)	2	0
Siluriformes	Ariidae	*Bagre Bagre* (Linnaeus, 1766)	1	0
	Aspredinidae	*Aspredinichthys filamentosus* (Valenciennes, 1840)	1	0
Tetraodontiformes	Tetraodontidae	*Sphoeroides psittacus* (Bloch & Schneider, 1801)	6	5
		Sphoeroides sp.	0	4

Source: Prepared by the authors

During the dry period, the most representative species were *Anchoa* sp., *Anchoviella* sp., *Lycengraulis grossidens* (Spix & Agassiz, 1829) and *Menticirrhus martinicensis* (Cuvier, 1830), which only occurred during this period (Tab. 2). The family Clupeidae had high occurrence in the rainy season with the species *Rhinosardinia amazonica*, followed by Engraulidae, with *Anchoviella lepidentostole*.. Some larvae species observed have not yet been collected in SMB: *Aspredinichthys filamentosus* (Valenciennes, 1840), *Chaetodipterus faber* (Broussonet, 1782), *Citharichthys spilopterus* (Günther, 1862), *Gobionellus oceanicus* (Pallas, 1770), *Lycengraulis grossidens*, *Menticirrhus marticinicensis*, *Micropogonias furnieri* (Desmarest, 1823) and *Strongylura timucu*, but their adult form have already been recorded in the region (e.g. Silva et al. 2018, Santana et al 2025).

The PERMANOVA results show that the period effect is significant (p = 0.0007), indicating a significant difference in community composition between the dry and rainy seasons, as reflected by the high pseudo-F value (33.381). In contrast, the points effect is not significant (p = 0.2678), suggesting that sampling points do not explain variations in community composition. The interaction between period and points is also not significant (p = 1), indicating that the Period effect is consistent across all points. Most unexplained variation is attributed to natural community variability (Table 3).

Table 3. Permutational multivariate analysis of variance (PERMANOVA) to verify significant differences in the structure of the ichthyoplankton community. * p<0.05.

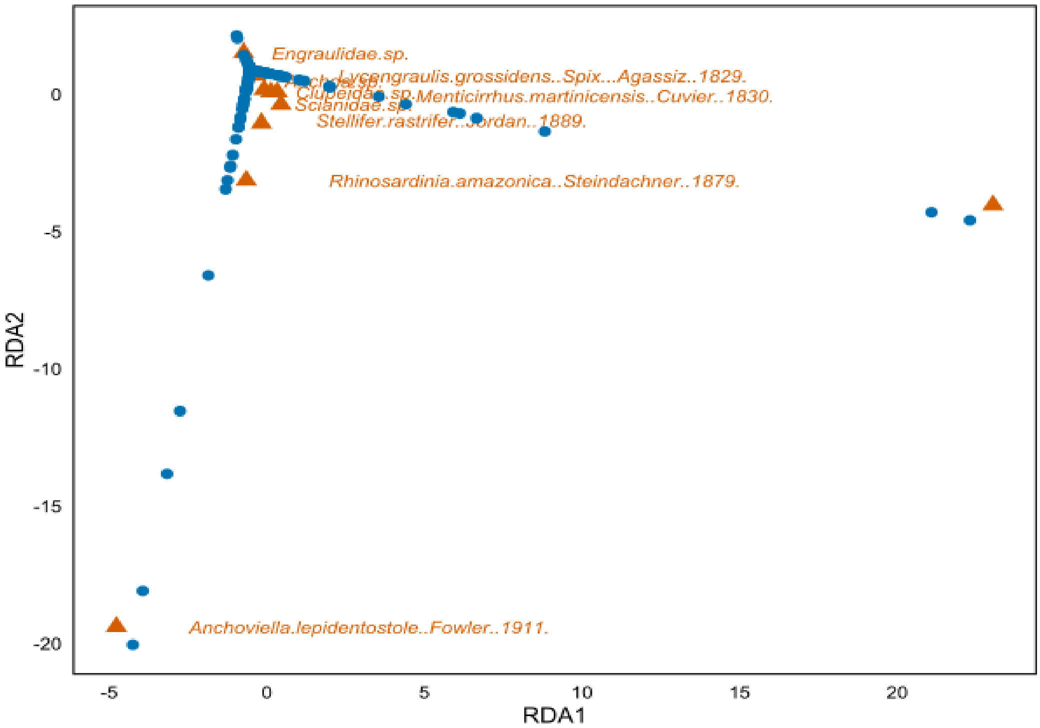
Term	df	Sum of squares	Mean square	Pseudo-F	p*
Period	1	142.879	14.288	33.381	0.0007
Points	6	280.366	0.46728	10.917	0.2678
Interaction	6	134.387	0.22398	0.52329	1
Residual	147	629.186	0.42802		
Total	160	68.495			

Source: Prepared by the authors

From the data obtained by NMDS, it was possible to observe that some campaigns (December 2018, 2019 and 2020, and June 2023) seem to form relatively well-defined clusters, suggesting more distinct communities, especially during the dry period. In other campaigns, such as September 2018 and 2023, December 2021 and 2022, and June 2022, it was more dispersed, indicating more intra-campaign variability compared to the others.

The analysis also suggests temporal variation, with campaigns carried out in different periods showing different patterns of similarity. Recent campaigns (2023) appear more dispersed, possibly indicating greater environmental heterogeneity or variation in colonization. It is possible to observe a similarity between communities from different campaigns, which may occur due to similar environmental conditions (Figure 2).

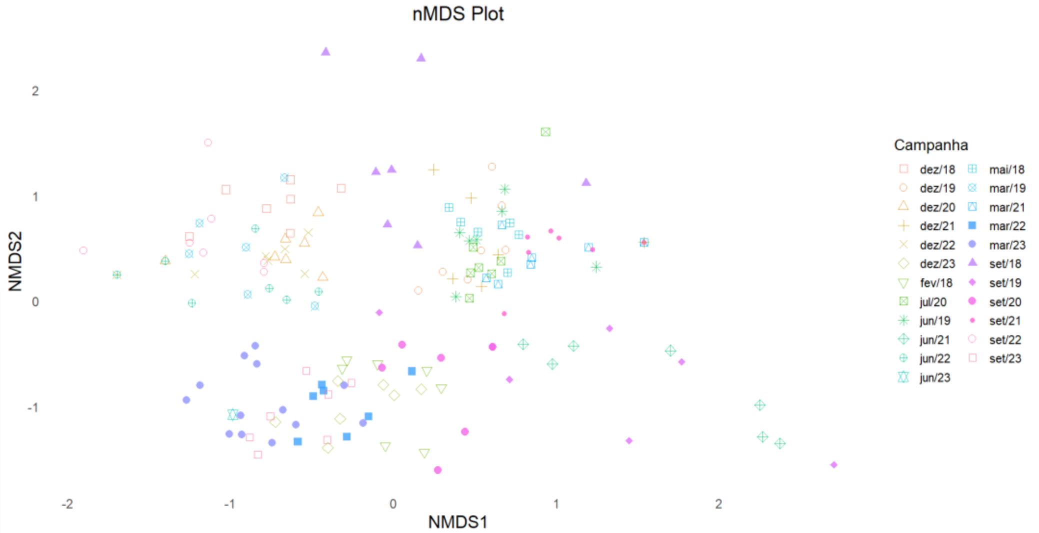
Figure 2. Redundancy Analysis (RDA) to evaluate the effect of environmental variables on the composition of fish larvae.



Source: Prepared by the authors

The redundancy analysis suggests that *Anchoviella lepidentostole* may have a specific environmental preference that is distinct from the others, which may be associated with better adaptation to environmental conditions, given that this species occurred in both seasons. The species grouped close to the center (*Lycengraulis grossidens*, *Menticirrhus martinicensis*) seem to respond in a similar way to the prevailing conditions, which corroborates the fact that the occurrence of these species is associated with the dry period. *Rhinosardinia amazonica* may be associated with environmental conditions closer to the values explained by the RDA2 axis, which may be associated with the conditions present in the rainy season, considering that there was a prevalence of occurrence in this season (Figure 3).

Figure 3. Comparison of the composition of the ichthyoplankton community over the months, using Non-Metric Multidimensional Scaling (NMDS).



Source: Prepared by the authors

4 DISCUSSION

The seasonal and spatial variation in salinity was very significant ($p < 0.05$), they were probably influenced by the region's rainfall regime, considering that when the amount of rainfall is high, salinity levels in the environment are lower (Santos et al., 2020).

The data recorded for the environmental variables, temperature, pH, salinity, turbidity and transparency, in SMB follow what is considered to be satisfactory for the ichthyoplankton survival and distribution. The patterns obtained in this study are similar to what was already observed in this area, by Santos et al. (2020), and in others tropical estuarine regions (Joyeux et al., 2004).

Similar results related to dissolved oxygen were also found (Costa et al., 2011; Macedo et al., 2024). Low dissolved oxygen concentration can be attributed to contamination by domestic effluents and excessive human activity in the port area, such as dredging and release of metal traces into estuarine waters (Pledger et al., 2020). Thus, the lowest recorded values of this variable may indicate an increase in the load of contaminants that are easily carried from the continent to the aquatic environment, as well as due to the presence of the port complex that generates large movements of ore loads at SMB.

The most frequent families in this study were Engraulidae, Clupeidae and Sciaenidae, which constitute part of the estuarine fish assemblage composition (Joyeux et al., 2004). Similar results were found in the region by Costa (2017), so it is considered a common pattern in coastal areas, mainly on the northern coast of Brazil (Zacardi et al., 2016). Many species prefer estuarine areas during the reproductive cycle, using these areas as nurseries, which contributes to an increase in the abundance of some ichthyoplankton species (Zacardi, 2015; Guerreiro et al., 2021). In these environments, the availability of food resulting from continental drainage guarantees greater primary productivity and, consequently, benefits larvae and eggs in the critical period (Prates et al., 2012). Silva et al. (2018) recorded a high occurrence in SMB of adult fish from these families, which means that these animals use this environment throughout their entire life cycle.

The family Engraulidae was the only dominant with *Anchoviella lepidentostole* being the most representative species presenting the highest density in both seasons, especially in the rainy season. This species can be considered common in São Marcos Bay due to its great abundance in both periods. Previous studies have identified a predominance of this species in the region (Costa et al., 2017; Silveira et al., 2024). Adults of this species have coastal behavior and move to the internal waters of estuaries for reproduction, preferring low salinity waters and frequently found in both tropical and temperate estuaries, which may explain the large number of specimens observed in the rainy season (Froese et al., 2013).

The species of the family Sciaenidae were also important in this study and are generally found in tropical estuaries (Blaber and Barletta, 2016; Silva et al., 2018; Santana et al., 2025). Sciaenidae species tend to be relatively tolerant of variations in salinity, which allows them to inhabit estuaries strongly influenced by freshwater (Camargo and Isaac, 2003). In their adult form, these organisms are considered semi-anadromous, they spawn near the mouths of estuaries and their eggs and larvae are transported by tides in estuarine streams. (Barlleta-Bergan et al., 2002). The most prominent species of this family during the dry period was *Menticirrhus martinicensis*. This species lives in coastal waters, usually in the mud and sand bottoms due to the high availability of food resources, with greater capture during the dry season (Camargo and Isaac, 2003).

The family Clupeidae had a large record in the rainy season due to the presence of the species *Rhinosardinia amazonica*. This species generally lives in coastal rivers, bays and estuaries, mainly in low salinity waters (Marceniuk et al., 2021) and their presence may be more associated with the rainy season due to low salinity levels.

Fish from tropical estuaries are subject to a range of interactions between physicochemical and biological factors that determine their patterns of occurrence, distribution and movement (Blaber, 2000). Cardoso et al. (2021) related the occurrence of this family to periods of high temperatures, corroborating our work in which the presence of *R. amazonica* occurred in the period when such temperatures were recorded. It is worth noting that the ichthyoplankton community is passive in relation to the fluid, being carried at all times by currents and changes in salinity appear to be the most important factor in explaining much of the spatial and temporal dynamics of biotic communities (Pauly, 1994).

Most families found are coastal and estuarine with the exception of Aspredinidae (*Aspredinichthys filamentosus*), which have preference to fresh and brackish waters (Nelson, 2006), Gobiidae (*Gobionellus oceanicus*) and Achiridae (*Trinectes paulistanus*), which are considered strictly estuarine (Camargo and Isaac, 2003). According to Haedrich (1983), the occurrence of coastal species in estuaries is due to the similarity of these two ecosystems.

The analyses showed that there is a statistically significant difference between the dry and rainy periods, with the highest rates of species diversity and occurrence found during the dry period. This is because many species prefer to spawn at this time of year, as the larvae have better conditions to survive, such as favorable reproduction conditions, feeding, reduced predation, and dispersal of larvae to external areas (Helfman et al., 2009). Similar results have already been found in São Marcos Bay by Soares et al. 2020.

Most larval species were considered rare, this composition is a common characteristic in some estuarine regions (Drake and Arias, 1991; Whitfield, 1999; Ramos

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et al., 2006). The richness in this study can be related to salinity, pointing out that the abundant and constant families withstand the salinity variations of the region (Pauly, 1994; Camargo and Isaac, 2003). Furthermore, the richness values of species found in estuaries can fluctuate due to several factors, such as variations in environmental conditions, latitude, degrees of contamination by agricultural and industrial waste, among other potentially polluting anthropogenic activities (Gurdek and Acuña-Plavan, 2017).

The coastal region of São Luís Island has become increasingly vulnerable due to rapid population growth, the installation of industries in the Gulf of Maranhão, and the scale of human activities (Souza and Feitosa, 2011; Calado et al., 2021). These impacts may hinder the recruitment of individuals during their larval stage. A reduction in ichthyoplankton populations could also result in lower fish stocks and disrupt the ecological balance in the estuary or nearby coastal areas (Silva-Falcão et al., 2007).

5 CONCLUSION

The results reveal that the structure and composition of ichthyoplankton is mainly determined by rainfall and variations in salinity, which tend to decrease with the increasing rainfall. The occurrence of the families Engraulidae, Clupeidae and Sciaenidae throughout these six years is mainly due to the fact that they tolerate salinity variations well, a factor that also explains the presence of *Anchoviella lepdentostole*, which was the most representative species in this study. On the other hand, most species have low occurrence, and this probably happens due to variations in the physicochemical conditions of the water, which limits the number of species to only those that can withstand sudden fluctuations. In addition, this environment is in a region of intense human activity and recurrent contamination due to the presence of the port complex, which can affect the composition and abundance of individuals.

The six-year survey in São Marcos Bay provided a comprehensive evaluation of ichthyoplankton taxonomic composition and spatio-temporal distribution, considering the variability of environmental parameters. This long-term dataset allowed the identification of consistent ecological patterns and offered insights into the role of environmental drivers in shaping ichthyoplankton dynamics. The findings are relevant for the development of monitoring programs and environmental management strategies in this economically important region. To improve the accuracy and breadth of ichthyoplankton identification, future research should integrate complementary approaches, thereby strengthening the outcomes of this study.

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