BOLETIM DO INSTITUTO DE PESCA
Scientific Article

Structure and diversity of the fish assemblage in a port area of the coastal zone of the Eastern Amazon in Brazil

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ABSTRACT

The aim of the present study was to characterize the ichthyofauna of the Coqueiros Strait in the state of Maranhão, Brazil. Sampling was conducted at three-month intervals from February to December 2022 at four sampling points using barrier nets with a 35-mm mesh between opposing knots, measuring 40 meters in length and approximately 6 meters in height. Both abiotic (salinity, temperature, dissolved oxygen, pH, and redox potential) and biotic data (weight, sex, and total length) were collected. A total of 41 species belonging to 25 families were recorded, with the families Ariidae and Sciaenidae being the most represented in terms of abundance distribution. Equitability was assessed, and the abundance-biomass comparison curve indicated an environment without significant degradation. The results indicate that the Coqueiros Strait region is crucial for the development of ichthyofauna in the Golfão Maranhense, highlighting the need for ongoing monitoring and sustainable management practices to protect these vital ecosystems.

Keywords: Abundance; Ichthyofauna; Ecological indices; Maranhão; Environment.

Estrutura e diversidade da assembleia de peixes em uma área portuária da zona costeira da Amazônia oriental Brasileira

RESUMO

O objetivo do presente estudo foi caracterizar a ictiofauna do Estreito de Coqueiros, no estado do Maranhão, Brasil. A amostragem foi realizada em intervalos de três meses, de fevereiro a dezembro de 2022, em quatro pontos de amostragem, utilizando redes de tapagem com malha de 35 mm entre nós opostos, medindo 40 m de comprimento e 6 m de altura. Foram recolhidos dados abióticos (salinidade, temperatura, oxigênio dissolvido, pH e potencial redox) e dados bióticos (peso, sexo e comprimento total). Foi registrado o total de 41 espécies pertencentes a 25 famílias, sendo as famílias Ariidae e Sciaenidae as mais representativas em termos de distribuição da abundância. A equitabilidade foi avaliada, e a curva de comparação de abundância-biomassa indicou um ambiente sem degradação significativa. Os resultados indicam que a região do Estreito de Coqueiros é crucial para o desenvolvimento da ictiofauna no Golfão Maranhense, destacando a necessidade de monitoramento contínuo e práticas de manejo sustentável para proteger esses ecossistemas vitais.

Palavras-chave: Abundância; Ictiofauna; Índices ecológicos; Maranhão; Meio ambiente.

Received: April 10, 2024 | **Approved:** January 20, 2025
Section editor: Welber Senteio Smith

INTRODUCTION

Estuarine environments are renowned for their high productivity and ecological complexity, playing a vital role as feeding, breeding, and sheltering grounds for various aquatic species, including those of commercial interest (Camargo & Isaac, 2004). Fishing activities are especially significant in these ecosystems, supporting local communities' livelihoods and contributing to the regional economy. Seasonality, characterized by fluctuations in precipitation regimes, directly influences estuarine hydrodynamics, altering environmental conditions and consequently affecting species composition and abundance (Silva et al., 2018).

In northeastern Brazil, the coast of Maranhão state is marked by seasonal periods characterized by intense rainfall and drought, as well as a rich diversity of ichthyofauna, partly due to the influence of large tidal systems and connections with extensive mangrove areas (Pessoa et al., 2019). The region is highly productive, which may be explained by the biological activity generated by the transport of organic matter from mangrove forests (Silva et al., 2023). Previous studies in the region have demonstrated the importance of seasonality in the diversity and structure of fish communities, with significant differences observed between dry and rainy periods. For instance, Castro et al. (2010) found that diversity and biomass tend to be higher during the dry season, while Silva Júnior et al. (2013) reported fluctuations in species abundance in response to seasonal changes.

Ichthyofauna is often used in the monitoring of aquatic ecosystems, as changes imposed on the estuarine environment contribute to a shift in its equilibrium point and have the immediate consequence of a change in the diversity pattern (Castro et al., 2014). Several indices contribute to the understanding of the distribution of ichthyofauna, especially species diversity, evenness and richness indices (Melo, 2008). Diversity indices provide a simple way to express the actual state of diversity of an environment (Semensatto Jr., 2003).

The coastal region of Maranhão, especially the São Marcos Bay and Coqueiros Strait area, also stands out for its economic importance, as it hosts port complexes that play a fundamental role in product transportation and income generation. Port activities contribute to the generation of income in the region through the transportation of people and products (Falcão & Correia, 2012) and assist in the growth of regional, national, and international trade (Wan et al., 2021). However, these port activities place considerable pressure on the estuarine environment, contributing to sedimentation, pollution, and potential ecological imbalances (Falcão & Correia, 2012; Silva, C. L., et al., 2018). These impacts can alter the structure of aquatic communities and specifically influence the distribution and abundance of ichthyofauna, which is often used as a bioindicator in environmental monitoring studies (Castro et al., 2010).

Despite contributions from previous studies, gaps remain in understanding the combined influence of seasonality and human activities on estuarine ichthyofauna in the region. This study aimed to characterize the fish assemblage in the port area of the Coqueiros Strait, providing a detailed analysis of ecological indices to identify potential changes in community structure. Unlike previous studies, this work focused specifically on an area under the direct influence of intense anthropogenic activities, contributing to a deeper understanding of environmental pressures on estuarine ecosystems. The results of this study can thus serve as a scientific basis for the sustainable development of fishery resources, as well as for the protection and management of aquatic ecosystems in the region.

MATERIAL AND METHODS

Study area

São Luís Island has an area of 1,453 km^2 and is located on the Brazilian continental platform in the center of the Golfão Maranhense (Azevedo et al., 2008). This region, characterized by diverse geoenvironmental features, divides the coast into the western coast, Golfão Maranhense, and eastern coast (Feitosa, 2006). The Golfão Maranhense, an estuarine system dominated by a semi-diurnal tidal regime, supports significant ichthyofaunal diversity and communicates directly with the South Atlantic Ocean through openings between Cumã and Tubarões bays, positioned between the eastern and western coasts of Maranhão (Azevedo et al., 2008; Bandeira, 2016; Silva et al., 2023).

The estuarine region lies in the northernmost portion of the state of Maranhão, where waters circulate through the 200-meter-wide Coqueiros Strait, situated between São Marcos and São José bays (Azevedo et al., 2008; Teixeira & Souza, 2007). This strait, a natural channel, connects São Marcos Bay to the north and Mosquitos Strait to the south, also receiving inflows from the Cachorros River (Castro, 1986; Porto, 2014). The region experiences strong tidal influence with a wide range (Ferreira, 1988). At the confluence of Coqueiros Strait and the Cachorros River lies the port of ALUMAR (Maranhão Aluminum Consortium) (Jardim, 2013). Sampling was performed at four points located in the Coqueiros Strait:

- P1: located near Santa Rita Creek;
- P2: located in Tarará Creek;
- P3: located in Arapopaí Creek;
- P4: located in Inhaúma Creek (Fig. 1).

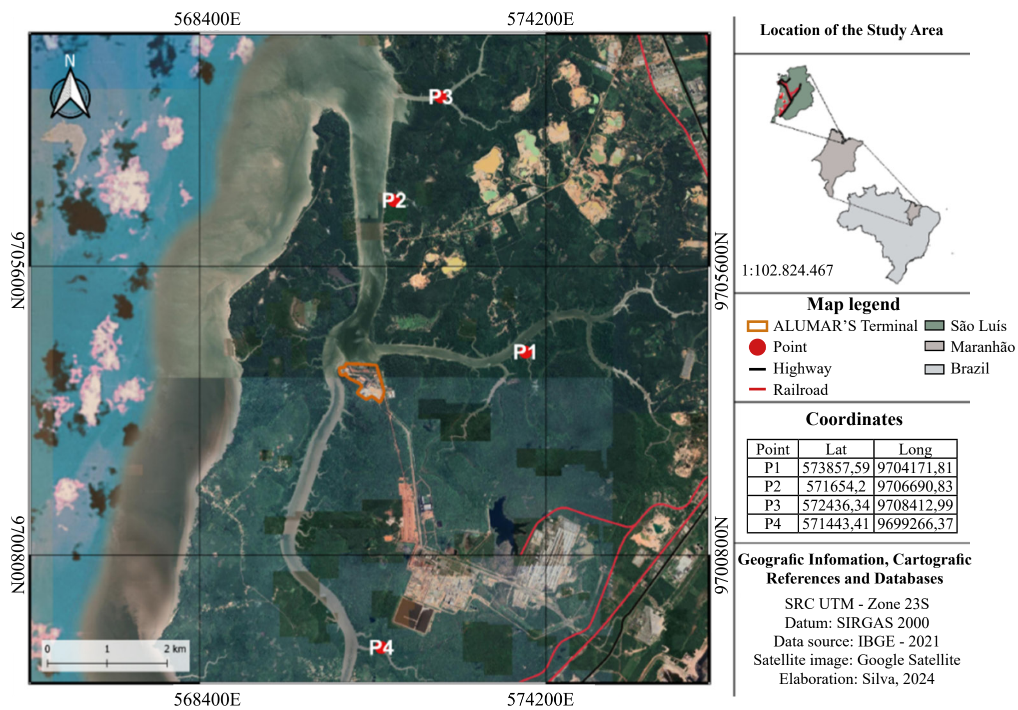


Figure 1. Map of the study location: the highlighted points refer to the creeks: P1) Santa Rita, P2) Tarará, P3) Arapopaí, P4) Inhaúma.

Data collection and processing

Four samplings were performed: two in the rainy period (February and June 2022) and two in the dry period (September and December 2022). Fish catches were conducted by artisanal fishermen from the Coqueiros Strait region, under collection permit no. 003/2022, issued by the Maranhão State Secretariat for the Environment and Natural Resources. Fish were captured using nets with a 35-millimeter mesh size between opposite nodes and lengths of 40 to 50 meters. Sampling took place during neap tide, with a standardized fishing effort of six hours at each location, covering the entire ebb tide cycle. Fishing was conducted at low tide, and captured fish were euthanized by thermal shock at low temperature, then stored in insulated boxes with ice and transported to the Ichthyology and Fisheries Resources Laboratory at the Universidade Federal do Maranhão.

In the laboratory, specimens were identified to the species level using the taxonomic keys of Figueiredo and Menezes (2000), and Fischer (1978). For each specimen, total length (cm), and weight (g) were measured. Sex and sexual maturity stage were determined through a longitudinal incision in the ventral region, following the Vazzoler's (1996) scale. After dissection, all specimens were either preserved for future analysis or ethically discarded following laboratory standards.

Data analysis

To assess the diversity of the fish assemblages, three principal diversity indices were calculated. The Shannon-Wiener (H'), Pielou's Evenness (J'), and Margalef's richness (d) indices were selected due to their extensive application and proven effectiveness in ecological studies for interpreting community structure and biodiversity levels.

The Shannon-Wiener diversity index (H') was specifically applied to quantify fish assemblage diversity across sampling periods, chosen for its sensitivity to species richness and evenness. Calculating H' monthly helped detect temporal variations potentially linked to environmental influences or seasonal patterns. The index was computed as Eq. 1:

$$H' = -\sum_{i=1}^{S} p_i \log_b p_i \qquad (1)$$

Where: S= the total number of species; p_i= the proportion of individuals of species i (ni) in relation to the total number of individuals (N), with p_i = ni/N.

Diversity was expressed as bits·ind^{-1}. According to Valentin et al. (1991), H' values were classified as high (H' ≥ 3.0), medium (2.0 ≤ H' < 3.0), low (1.0 ≤ H' < 2.0), or very low (H' < 1.0), aiding in assessing ecological stability. Higher values generally indicate stable, resilient environments, while lower values may suggest environmental stress. Temporal analysis of H' not only reflects current biodiversity levels, but also establishes a baseline for future studies, contributing to understanding seasonal dynamics in the region's fish assemblages.

The Pielou's Evenness index (J') was applied to quantify the evenness of species distribution across sampling periods and locations. This index provides insight into the balance of species abundances in the community, with higher values indicating a more uniform distribution among individuals. Temporal and spatial calculations were performed to detect potential changes in community structure related to environmental factors or seasonal influences. The index was computed using Eq. 2:

$$J = \frac{H'}{\ln(S)} \quad (2)$$

Where: H′= the Shannon-Wiener's diversity index; S= the total number of species.

The Margalef's Richness index (d) was applied to evaluate species richness relative to sample size, providing an effective measure for standardizing biodiversity comparisons across temporal and spatial scales. This index was selected due to its robustness in assessing species richness regardless individual abundance, allowing for consistent interpretation of community diversity across sampling efforts.

The index was calculated using Eq. 3:

$$d = \frac{(S-1)}{\ln N} \quad (3)$$

Where: S= the number of species; N= the total number of individuals in the sample.

Abundance-biomass-comparison (ABC) curves were plotted to assess potential disturbances in fish assemblages resulting from environmental impacts (Clarke & Warwick, 1994). This method compares dominance based on abundance and biomass on a Cartesian plane, in which species are ordered by decreasing dominance on the X-axis (logarithmic scale) and cumulative dominance percentage on the Y-axis (Pinto et al., 2006). Physicochemical variables of the water were also measured at the sampling sites during the fishing activity: potential of hydrogen (pH), redox potential, temperature (°C), dissolved oxygen (DO) and salinity.

RESULTS

A total of 5,986 individuals was caught, and 41 species were recorded, distributed among 14 orders and 25 families (Table 1).

The most abundant orders were Siluriformes, Perciformes, Cyprinodontiformes, Mugiliformes, and Tetraodontiformes. Siluriformes and Perciformes were the dominant orders in number of individuals, with higher numbers collected in the dry period. The order Cyprinodontiformes had a greater abundance of individuals in the rainy season (Fig. 2). Among all individuals collected, 2,130 were caught in the rainy season and 3,856 were caught in the dry season.

Juveniles were more abundant than adults in the study area (Fig. 3), reflecting a predominance of smaller, younger individuals across the sampling sites, while adults were observed in lower numbers.

The species that most contributed to abundance in the sampling period were *Sciades herzbergii* (1,779 individuals), *Anableps undecimalized* (937 individuals), and *Colomesus psittacus* (790 individuals), which together accounted for 58% of all individuals caught. In terms of biomass, *S. herzbergii* was again the most significant species, with a peak of 185,823.2 g in December, followed by *C. psittacus* and *Anableps anableps*, which showed significant contributions across the months.

Total biomass was highest in December 2022, during the dry season, and lowest in February 2022, in the rainy season, suggesting seasonal variation with biomass concentration in the dry months (Table 2).

The Shannon-Wiener's diversity index, Margalef richness index and Pielou's evenness index were used to investigate variations in the ichthyofauna. The analysis of the diversity index revealed little temporal variation among the sampling months, with medium diversity found for June (H' = 2.17), September (H' = 2.24), and December 2022 (H' = 2.13), and low diversity found in February 2022 (H' = 1.98).

Values of Margalef's richness index (d) remained below 5 across all sampling months, with slightly higher values in September and December 2022 compared to February and June 2022, indicating a modest seasonal variation in species richness, with greater species presence or diversity during the dry months. The highest Pielou's evenness was observed in June 2022, followed closely by September 2022. December 2022 showed intermediate values, while the lowest evenness was recorded in February 2022, reflecting varying levels of species distribution balance throughout the sampling period (Fig. 4).

Figure 5 illustrates how diversity varies with different values of alpha (α), representing distinct sensitivities to species abundance. The highest diversity values were observed in December and September, indicating greater species richness and evenness in these months, especially when alpha is low, which reflects a lower sensitivity to the most abundant species. In contrast, the lowest diversity values occurred in February

Table 1. Composition of ichthyofauna caught in 2022 in Coqueiros Strait, Maranhão, Brazil.

Order	Family	Species	Common name	N
Anguilliformes	Muraenidae	*Gymnothorax funebris*	Moréia	3
Acanthuriformes	Ephippidae	*Chaetodipterus faber*	Paru	12
Batrachoidiformes	Batrachoididae	*Batrachoides surinamensis*	Pacamão	56
Carangiformes	Carangidae	*Chloroscombrus chrysurus*	Favinha	1
		Caranx latus	Xaréu	17
Clupeiformes	Engraulidae	*Pterengraulis atherinoides*	Sardinha-de-gato	121
		Cetengraulis edentulus	Sardinha-verdadeira	11
	Clupeidae	*Sardinella janeiro*	Sardinha-papel	53
Cyprinodontiformes	Anablepidae	*Anableps anableps*	Tralhoto	937
Elopiformes	Elopidae	*Elops saurus*	Urubarana	4
Mugiliformes	Mugilidae	*Mugil gaimardianus*	Tainha pitiua	472
		Mugil curema	Tainha sajuba	419
Perciformes	Carangidae	*Oligoplites palometa*	Timbiro	55
	Centropomidae	*Centropomus undecimalis*	Camurim preto	44
	Gerreidae	*Diapterus rhombeus*	Peixe prata	23
	Haemulidae	*Genyatremus luteus*	Peixe pedra	294
	Sciaenidae	*Stellifer stellifer*	Cabeçudo branco	32
		Stellifer rastrifer	Cabeçudo vermelho	1
		Bairdiella ronchus	Corcoroca	62
		Cynoscion acoupa	Pescada amarela	421
		Cynoscion leiarchus	Pescada branca	10
		Macrodon ancylodon	Pescadinha gó	104
		Micropogonias furnieri	Cururuca	8
		Cynoscion microlepidotus	Corvina	62
		Stellifer naso	Cabeçudo preto	11
	Ephippidae	*Chaetodipterus faber*	Paru	11
	Polynemidae	*Polydactylus virginicus*	Barbudo	50
	Lobotidae	*Lobotes surinamensis*	Crauçu	1
	Lutjanidae	*Lutjanus synagris*	Carapitanga	8
Pleuronectiformes	Achiridae	*Achirus lineatus*	Solha	30
	Symphurinaea	*Symphurus plagusia*	Linguado	1
Scombriformes	Trichiuridae	*Trichiurus lepturus*	Guaravira	38
Siluriformes	Ariidae	*Bagre bagre*	Bandeirado	15
		Sciades herzbergii	Guribu	1779
		Amphiarius rugispinis	Jurupiranga	8
		Cathorops spixii	Uriacica amarelo	16
		Notarius bonillai	Uriacica branco	3
		Sciades proops	Uritinga	2
	Auchenipteridae	*Pseudauchenipterus nodosus*	Papista	9
Tetraodontiformes	Tetraodontidae	*Colomesus psittacus*	Baiacu açu	790
Rajiformes	Rajidae	*Dipturus oxyrinchus*	Raia bicuda	1

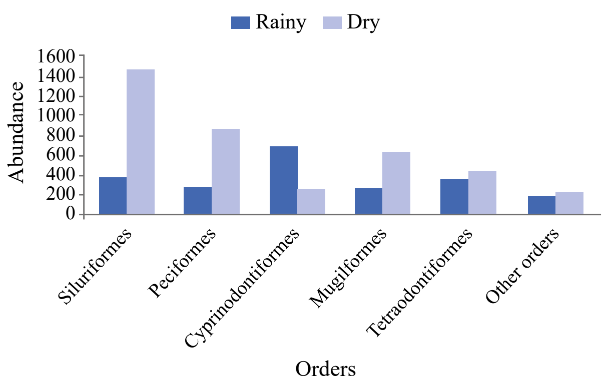


Figure 2. Number of species by order for ichthyofauna caught in Coqueiros Strait, Maranhão, Brazil, 2022.

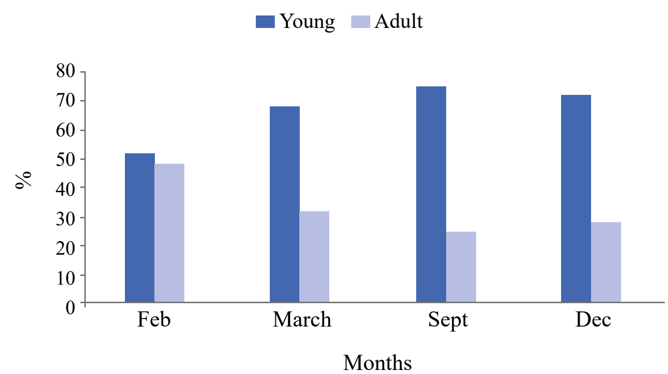


Figure 3. Frequency of juveniles and adults collected during four campaigns in Coqueiros Strait, Maranhão, Brazil, 2022.

Table 2. Temporal distribution of biomass (g) for species caught in Coqueiros Strait, Maranhão, Brazil, 2022.

Species	Feb-22	Jun-22	Sep-22	Dec-22
Colomesus psittacus	33,654.5	20,827.4	30,229.5	16,723.6
Bagre bagre	240.2	403.0	-	276.1
Polydactylus virginicus	-	-	-	1,469.0
Stellifer stellifer	-	532.9	-	-
Stellifer naso			134.7	134.4
Stellifer rastrifer	-	29.2	-	-
Lutjanus synagris	-	-	338.9	-
Centropomus undecimalis	2,974.8	235.7	2,603.7	2,297.8
Lobotes surinamensis	-	-	-	213.1
Bairdiella ronchus	106.6	58.5	-	1,377.3
Plagioscion squamosissimus	-	-	-	4,001.0
Micropogonias furnieri	-	-	147.5	47.5
Trichiurus lepturus	-	826.1	215.4	1,682.5
Sciades herzbergii	14,224.2	15,980.5	43,516.1	185,823.2
Gymnothorax funebris	2,018.8		122.3	-
Batrachoides surinamensis	723.9	7,228.2	2,892.6	4,731.3
Pseudauchenipterus nodosus	10.7	243.8	-	54.1
Chaetodipterus faber	214.8	-	19.6	1,451.9
Strongylura timucu	-	-	-	562.2
Selene setapinnis	-	-	14.7	-
Genyatremus luteus	2,032.3	572.2	3,356.2	3,955.7
Diapterus rhombeus	173.2	214.3	94.5	44.8
Cynoscion acoupa	1,428.2	4,741.6	10,429.9	10,479.3
Cynoscion leiarchus	38.2	24.1	-	316.9
Macrodon ancylodon	1,161.0	2,106.0	904.9	5,633.9
Dipturus oxyrinchus	-	-	6,000	-
Pterengraulis atherinoides	102.1	897.1	25.4	404.5
Sardinella janeiro	222.0	304.7	130.4	484.0
Cetengraulis edentulus	8.7		109.5	84.0
Achirus lineatus	198.7	1,491.1	2,220.3	1,064.9
Anableps anableps	9,330.5	31,545.9	6,562.1	5,714.4
Cathorops spixii	47.2	148.4	53.1	375.7
Cathorops agassizii	63.0	-	105.2	-
Sciades proops	84.4	-	92.8	-
Elops saurus	-	77.8	430.2	96.6
Caranx latus	-	-	256.7	297.2
Total	72,154.0	98,493.2	123,246.2	263,323.3

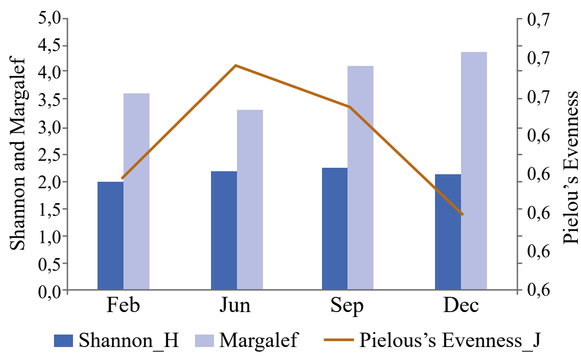


Figure 4. Ecological indices of ichthyofaunal collected in Coqueiros Strait, Maranhão, Brazil, 2022.

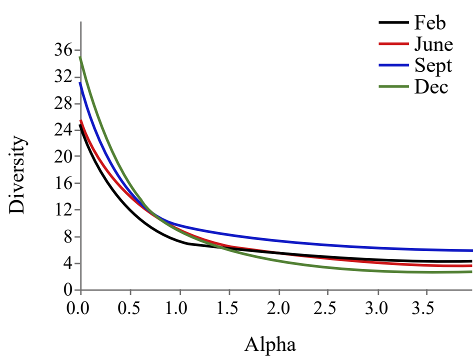


Figure 5. Hill's diversity profile of fish assemblage in Coqueiros Strait in February, June, September and December 2022.

and June, suggesting reduced species richness and evenness during these periods.

The shape of the curves shows a general decline in diversity as alpha increases, indicating a greater emphasis on dominant species. This trend highlights seasonal variations in community structure, with higher diversity during the dry season (September and December) and lower diversity in the rainy season (February and June).

In the analysis by sampling site, medium diversity values according to the Shannon-Wiener's index were observed at P1 (H' = 2.55), P2 (H' = 2.33), and P4 (H' = 2.29), whereas low diversity was recorded at P3 (Fig. 6). In terms of abundance, the highest values were found at P3 (Arapopaí Creek), with 2,407 individuals, followed by P1 (Santa Rita Creek), with 1,684 individuals, and P2 (Tarará Creek), with 1,124 individuals. The lowest abundance was observed at P4 (Inhaúma Creek) (n = 744).

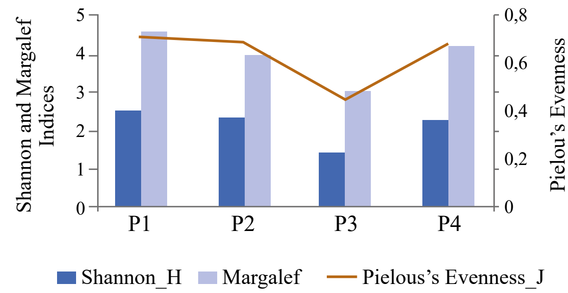


Figure 6. Ecological indices per sampling site in Coqueiros Strait, Maranhão, Brazil, 2022: P1 (Santa Rita Creek), P2 (Tarará Creek), P3 (Arapopaí Creek), P4 (Inhaúma Creek).

The highest richness value (Margalef's index) was recorded at P1, while the lowest was observed at P3, with all Margalef values remaining below 5. Evenness values were higher at P1, P2, and P4 than at P3, indicating a more balanced distribution of individuals among species at these sites. However, statistical analyses revealed no significant differences among the sampling sites.

Figure 7 shows Hill's diversity profile for the four sampling points: P1, P2, P3, and P4. P1 consistently exhibited the highest diversity values across all levels of α, followed by P4 and P2, while P3 displayed the lowest diversity values. As alpha (α) increases, emphasizing dominant species, the diversity differences between points become more evident, with P1 maintaining the highest values and P3 the lowest.

The rarefaction curves for species richness in Coqueiros during the sampling months showed a pattern of stagnation, indicating that sampling efforts likely captured most of the species present in each month (Fig. 8).

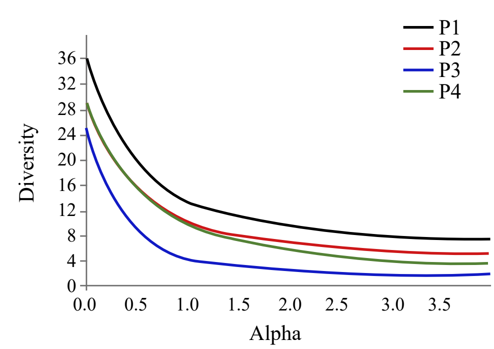


Figure 7. Hill's diversity profile of fish.

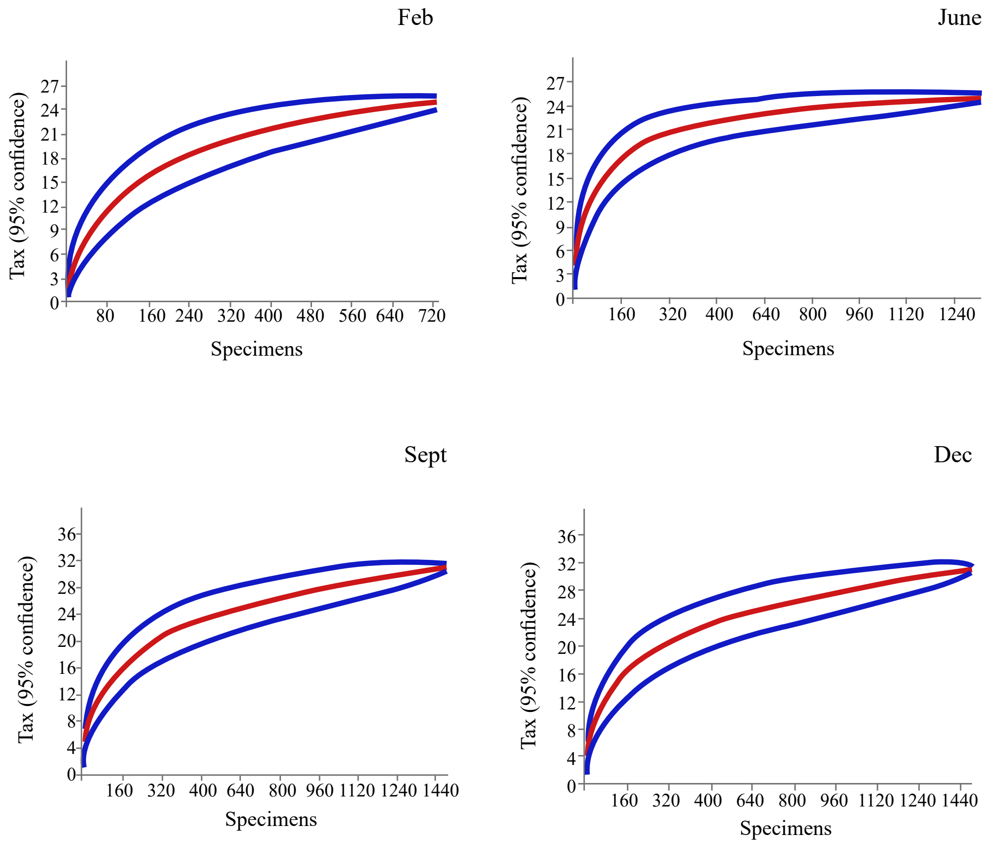


Figure 8. Rarefaction curves for species richness in Coqueiros Strait, Maranhão, Brazil, 2022, during sampling months.

ABC curves for the species assemblage in Coqueiros Strait across the sampling months. Throughout all months, the biomass curve remained consistently above the abundance curve, indicating a higher representation of biomass relative to abundance in each sampling period (Fig. 9).

The results of the physicochemical analyses of the water in the four campaigns (February, June, September and December) in Coqueiros Strait are presented in Table 3. Water temperatures were typical for the study area, which suggests that this variable was not influenced by disturbances in the environment. With regards to pH, the values were according to the range established by the National Environmental Council (CONAMA) (6.5 to 8.5) and were expected for the region of São Marcos Bay and the Coqueiros Strait. CONAMA's Resolution 357/2005 determines that salinity between 0.50 and 30‰ defines saltwater.

Thus, the salinity values in the present study were according to this range, and the entire environment was classified as estuarine waters. For DO, the CONAMA Resolution (2005) establishes that values should not be lower than 5 mg/L. Thus, all DO values met the expected standard.

Canonical correspondence analysis revealed strong correlations between the distribution of the most abundant species in the samples and the analyzed environmental variables (Fig. 10). The first two axes accounted for 62.05 and 27.6% of the total variance in the data, respectively, leading to a cumulative total of 89.65%.

The environmental variables most strongly associated with axis 1 included DO, pH, redox potential, and temperature. These variables showed a significant influence on species such as *Anableps anableps*, *Pterengraulis atherinoides*, *Mugil gaimardianus*, and *Colomesus psittacus*, which were primarily associated with the rainy season. This suggests that the conditions during this period favor the abundance of these species.

For axis 2, salinity was identified as a key factor affecting the distribution of species such as *Macrodon ancylodon*, *Sciades herzbergii*, *Cynoscion acoupa*, *Mugil curema*, and *Genyatremus luteus*. The results indicate that these species have specific salinity preferences, which play a crucial role in their presence in the Coqueiros Strait ecosystem.

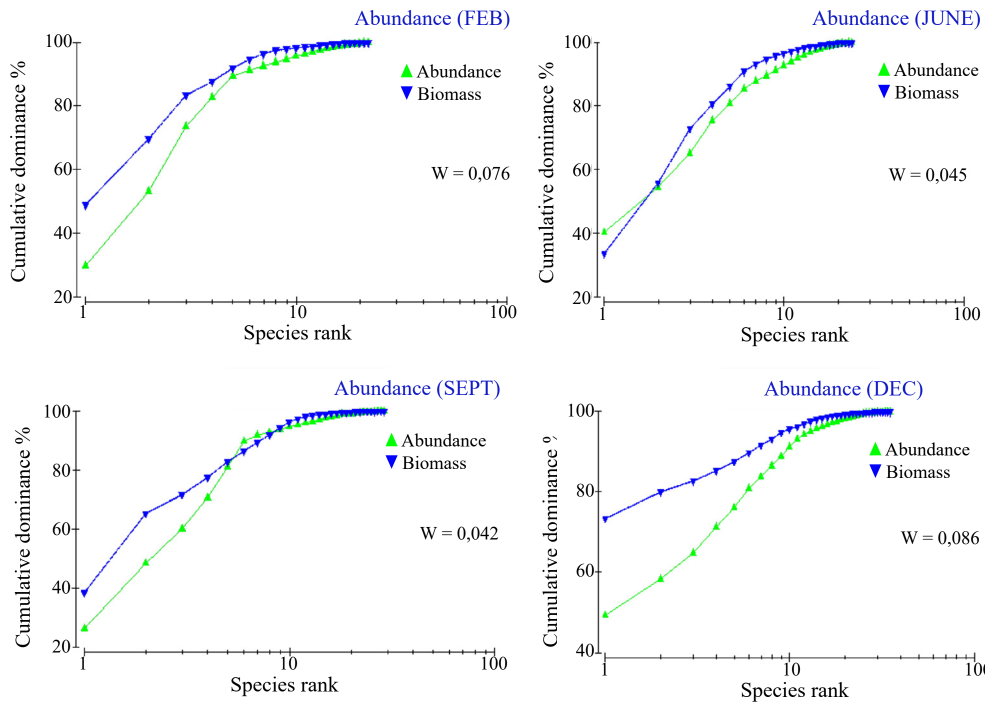
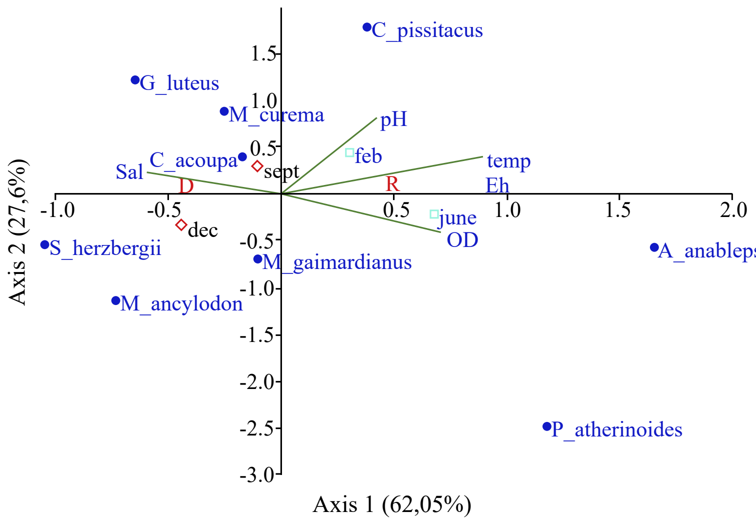


Figure 9. Abundance-biomass-comparison curves for species in Coqueiros Strait, Maranhão, Brazil, 2022, considering sampling month.

Table 3. Average values of abiotic variables sampled in Coqueiros Strait at fish collection points in different sampling months (February, June, September and December 2022).

Months	Points	Temperature	pH	Conductivity	Salinity	Dissolved oxygen	Redox
February	P1	28.06	7.98	22.74	13.66	4.62	-53.5
February	P2	29.66	8.17	23.9	14.39	3.34	-65.4
February	P3	29.33	8.12	39.26	24.89	2.19	-62
February	P4	29.27	8.05	13.49	7.73	5.1	-57.7
June	P1	29.03	8.16	16.6	9.43	5.77	-45.1
June	P2	30.1	7.93	27.9	17.43	6.79	-59.5
June	P3	29.18	7.84	27.31	16.77	6.41	-45.3
June	P4	27.94	7.86	8.63	4.8	5.98	-50
September	P1	30.51	7.84	20.97	12.55	2.24	-47.7
September	P2	28.41	8.25	14.91	8.15	6.75	-63.4
September	P3	27.94	7.97	34.56	21.63	4.9	-52.4
September	P4	28.77	8.42	31.99	19.89	5.77	-71.2
December	P1	28.62	7.80	38.24	24.27	4.03	-72.1
December	P2	28.13	7.72	42.85	27.42	3.92	-67.4
December	P3	28.56	7.64	43.02	27.58	4.17	-65
December	P4	28.71	7.86	37.18	23.45	2.9	-71.7



Temp: temperature (°C); cond: conductivity; Sal: salinity; DO: dissolved oxygen.

Figure 10. Canonical correspondence analysis of correlations between species distribution and environmental variables.

DISCUSSION

A total of 41 species was recorded in the investigated estuary, a number slightly lower than those reported in other studies conducted on São Luís Island. For instance, Castro et al. (2010) documented 44 species near the ALUMAR terminal, while M. H. L. Silva et al. (2018) identified 56 taxa in the port region of São Luís. These differences may reflect variations in sampling methodologies, temporal scope, or environmental conditions across sites, underscoring the importance of methodological consistency and localized environmental factors when assessing species richness in estuarine zones (França & de Souza, 2018).

Siluriformes and Perciformes were the predominant orders in the study area, which is expected for the coast of the Northern Region of Brazil (Silva et al., 2018). This predominance can be attributed to the specific characteristics of estuaries, which are transitional zones between marine and riverine environments, characterized by variations that influence the composition and abundance of species (Day et al., 1989).

The families Ariidae and Sciaenidae were the most abundant, as species from these families can tolerate considerable variations in their habitat conditions (Camargo & Isaac, 2004). The high catch rates may be also attributed to the fact that representatives of the family Sciaenidae form large schools during reproductive migration, increasing the likelihood of being caught in large quantities (Chao & Chiu, 2016). Studies like those of Martins et al. (2019) corroborate this observation, showing that the formation of Sciaenidae schools is an adaptive strategy during reproduction. The Ariidae family is particularly notable for its wide distribution in estuarine environments and its ability to tolerate significant salinity variations, making it one of the most common families in the region (Viana & de Souza, 2017).

Anableps anableps, recognized for its unique ability to tolerate both fresh and brackish waters, effectively utilizes the rich resources found in muddy substrates for foraging (Araújo & Cunha, 2018). The presence of these species highlights the ecological importance of mangrove ecosystems, as they not only provide habitat and food resources for various fish species, but also support the overall health and productivity of estuarine environments.

The values of the Shannon-Wiener's index (H') revealed little variation, indicating a balanced environment. A low Shannon-Wiener's index suggests the dominance of a particular taxon, while a high value indicates a uniform distribution of species (Melo, 2008). This stable diversity pattern may imply that certain species are well-established, allowing the ecosystem to function effectively. However, it also suggests vulnerability to disturbances; if a dominant species were to decline suddenly due to environmental changes or anthropogenic impacts, overall biodiversity could be severely affected (Meyer & Tate, 2003; Winemiller & Rose, 1992).

The region is subject to various anthropogenic activities, such as ports, shipping, fishing, dredging, urbanization, and mining. These human interventions can exert significant pressure on habitats, leading to changes in species composition and ecological dynamics. For instance, the operation of ports can result in habitat degradation, increased sedimentation, and pollution, which adversely affect fish communities

(Ferreira & Santos, 2020). Dredging can modify substrates and reduce habitat complexity, while pollution and increased boat traffic can negatively impact fish communities (Bartholomew & Baird, 2009; Poff & Allan, 1995). Thus, although the Shannon-Wiener's index suggests a balanced environment, its continuity depends on effective management of human activities and conservation of local ecosystems (Ferreira & Santos, 2020).

All Margalef's richness values were below 5, indicating that biological richness in the area is not high, as values above 5.0 are indicative of high richness (Margalef & Arenas, 2006). This suggests that ecological conditions may limit species coexistence. Factors like habitat complexity, resource availability, and anthropogenic impacts are significant in shaping species richness. Urbanization and industrial activities can reduce the diversity of niches available, further lowering biological richness (Meyer & Tate, 2003). Environmental stressors, including pollution and hydrological alterations, may also constrain the community composition of fish in the region (Poff & Allan, 1995; Winemiller & Rose, 1992).

Equitability is crucial for understanding the distribution of individuals among species in an ecological community. Melo (2008) highlights that high equitability indicates a more uniform distribution of individuals, suggesting a stable and resilient ecosystem, while low equitability implies the dominance of one or a few species, increasing the ecosystem's vulnerability to disturbances.

In contrast, the lower equitability recorded in February 2022 indicates a potential imbalance, likely due to environmental stressors or changes in habitat conditions. This reduction in equitability suggests that one or a few species may have outcompeted others, which could compromise the overall resilience of the ecosystem. This finding is consistent with the Margalef's richness index values, which were all below 5, indicating limited biological richness and suggesting that ecological conditions may restrict the number of coexisting species.

Habitat complexity and resource availability significantly influence equitability. Complex habitats generally support a diverse array of niches, facilitating a more even distribution of individuals. However, anthropogenic activities, such as urbanization and dredging, can simplify habitats, favoring a limited number of resilient species (Bartholomew & Baird, 2009).

The highest richness values were recorded in September and December, whereas the lowest were recorded in February and June 2022. The abundance of fish during the dry season is related to several environmental factors. During the dry season, water levels in rivers and lakes can decrease, concentrating fish in smaller areas. This makes it easier for them to reproduce and search for food, as resources become more accessible (Winemiller & Rose, 1992). Silva Júnior et al. (2013) suggest that temperatures are higher in the estuary in the dry period, leading to an increase in primary production and the availability of nutrients, which attract large schools.

Although diversity indices are important for revealing the status of a given community, these indices have some limitations. The choice of a particular index exerts an influence on the pattern encountered; one index may indicate a particular pattern, and another may indicate a different pattern (Hill, 1973). A solution for this indeterminacy is the use of diversity profiles, such as Hill's series (Melo, 2008), which can be used for the unified visualization of indices, thus providing a better portrait of the status of the environment (Hill, 1973).

The ABC curves for the study area indicated an environment with minimal disturbances, as the biomass curve consistently extended above the abundance curve. This is a pattern characteristic of stable conditions, whose community is often dominated by K strategists (Carvalho et al., 2013). These species, while contributing significantly to biomass, tend to be less abundant (Yemane et al., 2005).

According to Carvalho et al. (2013), in environments with mild disturbances, the dominant species tend to be R strategists, which exhibit rapid growth, and in these cases the biomass and abundance curves may cross at several points along their length, indicating a moderately polluted environment. In highly disturbed environments, the pattern shifts, with the abundance curve positioned above the biomass curve, suggesting a prevalence of opportunistic species that can quickly exploit available resources (Yemane et al., 2005).

Additionally, the stagnation of the rarefaction curve suggests that the number of species captured is approaching the actual number of species present in the region of the Coqueiros Strait. This implies that sampling efforts have adequately captured the local biodiversity, providing a reliable assessment of species richness in this estuarine environment.

The canonical correspondence analysis results indicated strong correlations between the distribution of abundant fish species and environmental variables. The first two axes explained a significant portion of the variance, with DO, pH, redox potential, and temperature being critical for species such as *Anableps anableps*, *Pterengraulis atherinoides*, *Mugil gaimardianus*, and *Colomesus psittacus* during the rainy season. This highlights the importance of maintaining high water quality in the Coqueiros Strait for the success of these species.

Conversely, salinity played a key role in the distribution of species like *Macrodon ancylodon*, *Sciades herzbergii*, *Cynoscion acoupa*, *Mugil curema*, and *Genyatremus luteus*. The specific preferences for salinity underscore the need for continuous monitoring of this variable, particularly considering climate change and anthropogenic impacts.

Additionally, the findings stress the significance of seasonal dynamics in fishery management. Protecting spawning habitats during the rainy season is crucial for sustaining fish populations. Overall, these insights enhance our understanding of the ecological relationships in the Coqueiros Strait and inform the development of effective conservation strategies to preserve fishery resources in this important estuarine ecosystem.

CONCLUSION

The findings of this study underscored the significance of the Coqueiros Strait region for the development of ichthyofauna in the Golfão Maranhense, with a notable presence of diverse representatives from families such as Sciaenidae, Ariidae, Anablepidae, Mugilidae, Haemulidae, and Tetraodontidae. The dominance of a few species with high abundance highlights the need for responsible management of port operations and continuous monitoring of anthropogenic impacts on these critical habitats.

The implications for food security are significant; sustainable management of fishery resources is crucial to prevent overfishing and ensure that these vital resources remain available for future generations. By prioritizing the conservation of diverse fish populations and their habitats, this study supports the development of public policies that promote the health of aquatic ecosystems, thereby contributing to environmental sustainability and enhancing food security for local communities.

CONFLICTS OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

All data were generated or analyzed in this study.

AUTHORS' CONTRIBUTIONS

Investigation: Carvalho, A.S., Castro, A.C.L., Azevedo, J.W.J., Teixeira, A.F., Silva, S.P.S., Silva, M.H.L.; **Methodology:** Carvalho, A.S., Azevedo, J.W.J., Teixeira, A.F., Silva, S.P.S., Silva, M.H.L.; **Writing – original draft:** Carvalho, A.S.; **Writing – review & editing:** Carvalho, A.S., Silva, M.H.L.; **Resources:** Castro, A.C.L.; **Data curation:** Azevedo, J.W.J., Teixeira, A.F.; **Formal analysis:** Azevedo, J.W.J., Soares, L.S.; Lourenço, C.B., Silva, M.H.L.; **Final approval:** Carvalho, A.S.

FUNDING

Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão

Grant: BM Quota UFMA - Acordo nº 01/2021 FAPEMA/UFMA

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

Finance code 001

ACKNOWLEDGMENTS

The authors would like to thank the Laboratory of Ichthyology and Fisheries Resources for providing the biological material and for their collaboration in data analysis, and the Graduate Program in Development and Environment at the Universidade Federal do Maranhão for institutional support and for providing the opportunity to carry out this study.

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