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AVALIAÇÃO DA QUALIDADE AMBIENTAL DO GOLFÃO MARANHENSE POR MEIO DE VARIÁVEIS BIOLÓGICAS, QUÍMICAS E FÍSICO-QUÍMICAS

MARCELO HENRIQUE LOPES SILVA

São Luís - MA
OUTUBRO/2019

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Tese apresentada ao Curso de Doutorado do Programa de Pós-Graduação em Biodiversidade e Biotecnologia da Rede BIONORTE, na Universidade Federal do Maranhão, como requisito para a obtenção do Título de Doutor em Biodiversidade e Conservação e Biotecnologia.

Orientador (a): Prof. Dr. Jorge Luiz Silva Nunes.
Co-orientador (a): Marianna Jorge Basso

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São Luís-MA
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RESUMO

A redução da biodiversidade aquática está entre as principais alterações que ocorrem no meio natural, como consequência da desestruturação do ambiente físico, químico e biológico, resultando em perda de qualidade e dificuldade na manutenção da integridade ambiental. Estudos que integrem diferentes áreas temáticas são necessários para que sejam formulados diagnósticos consistentes que retratem de maneira fiel o status da qualidade ambiental dos ecossistemas aquáticos, fornecendo as bases científicas para ações de gerenciamento desses sistemas. Nesta perspectiva, o presente trabalho objetiva avaliar a qualidade ambiental do Golfão Maranhense utilizando a dinâmica de nutrientes, os fatores físico-químicos e a comunidade de peixes como indicadores ambientais. As amostras de água foram coletadas da superfície usando um amostrador de água Van Dorn, onde foram analisadas as seguintes variáveis hidroquímicas: transparência da água (m), temperatura (°C), salinidade, condutividade (mS cm^{-1}), sólidos dissolvidos totais (TDS, g L^{-1}), pH, oxigênio dissolvido (mg L^{-1}), turbidez (NTU), sólidos totais em suspensão (TSS) e nutrientes dissolvidos (fosfato, nitrito e silicato). Também foram avaliadas as relações entre essas variáveis e a sazonalidade da região, estação chuvosa (janeiro a junho) e estação seca (julho a dezembro), bem como a influência na composição das comunidades de peixes. As coletas de peixes foram realizadas ao longo de 11 estuários localizados nas baías de São Marcos, São José e Arraial. As amostragens foram realizadas com uma rede de arrasto de fundo (trawnet) em três réplicas para cada ponto de coleta. Os resultados mostraram que a variabilidade espacial e temporal das variáveis físico-químicas analisadas neste estudo está associada à dinâmica local governada pela vazão do rio, movimentos das marés, correntes e eventos meteorológicos. O transporte fluvial dos rios do estado do Maranhão e outras fontes de água doce na região amazônica são aparentemente os principais contribuintes responsáveis pela manutenção da disponibilidade de nutrientes na plataforma continental do Maranhão. A composição da ictiofauna da Baía de São Marcos foi representada por um total de 56 espécies, distribuídas em 15 ordens e 29 famílias. A avaliação sazonal da assembleia de peixes não revelou diferença significativa. Entretanto, houve diferença entre os locais de captura onde abundância, biomassa e diversidade de Shannon mostraram-se distintas. A análise do NMDS (Análise de Escalonamento Multidimensional) e o teste ANOSIM (Análise de Similaridade) entre os meses e entre os locais de amostragem, com base na composição de espécies, revelaram uma diferenciação sazonal associada aos meses chuvosos e de estiagem, bem como uma diferenciação espacial, em função de um gradiente de profundidade e hidrodinâmica, resultante da maior distância das áreas de mangue. As estimativas dos parâmetros da relação peso-comprimento consistiram em um total de 2.888 espécimes analisados. Os valores do parâmetro *b* mostraram uma predominância do tipo de crescimento alométrico positivo, semelhantes aos de outros estudos realizados na região. A análise toxicológica não apresentou resultados que indiquem grau elevado de bioacumulação de metais-traço na ictiofaunada da região, porém foram verificadas amostras individuais com teores acima dos limites estabelecidos, indicando dessa forma que existe algum grau de contaminação na região. A aplicação de parâmetros de qualidade ambiental mostrou-se uma ferramenta útil para a tomada de decisões, para a elaboração do planejamento ambiental e para a avaliação da qualidade ambiental, verificadas as tendências de alteração nos ecossistemas aquáticos.

Palavras-Chave: Baía, ictiofauna, dinâmica ecológica, metal pesado, Litoral Amazônico brasileiro.

ABSTRACT

The reduction of aquatic biodiversity is among the main changes that occur in the natural environment, as a consequence of the disruption of the physical, chemical and biological environment, resulting in loss of quality and difficulty in maintaining environmental integrity. Studies that integrate different thematic areas are necessary to formulate consistent diagnoses that faithfully portray the status of the environmental quality of aquatic ecosystems, providing the scientific basis for management actions of these systems. In this perspective, the present work aims to evaluate the environmental quality of Golfão Maranhense using nutrient dynamics, physicochemical factors and fish community as environmental indicators. Water samples were collected from the surface using a Van Dorn water sampler, where the following hydrochemical variables were analyzed: water transparency (m), temperature (° C), salinity, conductivity (mS cm^{-1}), total dissolved solids. (TDS, g L^{-1}), pH, dissolved oxygen (mg L^{-1}), turbidity (NTU), total suspended solids (TSS) and dissolved nutrients (phosphate, nitrite and silicate). The relationships between these variables and the seasonality of the region, rainy season (January to June) and dry season (July to December), as well as the influence on the composition of fish communities were also evaluated. Fish were collected from 11 estuaries located in São Marcos, São José and Arraial bays. Samplings were performed with a trawnet in three replicates for each collection point. The results showed that the spatial and temporal variability of the physicochemical variables analyzed in this study is associated with the local dynamics governed by river flow, tidal movements, currents and meteorological events. Fluvial transportation of Maranhão State rivers and other freshwater sources in the Amazon region are apparently the main contributors responsible for maintaining nutrient availability in the Maranhão continental shelf. The composition of the Ichthyofauna of St. Mark's Bay was represented by a total of 56 species, distributed in 15 orders and 29 families. Seasonal evaluation of fish assemblage revealed no significant difference. However, there was a difference between the capture sites where Shannon abundance, biomass and diversity differed. The NMDS analysis (Multidimensional Scaling Analysis) and the ANOSIM (Similarity Analysis) test between months and between sampling sites, based on species composition, revealed a seasonal differentiation associated with rainy and drought months, as well as a spatial differentiation related to depth and hydrodynamic gradient resulting from the greater distance from the mangrove areas. Estimates of the weight-length ratio parameters consisted of a total of 2,888 specimens analyzed. The values of parameter b showed a predominance of positive allometric growth type, similar to other studies conducted in the region. Toxicological analysis did not show results that indicate high degree of bioaccumulation of trace metals in the ichthyofaunada of the region, but individual samples with levels above the established limits were verified, indicating that there is some degree of contamination in the region. The application of environmental quality parameters has proved to be a useful tool for decision-making, environmental planning and environmental quality assessment, checking for changing trends in aquatic ecosystems.

Keywords: Estuary, ichthyofauna, ecological dynamics, heavy metal, Brazilian Amazon Coast.

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1 INTRODUÇÃO GERAL

Na maioria dos países, as zonas costeiras são definidas por lei e, possivelmente, devido ao aumento da população e das atividades econômicas concentradas em cidades costeiras, estão se tornando objeto de estudo científico e gestão específica para promover seu desenvolvimento sustentável (SZLAFSZTEIN, 2012). O caráter predatório da exploração dos recursos naturais e a consequente degradação dos diversos ecossistemas vêm despertando, de maneira global, um compromisso para assegurar que o progresso econômico, social e tecnológico ocorra em harmonia com a natureza, por meio do manejo sustentável (FAO, 2018).

O ambiente natural tem sido usado para diversos fins ao longo dos anos e agregam muitas atividades e impactos humanos, incluindo empreendimentos residenciais e industriais e contínua expansão das áreas urbanas (HALL, 2001; ROCA, et al., 2009; VAZ et al., 2009, SILVA *et al*., 2013). Os ecossistemas aquáticos são os principais corpos receptores das descargas antropogênicas que, por sua vez, são capazes de gerar efeitos deletérios para toda biota aquática, tendo como principal consequência a redução da biodiversidade (CALLISTO, et al., 2005; MCGLASHAN & HUGHIES, 2001), através das altas frequências de ingestão de contaminantes acumulados nas áreas impactadas (THIEL, et al., 2018).

A contaminação no ambiente aquático ocorre principalmente através da descarga de lixos tóxicos provenientes de efluentes esgotos domésticos, industriais, processos de drenagem agrícola, derrames acidentais de lixos químicos que contaminam acentuadamente o ambiente com metais pesados, agrotóxicos e hidrocarbonetos aromáticos (ARIAS, et al., 2007). Além disso, a crescente quantidade de plásticos no ambiente marinho vem causando grande preocupação, pois são vetores de poluentes inorgânicos e orgânicos na água e representam risco para os animais aquáticos através da absorção (YANG, et al., 2018).

A zona costeira é a interface entre a terra e o mar e representa uma das áreas mais importantes do planeta por causa do enorme valor fornecido. A população densa e a troca frequente de material e energia na zona costeira, por sua vez, a tornarão particularmente sensível e vulnerável a mudanças naturais e antropogênicas (LU, et al., 2018). Os estuários, por sua vez, constituem os principais fornecedores de nutrientes para região costeira, onde estão geralmente associados com as vias de dispersão dos rios que descarregam uma elevada quantidade de sedimentos finos e podem vir a receber aportes significativos decorrentes da ação antrópica (ANTHONY, et al., 2010).

Todo esse aporte de nutrientes enquadra os ambientes estuarinos como os sistemas mais produtivos do mundo, com altas taxas de produção primária e teores elevados de biomassa autótrofa e heterótrofa (BRAGA et al. 2000; MATOS, et al., 2016; PEREIRA FILHO et al. 2001). Pesquisas recentes indicam esses ecossistemas como um componente importante de migração e uso de habitats de refúgio para os peixes (BRADLEY, et al., 2017; LINDFIELD, et al., 2016; WELLINGTON, et al., 2018).

Apesar de sua importância ecológica, o estuário é considerado um ambiente crítico, pois está exposto a vários contaminantes químicos que são introduzidos no ecossistema aquático como consequência das atividades antrópicas (AMIARD-TRIQUET & RAINBOW, 2009). Altas concentrações de metais pesados (Pb, Cr, Ni, Zn, As, Cd e Mn) (BRENNECKE et al., 2016), além de vários poluentes orgânicos, como hidrocarbonetos (ROCHMAN et al., 2013), bifenilos policlorados (VELZEBOER et al., 2014) e antibióticos (LI, et al., 2018). Nesse contexto, esses ambientes podem ser considerados frágeis frente aos diferentes tipos de contaminação e degradação que eles vêm sofrendo ao longo dos últimos anos (CAO, et al., 2017; LEBEUF, et al., 2019; NEWTON et al., 2014; WETZ & YOSKOWITZ, 2013;).

Registros na literatura assinalam que os metais não são degradados no ambiente e acabam sendo captados pelos seres vivos a partir dos sedimentos, alimentos e materiais particulados em suspensão na coluna d'água (OZSEKER, et al., 2014; ZHU, 2017). Em ambientes marinhos e dulcícolas, as formas metálicas podem estar complexadas ou livres, apresentarem diferentes composições químicas e associadas a compostos orgânicos ou inorgânicos (GEORGOPOULOS, et al., 2002).

Os poluentes lançados nos ecossistemas aquáticos podem provocar uma série de distúrbios metabólicos nos organismos, tais como infertilidade, baixa nas defesas imunológicas, diminuição do crescimento e patologias que podem levar à morte dos indivíduos (STEGEMAN, et al., 1992).

Ao mesmo tempo em que podem ser danosos, diversos metais são importantes e essenciais para o funcionamento dos seres vivos em pequenas quantidades, dentre os quais se ressalta o cobre (Cu), zinco (Zn), ferro (Fe) e manganês (Mn) (VILHENA, 2013;

Marchand, 2006). Por sua vez, o alumínio (Al), mercúrio (Hg), chumbo (Pb) e o cádmio (Cd) são considerados metais não essenciais, pois não possuem nenhuma função conhecida nos animais (BAINY, 1998).

Uma vez liberados no ambiente aquático, os metais não essenciais, e até mesmo os essenciais, em elevadas concentrações, podem ser altamente tóxicos para os animais, e no decorrer dos anos os efeitos ambientais e na saúde humana poderão ser crônicos (LIMA, et al., 2015; SOUSA, 2015), independentemente da posição ocupada na cadeia trófica (JAISHANKAR, et al., 2014).

Os peixes são organismos importantes na cadeia alimentar aquática, sensíveis à contaminação por metais pesados (BAWURO, 2018, RODRIGUES, et., 2017). Esses animais fazem a ingestão de metais via alimentação, como também através da água circulante, e apresentam uma distribuição característica desses elementos nos diferentes tecidos (McCARTHY & SHUGART, 1990). Estas diferenças resultam da afinidade dos metais para o tecido muscular do peixe, que apresentam diferentes taxas de absorção, deposição e excreção (BAWURO, 2018).

Inseridos na biota e abundantes nos ecossistemas aquáticos, os peixes vêm sendo descritos como excelentes modelos experimentais em estudos de biomonitoramento (LIONETTO, et al., 2013; VAN DER OOST, et al., 2003). As respostas biológicas apresentadas por esses organismos podem ser classificadas como biomarcadores, caracterizadas por alterações ou reações que variam em nível celular, molecular, fisiológico, ou ainda comportamental (FURNOS, 2014; VAN DER OOST, et al, 2003; RAMSDORF et al., 2012).

Sabe-se que para desenvolver ações de conservação dos estoques naturais de peixes são necessários conhecimentos sobre a sua biologia, ecologia e dinâmica populacional. A aplicação de modelos de avaliação de estoques exige coleta de informações biológicas básicas, que podem servir como parâmetro para avaliação da qualidade ambiental e a confirmação de possíveis interferências sobre a abundância e dinâmica das espécies.

O peso e o comprimento podem sofrer influência de uma série de fatores, principalmente os relacionados ao ambiente. Estas alterações podem afetar os valores estimados dos parâmetros da relação peso-comprimento (NASCIMENTO, et al., 2012). A ação antrópica contribui diretamente para mudanças voltadas aos parâmetros ambientais, o que confere instabilidade na biologia da espécie que pode ser alterada e, consequentemente, pode ser utilizada como parâmetro de comparação do estado de conservação dos ambientes aquáticos (AGOSTINHO, 2007).

A relação peso-comprimento representa um modelo simples, que é amplamente utilizado para abordagens descritivas, como estimativas de peso ou tamanho de um indivíduo, como uma inferência da maturação do peixe (FROESE, 2006), sendo úteis em avaliações de pesca para prever pesos a partir dos comprimentos mais facilmente medidos, avaliação de estoque e cálculo de biomassa (FROESE, et al. 2014).

Os dados obtidos da relação peso-comprimento individualmente de uma espécie fornecem indicações das condições do organismo em relação ao ambiente e estágios de desenvolvimento, através da estimativa do fator de condição, alinhado com o valor do coeficiente de crescimento, que definem a forma e o crecimento relativo das espécies de peixes. Assim, os valores do parâmetro b próximo de 3 indicam que o peixe cresce isometricamente, ao passo que valores diferentes de 3 indicam crecimento alométrico entre as variáveis comprimento e peso (AGUIAR-SANTOS, et al., 2018; GIARRIZZO, et al 2015; NUNES, et al. 2019).

Dessa forma, medidas de comprimento e peso de espécies de peixe têm sido utilizadas para transformar dados coletados de campo em índices apropriados (GOMIERO & BRAGA, 2003; LEMOS, et al., 2006; TAVARES-DIAS, et al., 2006). Sendo assim, durante amostragem de campo, comprimento e peso podem ser facilmente mensurados, e consequentemente, estimados quando a relação é conhecida para aquela determinada população (JOBLING 2002; TAVARES-DIAS, et al., 2006).

Por outro lado, destaca-se que estudos a longo prazo sobre a distribuição de peixes e estrutura da comunidade também são utilizados para a detecção de mudanças na ictiofauna sendo crucial para a compreensão da dinâmica de funcionamento dos ecossistemas costeiros, subsidiando ações para conservação dos recursos naturais (SILVA, et al, 2018).

Muitos estudos têm focado em modelos de distribuição espacial e temporal de informações ecológicas dos peixes, pois alguns mecanismos acabam influenciando essa distribuição nos sistemas costeiros (CARVALHO-NETA, et al., 2012). Considera-se que as condições ambientais locais selecionam espécies para assembleias do conjunto regional, (VILAR et al., 2013; RICKLEFS, 1987).

Os padrões de diversidade são resultado do equilíbrio entre os processos atuantes em escalas espaciais e temporais múltiplas e hierárquicas (RICKLEFS, 2004). Uma melhor compreensão dos padrões de diversidade de peixes nos ecossistemas costeiros, portanto, depende do conhecimento da estrutura hierárquica dos efeitos ambientais continentais e marinhos em diferentes escalas espaciais (CAMARA, et al., 2019).

As mudanças na qualidade ambiental alteram profundamente as comunidades aquáticas, favorecendo espécies resistentes que podem colonizar ambientes altamente poluídos, muitas vezes devido ao aumento da plasticidade trófica e adaptações morfológicas (CARVALHO, 2019). Identificar a estrutura das assembleias de peixes e entender como distúrbios nas características físicas, químicas e biológicas dos habitats estuarinos alteram os padrões de distribuição, alimentação, crescimento, reprodução e comportamento tanto de espécies migratórias quanto de espécies residentes, é essencial para gerenciar o ecossistema (WHITFIELD & ELLIOT, 2002; VENDEL, et al., 2003).

Neste cenário, destaca-se o Golfão Maranhense, que concentra uma das maiores biodiversidades da região amazônica, sobretudo devido suas extensas áreas estuarinas, uma das maiores do país, além das expressivas amplitudes de marés, ilhas, praias, manguezais e áreas de proteção ambiental.

Esses atributos ambientais transformam o golfão em uma área muito atrativa e desejada, tanto em nível urbano, quanto industrial, especialmente pelo potencial para abrigar terminais portuários e outros empreendimentos, transformando-o em zona de intensos conflitos de interesses e alta vulnerabilidade à degradação ambiental (RIBEIRO & CASTRO, 2017).

Apesar disso, o Golfão Maranhense tem recebido pouca atenção do ponto de vista de estudos dos ecossistemas, sendo bastante oportuna uma avaliação da qualidade desse ambiente a partir dos estudos relacionados à biodiversidade de peixes. Os estudos realizados na região não integram informações de diferentes áreas temáticas, nem tão pouco expandem os limites da investigação para além da Baía de São Marcos, uma vez que as baías de São José e Arrial também fazem parte do Golfão.

Entende-se que as atividades desenvolvidas na região produzem uma série de alterações na dinâmica dos elementos biológicos, químicos, físicos e antrópicos, em função da integridade e das complexas interações existentes entre os diferentes eixos. Por isso, esses aspectos devem ser largamente investigados, contribuindo para a conservação dos seus recursos naturais.

Dessa forma, pressupõe-se que as ações antrópicas causam alterações físicas e químicas no habitat aquático, provocando modificações na estrutura e nas interações da biota nesse ambiente, afetando as comunidades de peixes, as quais constituem indicadores sensíveis da qualidade ambiental desse ecossistema.

Portanto, o presente estudo pretende avaliar o cenário atual do Golfão Maranhense utilizando informações dos parâmetros biológicos, químicos e físico-quimicos, para a formação de uma base científica que fortaleça o desenvolvimento de estratégias de manejo nos diferentes compartimentos ambientais. Os resultados serão discutidos na forma de quatro artigos, sendo: a) o capítulo I, que analisará as variáveis físico-químicas e a concentração de nutrientes das massas d'água superficiais. b) o capítulo II, que abordará a variabilidade temporal da composição e estrutura ecológica dos peixes da baía de São Marcos. O capítulo III, que estimará os parâmetros da relação peso-comprimento de espécies de peixes e o Capítulo IV, que abordará os níveis de concentração de metais em espécies peixes de diferentes níveis tróficos.

2 OBJETIVOS

2.1 Objetivo Geral

Avaliar a qualidade ambiental do Golfão Maranhense utilizando a dinâmica de nutrientes, os fatores físico-químicos e a comunidade de peixes como indicadores ambientais.

2.2 Objetivos Específicos

- Avaliar a variação dos parâmetros físico-químicos e a concentração de nutrientes das massas d’água superficiais no Golfão Maranhense;
- Determinar a variação espaço-temporal da comunidade de peixes (biomassa, índice de diversidade, equitabilidade);
- Estimar os parâmetros da relação peso-comprimento de espécies capturadas no litoral maranhense;
- Verificar as concentrações de contaminantes químicos (metais pesados) em tecido muscular de peixes.

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4 CAPÍTULO 1: PHYSICOCHEMICAL PROPERTIES AND DISTRIBUTION OF NUTRIENTS ON THE INNER CONTINENTAL SHELF ADJACENT TO THE GULF OF MARANHÃO (BRAZIL) IN THE EQUATORIAL ATLANTIC

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH – **PUBLICADO**

(Qualis: B2 em Biodiversidade e B3 em Biotecnologia; Fator de Impacto: 0.877)

PROPRIEDADES FÍSICO-QUÍMICAS E DISTRIBUIÇÃO DE NUTRIENTES NA PLATAFORMA INTERNA ADJACENTE AO GOLFÃO MARANHENSE (BRASIL) NO ATLÂNTICO EQUATORIAL

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Abstract. The dynamics of the physical and chemical factors that regulate oceanographic processes on the continental shelf off the state of Maranhão (northeastern Brazil) was evaluated using a transect along São Marcos Bay (01°41'S-02°28'S and 43°47'W-44°13'W) in January, March, May, July and September 2014, with a total of seven sampling stations. Water samples were collected from the surface using a Van Dorn water sampler. The following hydrochemical variables were analyzed: water transparency (m), temperature (°C), salinity, conductivity (mS cm^{-1}), total dissolved solids (TDS, g L-1), pH, dissolved oxygen (mg L-1), turbidity (NTU), total suspended solids (TSS) and dissolved nutrients (phosphate, nitrite and silicate). The relationship between these variables and seasonality in the region [rainy season (January to June) and dry season (July to December)] were also evaluated. For data with normality and equal variances, a one-way analysis of variance (ANOVA) was used for the spatial and temporal comparisons of the physicochemical variables. Results showed that the spatial

and temporal variability of the physicochemical variables analyzed in this study is associated with local dynamics governed by river discharge, tidal movements, currents and meteorological events. The fluvial transport from the rivers of the state of Maranhão and other freshwater sources in the Amazon region are apparently the major contributors responsible for the maintenance of nutrient availability on the Maranhão continental shelf. The present paper aims to broaden the knowledge of the spatial and temporal variability in the physicochemical variables in continental shelves and adjacent waters the coast of Maranhão (North Brazil).
Key words: *surface water masses, hydrochemical variables, spatial distribution, dissolved nutrients, biogeochemical activity, influence of the discharge freshwater.*

Introduction

The continental shelf is an environment with strong biogeochemical activity due to matter transported from land combined with water-sediment interactions and processes of biological absorption, respiration and re-mineralization. Coastal waters receive sediments and discharge from freshwater and underground sources and are therefore more affected by human activities than the open ocean (Lefèvre et al., 2017).

Physicochemical variables are often used to characterize masses of water along continental shelves and adjacent coastal waters and are also important to the determination of biogeochemical processes in response to land and oceanic inputs (Braga et al., 2008). The dynamics of the physical and chemical factors that regulate oceanographic processes on the continental shelf off the state of Maranhão (northeastern Brazil) are not yet fully understood, especially those related to small-scale and medium-scale events governed by freshwater discharge, wave energy, trade winds, macro-tide patterns and the Intertropical Convergence Zone (ITCZ).

The seasonal cycle of the migration of the ITCZ in the tropical Atlantic reflects the behavior and position of surface currents (Stramma and Scott, 1999). The meso-scale circulation in the region of the continental shelf off the state of Maranhão is strongly influenced by the North Brazil Current, directly affecting the spread of the plume of the Amazon River (Nikiema et al., 2007). This cyclic phenomenon alters physicochemical properties and the concentration of nutrients in coastal waters of the São Marcos Estuarine Complex and controls the distribution and abundance of migrant fishing resources in the Gulf of Maranhão.

It is presumed that freshwater discharge from the São Marcos Estuarine Complex serves as an obstacle to the advance of lower temperature marine waters, while also exerting a strong influence on the input and redistribution of nutrients on the inner continental shelf. Thus, the determination of these variables would enable an understanding of the variability in the structure of surface water masses and contribute knowledge on the complex hydrodynamics of the Gulf of Maranhão.

Material and methods

Study Area

The coastal region of the state of Maranhão is classified as being on the northern coast of Brazil, based mainly on the morphology of the coast, climate, oceanographic variables, sediment coverage and width of the continental shelf. This stretch of the coast has been subdivided into three sectors form corresponding to the coast of Maranhão on the eastern Amazonian coast, with a large number of small estuaries bordered by hills formed by tertiary sediments of the Barreiras Formation, currently in complete regression (El Robrini et al., 2006). Mangroves occur in protected areas, accentuating the irregularities of the coastline and generating broad tidal plains (Mochel and Ponzoni, 2007).

The coast of Maranhão extends 640 km, with a wide continental shelf and relatively shallow waters under the influence of the discharge of a large number of rivers. The physical characteristics of the coastline enable a division into two distinct parts. The first extends from the border of the state of Pará to Tubarão Bay and is characterized by a low coast of mangroves and deep indentations forming a series of bays and estuaries (denominated the *Reentrâncias Maranhenses*). The second area extends from Tubarão Bay eastward to the mouth of the Parnaíba River. In this area, the coastline is regular and part is covered by a vast area of sand dunes, denominated the *Lençóis Maranhenses*.

The Gulf of Maranhão is located in the center of the coast and is where São Luís Island is located, which separates the gulf into two large bays. São Marcos Bay lies to the west, which is an active estuary where the Mearim and Pindaré Rivers converge. The most intense tides are recorded in the mouth of this bay. São José Bay to the east of the island is a region with shallow depths that receives waters from the Itapecuru and Munim rivers (Silva et al, 2018). Off the Gulf of Maranhão, the continental shelf has a mean width of 150 km and depths less than 45 m, reaching a depth of 75 m near the break of the shelf and dropping abruptly to 2.000 m at the base of the continental slope (Silva and Alvarenga, 1994).

The Maranhão continental shelf can be classified as a high-energy region due to the combined effects of the coastal currents generated by different hydrodynamic forces, such as tides, waves, trade winds and the discharge of the Itapecuru/Munim rivers and Pindaré/Mearim rivers that respectively form the São José Estuarine Complex and São Marcos Estuarine Complex. The volume transported from the Pindaré/Mearim Rivers to the São Marcos Estuarine Complex corresponds to 10 km^3 per year (Jennerjahn et al., 2010), with maximum discharge occurring in March/April, which is the peak of the rainy season.

Data collection

Data were obtained from a transect determined in São Marcos Bay (01°41’S-02°28’S and 43°47’W-44°13’W) in January, March, May, July and September 2014, involving seven sampling stations (Figure 4-1). Station 1 was located near the city of São Luís and Station 7 was located on the continental shelf before the 50-meter isobath at approximately 100 km from Station 1.

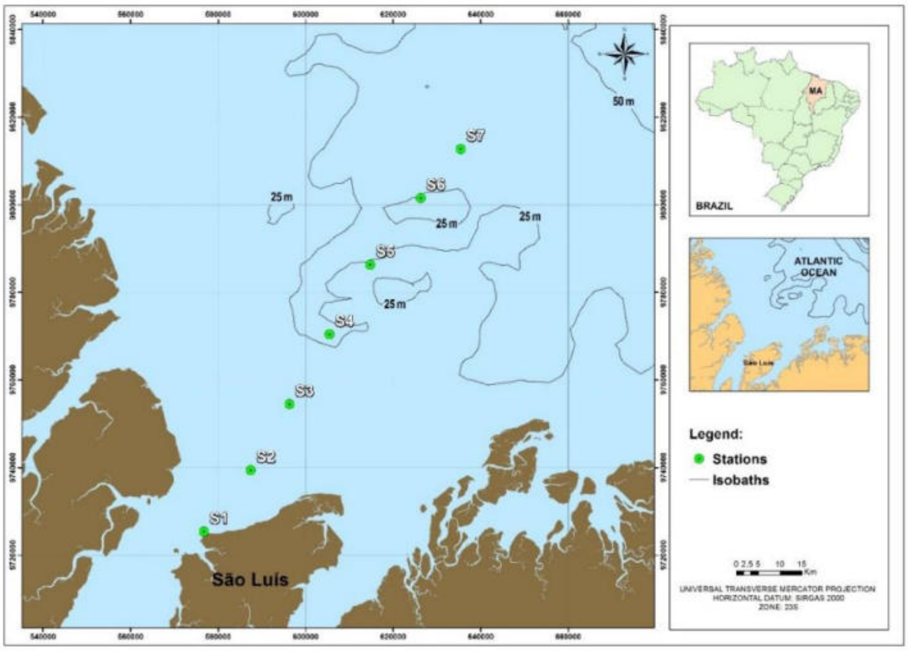

Figure 4-1. Location of sampling stations along transect on continental shelf off state of Maranhão

Water samples were collected from the surface using a van Dorn hydrographic bottle. The following hydrochemical variables were determined in the field: water transparency, measured by the depth of the disappearance of the Secchi disk (m); temperature (°C), salinity (g kg^{-1}), conductivity (mS cm^{-1}), total dissolved solids (TDS, g L^{-1}) and pH, using a HANNA HI-9828 multiparameter probe; dissolved oxygen (mg L^{-1}), using a HANNA HI-9146 oximeter together with the Winkler analytical method, as cited in Strickland and Parsons (1972); and turbidity (NTU), using a Tecnopon TB1000® turbidity meter. For the determination of total suspended solids (TSS), water samples were kept refrigerated at -4ºC until filtered and analyzed in the laboratory. TSS (mg L^{-1}) was measured using the gravimetric method, as described in APHA (2001). Dissolved nutrients (phosphate, nitrite and silicate) were determined using the method described by Grasshoff et al. (1999).

Climatologic data were acquired from the databank available by INMET (Brazilian Meteorological Institute) recorded by the São Luis meteorological station.

Data analysis

The physical and chemical variables were expressed as mean, standard deviation, minimum and maximum values determined for each sampling period. The relationship between these variables and seasonality in the region [rainy season (January to June) and dry season (July to December)] were also evaluated. The Shapiro-Wilk test and Levene's test were used to determine the normality of the data distribution and equal variance, respectively. For data with equal variances, one-way analysis of variance (ANOVA) was used for the spatial and temporal comparisons of the physicochemical variables. In cases for which the null hypothesis of variance was rejected, a multi-comparison test (Tukey's test) was used to identify which pairs of means differed significantly. For data with unequal variances, the spatiotemporal comparisons were made using the Kruskal-Wallis (H) test, followed by the Mann-Whitney U test when the null hypothesis was rejected. Principal component analysis was used to identify the main components responsible for the variations in the data on the Maranhão continental shelf, using the correlation matrix as the basis. The significance of Pearson's correlation table was calculated using a two-tailed *t*-test with two degrees of freedom. Excel 2010 and PAST 3.14 were used for the data analysis as well as the creation of the graphs and tables (Hammer et al., 2001). The statistical analyses were evaluated for a critical significance level of $\alpha = 0.05$ (Zar, 2010).

Results

Hydrological conditions

The accumulated monthly rainfall for 2014 at Station 1 showed values always higher than 100 mm in the months of January to June (Figure 4-2). In the oceanic region, the precipitation followed the same seasonal cycle compared to the coastal region, with usually slightly lower accumulated rainfall values. The INMET data gave higher rainfall during the wet season. The wet season was associated with the presence of the ITCZ located at its southernmost position in March-April.

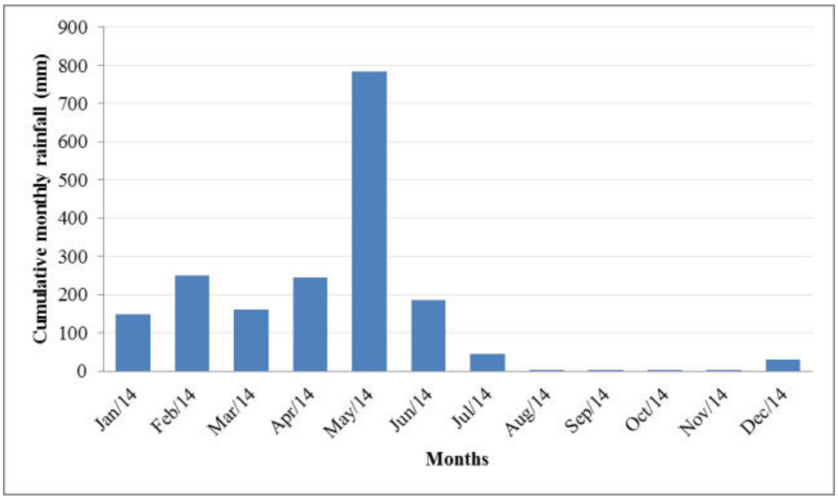

Figure 4-2. Accumulated monthly rainfall for 2014 at Station 1 (São Luís, Maranhão)

Source: BDMEP, INMET

Abiotic variables

Figure 4-3 displays the mean, standard deviation, maximum and minimum values for the physical and chemical variables of the surface waters measured on the Maranhão continental shelf. Water surface temperature ranged from 27.37°C to 30.33°C, corresponding to the wet and dry seasons, respectively (Figure 4-3a). The mean for all months analyzed was 28.7°C, which reflects the characteristic of the equatorial region, with small horizontal variations, mean amplitude of approximately 1°C in the rainy season and 2°C in the dry season. In statistical terms, temperatures were significantly lower in September 2014 (H = 14.59; p < 0.0001), but with no significant differences among the different sampling stations (F = 1.61; p > 0.05).

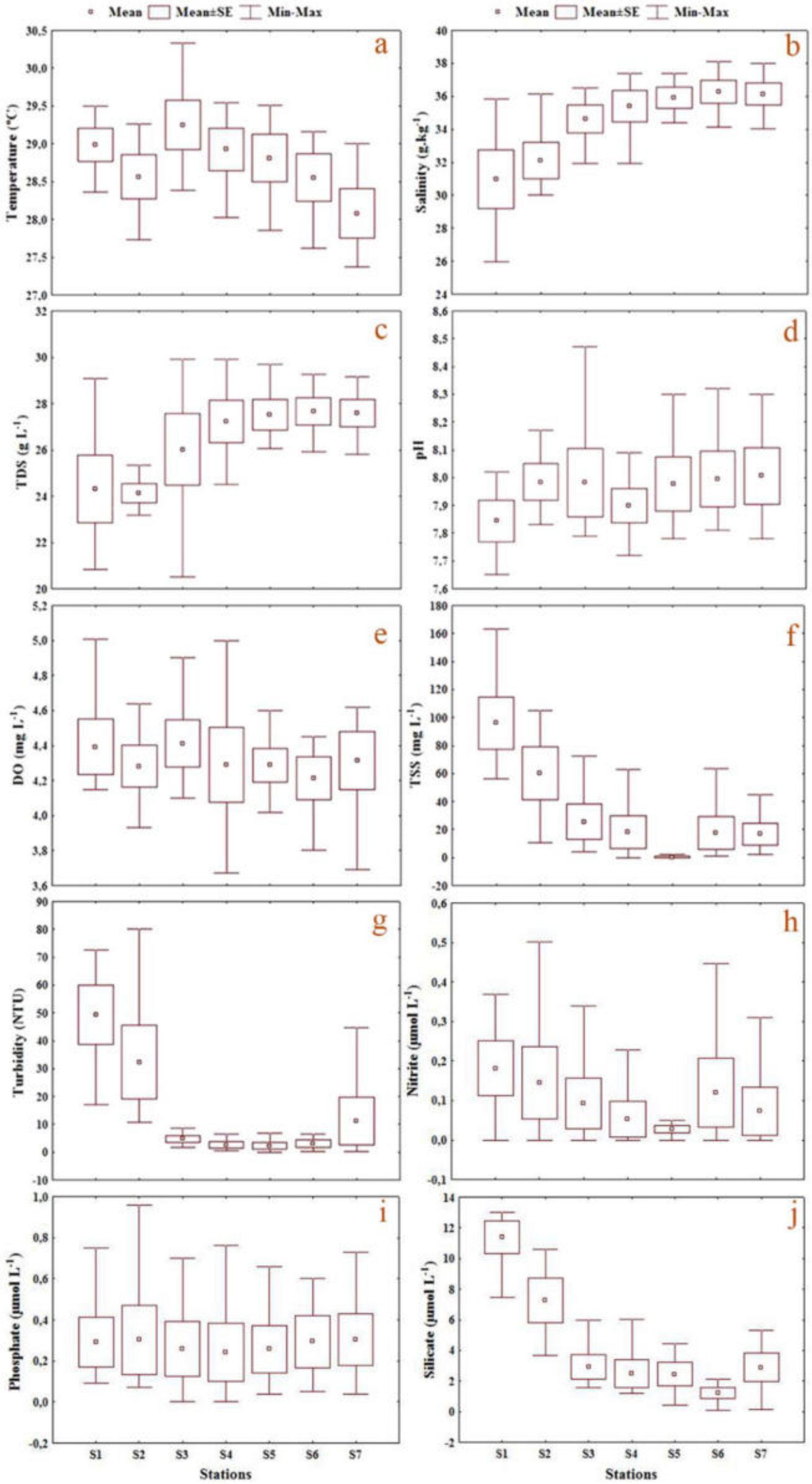

Figure 4-3. Spatial distribution of physical and chemical variables of the surface waters along Maranhão continental shelf in each sampling station. a – temperature, b - salinity, c - TDS, d - pH, e - DO, f - TSS, g - turbidity, h - nitrite, i - phosphate, j - silicate

Table 4-1. Mean, standard deviation, maximum and minimum values of physical and chemical variables collected on Maranhão continental shelf throughout study period

Period	Descriptive statistic	Temp (°C)	Sal (g kg^{-1})	TDS (g L^{-1})	Cond (mS cm^{-1})	pH	DO (mg L^{-1})	Secchi (m)	Turb (NTU)	TSS (mg L^{-1})	SiO_2 (µmol L^{-1})	PO_4^{3-} (µmol L^{-1})	NO_{2-} (µmol L^{-1})
Jan/14	Mean	28.84	36.72	28.82	57.40	8.11	4.12	4.26	17.80	21.43	3.75	0.05	0.05
	Deviation	0.72	0.61	1.83	4.20	0.19	0.12	3.50	24.45	31.78	4.06	0.02	0.05
	Maximum	29.50	37.39	29.90	59.80	8.32	4.30	10.37	72.50	91.00	12.78	0.09	0.15
	Minimum	27.73	35.84	24.75	48.01	7.92	3.93	0.13	6.05	1.00	1.51	0.03	0.00
Mar/14	Mean	28.90	36.20	27.48	54.62	7.81	4.16	5.07	19.57	29.14	4.73	0.11	0.07
	Deviation	0.36	2.22	1.57	3.57	0.07	0.21	3.52	33.13	45.77	4.98	0.03	0.10
	Maximum	29.50	38.08	28.68	57.36	7.87	4.27	8.20	80.00	100.00	12.99	0.15	0.27
	Minimum	28.57	32.78	25.35	48.37	7.72	3.69	0.26	0.13	0.00	0.92	0.07	0.00
May/14	Mean	29.28	32.19	24.19	48.56	8.11	4.51	7.57	9.16	19.53	5.76	0.52	0.06
	Deviation	0.20	3.44	2.77	5.55	0.24	0.39	5.48	11.00	27.09	3.41	0.28	0.09
	Maximum	29.54	35.60	27.03	53.84	8.47	5.00	15.26	33.00	70.00	12.85	0.76	0.23
	Minimum	29.00	25.95	20.51	40.61	7.65	3.80	0.41	2.40	0.00	2.14	0.09	0.00
Jul/14	Mean	28.66	33.75	25.74	51.49	7.89	4.54	6.31	19.53	65.17	4.77	0.16	0.32
	Deviation	0.95	3.30	2.25	4.50	0.15	0.24	4.94	27.09	51.34	3.70	0.13	0.15
	Maximum	30.33	36.26	27.42	54.85	8.17	5.01	12.00	70.00	163.00	10.84	0.33	0.50
	Minimum	27.37	28.14	21.90	43.80	7.78	4.30	0.22	0.00	0.00	1.43	0.00	0.05
Sep/14	Mean	28.00	33.61	25.51	51.02	7.86	4.24	3.46	9.27	32.23	2.87	0.55	0.00
	Deviation	0.40	1.43	0.95	1.90	0.03	0.28	2.86	15.43	36.93	3.79	0.23	0.00
	Maximum	28.38	34.98	26.35	52.70	7.89	4.49	7.70	41.50	104.81	9.18	0.96	0.00
	Minimum	27.37	31.48	24.08	48.17	7.82	3.67	0.14	0.15	0.00	0.08	0.35	0.00

The spatial distribution of salinity (Figure 4-3b) ranged from 25.95 g kg^{-1} to 38.08 g kg^{-1} throughout the study. The means per station were 30.98, 32.11, 34.64, 35.39, 35.91, 36.28 and 36.14 g kg^{-1} for S1, S2, S3, S4, S5, S6 and S7, respectively.

A progressive increase in salinity was found with the increase in distance from the coast, with significantly higher values at Stations 5, 6 and 7 in comparison to Station 1 ($F = 4.22$; $p < 0.05$. Mean salinity was 35.04 g kg^{-1} in the rainy season and 33.68 g kg^{-1} in the dry season, with significantly higher values in January 2014 ($Hc = 16.33$; $p < 0.0001$). In May 2014, the lowest salinity was found at Station 1 (25.95 g kg^{-1}), which contributed to the mean value in the rainy season (32.2 g kg^{-1}) and coincides with the period of greater rainfall intensity in the region, with an accumulated rainfall of 784.3 mm in May 2014. The highest mean salinity was found in January 2014 (36.72 g kg^{-1}), which was likely due to the low rainfall in the final trimester of the previous year.

On the Maranhão continental shelf, total dissolved solids (TDS) ranged from 20.51 g L^{-1} to 29.90 g L^{-1}, with means of 25.62 g L^{-1} and 26.83 g L^{-1} in the dry and rainy seasons, respectively (Figure 4-3c). In statistical terms, TDS demonstrated similar patterns to salinity, with higher concentrations in January 2014 ($F = 6.05$; $p < 0.00$). The value at Station 2 was significantly lower in comparison to the values found at Stations 4, 5, 6 and 7 ($F = 2.54$; $p < 0.05$).

The pH values remained basic, ranging from 7.65 to 8.47 throughout the study, with a mean of 8.01 in the rainy season and 7.88 in the dry season ((Figure 4-3d). Values were higher in January 2104 compared to March and September 2014 ($F = 5.97$; $p < 0.0001$).

Dissolved oxygen (DO) concentrations ranged from 3.67 mg L^{-1} to 5.01 mg L^{-1}, with a mean of 4.26 mg L^{-1} in the rainy season and 4.39 mg L^{-1} in the dry season (Figure 4-3e). The seasonal and spatial distribution of DO demonstrated similar concentrations, indicating a homogeneous pattern for this variable throughout the Maranhão continental shelf.

Spatial distribution of total suspended solids (TSS) concentrations ranged from 0.40 mg L^{-1} to 163.00 mg L^{-1}, with mean concentrations from 23.37 mg L^{-1} in the rainy season to 48.70 mg L^{-1} in the dry seasons, with no statistically significant difference (Figure 4-3f). Higher concentrations of TSS were found near the coast, with a progressive reduction toward oceanic regions, especially during the campaigns performed in the dry season. The highest concentration was 163.00 mg L^{-1} at Station 1, which differed significantly from all other stations ($H = 21.02$; $p < 0.0001$), except Station 2. The finding suggests the influence of inputs from the mainland combined with tide dynamics.

Turbidity ranged from 0.13 NTU to 80.00 NTU, with a mean of 15.51 NTU in the rainy season and 14.40 NTU in the dry season, demonstrating no significant seasonal difference (Figure 4-3g). A spatial gradient was found during all sampling campaigns, with greater turbidity near the coast (Stations 1 and 2) and a progressive reduction toward the oceanic region to values close to 0 ($H = 20.4$; $p < 0.0001$). Such a pattern was expected due to the influence of total suspended solids and organic matter due to river discharge and the influence of the estuarine plume.

The spatial distribution of nitrite in the surface waters of the Maranhão continental shelf showed a maximum of 0.50 μmol L^{-1}. The highest values were found in July 2014 ($H = 17.6$; $p < 0.0001$), probably due to the advance of the estuarine plume toward the continental shelf. This is corroborated by the increase in organic and inorganic mater demonstrated by the variations in TSS and turbidity, which were higher at the end of the rainy season. Nitrite concentrations were lower than 1 μmol L^{-1} at all sampling stations (Figure 4-3h).

Phosphorus concentrations ranged from 0.03 µmol L^{-1} to 0.96 µmol L^{-1}, with a mean of 0.23 µmol L^{-1} in the rainy season and 0.35 µmol L^{-1} in the dry season (Figure 4-3i). Small variations in phosphate concentration were found during the sampling campaigns, with significantly higher concentrations in May 2014 (0.52 ± 0.28 µmol L^{-1}) and September 2014 (0.55 ± 0.23 µmol L^{-1}) ($H = 22.5$; $p < 0.0001$), likely due to the contributions of river runoff and rainfall. In spatial terms, no significant differences were found throughout the sampling stations along the Maranhão continental shelf.

Silicate concentrations ranged from 0.08 µmol L^{-1} to 12.99 µmol L^{-1}, with a mean of 4.75 µmol L^{-1} in the rainy season and 3.82 µmol L^{-1} in the dry season (Figure 4-3j). Although this transport is evidenced on the Maranhão continental shelf by the increase in rainfall, however no statistically significant difference was found ($F = 0.52$; $p = 0.72$), demonstrating a lack of seasonal heterogeneity with regard to the concentration of silicate. On the spatial scale, however, sampling stations closer to the coast (Stations 1 and 2) had higher silicate concentrations throughout all campaigns ($F = 14.83$; $p < 0.0001$), which was likely due to the strong influence of rainfall and river discharge.

In the principal component analysis of the environmental variables, the first two axes explained 58.3% of the variability in the data (Figure 4-4). The significance of the axes was tested using the “broken stick” random model with 9999 bootstrap replicates (Jackson, 1993), which indicated that Components 1 and 2 were sufficient to represent the factorial variance.

Component 1 (41.1%) was positively related to turbidity, total suspended solids, silicate, dissolved oxygen and phosphate, with a tendency toward higher values in the rainy months (January, March and May) as well as at sampling sites closer to the coast, especially Stations 1 and 2. Although July and September are considered to be part of the dry season, both months apparently demonstrated the influence of adjacent drainage stemming from rainfall in the previous months, leading to the maintenance of high turbidity, suspended solids, DO, silicate and nitrite.

Component 1 was negatively correlated with TDS, conductivity, salinity and transparency, with an absence of a pattern in seasonal terms and an expected increase in values at sampling sites more distant from the coast (Stations 3, 4, 5, 6 and 7), which are characterized by greater transparency and dissolved minerals.

Component 2 (17.2%) was negatively correlated with phosphate (PO_4^{3-}) and pH. Phosphate was associated more with May and September. Moreover, the similar distribution throughout the sampling stations suggests the absorption of this nutrient, making its concentration quite homogeneous throughout the Maranhão continental shelf. pH was associated more with May, when the highest values were found, as well as sampling sites more distant from the coast (Stations 5, 6 and 7), which is an expected pattern due to the alkaline tendency of oceanic water.

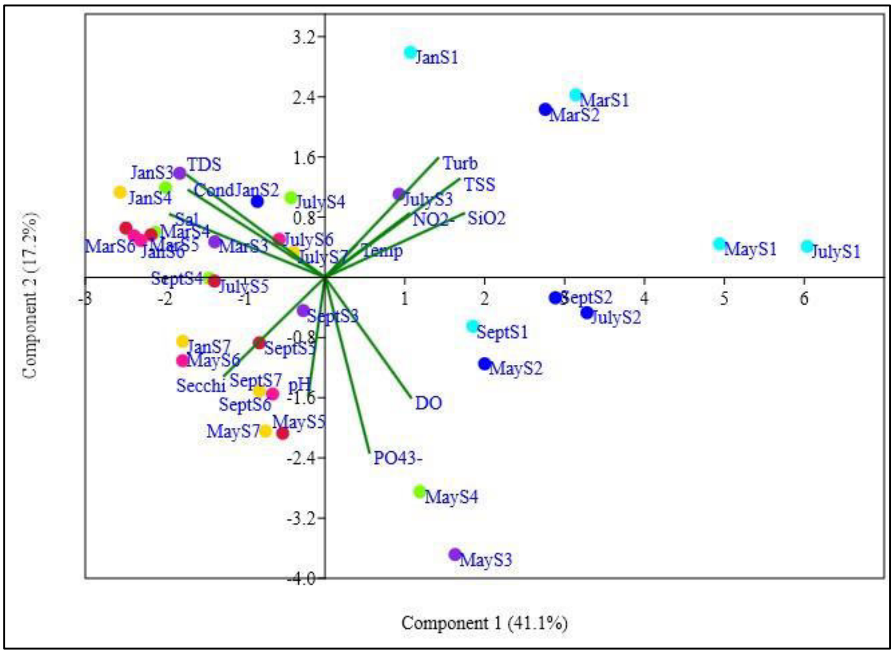

Figure 4-4. Principal component analysis of environmental variables sampled on Maranhão continental shelf. Turb = turbidity, TSS = total suspended solids, Temp = temperature, DO = dissolved oxygen, Secchi = transparency, Sal = salinity, Cond = conductivity, TDS = total dissolved solids

In the correlation analysis of the environmental variables (Table 4-2), salinity, TDS and conductivity had the largest number of significant correlations with other variables and were positively correlated with transparency and negatively correlated with DO, TSS, silicate, phosphate and nitrate. Silicate was negatively correlated with transparency (r = -0.53) and positively correlated with both turbidity (r = 0.79) and TSS (r = 0.74), confirming the influence of river discharge and rainfall, with higher concentrations of silicate at sites closer to the coast. Nitrite was positively correlated with DO (r = 0.38) and TSS (r = 0.57), which demonstrates its contribution to the increase in biological activity associated with primary productivity and a greater concentration of particulate matter.

Table 4-2. Correlation matrix (Pearson's r) for environmental variables sampled on Maranhão continental shelf. Coefficients in bold denote significant correlations ($p < 0.05$, t-test)

Variables	**Temp**	**Sal**	**TDS**	**Cond**	**pH**	**DO**	**Secchi**	**Turb**	**TSS**	**SiO_2**	**PO_{43-}**	**NO_{2-}**
Temp	1.00											
Sal	-0.16	1.00										
TDS	-0.03	**0.90**	1.00									
Cond	-0.06	**0.90**	**0.83**	1.00								
pH	0.17	0.03	-0.02	0.02	1.00							
DO	0.10	**-0.51**	**-0.52**	**-0.49**	0.19	1.00						
Secchi	-0.14	**0.52**	**0.41**	**0.34**	0.22	0.03	1.00					
Turb	0.07	**-0.41**	-0.27	-0.28	-0.15	0.13	**-0.50**	1.00				
TSS	0.16	**-0.57**	**-0.42**	**-0.44**	-0.24	0.24	**-0.52**	**0.77**	1.00			
SiO_2	0.28	**-0.65**	**-0.52**	**-0.51**	-0.07	0.22	**-0.53**	**0.80**	**0.75**	1.00		
PO_{43-}	-0.14	**-0.37**	**-0.46**	**-0.34**	0.20	0.32	0.12	-0.03	0.06	0.15	1.00	
NO_{2-}	0.07	**-0.36**	-0.28	-0.33	-0.11	**0.38**	-0.13	0.30	**0.57**	0.31	-0.31	1.00

Discussion

The distribution of surface temperature in the ocean is approximately zonal and temperature isolines approximately follow latitude parallels, reaching around 28ºC just north of the equator and diminishing to -2ºC at polar latitudes (Pickard and Emery, 1990). Evidence indicates that inter-annual variability in surface water temperature in the tropical Atlantic occurs more due to local dynamics and interactions with the ocean-atmosphere interface than external perturbations, such as those caused by the El Niño-Southern Oscillation (Hameed et al., 1993; Hastenrath and Greischar, 1993).

Eschrique (2011) found that temperatures demonstrated typical characteristics of the northeastern region of Brazil, with high values throughout the year and stability regarding the period and degree of solar radiation in tropical regions. In studies conducted on the continental shelf off the state of Pará on the border with the state of Maranhão, Nogueira Neto (2013) found surface temperatures around 29.50°C. Silva et al. (2007b) found a temperature of 28.50°C in the dry season in an oceanic area adjacent to the Maranhão continental shelf. In studies conducted in the coastal zone of the state of Pará, Martorano et al. (1993) report that high temperatures are typical of equatorial environments, describing a range between 22°C and 30°C and monthly means ranging from 24 to 28°C.

The salinity range is greater in regions that receive with large volumes of river discharge. The influence of the rivers, together with rainfall, are the main factors responsible for the dynamics of the salinity gradient in the region, which is also strongly affected by the discharge from the Amazon river (Silva et al., 2007a; Araujo et al. 2011). Santos et al. (2008) found a range of 2.49 g kg^{-1} to 36.17 g kg^{-1} along the plume of the Amazon River, with lower values in coastal regions closer to the mouth of the river and higher concentrations in areas more distant from the coast, confirming the enormous influence of the Amazon River on equatorial marine waters. Different behavior is found on the Maranhão continental shelf during the dry season, when rivers contribute very little to the fluvial volume. This explains the increase in salinity at sampling stations closer to the coast due to the oceanic characteristics of tropical water. The increase in the evaporation rate, low river input and high surface water temperatures are directly associated with the intrusion of more saline oceanic water on the Maranhão continental shelf (Pontes and El-Robrini, 2008).

The spatial and seasonal distribution of electrical conductivity demonstrated a similar pattern to that found for salinity, which confirms the correlation between these two variables described by Millero (2006), who states that condumetric ratios have the same proportion as salinity, even if the composition of the salts in surface waters differs. Conductivity depends on concentrations of ions and indicates the amount of salts in water, increasing with the increase in the amount of dissolved solids and demonstrating a close relationship with salinity.

With regard to total dissolved solids (TDS), an understanding of the diverse processes involved enables the identification of interferences in hydrodynamics, affecting tide propagation and the dispersion of suspended nutrients and matter from the mainland basin to the ocean (Vilela, 2011). According to Tundisi and Matsumura Tundisi (2008), all minerals in the water are part of the TDS, including non-ionic components and dissolved organic compounds. Therefore, this variable has a direct and proportional correlation with electrical conductivity due to the concentration of ions, as demonstrated in the present study, in which TDS demonstrated quite similar spatial distribution to that found for salinity and conductivity.

PH is governed by tidal cycles and photosynthesis and/or respiration rates. In aquatic ecosystems, a process of neutralization occurs due to the buffer effect, which maintains pH in a stable balance, with maximum values obtained in environments with greater salinity (Macêdo et al., 2000). Although no significant spatial differences were found, the pH was slightly lower at sampling stations closer to the coast, likely due to the input of freshwater, which has more acidic characteristics stemming, above all, from the large quantity of dissolved organic acids, such as sulfuric, nitric, oxalic, acetic and carbonic acids made available by the metabolic interactions of microorganisms in aquatic environments (Esteves, 1988). The gradual increase in pH toward the open ocean corresponds to carbonate and bicarbonate reactions, which dissociate and increase the alkalinity of surface waters. Santos et al. (2008) found pH values ranging from 7.46 to 8.56 in a transect influenced by the plume of the Amazon River and lower variability in oceanic regions (8.13 to 8.44), which is in agreement with the present study, as pH demonstrated smaller variations at sampling stations located more distant from the coast. According to Millero (2006), this relative stability is characteristic of the Atlantic Ocean, unlike records for the Pacific Ocean, for which a range of 7.2 to 8.2 is described.

In tropical coastal regions, the concentration of dissolved oxygen (DO) in the surface layer is subject to rapid fluctuations influenced by external agents, such as river inputs, rainfall, evaporation, winds and tidal patterns, whereas photosynthetic production can contribute to an increase in DO concentrations in the open ocean (Demaster et al., 1996; Santos et al., 2008; Macêdo et al., 2009). In studies conducted in the region of the Saint Peter and Saint Paul Archipelago within the scope of the REVIZEE [Live Resources of the Exclusive Economic Zone] Program, Becker (2001) found minimum and maximum DO values of 2.56 and 4.41 mg L^{-1}, respectively. DO levels $\leq$ 4 mg L^{-1} in natural waters favor anaerobic processes, which produce a large amount of reducing substances that consume a large quantity of the available oxygen for their oxidation (Esteves, 2011).

With regard to suspended particulate matter, the influence of the tide, geomorphology of the coast and outflow bathymetry in shallow coastal environments are determinants of the re-suspension process. In the present study, Stations 1 and 2 were subject to a greater influence of tidal flow, producing higher TSS values, with lower values at sampling stations more distant from the coast. According to Millero (2006), the decrease in the frequency and intensity of the agitation of bottom layers and the emergence of inorganic and biological reactions in oceanic regions lead to a reduction in suspended particulate matter and more stable TSS values. The values found in the present study were higher than those reported by Souza et al. (2003) in the coastal zone of the continental shelf off eastern Brazil. The authors recorded the distribution of suspended solids in two sampling campaigns conducted off the states of Sergipe, Bahia, Espírito Santo and Rio de Janeiro, with TSS values of 13 mg L^{-1} in the dry season and 90 mg L^{-1} in the rainy season.

On the Maranhão continental shelf, contrary to the expected behavior, the concentration of TSS was greater in the transition between the rainy and dry seasons, with a maximum value in July 2014. This increase may be explained by the periodic dragging of the canals that offer access to the Itaqui port complex, which invariably redistributes the sediment stored on the bottom to the surface layer, thereby contributing to an increase in the concentration of TSS in regions closer to the coast, which are subsequently transported by tidal currents and/or winds to other compartments of the Maranhão continental shelf.

Suspended solids are directly related to turbidity, water transparency and primary productivity, as a greater amount of TSS results in greater turbidity and lower transparency (Macedo, 2003). An increase in the concentration of TSS exerts a direct influence on the reduction in the rate of photosynthesis due to the extinction of light in the photic zone and exerts an negative impact on the availability of food for some species, leading to an imbalance in the marine food chain. Moreover, suspended sediment can be contaminated with pesticides, heavy metals and other toxic substances, which can have a negative impact on the reproduction of fish and other species (Silva, 2006). Da Silva et al. (2009) found higher turbidity in the coastal zone of Maranhão, evidencing the influence of the estuarine sediment plume and the hydrodynamic energy of tidal forces, with the re-suspension of sediments in the water column leading to a turbidity range of 14.80 to 39.29 NTU in the dry season and 55 to 200 NTU in the rainy season.

Dissolved inorganic nutrients (nitrite, phosphate and silicate) were recorded in the present study, as the occurrence of these nutrients indicates mainland inputs that affect primary production in marine environments. The allochthonous origin stems from processes such as atmospheric deposition, the infiltration of ground water by lixiviation, the entrance of marine water in estuaries and the flow of rivers, whereas the internal contribution is based mainly on the benthic and pelagic re-mineralization of organic matter. Understanding nutrient distribution patterns and marine biogeochemical cycles remains a considerable challenge (Conkright et al., 2000). Continental shelves are transition zones between the mainland and ocean with a large supply of particulate and dissolved matter stemming from river discharge (Nittrouer et al., 1995), where complex oceanographic processes co-occur on distinct spatial and temporal scales (Arndt et al., 2011).

The increase in biological activity associated with nutrient availability may be attributed to both biogeochemical processes and other oceanographic processes that cause the re-suspension of organic matter (upwelling, small vortices or internal waves), leading to an increase in biological production (Admiraal et al., 1990; Turner and Rabalais, 1994). Along the continental shelf, the spatial distribution of dissolved nutrients is controlled by vertical and horizontal mixtures caused by tides, waves and wind on the water surface (Sánchez-Arcilla and Simpson, 2002). The synergic action of these variables can cause an increase in dissolved nutrients and total suspended solids, thereby increasing primary production (Mann and Lazier, 1996). In coastal zones of tropical regions, estuarine systems serve as a storage site for suspended nutrients, which then become available to the adjacent continental shelf (Ovalle et al., 1999). For instance, Amazon coastal zone is potentiated by the abundance of mangroves and high hydrodynamic energy, creating a rich supply of dissolved nutrients directed to the continental shelf region (Demaster et al., 1996; Kineke et al., 1996; Nittrouer and Demaster, 1996; Pereira et al., 2010).

On the Maranhão continental shelf, nitrite values were low and very similar among all sampling stations ($F = 0.67$; $p > 0.05$), which is in agreement with data described by Demaster and Pope (1996) for various transects determined on the continual shelf of the Amazon. Low nitrite values are typical of tropical waters, except when resulting from re-mineralization, re-suspension of the bottom or input from rivers. Santos (2012) confirms this nitrite instability on the continental shelf off the northeastern region of Brazil, with mean values ranging from 0.02 to 0.05 µmol L^{-1}, which is characteristic of oligotrophic environments. In the period between the rainy and dry seasons (July 2014), an increase was found in the variation of nitrite concentrations, with a mean of 0.32 µMol L^{-1}. This increase can lead to an increase in biological production rates, a greater availability of suspended matter as well as increases in OD, TSS and turbidity, suggesting an increase in the photosynthetic rate and primary production at stations in oceanic regions. All these aspects contribute to an increase in the production of aquatic organisms in this period in regions more distant from the coast. In contrast, lower values were found in the dry season, as occurred in September 2014, when no nitrate was detected. Therefore, nitrate became more unstable in this period, favoring the development of bacterial oxidation, which increases the availability of ammonia. Pereira et al. (2012) report different behavior in a study conducted in the Amazon coastal zone; the authors found mean nitrite values of 0.11 µmol L^{-1} at the end of the rainy season and 0.49 µmol L^{-1} in the dry season.

Phosphate concentrations fluctuate little in tropical estuaries. The mainland is the main source of these nutrient in the marine environment, with concentrations tending to diminish with the distance from the source (Eschrique et al., 2010). Monteiro et al. (2015) report values of 0.11 µmol L^{-1} to 1.08 µmol L^{-1} in an Amazonian estuary near the island of Marajó in the state of Pará. However, Lara and Dittmar (1999) found phosphate concentrations between 1.5 and 5.0 µM L^{-1} in a tidal channel in the municipality of Bragança in the same state. Pereira et al. (2012) found low concentrations (mean: 0.11 µmol L^{-1} in the rainy season and 0.92 µmol L^{-1} in the dry season) in a coastal environment in northeastern

Brazil, demonstrating the low influence of seasonality on the final concentration of phosphate in this environment.

The rapid absorption of phosphate in oceanic areas by primary producers and bacteria explain its low concentration and availability. In the present study, concentrations were low at the majority of sampling stations. Valiella (1984) and Eschrique et al. (2006) report that phosphate regeneration processes through re-mineralization, excretion by zooplankton and absorption by phytoplankton occur at an accelerated rate, making its residence time in oligotrophic waters extremely short (a matter of minutes) and making its particulate form the main compound found in oceanic waters. The coastal region of the Maranhão continental shelf, which is influenced by a large number of mangroves, is an important vehicle for the transport of nutrients to the oceanic region.

Scientific records describe a reduction in the concentration of dissolved nutrients from the estuary to the coastal region, favoring the development of mixture diagrams as a powerful tool for the characterization of nutrient removal processes from masses of water. According to Noernberg (2001), the transport of sediment through the coastal zone reaches an average of 15 nautical miles in the direction of the open sea, with the coastal environment the main redistribution route of nutrients to oceanic regions. Santos et al. (2008) found high nutrient concentrations in the rainy season at a distance of 120 km from the coast on the continental shelf off the state of Pará, with silicate as the most representative nutrient (range; 14.48 $\mu mol\ L^{-1}$ to 108.59 $\mu mol\ L^{-1}$), confirming the considerable capacity and influence of Amazonian rivers in the distribution of this nutrient to the open ocean. In the present study, silicate demonstrated dispersion capacity through the plume of rivers, thereby reflecting the influence of transport from rivers to oceanic regions of the Maranhão continental shelf and giving this nutrient the greatest capacity for concentration and distribution in the area investigated.

The ordination analysis revealed the influence of river discharge and rainfall on the concentration patterns of different physicochemical variables, which is in agreement with data described by Pereira Filho et al. (2009). Pereira Filho et al. (2003) also report the influence of river discharge on the greater presence of nitrogenated nutrients, which are involved in the nutritional process of phytoplankton. Braga et al. (2008) report that the availability of phosphate is closely linked to the mainland input, with the influence of the Prata River and upwelling in the region of Cape Santa Marta in the state of Santa Catarina (southern Brazil). In the present study, the considerable outflow from the mainland, especially from the Mearim and Pindaré Rivers, and the macrotide conditions, with the capacity to transport nutrients from the mangroves, contributed greatly to the availability of phosphate on the Maranhão continental shelf, with means ranging from 0.05 $\mu mol\ L^{-1}$ in January 2014 to 0.55 $\mu mol\ L^{-1}$ in September 2014. Braga et al. (2008) report similar figures for the Santa Catarina continental shelf, whereas Santos et al. (2008) report lower figures for the Amazon continental shelf.

Silicate is a potential tracer of sediment transported from rivers to oceanic regions, enabling the identification of the distribution caused by this flow (Braga et al., 2008). The analyses also indicate an association between silicate and sampling points closer to the coast, demonstrating negative correlations with salinity, TDS and conductivity, for which higher values were found at more external sampling stations along the Maranhão continental shelf. Ciotti et al. (1995) and Weber et al. (1994) also found a greater concentration of silicate in waters closer to the coast. Braga et al. (2008) describe freshwater and terrestrial inputs along the coast as being major contributors to the high concentrations of silicate on the southern/southeastern continental shelf in summer, which is in agreement with the present findings and demonstrates the importance of climate as a regulating agent for the availability of this nutrient. It is therefore important to maintain the levels of river outflow due to the transport of nutrients to the Maranhão continental shelf, which contribute to biological development as well as the maintenance of trophic, reproductive and developmental aspects of species and, consequently, fishing resources, which have dietary, economic and cultural importance to tropical cities in coastal areas.

Conclusion

The spatial and temporal variability in the physicochemical variables analyzed (transparency, temperature, salinity, conductivity, dissolved oxygen and suspended solids) is associated with local dynamics governed by river discharge, tidal movements, currents and climatologic events;

Very low salinity was associated with higher concentrations of nutrients, indicating the influence of terrestrial inputs to the Maranhão continental shelf, especially in areas closer to the coast.

Phosphate concentrations were similar throughout the sampling stations and lower than silicate concentrations. In turn, silicate concentrations were significantly higher in areas closer to the Gulf of Maranhão;

The highest nitrite concentrations were found in July 2014, soon after the period of greater rainfall in the region, demonstrating a direct association with mainland inputs and a greater biological production rate, as nitrite values were positively correlated with dissolved oxygen and total suspended solids;

The fluvial transport from the rivers of the state of Maranhão and other freshwater sources in the Amazon region are apparently the major contributors responsible for the maintenance of nutrient availability on the Maranhão continental shelf, where seasonal influences affect phosphate and nitrite availability, with higher concentrations during and soon after the rainy season. In contrast, silicate values are similar throughout the year.

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5 CAPÍTULO 2: FISH ASSEMBLAGE STRUCTURE IN A PORT REGION OF THE AMAZONIC COAST

IHERINGIA SÉRIE ZOOLOGIA – **PUBLICADO**

(Qualis: B2 em Biodiversidade e B4 em Biotecnologia; Fator de Impacto: 0.0303)

ESTRUTURA DA ASSEMBLEIA DE PEIXES EM UMA REGIÃO PORTUÁRIA DA COSTA AMAZÔNICA

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Fish assemblage structure of the Amazonic coast

ABSTRACT. The fish assemblage structure in a port area in São Marcos Bay (Amazonic coast) was evaluated based on the spatial and temporal distributions to identify potential changes in response to anthropic pressure increases associated with industrial and port activities in region. The samples were taken between March 2011 and November 2015. The ichthyofauna was represented by a total of 56 species, distributed in 15 orders and 29 families. Captures were dominated by *Genyatremus luteus*, but *Sciades proops* was the most representative in terms of biomass. Seasonal distributions of fish assemblage did not reveal significant differences. However, there was a difference between catch sites, abundance, biomass and Shannon diversity index was higher in the Site 1 and evenness in Site 4. The analysis NMDS and the test ANOSIM between months and between sampling sites, based on species composition, revealed a seasonal differentiation associated with the rainy and drought months, as well as spatial differentiation, in function of a depth gradient and hydrodynamics, resulting from greater distance from mangrove areas. The low diversity recorded may be a reflection of port activities that historically occur in the area investigated. However, there was still a maintenance of regional diversity throughout the period under analysis. Thus, temporal and spatial scales become important for the detection and understanding of fish biodiversity in an Amazonian estuary, reflecting, the importance of mangroves for the maintenance of the ichthyofaunistic diversity in the area. In this context, the present study may subsidize possible conservation projects in the area since information of this nature is almost non-existent for estuarine fish from the Maranhão Amazon.

KEYWORDS: Ichthyofauna, estuary, seasonal variability, spatial patterns, Maranhão Amazon.

RESUMO. **Estrutura da assembleia de peixes em uma região portuária da costa amazônica**. A estrutura da assembleia de peixes em uma área portuária na Baía de São Marcos (Costa Amazônica) foi analisada com base nas distribuições espaciais e temporais para identificar potenciais mudanças na resposta aos aumentos de pressão antrópica associados às atividades industriais e portuárias na região. As amostras foram realizadas entre março de 2011 a novembro de 2015. A composição da ictiofauna foi representada por um total de 56 espécies, distribuídas em 15 ordens e 29 famílias. As capturas foram dominadas por *Genyatremus luteus*, mas *Sciades proops* foi o mais representativo em termos de biomassa. A avaliação sazonal da assembleia de peixe não revelou diferença significativa. Entretanto, houve diferença entre os locais de captura onde abundância, biomassa e diversidade de Shannon foram mais relevantes no Ponto 1 e a equitabilidade no Ponto 4. A análise

NMDS e o teste ANOSIM entre os meses e entre os locais de amostragem, com base na composição de espécies, revelaram uma diferenciação sazonal associado aos meses chuvosos e de estiagem, bem como uma diferenciação espacial, em função de um gradiente de profundidade e hidrodinâmica, resultante da maior distância das áreas de mangue. A baixa diversidade registrada podem ser reflexos das atividades portuárias que historicamente ocorrem na área investigada. Porém, ainda sim, percebeu-se uma manutenção da diversidade regional, ao longo do período em análise. Assim, as escalas temporais e espaciais tornam-se importantes para detecção e compreensão da biodiversidade de peixes em um estuário amazônico, refletindo, a importância dos manguezais para a manutenção da diversidade ictiofaunística na área. Mediante este contexto, o presente estudo pode subsidiar possíveis projetos de conservação na área, uma vez que informações desta natureza são quase inexistentes para peixes estuarinos da Amazônia maranhense.

PALAVRAS-CHAVE: Ictiofauna, estuário, variabilidade sazonal, padrões espaciais, Amazônia maranhense.

Estuaries are important examples of high species richness, abundant biomass, and diversity of biological (spawning, reproduction, recruitment, nursery) and ecological (freshwater, estuarine and marine species migrations/movements, regulation of nutrients, coastal waters fertilization, land-sea connectivity) processes (BARLETTA *et al.*, 2008). Therefore, as a result of its productivity and readily available resources, estuaries have always been directly responsible for the maintenance of the daily lives, and long term survival, of traditional populations worldwide (BARLETTA & COSTA, 2009).

Along the northern Brazilian coast (Maranhão Gulf) are the most extensive estuarine areas due to the influence of macro tides (6 to 7 m), when creeks of mangrove forests are flooded during high tide. Scientific knowledge about the fish fauna of the northern coast of Brazil is still scarce, with diffuse information and several geographic gaps. Studies carried out between Amapá and Maranhão recorded about 303 species belonging to 23 orders and 86 families, which are distributed between two main subareas: the Maranhenses-Paraenses estuaries and the region between the Amazonian estuary and the Amapá coast (CAMARGO & ISAAC, 2003). Tropical estuaries are exposed to marine and terrestrial processes, which influences their structural characteristics, affecting the distribution patterns of fish communities (NERO & SEALEY, 2006).

Estuarine environments, particularly the São Marcos Bay (Brazil), where there is a port area of national and international importance (CARVALHO-NETA *et al.*, 2014), are characterized by high primary productivity and provide feeding and breeding places for many species of fish and other aquatic organisms, many of which are of commercial value (VIANA & LUCENA FRÉDOU, 2014). In this region it is inserted the second largest port complex in the country, which is the main driver of economic and social development in the state of Maranhão (ASSIS *et al.,* 2013). In this area, the catching of estuarine and marine fish is still of great relevance for the adjacent fishing communities.

Fish communities have great biological importance, as they can influence the composition, abundance and distribution of other biotic communities in estuaries (BORGES *et al.,* 2010). Many species of ichthyofauna depend on estuaries at some stage of their lives for recruitment, breeding and feeding activities (LONERAGAN, 1999; KIMMERER, 2002). Changes in the composition of communities act as an important parameter to indicate the quality of the ecosystem. Thus, several studies have highlighted the ichthyofaunistic community as an indicator of environmental quality (FALCÃO *et al.*, 2008; SILVA-JÚNIOR *et al.,* 2013; MOURÃO *et al.,* 2015; FISCH *et al.*, 2016).

There are different approaches used in describing fish assemblages as well as the factors that influence their variation. Some studies focus on environmental influences on the structure of communities (THIEL *et al.,* 1995; LARA & GONZÁLEZ, 1998; MARSHALL & ELLIOTT, 1998; ARAÚJO *et al.*, 2002), others describe seasonality (MAES *et al.,* 1998) and some only consider spatial patterns (ARAÚJO *et al.,* 1997; ARAÚJO *et al.*, 1998), without determining an effective cause. It is important to take into account anthropic actions in the estuarine habitats and, consequently, in the fish assemblages associated with them, which may directly affect the biological, physiological and behavioral patterns of the species (WHITFIELD & ELLIOTT, 2002).

Currently, little is known about the temporal dynamics of fish communities in an estuarine environments belonging to the Eastern Amazon. Thus, it is extremely important to identify possible changes in the fish assemblages. Therefore, the aim of this study was to determine the differences in the fish composition, abundance, biomass and diversity, based on a spatial and temporal assessment, and possible influences of anthropic pressure increases associated with industrial and port activities in São Marcos Bay (Amazonic coast).

Materials and Methods

The coast of Maranhão is located between the mouth of the Gurupi River, State of Pará, and the mouth of the Parnaíba River, State of Piauí, approximately 640 km long. For descriptive purposes it is divided into three distinct areas, West Coast, Maranhense Gulf and East Coast. The Maranhense Gulf is situated in the center region of the coast, where there are two large bays, São Marcos and São José, which are separated by and island called the Island of Maranhão.

Regarding the climate, the coastal region of Maranhão is characterized by the transition between the humid climate of the Amazon and the semi-arid region of the Northeast. In the study area the tropical humid climate is predominant and the average temperature is 24 °C, with rainfall averages ranging from 1600 mm to 2000 mm, with the relative humidity of 80% (STRIDE, 1992). The climate in this region is also characterized by two seasons: dry season and rainy season.

In this study, the sampling was carried out in four distinct sites in São Marcos Bay. The sites are characterized by strong anthropic interference (industrial activities) and by activities developed in the Itaqui port region. Site 1 (44° 22' 19.745" W and 2° 33' 34.062" S), which is a more sheltered and the densest area of mangrove plant species; Site 2 (44° 21' 59.359" W and 2° 33' 21.469" S) and Site 3 (44° 21' 47.033"W and 2° 33' 7,150" S), areas closer to the mainland and under the influence of the port complex; Site 4 (44° 22' 5.857" and W 2° 32' 42.265" S), which is the farthest site from the port, it is also the deepest site (Figure 5-1Figure 5-2).

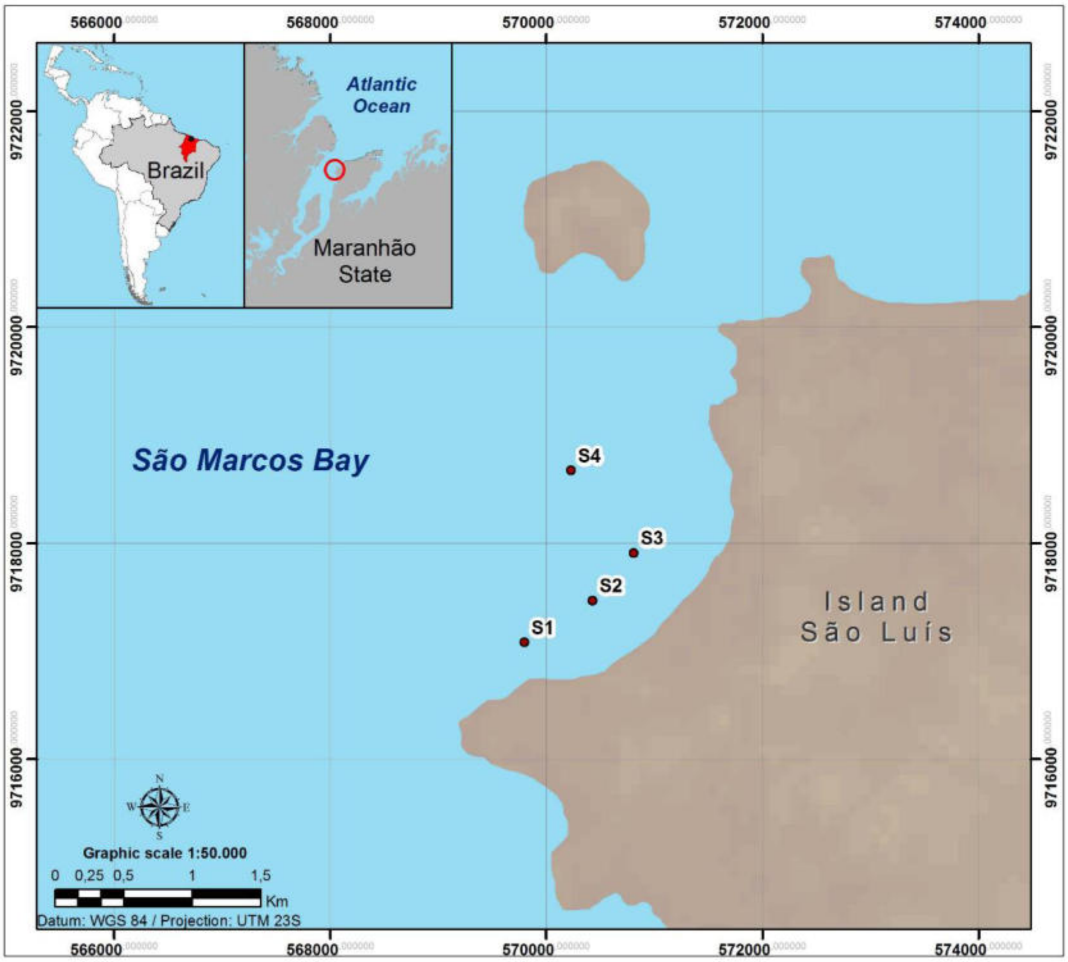

Figure 5-1. Study área: São Marcos Bay. Sites location, Maranhão, Brasil.

Fish samples were performed from May/2011 to November/2015, with a total of 18 sampling. The species were collected in 4 sites (S1, S2, S3 and S4) using gillnets, with meshes ranging from 18 mm to 60 mm between opposing nodes. The gillnets were installed at the end of the high tide and continued throughout the entire ebb tide cycle (standardized in approximately 6h at each sites).

The samples were placed in plastic bags, stored in the ice and taken to the Laboratory of Ichthyology of the Federal University of Maranhão. The biological material was identified up to the species level, using the studies developed by FISCHER (1978), CERVIGÓN *et al.* (1992) and FIGUEIREDO *et al.* (1980, 2000). In addition, some identifications were updated using the Fishbase database (FROESE & PAULY, 2009). For each specimen, the total length (cm), standard length (cm) and total weight (g) were obtained. Part of the identified material was fixed in 10% diluted formaldehyde and later preserved in 70% alcohol. Then, it was stored in the Collection Room of the Laboratory of Hydrobiology of the Federal University of Maranhão.

Fish community parameters (number of fish, biomass, diversity, through Shannon-Wiener index and evenness J' index) were compared between seasons and catching sites. The graphical representation of the data, through the box plot, was made with the aid of the software STATISTICA version 7.0 (Statsoft Corp, USA).

Assumptions of normality and homogeneity of variance were analyzed by Shapiro-Wilk test (SHAPIRO & WILK, 1965) and Levene test, respectively. When necessary, data were transformed with log (x) or log (x+1). Parametric analysis of variance (ANOVA) or non-parametric Kruskal-Wallis (KW) was used depending on the fulfillment of the assumptions. A post-hoc Tukey's Test or Mann-Whitney was used to test for multiple comparisons between months and sites. The statistical analyzes were performed using the PAST program 3.14 (HAMMER, 2001), with significance level of $\alpha = 0.05$ (SOKAL & ROHLF, 1969).

Temporal variation in the structure of the fish assemblages were evaluated by non-metric multidimensional scaling (NMDS) with 1000 iterations, derived from a Bray-Curtis similarity matrix constructed from the fish abundance data, with data transformed to log (x+1). The R-statistic values determined by ANOSIM for significant comparisons were used to ascertain the degree to which *a priori* seasonal groups (dry and rainy seasons) and site groups (S1, S2, S3 and S4) were dissimilar (CLARKE, 1993). Similarity Percentages

(SIMPER) (CLARKE & WARWICK, 1994) were employed to determine which species contributed the most to any similarities within exposure groups. These analyses were performed with the statistics program PRIMER v. 6 (CLARKE & GORLEY, 2006).

Results

A total of 4,257 individuals from 56 species were collected at four sites along São Marcos Bay between the years of 2011 and 2015. The species were distributed in 14 orders and 29 families, of which 45% belongs to the order Perciformes, 13% to the order Siluriformes and 10% to the Clupeiformes. The orders Mugiliformes, Pleuronectiformes and Tetraodontiformes represented 5% each, Beloniformes 3%, Rajiformes 3% and the remaining represented 12%. The families with the highest number of species were Sciaenidae (12), Ariidae (7), Carangidae (4), Engraulidae (4) and Mugilidae (3).

The species *Genyatremus luteus*, *Sciades proops*, *Macrodon ancylodon*, *Bairdiella ronchus*, *Bagre bagre, Mugil gaimardianus*, *Sciades herzbergii* and *Sardinella janeiro* were dominant in numbers of individuals representing 63% of the total catch (Table 5-1). *Genyatremus luteus* was the most abundant taxon, accounting for 10% of the total catch or 417 individuals.

The total catch weight was 544 kg, in which *Sciades proops* was the most representative with 20% (109,9 kg) of the total catch, followed by *Macrodon ancylodon, Bagre bagre, Centropomus undecimalis, Genyatremus luteus, Sciades herzbergii, Cynoscion acoupa* and *Trichiurus lepturus*, with a total of 75% of the sample.

Table 5-1. Absolute and relative frequencies (%) of the number (N) and weight (W) of fish species collected São Marcos Bay, state of Maranhão, Brazil in the period of May/2011 to November/2015.

Species	Commom name	N	%(N)	W (g)	%(W)
Achirus lineatus (Linnaeus, 1758)	Lined sole	140	3%	7.694,62	1%
Aluterus monoceros (Linnaeus, 1758)	Unicorn leatherjacket	1	0%	140,00	0%
Amphiarius rugispinis (Velenciennes, 1840)	Jurupiranga	71	2%	13.939,29	3%
Anchoa spinifer (Valenciennes, 1840)	Spicule Anchovy	6	0%	192,50	0%

Species	Commom name	N	%(N)	W (g)	%(W)
Aspistor quadriscutis (Valenciennes, 1840)	Bressou sea catfish	2	0%	421,04	0%
Aspredinichthys tibicen (Valenciennes, 1839)	Tenbarbed banjo	2	0%	40,90	0%
Bagre bagre (Linnaeus, 1766)	Coco sea catfish	317	7%	51.929,79	10%
Bairdiella ronchus (Cuvier, 1830)	Ground croaker	365	9%	4.847,86	1%
Batrachoides surinamensis (Bloch & Schneider,	Pacuma toadfish	15	0%	5.376,78	1%
Caranx latus (Agassiz, 1831)	Horse-eye Jack	1	0%	2,10	0%
Cathorops spixii (Agassiz, 1829)	Madamango sea catfish	41	1%	1.690,69	0%
Centropomus parallelus (Poey 1960)	Fat snook	4	0%	1.690,83	0%
Centropomus undecimalis (Bloch,1792)	Common snook	109	3%	50.276,72	9%
Cetengraulis edentulus (Cuvier, 1829)	Atlantic anchoveta	42	1%	1.102,74	0%
Chaetodipterus faber (Broussonet, 1782)	Atlantic spadefish	13	0%	150,88	0%
Colomesus psittacus (Bloch & Schneider, 1801)	Banded puffer	8	0%	1.768,26	0%
Cynoscion acoupa (Lacepède, 1801)	Acoupa weakfish	98	2%	33.738,16	6%
Cynoscion jamaicensis (Vaillant & Bocourt, 1883)	Jamaica weakfish	11	0%	1.394,70	0%
Cynoscion leiarchus (Cuvier, 1830)	Smooth weakfish	27	1%	2.801,20	1%
Cynoscion microlepidotus (Cuvier, 1830)	Corvina	32	1%	6.227,11	1%
Dasyatis guttata (Bloch & Schneider, 1801)	Longnose stingray	3	0%	799,29	0%
Diapterus rhombeus (Cuvier, 1829)	Caitipa mojarra	3	0%	59,90	0%
Elops saurus (Linnaeus, 1766)	Ladyfish	11	0%	1.248,64	0%
Genyatremus luteus (Bloch, 1790)	Torroto grunt	417	10%	38.709,00	7%
Gymnura micrura (Bloch & Schneider, 1801)	Smooth butterfly ray	3	0%	336,51	0%
Hexanematichthys bonillai (Miles, 1945)	New Granada sea catfish	19	0%	1.216,10	0%
Lile piquitinga (Schreiner & Ribeiro, 1903)	Atlantic piquitinga	93	2%	383,04	0%
Lobotes surinamensis (Bloch, 1790)	Tripletail	1	0%	824,00	0%
Lutjanus jocu (Bloch & Schneider,1801)	Dog snapper	9	0%	1.088,11	0%
Macrodon ancylodon (Bloch & Schneider, 1801)	King weakfish	370	9%	56.974,09	10%
Menticirrhus americanus (Linnaeus, 1758)	Southern kingcroaker	62	1%	4.173,79	1%
Micropogonias furnieri (Desmarest, 1823)	Whitemouth croaker	31	1%	13.950,41	3%
Mugil curema (Valenciennes, 1836)	White mullet	95	2%	6.033,26	1%
Mugil gaimardianus (Desmarest, 1831)	Redeye mullet	291	7%	8.071,52	1%
Mugil incilis (Hancock, 1830)	Parassi mullet	33	1%	11.637,60	2%
Nebris microps (Cuvier, 1830)	Smalleye croaker	1	0%	260,00	0%
Ogcocephalus vespertilio (Linnaeus,1758)	Seadevil	2	0%	52,65	0%
Oligoplites palometa (Cuvier, 1832)	Maracaibo leatherjacket	8	0%	1.582,26	0%
Pellona castelnaeana (Valenciennes, 1847)	Amazon pellona	26	1%	14.044,53	3%

There were higher catches in May/2011, July/2013, August/2015 and November/2015 (Figure 5-2), and the species that contributed most to this result were *Genyatremus luteus, Lile piquitinga, Bairdiella ronchus, Sciades proops, Sardinella janeiro, Macrodon ancylodon* and *Mugil gaimardianus*. The months with the lowest catch rates were February and August 2015.

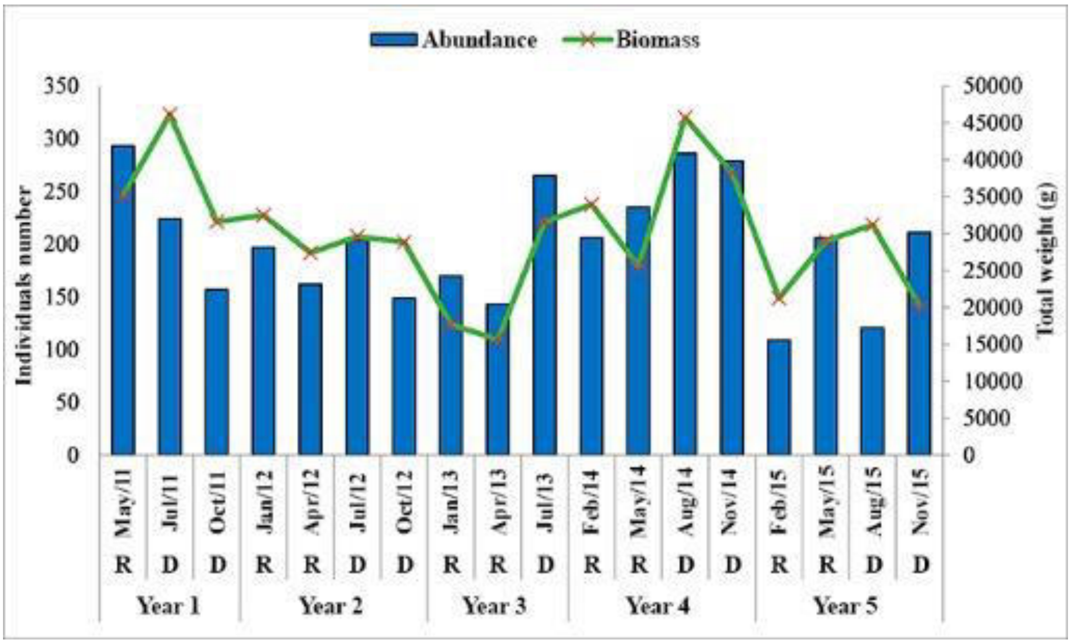

Figure 5-2. Temporal variation of the number of individuals collected and biomass (D = drought, R = rainy).

Regarding total biomass, the highest catches were observed in the months of July/2011, followed by August and November/2014 (Figure 5-2). The species that contributed most to this increase were *Amphiarius rugispinis, Bagre bagre, Centropomus undecimalis, Cynoscion acoupa, Macrodon ancylodon, Micropogonias furnieri* and *Sciades proops* The results of the statistical tests also indicated seasonal similarity in the distribution of abundance ($F = 0.46$; $p > 0.05$) and biomass ($KW = 0.83$; $p > 0,05$), from May/2011 to November/2015. The Shannon diversity index was high in May/2011, January/2012 and August/2015 (Figure 5-3 [3]). The evenness was always high, with the highest averages for the months of April/2013 and August/2015 (Figure 5-3 [4]). The ANOVA did not indicate difference between the months for the diversity indexes of Shannon ($F = 0,7454$; $p>0,05$) and evenness ($F = 0.92$; $p > 0.05$).

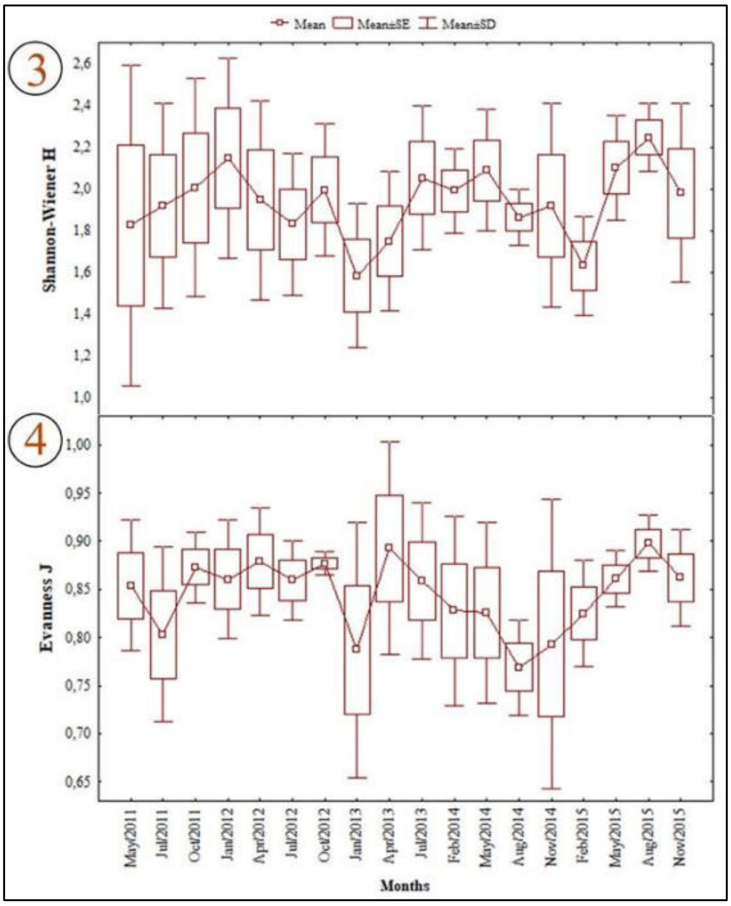

Figure 5-3. Seasonal variation of the ecological indexes frow species of fish collected in São Marcos Bay, State of Maranhão: 3, Shannon-Wiener; 4, Evenness.

The Kruskal-Wallis test indicated a significant difference in the species abundance between the sites (KW = 25.81; $p < 0.05$), but only the Site 1 showed difference in relation to the others, confirming the preference of individuals for this area. Regarding the variation of the indexes between sites, the higher diversity of Shannon was observed for S1 (Figure 5-4 [5]). For the evenness, it was verified that Site 4 showed better uniformity for the dominance of the species. The analysis of the indexes showed heterogeneity between the sites (Figure 5-4 [6]).

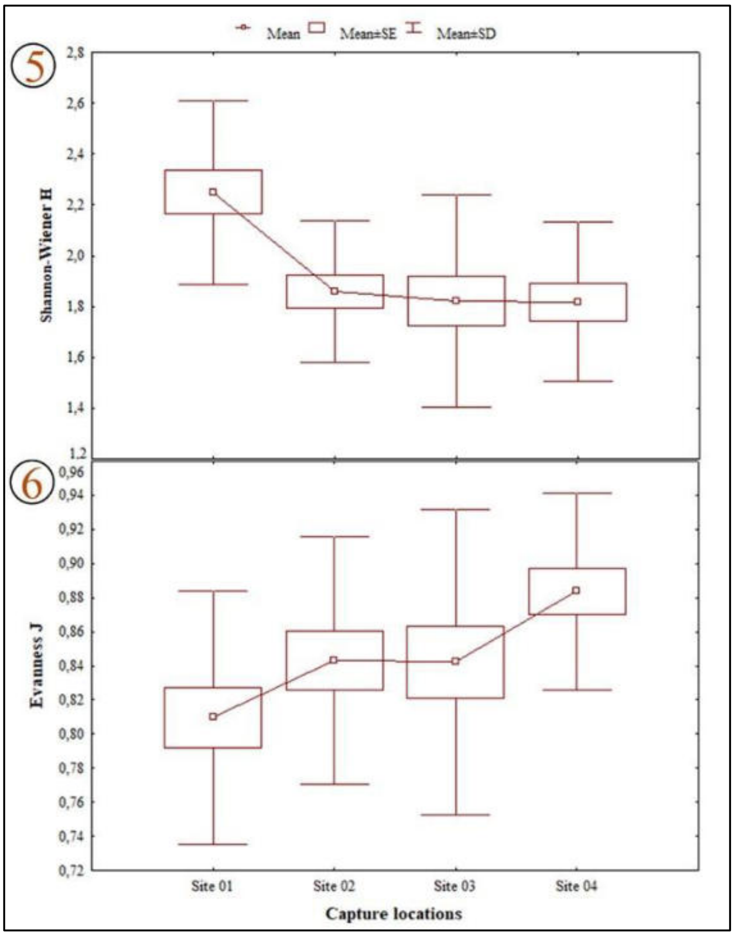

Figure 5-4. Spatial variation of the ecological indexes frow species of fish collected in São Marcos Bay, State of Maranhão: 5, Shannon-Wiener; 6, Evenness.

Non-metric multidimensional scaling (NMDS) for the sampled months revealed the formation of two seasonal groups. The group A, with similarity of 61.6%, formed mostly by months of dry season, and the group B with similarity of 60.4%, formed mainly by months of rainy season (Figure 5-5). The similarity between species indicated the formation of three groups (1, 2, 3) (Figure 5-6). Group 1 was formed by the vast majority of the fish with great influence on the abundance, biomass and frequency of observations. Group 2 was formed by the species *C. jamaicensis*, *L. piquitinga*, *S. stellifer*, *D. rhombeus*, *A. tibicen*, *C. leiarchus*, *T. falcatus* and *R. horkelli*. In group 3 *A. quadriscutis*, *R. lalandii* and *A. monoceros* and *N. microps*.

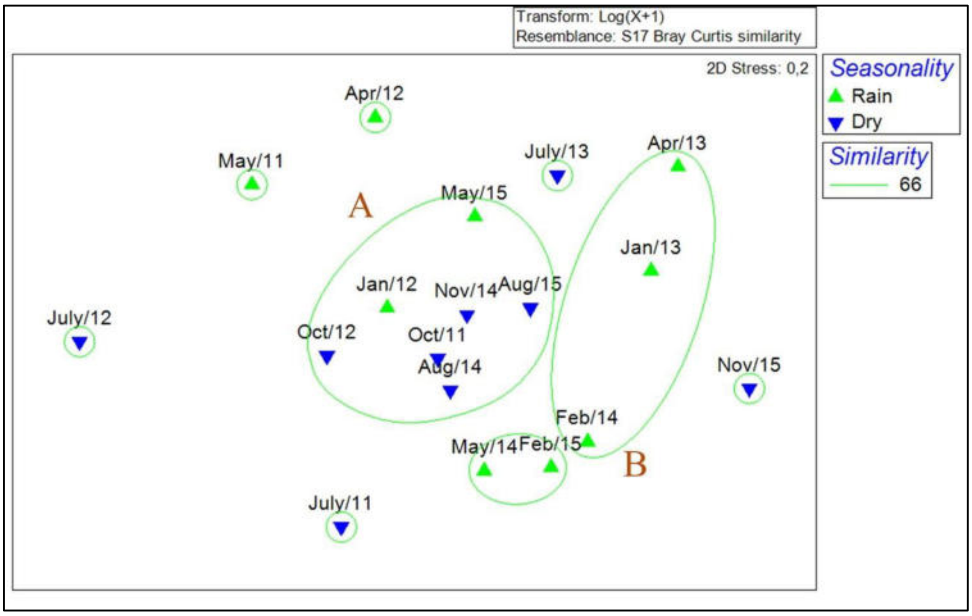

Figure 5-5. Non-metric Multidimensional Scaling (NMDS) for abundance among fish assemblages for the months of capture in São Marcos Bay, Maranhão, Brazil.

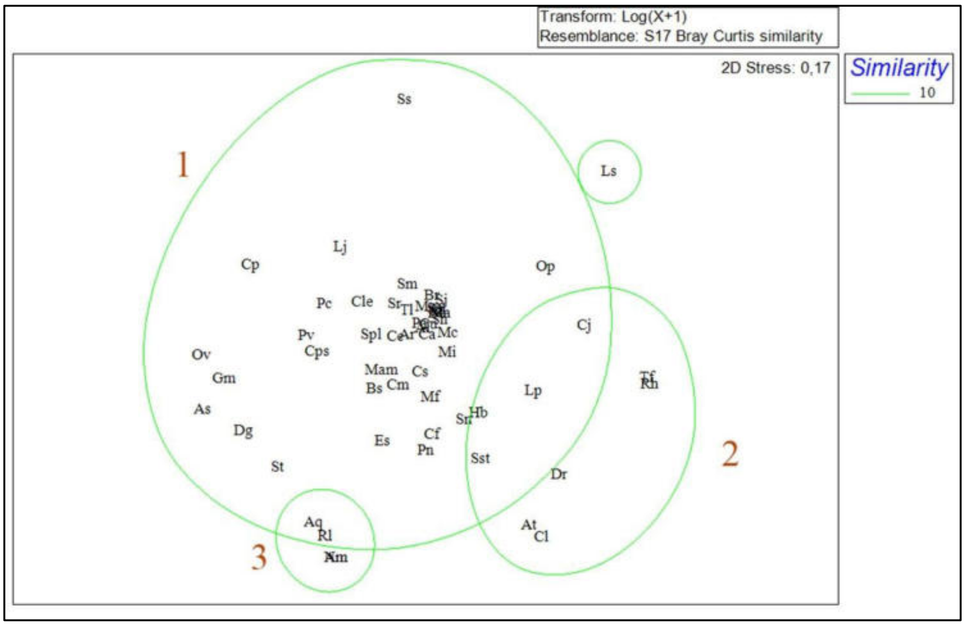

Figure 5-6. Non-metric Multidimensional Scaling (NMDS) for abundance among especies capture in São Marcos Bay, Maranhão, Brazil (Al: *A. lineatus*; Am: *A. monoceros*; Ar: *A. rugispinis*; As: *A. spinifer*; Aq: *A. quadriscutis*; At: *A. tibicen*; Bb: *B. bagre*; Br: *B. ronchus*; Bs: *B. surinamensis*; Cl: *C. latus*; Cs: *C. spixii*; Cp: *C. parallelus*; Cu: *C. undecimalis*; Ce: *C. edentulus*; Cf: *C. faber*; Cps: *C. psittacus*; Ca: *C. acoupa*; Cj: *Ci jamaicensis*; Cle: *Ci leiarchus*; Cm: *C. microlepidotus*; Dg: *D. guttata*; Dr: *D. rhombeus*; Es: *E. saurus*; Gl: *G. luteus*; Gm: *G. micrura*; Hb: *H. bonillai*; Lp: *L. piquitinga*; Ls: *L. surinamensis*; Lj: *L. jocu*; Ma: *M. ancylodon*; Mam: *M. americanos*; Mf: *M. furnieri*; Mc: *M. curema*; Mg: *M. gaimardianus*; Mi: *M. incilis*; Nm: *N. micros*; Ov: *O. vespertilio*; Op: *O. palometa*; Pc: *P. castelnaeana*; Pv: *P. virginicus*; Pn: *P. nodosus*; Pa: *P. atherinoides*; Rh: *R. horkelli*; Rl: *R. lalandii*; Sj: *S. janeiro*; Sh: *S. herzbergii*; Sp: *S. proops*; Ss: *S. setapinnis*; Sn: *S. naso*; Sr: *S. rastrifer*; Sst: *S. stellifer*; Sm: *S. marina*; St: *S. timucu*; Spl: *S. plagusia*; Tf: *T. falcatus*; Tl: *T. lepturus*).

Considering the sampling sites, the classification analysis showed the formation of three groups (I, II, III) (Fig. 9): Group I formed by the samplings carried out at site S1, located in shallower areas near the mangrove, Group II was formed by the sites S2 and S3, located in an intermediate profile regarding the hydrodynamic gradient and depth, and Group III that was represented by the site S4, which is characterized by the greater depth, greater speed of the currents and it is also located in the route of the ships that access the port terminals in the Maranhense Gulf.

SIMPER analysis performed on ichthyofaunal data detected which the species that contributed the most to the formation of group A were *M. ancylodon*, *B. bagre* and *G. luteus*, whereas *S. proops*, *B. ronchus*, *G. luteus* were the species that most contributed to the formation of group B. The dissimilarity between the seasonal groups was 39.17%, and the species with the highest contribution percentage were *S. janeiro*, with a higher incidence in the dry season and *M. gaimardianus*, more abundant in the rainy season. Regarding the sampling sites, *B. ronchus* contributed the most to the differentiation of S1 when compared to S2, S3 and S4. It is important to highlight that 82.6% of individuals of this species were captured in S1. The dissimilarity of S4 in relation to S2 and S3 was associated to the higher contributions of *B. bagre* (more abundant in S2) and *M. ancylodon* (more abundant in S3).

The evaluation of the results, considering the regional seasonality (rainy and dry season), showed significant differences for the composition of the taxa, being influenced mainly by the greater abundance of the Scianidae in the dry season (ANOSIM, $R = 0.183$, $p = 0.02$). Considering the sampling points ANOSIM also indicated significant differences, with the site S1 presenting a differentiated composition in relation to the others, as well as S4 in relation to S2 ($R = 0.272$, $p = 0.0001$).

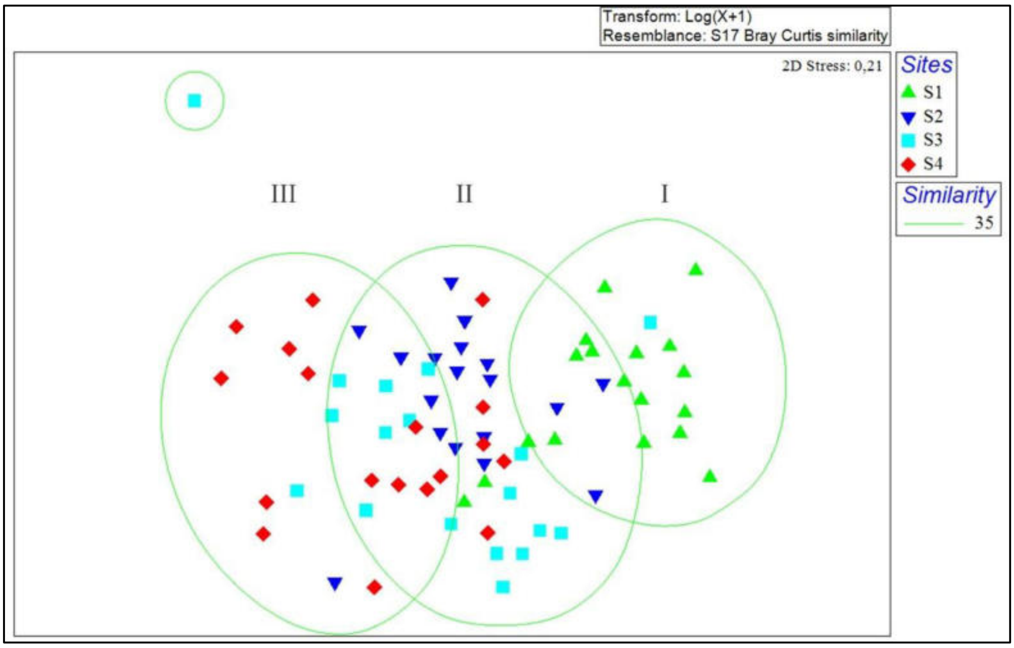

Figure 5-7. Non-metric Multidimensional Scaling (NMDS) representing the results for fish abundance by sites of São Marcos Bay, Maranhão, Brazil.

Discussion

The research carried out between March/2011 and November/2015 indicates that the richness of the fish species of São Marcos Bay is inferior to those found in other tropical estuaries (ARAÚJO *et al*., 2008; PAIVA *et al*., 2008; CAMPOS *et al*., 2010; SANTOS *et al*., 2015; CATTANI *et al*., 2016;). In addition, studies carried out by CASTRO (1997, 2001) in adjacent regions (Cururuca, Paciência, Estreito, Baías, Tibiri and Paciência River) also corroborate with the most significant results in terms of the number of species recorded. However, studies evaluating the ichthyofauna in sites that are part of the same estuarine system presented species richness below the values obtained in this study. PINHEIRO-JÚNIOR *et al.* (2005) recorded in the Anil River 43 species, while CARVALHO-NETA (2008) in a study carried out in the Caranguejo Island, obtained a list of 32 species.

The variation of species richness among the estuaries may be associated to factors such as latitude, seasonal variability, degree of contamination by chemical pollutants and impacts that result from the joint action of several factors such as urbanization, landfills, industrial poles implantation, construction and maintenance of ports (FRANCA *et al.*, 2011; PASQUAUD *et al.*, 2015; GURDEK & ACUÑA-PLAVAN, 2017; CASTRO, *et al.*, 2017). In the specific case of São Marcos Bay, which has the second largest port structure in Brazil, several studies have identified contamination in water and sediments as a result of anthropic activities, including bioaccumulation of contaminants in fish, which may affect marine ecosystems and aquatic organisms (CARVALHO-NETA *et al.*, 2012; SOUSA *et al.*, 2013; CASTRO *et al.*, 2018).

The predominance of species belonging to the Perciformes and Siluriformes orders with the expected pattern along the northern Brazilian coast is due to their tolerance to salinity variations, such as the species of the families Sciaenidae and Ariidae that explore estuarine habitats (CAMARGO & ISAAC, 2003). However, significant results of species belonging to the order of the Clupeiformes were verified. The fish assembly of São Marcos Bay is strongly inhabited by small individuals mainly of the Engraulidea family, which is characterized by the formation of shoals. In the coastal region of Rio Grande do Norte, Brazil, the order Clupeiformes showed relative abundance among the species that occur in the region of Ponta Negra (GURGEL, 2012), even as Jaguaribe beach, Itamaracá, Pernambuco (LIRA & TEIXEIRA, 2008).

The dominance of the Sciaenidae and Ariidae families is consistent with the results found in other estuaries in the North and Northeast regions of Brazil (LIRA & TEIXEIRA, 2008; SANDERS & HJORT, 2011; CHAO *et al.*, 2015, DANTAS *et al.*, 2016). Both families are composed of generalist species that normally inhabit sandy-muddy soft bottoms (MENEZES & FIGUEIREDO, 1980; LE BAIL *et al.*, 2000). Thus, the cyanide and aryid predominance may be associated with the favorable conditions found in the substrates of the estuarine environments of the region, mainly formed by sand and mud (MORAIS, 1977; SOUZA FILHO, 2005).

Fish assemblage of the study area was dominated by a few fish species, mainly by the sciaenid *G. Luteus*. The taxon *G. luteus* is a widely distributed species along the western regions below the Antilles and the north coast of South America, from the eastern portion of Colombia to Brazil, classified as estuarine-marine inhabits coastal waters, especially estuaries and lagoons, with mud, sand and gravel (CERVIGÓN, 1966; FISHER, 1978; GIARRIZZO & KRUMME, 2007). It should be noted that *G. Luteus* was captured during all study period, indicating high capacity of tolerance to the seasonal variations of salinity in São Marcos Bay. According to AZEVEDO *et al.* (2008), the Maranhense Gulf may present salinity of 21.8 in the rainy season, when the precipitation and discharge levels of the rivers are higher, and salinity up to 36 in the dry period, when the sun light and evaporation are more intense.

Sciades proops stands out for its high contribution to biomass and occurrence throughout the year, indicating the strong adaptive capacity that this species has developed due to oceanographic conditions in these outermost areas of São Marcos Bay. Studies about first gonadal maturation developed in this same region for *S. proops* show an atypical variation in the size of individuals as they begin their involvement in the reproductive cycle (AZEVEDO *et al.*, 2010). The authors attributed such variations to the adaptation processes resulting from physicochemical and climatic variables that are changing in the region, as well as a response to the fishing effort directed to this species.

Studies in Brazilian estuaries show that estuarine fish assemblages undergo clear seasonal fluctuations in biomass and diversity, which may be related to reproductive patterns, increased recruitment, and, even indirectly, to rainfall (BARLETTA-BERGAN *et al.* 2002; BARLETTA *et al.* 2003, 2007; VILAR *et al.*, 2011). Such temporal changes in abundance in the community in this area, although not addressed in any integrated analysis among the fish, did not present significant differences.

Collectively, fish assemblages during both seasons were comprised of many rare species and a few species in large numbers, a frequent characteristic for estuarine fish populations (WHITFIELD 1989, 1999; TZENG & WANG, 1992; NEIRA & POTTER, 1994; BARLETTA-BERGAN *et al*., 2002, 2003). However, fish fauna peaked in abundance in the dry season. This pattern was mainly driven by *G. luteus, L. piquitinga, B. ronchus, S. proops, S. janeiro, M. ancylodon* and *M. gaimardianus*. The species that contributed the most to the total biomass are highly predominant in the coast of Maranhão (AZEVEDO *et al*., 2008; CARVALHO-NETA, 2008; CARVALHO-NETA *et al*., 2012; AZEVEDO *et al*., 2012; ALMEIDA *et al*., 2016; AZEVEDO *et al*, 2017). Cyclic changes in the intertidal fish fauna did not affect overall density and biomass throughout the years. Similar numbers and standing stock was apparently maintained year-round. This suggests that the increases in abundance or weight in some species were compensated by reductions in others (GIARRIZZO & KRUMME, 2007).

The sites 2, 3 and 4 analyzed in the present study are located furthest from the areas of mangrove vegetation, while the site 1 is located in a more sheltered area, with an lower interference from the port area. Mangrove areas act as shelter, breeding ground and food source for various organisms, while several fish species use this habitat for their biological and ecological activities (MOREIRA OSÓRIO *et al*., 2011). GIARRIZZO & KRUMME (2007) propose that landscape factors may be important in structuring mangrove fish assemblages, for example, the position relative to the ocean or to the mainland, irrespective of salinity, as well as the proximity to an extensive subtidal resting area where the intertidal fishes may spend the low tide period. The natural characteristics of each environment and the environmental factors may explain the observed differences between the sampling points.

Analysis of similarity showed a differentiated seasonal occurrence for composition of fish assemblage in São Marcos Bay. Similar results were verified by MOURÃO *et al*. (2015) in Amazon Estuary of Pará, and VEIGA *et al*. (2006) in southern Portugal, at where such seasonal variations in composition of fish were justified as a common feature of dynamic ecosystems, such as estuaries. GURDEK & ACUÑA-PLAVAN (2016) observed regular seasonal changes in the fish community structure in the lower portion of an estuary in the Estuary of Pando, Uruguay, which reinforces the idea of considering both environmental variability and life cycles of fish species when addressing temporal variability in estuarine environments. Some taxa form shoals and seek estuarine areas to carry out their breeding activities. Seasonal peaks are generally attributed to the arrival of juveniles of many marine species that use shallow water ecosystems as nurseries (DULCIC *et al*., 1997; CABRAL, 1999).

The NMDS showed differentiation of the species with occurrence both in the rainy season and in the dry season. This situation can be attributed mainly to the registration of occasional species in the area, since many juvenile species were present in the samplings, suggesting that the area acts as a nursery and as a place of growth of many organisms. In the estuary of Michoacan, SANDOVAL-HUERTA *et al*. (2014) verified the occurrence of several juvenile individuals, evidencing the fish preference for these areas, in the initial stage of life.

The similarity of group 1, observed for the 56 taxa identified in São Marcos Bay - Amazônia Oriental, connected two major subgroups, the first one formed by species present in all campaigns, with high values of abundance and biomass, in addition to high relevance for artisanal fishing in the region. CARVALHO-NETA (2008) states that the presence of these individuals, in the São Marcos Bay, indicates that this estuarine presents an important ecological role for breeding fish that have an economic importance for artisanal fishing in the state of Maranhão. Group 2 showed species present only at certain periods of the year, showing defined intolerance to variations in the environment, considering that the temporal distribution of adults and juveniles is strongly influenced by changes in environmental factors such as temperature and salinity (YÁÑEZ-ARANCIBIA, 1985; LAROCHE *et al.,* 1997).

The group 3 included species where the grouping pattern presented seems to be associated to the low levels of occurrence of the individuals, which suggests that these species are rare in the area where the study was carried out. The richness and composition of rare species may be related to the characteristics of the estuary, such as the degree of connectivity with the ocean and the volume of the water body (MENDOZA *et al*., 2009).

The low diversity observed during the study may be a reflection of the port activities that historically take place in the study area. However, it was still observed that regional diversity was maintained throughout the study period. However, the spatial distribution of the species showed variation regarding the sampling sites, with richness presenting patterns of differentiation similar to diversity. These data indicate the need for water and sediment quality monitoring, as well as the use of bioindicators capable of predicting relation between habitat integrity and fish species, as commonly provided by environmental monitoring programs (OLIVEIRA *et al*., 2008).

The wide use of the São Marcos Bay area by different ichthyofaunistic groups reveals its importance for the development of the ichthyofauna of the Maranhense Gulf, with the continuous presence of several representatives of the families Scianidae, Mugilidae, Clupeidae and Engraulidae. The present results provide a better understanding of the importance of ecological information about ichthyofauna in tropical estuaries in order to include appropriate descriptors in conservation or restoration processes of marine communities and habitats.

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6 CAPÍTULO 3: RELAÇÃO PESO-COMPRIMENTO DE 19 ESPÉCIES DE PEIXES ESTUARINOS DO LITORAL AMAZÔNICO BRASILEIRO

Artigo a ser submetido ao periódico JOURNAL OF APPLIED ICHTHYOLOGY
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Resumo

O presente estudo registra as relações comprimento-peso (RPCs) para 19 espécies de peixes estuarinos encontradas no Golfão Maranhense. As coletas foram realizadas ao longo de 12 estuários localizados nas baías de São Marcos, São José e Arraial. As amostragens foram realizadas com uma rede de arrasto de fundo (trawlnet) em três réplicas para cada ponto de coleta. As estimativas dos parâmetros da relação peso-comprimento consistiram em um total de 2.888 espécimes analisados. Os resultados indicaram um padrão de crescimento dentro dos intervalos esperados. Nesse contexto, não foram encontrados indícios de alteração na estrutura das populações. O estudo fornece informações atualizadas que podem ser incorporadas nos conjuntos de dados normalmente necessários para o gerenciamento da pesca.
Palavras-chave: complexo estuarino, Golfão Maranhense, crescimento, Atlântico equatorial.

Abstract

The present study records the length-weight ratios (RPCs) for 19 estuarine fish species found in Golfão Maranhense. The collections were performed along 12 estuaries located in the bays of São Marcos, São José and Arraial. Samplings were performed with a trawlnet in three replicates for each collection point. Estimates of the weight-length ratio parameters consisted of a total of 2,888 specimens analyzed. Results indicated a growth pattern within the expected ranges. In this context, no evidence of alteration in population structure was found. The present study provides some up-to-date information that can usefully be incorporated into data sets commonly required for fisheries management.
Keywords: estuarine complex, Golfão Maranhense, growth, Equatorial Atlantic.

Introdução

As relações entre as medidas morfométricas têm sido frequentemente utilizadas como ferramenta em estudos taxonômicos, filogenéticos e evolutivos, e até mesmo a biologia pesqueira fez uso desta ferramenta para explorar a morfologia externa de peixes (Karahan et al., 2014). Neste sentido, a relação peso-comprimento é uma aplicação que representa um modelo simples e bastante utilizado (Le Cren, 1951). Os parâmetros da relação para uma determinada espécie podem mudar temporariamente e/ou espacialmente e, portanto, devem ser regularmente atualizados e estimados para cada população separadamente (Ismen et al., 2007).

Esses parâmetros de peso-comprimento são utilizados com frequência em populações de peixes de importância econômica (Agboola & Anetekhai, 2008; Caetano & Jané, 2018; Treer et al., 2008), pois geram resultados importantes no que diz respeito ao tipo de crescimento das espécies estudadas (Laarman & Gowing, 2000; Rêgo et al., 2008), muito embora seja pouco conhecido para peixes da Costa Equatorial da Amazônia (Aguiar-Santos, 2018).

A relação peso-comprimento (RPC) pode ser um bom indicativo das atividades alimentares e reprodutivas, tendo em vista que descreve as formas de crescimento nos diferentes estágios do ciclo de vida das espécies de peixes (Weatherley, 1972). Adicionalmente, serve para comparar o grau de estresse em diferentes condições ambientais (Bolger & Connolly, 1989) e o histórico de vida entre diferentes espécies de peixes, ou entre populações de peixes de diferentes habitats (Gonçalves et al., 1997; Petrakis & Stergiou, 1995).

O conhecimento da relação comprimento-peso (RPC) em peixes é muito importante na biologia pesqueira, pois fornece dados básicos para serem usados em conjunto com outros parâmetros-chave, por exemplo, o fator de condição, essencial para a gestão da pesca com informações do bem-estar e higidez das espécies explotadas (Darvishi & Farkhondeh Shilsar, 2017; Saberi; Paighambari). Estas espécies constituem uma parte importante do pescado capturado nas pescarias artesanais e também contribuem significativamente para a subsistência das populações que vivem na zona costeira do Golfão Maranhense.

Material e Métodos

A costa do Maranhão está localizada entre a foz do Rio Gurupi, Estado do Pará, a foz do Rio Parnaíba, Estado do Piauí, com aproximadamente 640 km de extensão. Para fins descritivos, divide-se em três áreas distintas: Litoral Oriental, Golfão Maranhense e Litoral Ocidental. O Golfão Maranhense está situado na região central da costa, onde existem três baías, São Marcos, Arraial e São José, que são separadas pela Ilha do Maranhão (Silva et al., 2018) (Figura 6-1).

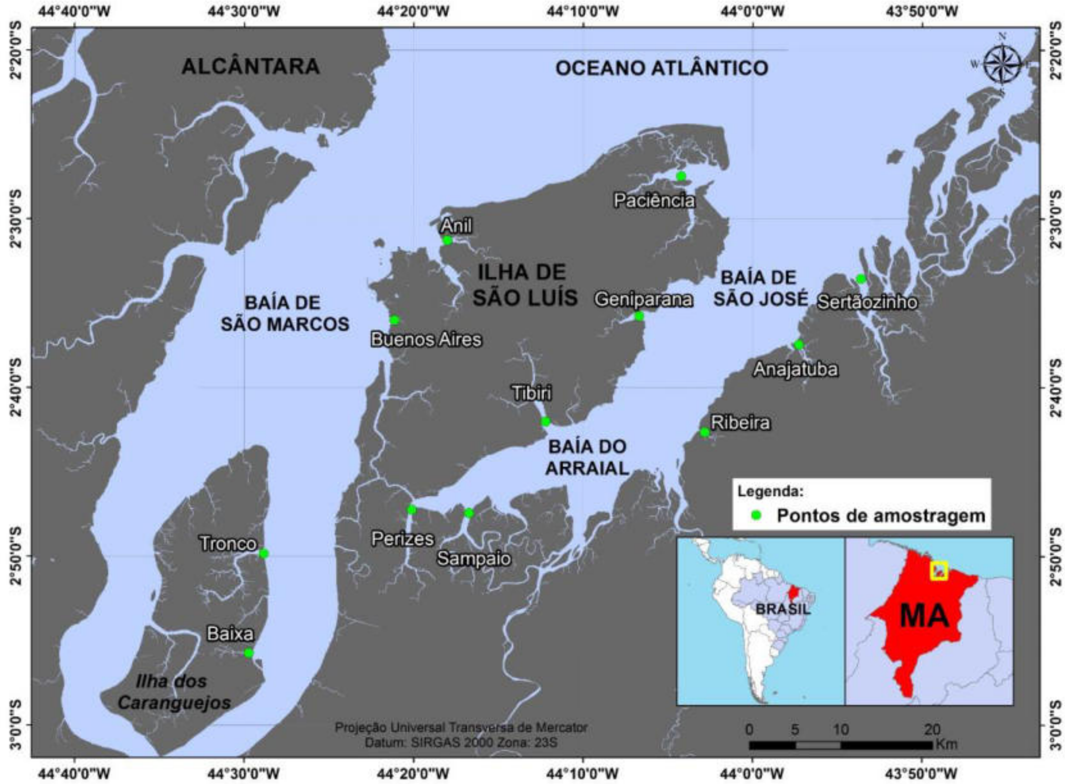

Figura 6-1. Pontos de coleta dos peixes analisados no presente estudo.

Os peixes foram capturados em 11 (onze) estuários localizados nas baías de São Marcos, Arraial e São José com o auxílio de uma rede de arrasto de porta (trawnet) com 6,0 m de comprimento, 3,0 m de largura e abertura de malha de 1,0 cm.

Após a coleta, os peixes foram acondicionados em sacos plásticos etiquetados, colocados em caixas de isopor contendo gelo e transportados para o laboratório, onde foram determinadas as características biométricas e efetuada a identificação das espécies baseada em Carpenter (2002), Cervigón (1992) Figueiredo (1977) e Figueiredo & Menezes (1978, 1980).

Para cada exemplar foi registrado o comprimento total (Lt) em centímetros e o peso total (Wt) em gramas. A relação entre comprimento total e peso total foi estimada através de regressão não-linear dos pontos observados no gráfico de dispersão, de acordo com o ajustamento da curva ao modelo potencial representado pela expressão matemática: $\boldsymbol{Wt = aLt^b}$, onde: Wt = peso total; Lt = comprimento total; (a) fator de condição relacionado com o grau de engorda e (b) coeficiente de alometria relacionado com a forma de crescimento do indivíduo. A partir da transformação logarítmica, a expressão matemática anterior resultou na seguinte equação: LnWt = LnA+B LnLt, onde Ln *a*=A e *b*=B.

O coeficiente de determinação (R^2) foi usado na relação peso e comprimento para a definição do modelo da qualidade da regressão (Araújo, 2002). Os coeficientes de simetria e curtose (Zar, 1996) foram usadas para verificar a normalidade da distribuição dos valores de *b* a fim de realizar o teste de hipótese do crescimento alométrico para todas as espécies analisadas, além disso o intervalode de confiança adotado (95%) foi aplicado nos parâmetros *a* e *b* (Froese, 2006).

Resultados e Discussão

As estimativas dos parâmetros da relação peso-comprimento para dezenove espécies de peixes estuarinos foram calculadas a partir da análise de 2.888 espécimes (Tabela 6-1). O número de amostras variou de 13 indivíduos para *Sciades herzbergii* até 1.555 para *Stellifer rastrifer*. Quanto ao tamanho dos indivíduos, o comprimento total variou de 2,2 cm para *Cathorops spixii* e 28,7cm para *S. herzbergii*, enquanto o peso total apresentou a variação de 0,2g para *Anchoa spinifer, Stellifer stellifer* e *S. rastrifer* até 148,3g em *S. herzbergii.*

O parâmetro *a* variou de 0,0017 (*Macrodon ancylodon*) a 0,0248 (*Sphoeroides greeleyi*), enquanto o valor de *b* foi de 2,35 para *Anchoviella elongata* a 3,48 para *Macrodon ancylodon*. O tipo de crescimento revelou que quatro espécies, *Lycengraulis grossidens, Sciades herzbergii, Stellifer naso* e *Stellifer rastrifer*, apresentaram crescimento isométrico ($b = 3$). Seis espécies, *Achirus achirus*, *Achirus lineatus*, *Colomesus psittacus*, *Menticirrhus littoralis* e *Stellifer stellifer*, apresentaram crescimento alométrico positivo ($b > 3$) e para as outras espécies foi observado o crescimento do tipo alométrico negativo ($b < 3$).

Tabela 6-1. Estatística descritiva e parâmetros de LWRs para 19 espécies estuarinas capturadas no litoral norte amazônico, maranhão, brasil.

Espécies	N	Comprimento total (cm)		Peso (g)		Parâmetros de regressão			IC de 95% a	IC 95% b
		Min	Máx	Min	Máx	*a*	*b*	r^2		
Achirus achirus	16	4,5	26,3	1	311,6	0,0094	3,19	0,95	0,0033-0,0267	2,76-3,63
Achirus lineatus	10	4,5	13,5	0,8	34,5	0,0058	3,38	0,94	0,0015-0,0228	2,66-4,09
Anchoa spinifer	21	3	12,9	0,2	14,4	0,0100	2,82	0,97	0,0060-0,0165	2,58-3,07
Anchoviella elongata	46	4,2	15,9	0,6	17	0,0236	2,35	0,96	0,0169-0,0329	2,20-2,51
Aspredinichthys tibicen	216	5,8	22,9	0,6	20,3	0,0039	2,65	0,86	0,0026-0,0057	2,51-2,80
Bagre bagre	16	6,5	15	1,8	14,9	0,0145	2,56	0,95	0,0070-0,0298	2,24-2,88
Cathorops agassizii	42	6,1	19,5	1,5	57,3	0,0094	2,91	0,96	0,0061-0,0143	2,72-3,10
Cathorops spixii	584	2,2	25,6	0,4	101,8	0,0095	2,92	0,9	0,0080-0,0113	2,84-3,00
Cetengraulis eduntulus	159	5,3	14,8	1,6	24,7	0,0116	2,85	0,84	0,0072-0,0185	2,66-3,05
Colomesus psittacus	99	3,7	19,8	1,0	193,9	0,0145	3,19	0,93	0,0101-0,0207	3,02-3,36
Lycengraulis grossidens	15	6	16,5	1,5	38,3	0,0073	3,05	0,95	0,0027-0,0195	2,62-3,49
Macrodon ancylodon	94	5,3	23,5	0,4	97,2	0,0017	3,48	0,96	0,0012-0,0023	3,34-3,62
Menticirrhus littoralis	21	5,7	21,3	1,3	48,7	0,0023	3,18	0,85	0,0004-0,0133	2,55-3,81
Odontognathus mucronatus	27	5,7	16	0,8	14,9	0,0062	2,79	0,98	0,0041-0,0095	2,60-2,97
Sciades herzbergii	13	11,8	28,7	5,5	148,3	0,0057	3,02	0,88	0,0007-0,0483	2,26-3,77
Sphoeroides greeleyi	30	3,5	22,6	1,1	180,1	0,0248	2,92	0,95	0,0142-0,0435	2,67-3,18
Stellifer naso	202	4,2	14,1	1,0	32,4	0,0086	3,08	0,97	0,0072-0,0102	3,00-3,16
Stellifer rastrifer	1555	2,5	12,4	0,2	24,7	0,0091	3,08	0,89	0,0083-0,0101	3,03-3,13
Stellifer stellifer	47	3,4	11,2	0,2	16,1	0,0072	3,15	0,93	0,0045-0,0115	2,89-3,40

Os valores do parâmetro do *b* pertencentes a faixa de 2,38 a 3,48 determinada no presente estudo é semelhante aos valores registrados por Silva-Júnior et al. (2010), que determinaram a RPC para 34 espécies de um estuário da Ilha do Maranhão, e Aguiar-Santos et al. (2018), que listaram seis espécies para a Baía de São Marcos. De acordo com Tesch (1971) o expoente *b* tipicamente tem um valor próximo a 3, mas pode variar entre 2 e 4, sendo que o valor de 3 indica que o peixe tem crescimento isométrico, já valores diferentes indicam crescimento alométrico. Ricker (1975) estabeleceu que valores de *b* fora do intervalo de 2,5-3,5 são geralmente considerados atípicos. No presente estudo quase todos os valores estimados da inclinação de *b* apresentram valores considerados normais, a exceção foi o valor de 2,38 obtido para *A. elongata*.

Quanto às previsões Bayesiana RPC disponíveis (*e.g.* FishBase), nove espécies apresentaram valores semelhantes, enquanto onze das espécies estudadas tiveram valores de *b* fora dos limites de confiança de 95% mostrados na base de dados. As diferenças observadas entre as localidades podem ser explicadas por vários fatores, incluindo estação, temperatura, salinidade, disponibilidade de alimentos, número de espécimes e as variações na extensão do comprimento das populações da amostra (Pauly, 1984; Weatherley & Gill, 1987). Além disso, outros componentes bióticos e abióticos podem influenciar esses valores, incluindo sexo, maturidade sexual, condições ambientais, disponibilidade de alimentos, região geográfica e mudanças climáticas (Correia et al., 2015; Freitas et al., 2011; Froese, 2006; Hossain et al., 2006).

Todas as regressões foram altamente significativas ($p<0,01$), com o coeficiente de determinação elevado (R^2) e variando de 0,84 (*Cetengraulis eduntulus*) a 0,98 (*Odontognathus mucronatus*). Além disso, 74% dos RPC apresentaram valores de R^2 maiores que 0,90, enquanto 26% proporcionaram valores de R^2 entre 0,8 e 0,9, indicando que todas as regressões foram significantes quando submetidas ao Teste-t ($P<0,05$). De acordo com Araújo (2002), o coeficiente de determinação (R^2) é um parâmetro que indica quanto de variação da variável dependente está associada com a variação da variável independente. Sendo que esse coeficiente indica que a variação do peso corporal é explicada pela quase totalidade (90%) da variação do comprimento corporal, para as espécies estudadas (Rocha et al. 2005).

Em conclusão, o presente estudo fornece algumas informações básicas que podem ser utilmente incorporadas nos conjuntos de dados normalmente necessários para o gerenciamento da pesca.

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7 CAPÍTULO 4: DETERMINAÇÃO DE METAIS PESADOS EM PEIXES DE DIFERENTES NÍVEIS TRÓFICOS CAPTURADOS EM TRÊS BAÍAS DA REGIÃO AMAZÔNICA MARANHENSE, BRASIL

Artigo a ser submetido ao periódico BULLETIN OF ENVIRONMENTAL CONTAMINATION AND TOXICOLOGY (Qualis: B2 em Biodiversidade e Biotecnologia; Fator de Impacto: 1.650)

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Resumo

No presente estudo foram avaliadas a concentração de metais (Cadmium, Chrome, Copper, Iron and Manganese) em tecido muscular de peixes (*Sciades herzbergii, Cetengraulis edentulus, Macrodon ancylodon, Pseudauchenipterus nodosus* e *Stellifer rastrifer*) capturados nas baías de São Marcos, São Jose e Arraial, pertencentes ao sitema do Golfão Maranhense. Nas capturas foram utilizadas redes de arrasto de fundo (trawlnet). Foram analisadas um total de 45 amostras. As concentrações dos elementos metálicos foram determinadas a partir da técnica de Espectrometria de Emissão Óptica com Plasma. Os resultados demonstraram que os elementos Fe e Mn apresentaram os maiores níveis entre as espécies. Foram detectadas, em amostras individuais, concentrações acima do limite máximo permitido pela legislação brasileira para Cádmio (Cd) nas espécies *Cetengraulis edentulus* e *Macrodon ancylodon* e Cromo em *Macrodon ancylodon* e *Pseudauchenipterus nodosus*. Com relação ao Cobre (Cu) não foi detectado nenhum valor acima dos níveis estabelecidos pela legislação brasileira. Embora não existam leis nacionais que regulem as concentrações de Ferro (Fe) e Manganês (Mg) no tecido muscular dos peixes, foram detectadas concentrações desses elementos em todas as espécies analisadas, algumas amostras apresentaram valores muito elevados quando comparados à média geral do estudo. A análise espacial permitiu identificar diferença entre os locais de captura para os elementos analisados.
Palavras-chave: bioacumulação, bioindicadores, poluição ambiental, toxicidade.

Abstract

In the present study we evaluated the concentration of metals (Cd, Cr, Cu, Fe and Mn) in fish muscle tissue (*Sciades herzbergii, Cetengraulis edentulus*, *Macrodon ancylodon, Pseudauchenipterus nodosus* and *Stellifer rastrifer*) captured in São Marcos, São Jose and Arraial Bays, belonging to the Golfão Maranhense system. A total of 45 sample size for each species. The animals were caugth in trawling. Metallic element concentrations were determined by the Plasma Optical Emission Spectrometry technique. The results showed that the elements Fe and Mn presented the highest levels among the species. Concentrations above the maximum limit permitted by Brazilian legislation of cadmium (Cd) were detected in individual samples of *Cetengraulis edentulus* and *Macrodon ancylodon* of chromium (Cr) in *Macrodon ancylodon* and *Pseudauchenipterus nodosus*. Regarding Copper (Cu) no value was detected above the levels established by the Brazilian legislation. Although there are no national laws regulating iron (Fe) and manganese (Mg) concentrations in fish muscle tissue, concentrations of these elements were detected in all species analyzed, with some samples exhibiting elevated values when compared to presente study average. Spatial analysis allowed us to identify differences between the capture sites for the elements analyzed.
Keywords: bioaccumulation, bioindicators, environmental pollution, toxicity.

Introdução

As atividades humanas aumentaram as emissões de metais pesados nos ecossistemas aquáticos (Nriagu e Pacyna, 1988; Asante et al. 2008; Squadrone et al. 2016b), especialmente os ecossistemas estuarino-costeiros (Spencer et al. 2003; Delgado et al. 2010), onde ocorre um sumidouro importante para esses elementos provenientes de rios, escoamentos e fontes pontuais terrestres (Liu et al. 2017).

A contaminação por metais pesados nos ambientes aquáticos vem causando preocupação mundial e por isso tem sido objeto de intensas investigações relacionadas aos seus efeitos e acumulação na biota aquática (Bonai et al. 2009; Fu et al. 2014; Alves et al. 2014; Squadrone et al. 2016;). Os efluentes são tóxicos, persistentes a longo prazo, bioacumuláveis, não biodegradáveis e biomagnificam na natureza (Rahman et al., 2013; Seixas et al. 2014; Adel et al. 2016b; Hossain et al. 2018; Liu 2018; Zafarzadeh et al. 2018). Embora muitos desses elementos circulem nas vias do metabolismo dos organismos, um dos aspectos mais sérios referentes à introdução ou aumento da concentração nos ecossistemas aquáticos é a bioacumulação na cadeia trófica (Luoma e Rainbow 2008; Campos 2018).

Os organismos marinhos podem absorver metais pesados da água e dos sedimentos circundantes, bem como através de seus alimentos (Ginsberg e Toal 2009; Hao et al. 2013; Velusamy et al. 2014; Jiang et al. 2015; Bosch et al. 2016).

O peixe é conhecido como bioacumulador e é capaz de biomagnificar metais pesados em diferentes níveis tróficos (Taweel et al. 2013; Ahmed et al. 2015, Islam et al. 2015; Saha et al. 2016; Tyokumbur 2016). Portanto, podem servir como indicadores no monitoramento a longo prazo da acumulação de metais (Burger et al. 2002; Zhong et al. 2015; Gu et al. 2017). Dessa forma, altas concentrações de metais pesados em organismos marinhos refletem os níveis de poluição no ambiente aquático (Hao 2019).

O acúmulo de metais nos peixes depende da localização, distribuição, preferências de habitat, nível trófico, hábitos alimentares, idade, tamanho, duração da exposição a metais e atividade de regulação homeostática (Sankar et al. 2006). Os estudos que utilizam peixes como bioindicadores de poluição por metais pesados devem contemplar espécies que ocupem diferentes níveis na cadeia, pois a taxa de acumulação pode variar de acordo com habitats e necessidades ecológicas, capacidade metabólica e hábitos alimentares (Amundsen et al. 1997; Ayse 2003; Chi et al. 2007; Singh et al. 2007).

Os elementos traços podem bioacumular em órgãos vitais de peixes, como fígado, rins e brânquias, músculos, centenas de vezes mais altas do que as detectadas no ambiente circundante (Chua et al. 2018). Nos últimos anos, as pesquisas sobre contaminação por metais pesados em músculos de peixes foram intensificadas, tendo em vista que este órgão é a principal parte do consumo humano (Mendil e Uluozlu 2007; Rahman et al. 2012).

O Golfão Maranhense está localizado ao sul do delta da Amazônia (Equador), em uma região que abriga manguezais e recebe elevada descarga continental de água doce (Lefèvre, 2017), além disso, concentra um importante pólo industrial e possui intensa atividade portuária (Silva 2018). Para essa ampla área, são necessárias pesquisas que avaliem os possíveis impactos decorrentes da ação antrópica, que podem ser refletidos através de estudos que determinem a presença de metais pesados em peixes do litoral estuarino do Maranhão.

Estudos dessa natureza são necessários para avaliar o grau de contaminação por metais pesados nas regiões onde existem elevados índíces de interferências humanas. Desta forma, este estudo tem como objetivo analisar a concentração de cádmio, cobre, ferro, manganês e cromo em peixes de diferentes níveis tróficos capturados nas baías de São Marcos, São José e Arraial que formam o Golfão Maranhense.

Material e Métodos

Área de estudo

O Golfão Maranhense está localizado no extremo norte do Estado do Maranhão e é constituído pelas baías de São Marcos e São José, que se encontram separadas pela Ilha do Maranhão (Figura 7-1). Esta região costeira apresenta vários estuários margeados por manguezais regidos por fenômenos oceanográficos marcantes como elevadas amplitudes de marés, maré semidiurnas caracterizadas por macromarés (Souza-Filho, 2005; Teixeira & Souza-Filho, 2009). O clima tropical úmido apresenta elevado índice de pluviosidade que associado aos grandes volumes de descarga de água doce continental provenientes de inúmeros rios configuram um extenso e complexo sistema de manguezais (Rebelo-Mochel 1997).

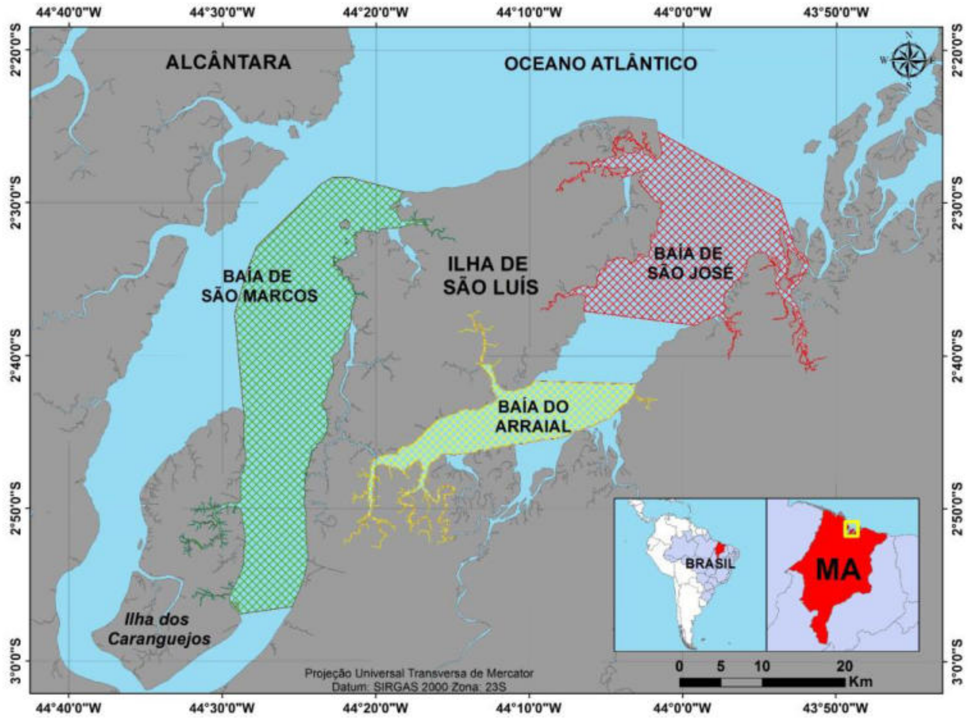

Figura 7-1. Mapa de Localização do Golfão Maranhense.

Amostragem

As espécies foram capturadas em 11 (onze) estuários localizados nas baías de São Marcos, Arraial e São José com o auxílio de uma rede de arrasto de porta (trawlnet) com 6,0 m de comprimento, 3,0 m de largura e abertura de malha de 1,0 cm.

Todos os peixes coletados foram acondicionados em sacos plásticos, conservados no gelo e transportados para o Laboratório. O material biológico foi identificado até o nível de espécie, utilizando os trabalhos de Fischer (1978), Cervigon et al. (1992), Figueiredo et al. (1980, 2000). Além disso, algumas identificações foram atualizadas utilizando o banco de dados do Fishbase (Froese e Pauly 2009).

Foram definidas cinco espécies com diferentes hábitos alimentares: *Sciades herzbergii* (onívora), *Cetengraulis edentulus* (herbívora), *Macrodon ancylodon* (carnívora), *Pseudauchenipterus nodosus* (dentritívora) e *Stellifer rastrifer* (carnívora).

Digestão do músculo dos espécimes coletados

Escolheu-se a parte do músculo por ser a parte comestível do peixe. Foi realizada a biometria das espécies, retirada uma porção sem espinha da parte muscular dos peixes para o armazenamento em tubos do tipo Falcon (15 mL). As amostras foram maceradas e logo após pesadas, em balança digital de precisão, alíquotas de aproximadamente 0,5 g.

A desidratação dos músculos foi realizada em estufa (60° C) até atingir o peso constante (cerca de 2 semanas). Posteriormente, as amostras foram pulverizadas com gral e almofariz e armazenadas até posterior digestão em tubos de teflon. Para tanto, cerca de 0,1 g de amostra foi digerida com 2 mL de HNO_3 (65 %) em forno micro-ondas (Mars 6; One Touch Technology) de acordo com as especificações técnicas apresentadas na Tabela 7-1.

Tabela 7-1. Especificações técnicas do forno de micro-ondas para digestão dos tecidos dos peixes.

Steps	Potência (Watts)	Temperatura (ºC)	Duração (min:seg)
Ramp time (pré-aquecimento)	1100	Subindo até 200	59:00
Hold time (aquecimento)	1100	200	55:00
Cooling (resfriamento)	----	----	15:00

Descontaminação de frascos e filtros

Os procedimentos de descontaminação do material utilizado seguiram as recomendações da APHA (1998) e adaptações, sendo o material mantido em banho Extran (20 %) por 24 h, enxaguados com água ultrapura, colocados em banho ácido (HNO_3 a 10 %) por 24 h, enxaguados novamente e secos em estufa (SP Labor - SP-100/180-A) a 60 ºC. Já os filtros de fibras de vidro (0,45 µm e 47 mm, Merck Millipore) foram lavados primeiramente com 60 mL de água ultrapura, seguido de 20 mL de HNO_3 (10 %) e 20 mL de água ultrapura.

Procedimentos analíticos

As concentrações dos elementos metálicos (Cádmio, Cromo, Cobre, Ferro e Manganês) nos peixes foram determinadas na Central Analítica de Química pertencente ao Departamento de Química da Universidade Federal do Maranhão, usando a Espectrometria de Emissão Óptica com Plasma - ICP OES (ICPE-9800; Shimadzu). A calibração dos resultados foi determinada com base em curvas padrão construídas a partir de soluções padrões multielementares (SpecSol, Brasil) na faixa de 0,001 mg/L e 1 mg/L, e os resultados expressos em mg/kg. As condições operacionais do aparelho estão descritas na Tabela 7-2.

Tabela 7-2. Condições operacionais do ICP-OES para as análises de metais em peixes. LD: limite de detecção; LQ: limite de quantificação.

Elementos	Comprimento de onda (nm)	LOD	LOQ	r^2
Cd	226.502	0,10	0,30	0,99997
Cu	324.754	0,50	1,70	0,99998
Cr	267.716	0,30	1,00	0,99996
Fe	238.204	0,10	0,30	0,99977
Mn	257.610	0,03	0,01	0,99998

O limite de detecção (LD) e limite de quantificação (LQ) instrumental foram calculados de acordo com as especificações da Shimadzu e a exatidão do método foi calculada utilizando materiais de referências (TORT-3: Lobster Hepatopancreas e ERM®-CE278k: Mussel). Sendo a recuperação dos elementos valores médios de 80 % (Cd), 88% (Cr), 89 % (Cu), 91 % (Fe), 83 % (Mn).

Análise dos dados

Para testar a normalidade dos dados foi utilizado o teste de Shapiro-Wilk. A fim de avaliar a diferença entre as estações de amostragens, período de coleta e comparar as médias foi utilizada uma Análise de Variância (ANOVA- One way, post hoc de Tukey, $p<0,05$), após o atendimento dos pressupostos de normalidade e homogeneidade das variâncias (Zar 1996). Quando tais pressupostos não foram atendidos, utilizou-se uma análise não-paramétrica de Kruskall-Wallis ($p<0,05$), com posterior teste de Mann-Whitney sob correção de Bonferroni, para localização das diferenças entre grupos.

A Análise de Componentes Principais (ACP) foi o método de ordenação utilizado para identificar os principais componentes responsáveis pela variação dos dados no Golfão Maranhense, tendo como base a matriz de correlação. A significância da tabela de correlação de Pearson foi calculada por meio do teste *t* bicaudal, com 2 graus de liberdade.

Todas as análises foram realizadas com auxílio do programa, PAST, versão 3.14 (PAleontological STatistics - HAMMER et al. 2003), ao nível de 0,05 de significância.

Resultados

Os resultados das análises de metais pesados presentes nos tecidos das espécies *Sciades herzbergii, Cetengraulis edentulus, Macrodon ancylodon, Pseudauchenipterus nodosus* e *Stellifer rastrifer* são apresentadas na Tabela 7-3.

No Brail existem normas que tratam sobre a concentração aceitável de metais nos alimentos, as quais serviram de base para comparar com os valores de alguns elementos encontrados no tecido muscular das espécies analisadas neste estudo, a fim de verificar se existe concentração acima dos limites estabelecidos (Tabela 7-3). A legislação aplicável é o Decreto nº 55.871/65 e a Resolução da Diretoria Colegiada nº42/13, desconsiderando os valores estabelecidos na Portaria nº685/88 da ANVISA, dada sua revogação, realizando-se a comparação dos resultados obtidos com os limites legalmente estabelecidos.

Foram detectadas, em amostras individuais, concentrações acima do limite máximo permitido de Cádmio (Cd) nas espécies *Cetengraulis edentulus* e *Macrodon ancylodon* e Cromo (Cr) em *Macrodon ancylodon* e *Pseudauchenipterus nodosus*. Com relação ao Cobre (Cu) não foi detectado nenhum valor acima dos níveis estabelecidos pela legislação brasileira. Embora não existam leis nacionais que regulem as concentrações de Ferro (Fe) e Manganês (Mn) no tecido muscular dos peixes, foram detectadas concentrações desses elementos em todas as espécies analisadas, algumas amostras apresentaram valores muito elevados quando comparados à média geral do estudo.

Os elementos Mn e Fe apresentaram as maiores concentrações nas espécies *C. edentulus* e *M. ancylodon* e a menor concentração em *S. rastrifer*. Os valores do Cd foram maiores em *M. ancylodon* e menores no *S. herzbergii*, para o Cobre (Cu) foram observadas maiores concentrações no *S. herzbergii* e menores em *S. rastrifer*. Para o Cromo (Cr), *P. nodosus* e *C. edentulus* foram as espécies com maiores e menores teores, respectivamente (Figura 7-2).

Com relação às áreas de captura, os resultados apontaram a Baía de São Marcos com maior concentração média para Fe, em contrapartida demonostrou a menor média para Cr e Cu. A Baía de São José obteve média numericamente superior para o Mn e ligeiramente inferior para Cd. A análise dos dados apontou ainda que a Baía do Arraial sinalizou a maior média para Cd e Cu, porém apresentou menor média para Mn (Figura 7-3).

A análise estatística indicou diferença entre as Baía de São José e a Baía do Arraial quando comparados os valores de concentração do Cd para os dois locais (Figura 7-4). No que diz respeito aos elementos Cr, Cu e Mn os testes apontaram diferença entre a Baía de São Marcos e a Baía de São José. Para o Fe não foram encontradas diferenças entre as três baías, indicando dessa forma homogeneidade nas concentrações dos metais encontradas nos tecidos das espécies analisadas.

Tabela 7-3. Concentração de metais em peixes estuarinos capturados no Golfão Maranhense. Em negrito estão destacados os valores acima do limite permitido pela legislação brasileira. LD = Limite Detectável. O=Onívoro; H=Herbívoro; C=Carnívovo; D=Dentritívoro.

Local	Espécies	Concentração em mg/kg					Hábito alimentar
		Cd	Cr	Cu	Fe	Mn	
Baía de São José	*Sciades herzbergii*	0,121	**0,197**	<LD	4,923	0,164	O
		0,011	0,076	0,095	<LD	0,050	
		<LD	0,036	<LD	5,252	0,129	
		0,012	0,019	0,034	4,230	0,086	
		0,007	0,064	0,152	3,462	0,059	
	Cetengraulis edentulus	0,001	0,002	0,002	0,158	0,011	H
		0,004	0,050	0,161	0,161	105,532	
		<LD	<LD	<LD	4,886	0,276	
	Macrodon ancylodon	0,005	0,063	0,054	4,050	84,532	C
		0,011	0,057	0,128	4,530	0,046	
		0,039	**0,136**	0,244	3,306	0,170	
		0,001	0,071	0,080	2,082	0,042	
		<LD	0,054	0,086	1,962	0,035	
	Pseudauchenipterus nodosus	0,173	0,402	<LD	8,985	0,237	D
		<LD	0,051	<LD	10,658	0,135	
		<LD	0,028	0,055	2,682	0,194	
		<LD	0,010	<LD	2,994	0,023	
Baía de São Marcos	*Macrodon ancylodon*	<LD	0,019	<LD	2,082	0,123	C
		<LD	0,010	0,014	1,374	0,106	
		<LD	<LD	<LD	1,164	0,031	
		<LD	0,003	<LD	3,937	0,028	
		<LD	0,001	<LD	0,918	0,008	
	Pseudauchenipterus nodosus	<LD	**0,115**	<LD	4,555	<LD	D
		<LD	0,076	<LD	5,487	0,032	
		<LD	<LD	<LD	2,769	0,016	
		<LD	0,004	<LD	2,552	0,015	
		<LD	<LD	<LD	1,014	<LD	
	Cetengraulis edentulus	<LD	0,007	<LD	16,978	0,636	H
		0,586	0,016	0,147	2,658	0,029	
		1,178	<LD	<LD	5,783	0,209	
		1,394	<LD	<LD	6,243	0,351	
Baía do Arraial	*Macrodon ancylodon*	0,969	0,003	0,021	2,214	0,066	C
		0,582	0,049	0,122	22,050	0,144	
		0,721	0,026	0,443	2,949	0,024	
		1,833	**0,145**	<LD	3,054	0,017	
	Stellifer rastrifer	0,576	<LD	<LD	2,310	0,018	D
		0,580	<LD	<LD	2,550	0,206	
		0,574	<LD	<LD	3,438	0,085	
		0,579	<LD	<LD	2,262	0,086	
		0,576	0,052	0,017	3,930	0,115	
	Sciades herzbergii	<LD	0,004	<LD	2,526	0,042	O
		<LD	<LD	6,584	1,644	0,050	
		<LD	<LD	<LD	1,272	0,277	
		<LD	<LD	<LD	1,824	0,107	
		<LD	<LD	<LD	1,776	0,068	
Limite estabelecido pela Legislação (mg/kg)		1,0[a,b]	0,1[b]	30,0[b]	-	-	

[a] ANVISA, Portaria n° 685, 27 de agosto de 1998.

[b] BRASIL, Decreto n° 55.871, 26 de março de 1965.

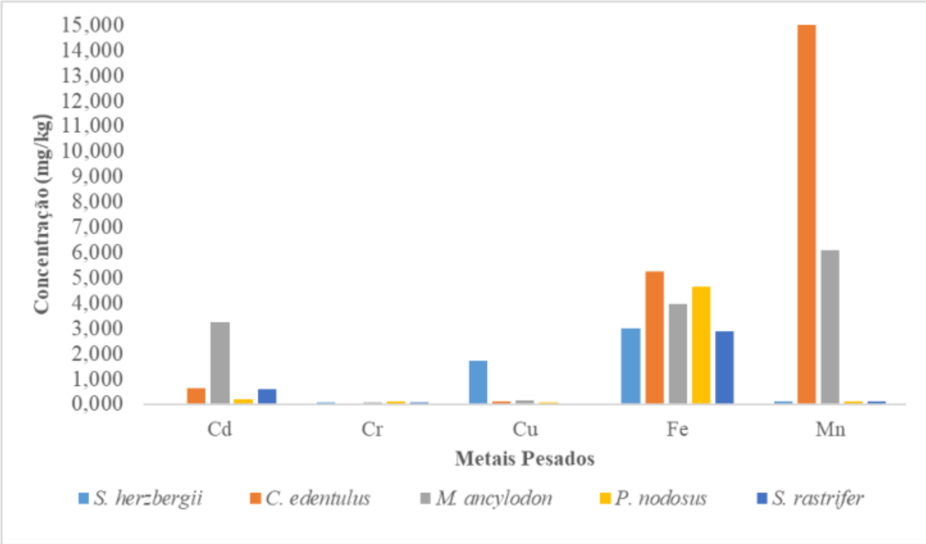

Figura 7-2. Concentração de Cd, Cr, Cu, Fe e Mn nos músculos das espécies de peixes capturadas no Golfão Maranhense.

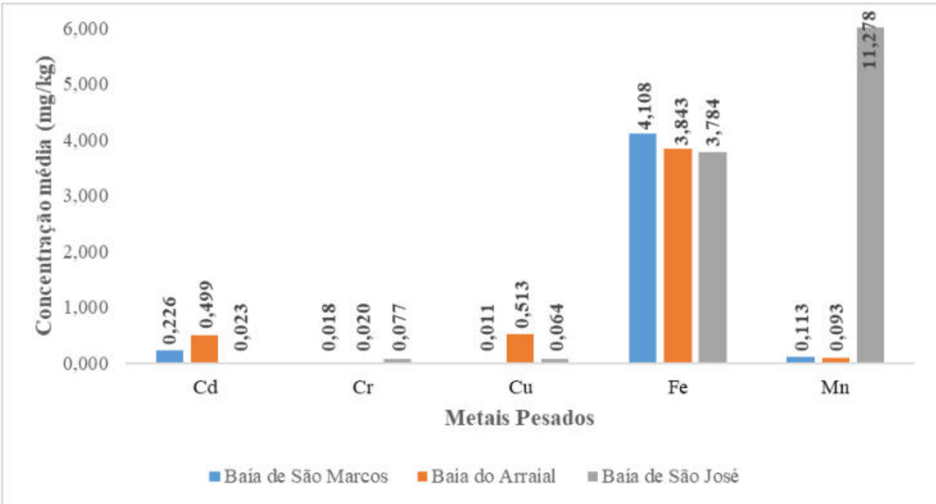

Figura 7-3. Concentração de Cd, Cr, Cu, Fe e Mn nos nas Baías do Golfão Maranhense.

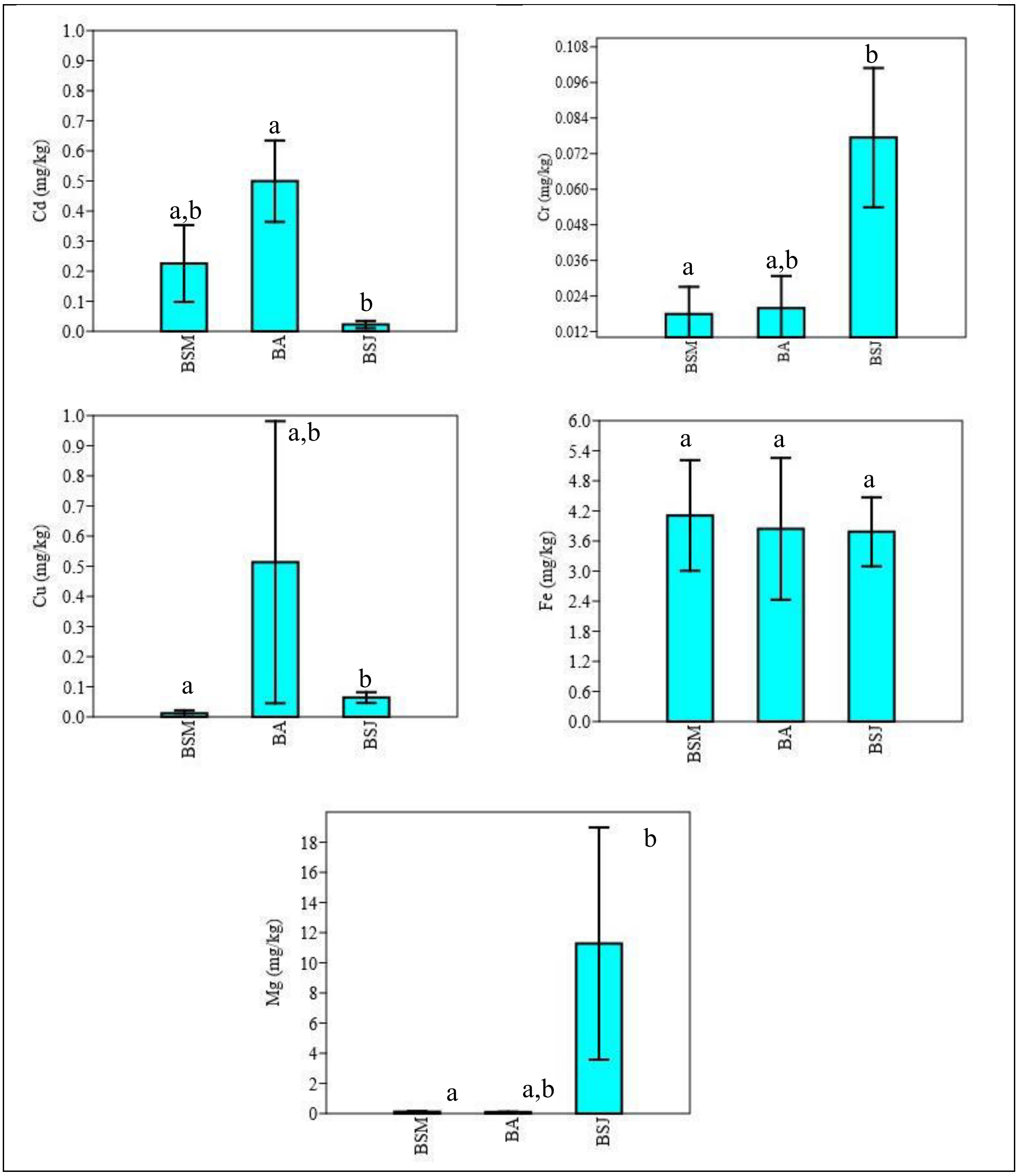

Figura 7-4. Resultados da ANOVA para a concentração dos metais (Cd, Cr, Cu, Fe e Mg) em cada local de amostragem.

A partir da Análise de Componentes Principais (ACP) realizada para a concentração de metais pesados para cada espécie de peixe, por local de amostragem e por nível trófico, foi possível observar que os dois primeiros eixos explicaram 68,3% da variabilidade total dos dados (Figura 7-5). A significância dos eixos foi testada através de uma randomização no modelo aleatório Broken Stick com 9.999 réplicas por Bootstrap (Jackson 1993), o qual indicou os Componentes 1 e 2 como suficientes para representar a variância fatorial.

O Componente 1 (41,44%) esteve relacionado positivamente com Cd e Fe, indicando maiores concentrações desses elemementos nas Baías de São Marcos e Arraial, associados às espécies de hábito alimentar carnívoro, *S. rastrifer, M. ancylodon,* e herbívoro, *C. edentulus*.

Correlacionados negativamente ao componente 1 têm-se o metal Mn, as espécies *C. edentulus e M. ancylodon*, com tendência de maior concentração para a Baía de São José. Estas espécies caracterizaram-se pelos hábitos herbívoros e carnívoros.

No concernente ao Componente 2 (26,79%), o elemento que apresentou a maior correlação foi o Cu, relacionado negativamente ao eixo, com as maiores concentrações na Baía de São Marcos, associado à espécie *M. ancylodon* (hábito carnívoro), e na Baía do Arraial, com valores mais elevados em *S. herzbergii* (hábito onívoro).

O Cr esteve correlacionado positivamente no componente 2 com maiores concentrações na Baía de São José associado, ainda, a todos os hábitos alimentares analisados neste estudo.

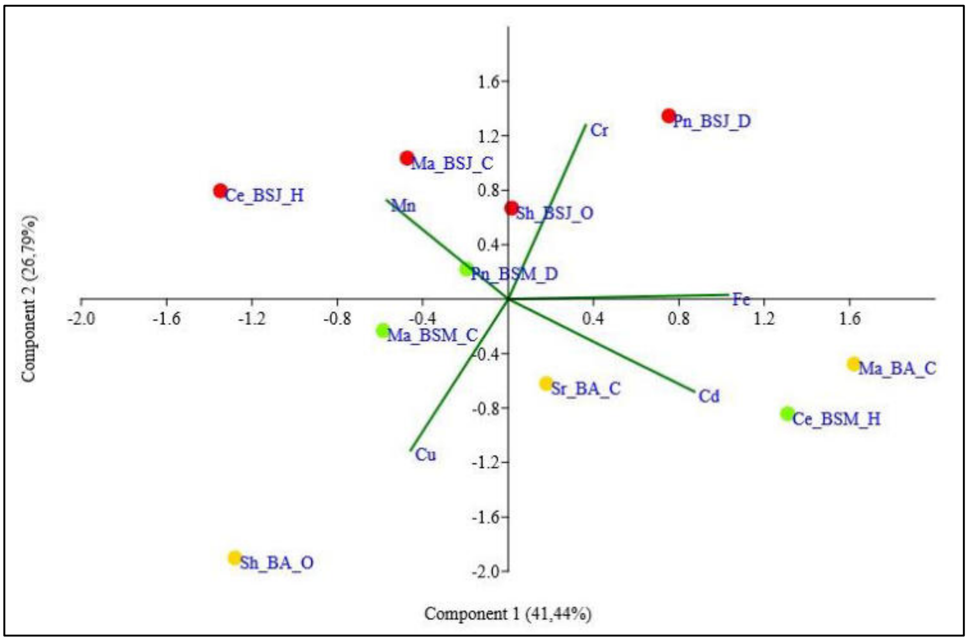

Figura 7-5. Análises de componentes principais (PCA) mostrando a relação da bioacumulação de metais (Cd, Cr, Cu, Fe e Mn), as espécies de diferentes níveis tróficos e os locais de captura. Sh=*Sciades herzbergii*; Ce=*Cetengraulis edentulus*; Ma=*Macrodon ancylodon*; Pn=*Pseudauchenipterus nodosus* e Sr=*Stellifer rastrifer*. BA=Baía do Arraial; BSJ=Baía de São José; BSM=Baía de São Marcos. O=Onívoro; H=Herbívoro; C=Carnívovo; D=Dentritívoro.

Discussão

Os resultados evidenciaram a presença de Cd, Cr, Cu, Fe Mn em todas as espécies coletadas no Golfão Maranhense, além disso foram encontrados níveis de concentração acima do limite máximo permitido, bem como as baías apresentam níveis elevados desses elementos. Os peixes são uma importante fonte de alimento e representam uma parte importante de muitas cadeias alimentares naturais. Portanto, os níveis de contaminantes nos peixes são de particular interesse devido aos efeitos potenciais dessas substâncias poluentes nos peixes e nos organismos que os consomem, incluindo os seres humanos (Burger e Gochfeld 2005). O aumento gradual da industrialização e expansão urbana do Distrito Industrial da cidade de São Luís potencializa a introdução de quantidades indesejáveis de poluentes no ambiente aquático (Santos et al. 2019).

A ocorrência da concentração de Cd e Cr, em níveis acima do limite estabelecido pelos órgãos brasileiros, nos tecidos de algumas espécies, pode estar relacionada com os movimentos de migração das espécies. Dessa forma, serve de alerta o processo de bioacumulação desses elementos, tendo em vista que as espécies analisadas fazem parte da cadeia produtiva da pesca artesanal. O Cd é altamente tóxico para o rim e se acumula nas células tubulares proximais em concentrações mais altas, o Cr, por sua vez, pode induzir danos ao DNA causando aberrações cromossômicas e alterações na replicação e transcrição de DNA (O'Brien et al. 2001; Matsumoto et al. 2006; Jaishankar et al. 2014).

Foram observados altas concentração de Fe para os organismos, tendo em vista que todas as espécies apresentaram níveis que variaram de 0,161 a 22,050 mg/kg. Santos et al. (2019), encontraram resultados similares em estudos realizados no estuário do Rio dos Cachorros, área de transição entre a Baía de São Marcos e a Baía do Arraial. Uma das principais fontes de Fe dissolvido para os oceanos é representada pela descarga dos rios (Bergquist e Boyle 2006), a contribuição da drenagem fluvial na região do Golfão é muito alta. Além disso, a região portuária recebe navios graneleiros que transportam grandes toneladas de minério de ferro, que pode explicar a concentração destacada desse elemento nas amostras analisadas.

Quanto ao elemento metálico Mn, foram detectados níveis elevados principalmente nas espécies capturadas na Baía de São José, sugerindo uma relação com com fontes pontuais presentes na região. A acumulação observada não parece ser influenciada pelos padrões geoquímicos do Golfão, pois não há um padrão homogêneo de concentração para todos os locais de captura. A fonte mais comum desses elementos no sistema estuarino são lançamento de efluentes industriais e esgotos domésticos (Butler e Timperley 1996).

Apesar de não existir legislação específica para a quantidade de Mn em alimentos, a ANVISA relata uma ingestão diária recomendada (IDR) de 360 mg por dia para adultos (Brasil 2005). Grotto et al. (2012) encontraram um valor médio de 265 mg/kg de Mg em amostras de peixes de rio.

As concentrações de Cu encontradas no tecido muscular dos peixes não ameaçam a saúde dos mesmos e não representa risco de contaminação para a população local, pois ficaram bem abaixo do limite máximo. De acordo com Kalay e Canli (2000), Pereira et al. (2010) e Lima et al. (2015) o metal Cu é um elemento essencial para o organismo e, dessa maneira, é facilmente regulado pelo metabolismo sendo difícil seu acúmulo.

A análise espacial da concentração de metais indicou diferenças significativas entre Cd, Cr, Cu e Mn, que pode estar relacionado à diferentes variáveis como: características locais e ações antrópicas, que podem influenciar a variação nos níveis de assimilação das espécies em locais distintos. Em contrapartida, os valores encontrados neste estudo foram inferiores a sistemas altamente impactos como Baía de Guanabara (Abreu et al. 2016), Baía de Sepetiba (Fonseca et al. 2013), Complexo Estuarino de Paranaguá (Sá et al. 2006; Anjos et al. 2012).

Cádmio e Ferro apresentaram forte correlação com as Baías do Arraial e São José, e o Mn somente esta última baía, com tendência para as espécies carnívoras e herbívoras. Concentrações relativamente altas de metais podem estar relacionadas ao hábito alimentar, uma vez que espécies de peixes com hábito alimentar carnívoro alimentam-se especificamente de alevinos, camarões e zooplâncton, e são conhecidos por serem ativos na natação. Essas atividades são conhecidas por acumularem altos níveis de metais pesados no corpo (Karadede et al. 2004). Embora os herbívoros tendem a acumular menor quantidade de metal, em virtude da alimentação de plantas, a absorção pode ocorrer através dos processos de respiração (Pereira et al. 2010; Jabeen et al. 2012; Mert et al. 2014).

Para o Cobre, verificou-se maior correlação com as Baías de São Marcos e Arraial, sendo que as espécies *M. ancylodon* (hábito carnívoro) e *S. herzbergii* (hábito onívoro) apresentaram maior relação com este elemento. Concentrações elevadas de Cu detectadas no músculo podem refletir os altos níveis de proteínas de ligação no tecido muscular, tendo em vista que este elemento faz parte do metabolismo dos peixes (Subotić et al. 2013).

Em conclusão, as análises realizadas neste estudo indicam que os peixes estão respondendo aos efeitos diretos causados por mudanças ambientais. A região apresenta indicativos de que existe certo grau de contaminação por metais pesados. Os efeitos dessa contaminação não estão restritos somente à Baia de São Marcos, teoricamente o ambiente mais antropizado, tendo em vista que também foram encontrados teores elevados nas baías de São Marcos e São José. Os elementos químicos analisados mostram resultados consistentes em todas as categorias tróficas, sendo assim, entende-se que existe risco com relação ao consumo dos recursos pesqueiros provenientes da pesca artesanal. Os resultados deste estudo exigem a necessidade de monitoramento contínuo em toda a região do Golfão Maranhense.

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8 CONSIDERAÇÕES FINAIS

A elaboração dos parâmetros de qualidade ambiental para o Golfão Maranhense permite afirmar que os atributos físico-químicos, biológicos e químicos são sensíveis às mudanças ambientais decorrentes da ação antrópica.

A avaliação dos parâmetros físico-químicos permitiu inferir que existe uma iminente relação entre as variáveis analisadas e os fatores ambientais que atuam na região. Dessa forma, é possível afirmar que ações naturais como descarga fluvial, marés, correntes e eventos climatológicos, se sobrepõem a outros fatores e determinam o comportamento espacial e temporal da salinidade, transparência, temperatura, condutividade, oxigênio dissolvido e material em suspensão das massas d´água atuantes no Golfão Maranhense.

Na Plataforma Continental Maranhense foi possível observar que a distribuição e manutenção de nutrientes são influenciadas, diretamente, por dois aspectos característicos da região Amazônica, o aporte fluvial dos rios maranhenses e a sazonalidade definida pelas estações seca e chuvosa bem delineadas na região equatorial.

Neste estudo foi possível analisar o comportamento espacial e temporal das espécies de peixes presentes na Baía de São Marcos, que apresenta modificações e intervenções humanas ao longo das últimas décadas. Dentro de uma escala de cinco anos de amostragem não foram observadas modificações nos índices analisados, assim, entende-se que possíveis impactos nas comunidades ícticas foram absorvidos e não aparentam variações perceptíveis. Cabe ressaltar, que foram notadas influências comportamentais das espécies no que tange os aspectos sazonais, sugerindo que a presença e abundância de algumas espécies estiveram relacionadas aos períodos chuvoso e de estiagem.

Com relação à análise espacial da ictiofauna, identificaram-se algumas diferenças entre os locais de captura, os níveis de abundância e diversidade foram menores no local onde estão localizadas a grande maioria das atividades provenientes da ação humana. Desta forma, entende-se que existe modificação na qualidade ambiental dessa região, que apresenta indícios de que está potencialmente comprometida em função da rota portuária, destacando-se o intenso tráfego de navios, processos de dragagem, responsáveis pela modificação dos sedimentos e desestruturação dos hábitats dos diferentes organismos que viabilizam a cadeia trófica das espécies de peixes.

Sob o ponto de vista regional, não foi possível extrapolar os resultados para todo o Golfão, tendo em vista que os resultados são oriundos apenas de uma baía que compõe o sistema. Neste sentido, entende-se que são necessários estudos futuros para que sejam comparadas todas as áreas e, assim, verificar se há impactos nas comunidades de peixes para analisar a qualidade ambiental utilizando este parâmetro biológico.

Para a relação peso-comprimento de 19 (dezenove) espécies capturadas em estuários localizados no Golfão, as análises não indicaram alterações nos padrões de crescimento dos peixes. Sendo assim, é possível que não haja interferência para essa característica biológica, indicando que os aspectos antrópicos atuantes na região não afetam as condições naturais de desenvolvimento das espécies comumente capturadas nas zonas costeiras e estuarinas dessa parte central do litoral maranhense.

No que concerne ao parâmetro de avaliação química, não foram encontradas evidências contundentes capazes de afirmar que existe bioacumulação de elementos metálicos nos peixes do Golfão Maranhense. No geral, os dados resultantes do processo de análise dos tecidos musculares foram considerados aceitáveis, quando comparados com a legislação brasileira que estabelece os níveis máximos permitidos de metais pesados nos pescados. Entretanto, foram verificadas amostras individuais com teores acima dos limites estabelecidos, indicando dessa forma que existe algum grau de contaminação na região. Além disso, foi possível verificar que não houveram semelhanças entre as três baías, acenando para possíveis impactos pontuais que determinam essa diferença relacionada com cada metal com maior e menor escala de concentração.

A integração dos resultados obtidos a partir dos parâmetros utilizados neste estudo, mostra que a região do Golfão Maranhense apresenta características ambientais importantes que influenciam a distribuição das variáveis físico-químicas ao longo da sua zona costeira. As ações naturais provocadas pela sazonalidade e descarga fluvial são mais intensas e atuantes sob o ponto de vista de distribuição dos nutrientes, dificultando determinar possíveis influências não naturais nesse processo. É plausível considerar também, que os aspectos biológicos e químicos apresentaram poucas alterações, mas indicaram a necessidade de estudos futuros atrelados a monitoramentos constantes, principalmente nas áreas de maiores atividades antrópicas.

A aplicação de parâmetros de qualidade ambiental mostrou-se uma ferramenta útil para a tomada de decisões, para a elaboração do planejamento ambiental e para a avaliação da qualidade ambiental, verificadas as tendências de alteração nos ecossistemas aquáticos.

ANEXOS

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Fish assemblage structure in a port region of the Amazonic coast

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ABSTRACT. The fish assemblage structure in a port area in São Marcos Bay (Amazonic coast) was evaluated based on the spatial and temporal distributions to identify potential changes in response to anthropic pressure increases associated with industrial and port activities in region. The samples were taken between March 2011 and November 2015. The ichthyofauna was represented by a total of 56 species, distributed in 15 orders and 29 families. Captures were dominated by *Genyatremus luteus* (Bloch, 1790), but *Sciades proops* (Valenciennes, 1840) was the most representative in terms of biomass. Seasonal distributions of fish assemblage did not reveal significant differences. However, there was a difference between catch sites, abundance, biomass and Shannon diversity index was higher in the Site 1 and evenness in Site 4. The analysis NMDS and the test ANOSIM between months and between sampling sites, based on species composition, revealed a seasonal differentiation associated with the rainy and drought months, as well as spatial differentiation, in function of a depth gradient and hydrodynamics, resulting from greater distance from mangrove areas. The low diversity recorded may be a reflection of port activities that historically occur in the area investigated. However, there was still a maintenance of regional diversity throughout the period under analysis. Thus, temporal and spatial scales become important for the detection and understanding of fish biodiversity in an Amazonian estuary, reflecting, the importance of mangroves for the maintenance of the ichthyofaunistic diversity in the area. In this context, the present study may subsidize possible conservation projects in the area since information of this nature is almost non-existent for estuarine fish from the Maranhão Amazon.

KEYWORDS. Ichthyofauna, estuary, seasonal variability, spatial patterns, Maranhão Amazon.

RESUMO. Estrutura da assembleia de peixes em uma região portuária da costa amazônica. A estrutura da assembleia de peixes em uma área portuária na Baía de São Marcos (Costa Amazônica) foi analisada com base nas distribuições espaciais e temporais para identificar potenciais mudanças na resposta aos aumentos de pressão antrópica associados às atividades industriais e portuárias na região. As amostras foram realizadas entre março de 2011 a novembro de 2015. A composição da ictiofauna foi representada por um total de 56 espécies, distribuídas em 15 ordens e 29 famílias. As capturas foram dominadas por *Genyatremus luteus* (Bloch, 1790), mas *Sciades proops* (Valenciennes, 1840) foi o mais representativo em termos de biomassa. A avaliação sazonal da assembleia de peixe não revelou diferença significativa. Entretanto, houve diferença entre os locais de captura onde abundância, biomassa e diversidade de Shannon foram mais relevantes no Ponto 1 e a equitabilidade no Ponto 4. A análise NMDS e o teste ANOSIM entre os meses e entre os locais de amostragem, com base na composição de espécies, revelaram uma diferenciação sazonal associado aos meses chuvosos e de estiagem, bem como uma diferenciação espacial, em função de um gradiente de profundidade e hidrodinâmica, resultante da maior distância das áreas de mangue. A baixa diversidade registrada podem ser reflexos das atividades portuárias que historicamente ocorrem na área investigada. Porém, ainda sim, percebeu-se uma manutenção da diversidade regional, ao longo do período em análise. Assim, as escalas temporais e espaciais tornam-se importantes para detecção e compreensão da biodiversidade de peixes em um estuário amazônico, refletindo, a importância dos manguezais para a manutenção da diversidade ictiofaunística na área. Mediante este contexto, o presente estudo pode subsidiar possíveis projetos de conservação na área, uma vez que informações desta natureza são quase inexistentes para peixes estuarinos da Amazônia maranhense.

PALAVRAS-CHAVE. Ictiofauna, estuário, variabilidade sazonal, padrões espaciais, Amazônia maranhense.

PHYSICOCHEMICAL PROPERTIES AND DISTRIBUTION OF NUTRIENTS ON THE INNER CONTINENTAL SHELF ADJACENT TO THE GULF OF MARANHÃO (BRAZIL) IN THE EQUATORIAL ATLANTIC

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Abstract. The dynamics of the physical and chemical factors that regulate oceanographic processes on the continental shelf off the state of Maranhão (northeastern Brazil) was evaluated using a transect along São Marcos Bay (01°41'S-02°28'S and 43°47'W-44°13'W) in January, March, May, July and September 2014, with a total of seven sampling stations. Water samples were collected from the surface using a Van Dorn water sampler. The following hydrochemical variables were analyzed: water transparency (m), temperature (°C), salinity, conductivity (mS cm^{-1}), total dissolved solids (TDS, g L^{-1}), pH, dissolved oxygen (mg L^{-1}), turbidity (NTU), total suspended solids (TSS) and dissolved nutrients (phosphate, nitrite and silicate). The relationship between these variables and seasonality in the region [rainy season (January to June) and dry season (July to December)] were also evaluated. For data with normality and equal variances, a one-way analysis of variance (ANOVA) was used for the spatial and temporal comparisons of the physicochemical variables. Results showed that the spatial and temporal variability of the physicochemical variables analyzed in this study is associated with local dynamics governed by river discharge, tidal movements, currents and meteorological events. The fluvial transport from the rivers of the state of Maranhão and other freshwater sources in the Amazon region are apparently the major contributors responsible for the maintenance of nutrient availability on the Maranhão continental shelf.

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Histological and Genotoxic Biomarkers in *Prochilodus lacustris* (Pisces, Prochilodontidae) for Environmental Assessment in a Protected Area in the Northeast of Brazil

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Abstract
The quality of aquatic environments all around the world is being altered by different human activities that represent direct threat to the ecological system and the aquatic biota. This study aimed to evaluate the occurrence of histological and genotoxic alterations in *Prochilodus lacustris* as indicators of anthropic impacts in a lacustrine environment in northeast Brazil. The histological alterations were evaluated using the histological alteration index, and the genotoxic alterations were detected using the micronuclei test, at three sampling stations (S1, S2 and S3). The gills presented lesions with three stages of severity, with mild lesions more frequent in the specimens collected at station S1. Mild hepatic tissue lesions were the most frequent type in both areas. Micronucleus analysis showed that station S3 was the most affected. The biological responses observed indicated that the fish are under influence of environmental changes. It is important to highlight that the organisms collected at station S3 had a more compromised health status.

Keywords Liver · Gill · Histopathology · Micronuclei · Biomarkers

Surface water bodies such as lakes, rivers and seas, are receptacles of a complex variety of compounds and substances that arise from both metabolic activities of organisms and waste produced by anthropic actions, which normally find their final destination in such environments (He et al. 2011; Liu et al. 2014; Santana et al. 2018). The variety of compounds and substances includes contaminants and toxic agents that are a direct threat to biota (Chang and Sibley 1993, Ip et al. 2005; Rotter et al. 2011).

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Original Article

Feeding activity of the cayenne pompano *Trachinotus cayennensis* (Cuvier 1832) (Perciformes, Carangidae) in estuaries on the western coast of the state of Maranhão, Brazil

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(With 6 figures)

Abstract

The present paper addresses the feeding activity of *Trachinotus cayennensis,* collected in Lençóis Bay (1°18'S – 1°19'S; 44°51'W – 44°53'W) on the western coast of the state of Maranhão, Brazil. Sampling was conducted between June 2012 and June 2013 using driftnets with stretch mesh sizes from 95 to 100 mm. A total of 205 individuals (114 females and 91 males) were analyzed. Statistically significant differences in the sex ratio were found in June, September and December 2012. Food items were analyzed based on frequency of occurrence and volumetric method, with the subsequent calculation of the alimentary importance index. Three size groups were defined to determine possible ontogenetic changes in eating habits based on the size range of the individuals collected: I (< 29 cm), II (29.1 to 37.0) and III (≥ 37.1). Eleven food item categories were identified: mollusks, polychaetes, crustaceans, nematodes, insects, algae, bryozoans, ophiuroids, fishes, vegetal matter and sediments. The variety of items in the diet of *T. cayennensis* indicates considerable feeding plasticity and opportunistic behavior. Seasonal variations influenced the feeding pattern of the species, with greater feeding activity in the dry season. The considerable availability of resources in estuarine habitats of the western coast of Maranhão constitutes another factor that influences the feeding behavior of this species.

Keywords: diet composition, food items, stomach, trophic pattern.

Atividade alimentar do pampo *Trachinotus cayennensis* (Cuvier 1832) (Perciformes, Carangidae) em estuários do litoral ocidental do Estado do Maranhão, Brasil

Resumo

Atividade alimentar do pampo *Trachinotus cayennensis* (Cuvier 1832) (Perciformes, Carangidae) em estuários na costa ocidental do Maranhão, Brasil. O presente trabalho descreve a atividade alimentar do *Trachinotus cayennensis*, coletado na Baía de Lençóis (1°18'S – 1°19'S; 44°51'W – 44°53'W) na costa oeste do Maranhão. Amostragens foram realizadas entre junho de 2012 e junho de 2013, utilizando redes de emalhar à deriva com tamanho de malha de 95 a 100 mm. Foram analisados 205 indivíduos (114 fêmeas e 91 machos). Encontraram-se diferenças estatisticamente significativas na proporção sexual nos meses de junho, setembro e dezembro de 2012. Os itens alimentares foram analisados com base na frequência de ocorrência e utilizando o método volumétrico, com o subsequente cálculo do índice de importância alimentar. Três grupos de tamanho foram definidos para determinar possíveis mudanças ontogenéticas nos hábitos alimentares com base na faixa de tamanho dos indivíduos coletados: I (< 29 cm), II (29,1 a 37,0) e III (≥ 37,1). Foram identificadas 11 categorias de alimentos: moluscos, poliquetas, crustáceos, nematoides, insetos, algas, briozoários, ophiuro, peixes, matéria vegetal e sedimentos. A variedade de itens na dieta de *T. cayennensis* indica uma plasticidade alimentar considerável e um comportamento oportunista. As variações sazonais influenciaram o padrão alimentar da espécie, com maior atividade de alimentação na estação seca. A considerável disponibilidade de recursos nos habitats estuarinos da costa oeste do Maranhão constitui outro fator que exerce influência sobre o comportamento alimentar desta espécie.

Palavras-chave: composição da dieta, itens alimentares, estômago, padrão trófico.

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Mineral content in fishes in the lower course of the itapecuru river in the state of Maranhão, Brazil

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Abstract–Concentrations of calcium, iron, potassium, magnesium, phosphorus, zinc, copper, selenium and nickel were determined in the muscle tissue of seven species of fish (*Plagioscion squamosissimus*, *Geophagus surinamensis*, *Prochilodus lacustres*, *Curimata* sp., *Schizodon dissimilis*, *Ageneiosus ucayalensis* and *Hypostomus plecostomus*) collected from the lower course of the Itapecuru River in the state of Maranhão, Brazil. The samples were digested in a nitric-perchloric solution and analyzed using an inductively coupled plasma atomic emission spectrometer, with the construction of specific calibration curves for each element. The highest concentrations of constituent minerals were found for phosphorus, potassium, nickel and magnesium (399.83, 144.60, 90.20 and 29.49 mg 100 g^{-1}, respectively) in *G. surinamensi*, *P. lacustres* and *Curimata* sp. The lowest concentrations were found for copper, zinc, iron and selenium (0.12, 0.51, 1.05 and 8.31 mg 100 g^{-1}, respectively) in *Curimata* sp., *S. dissimilis*, *A. ucayalensis* and *P. squamosissimus*. The concentrations of all minerals can be considered low and are below the maximum limit established by Brazilian legislation for the human ingestion of fish meat. A comparison of the seven species of fish investigated revealed no statistically significant differences regarding the concentrations of minerals, suggesting that size and different dietary habits do not exert an influence on absorption. The low concentrations of metals, such as Fe, Cu, Zn and Ni, may be related to the environmental conditions of the mouth of the river, which receives ocean inputs that produce particular tide cycles with a strong dispersion capacity, thereby diminishing residence time in the water column and reducing the availability of these metals to species of fish.

Keywords: Fish, Soft Tissue, Minerals, Spectrophotometry

INTRODUCTION

Fish meat is generally considered a valuable source of calcium and phosphorus as well as reasonable amounts of sodium, magnesium, manganese, chloride, sulfur, selenium, chromium, nickel, aluminum, cobalt, zinc, potassium, copper and iron [4]. Some are macronutrients, meaning that the daily requirement reaches 100 mg/day for an adult human. Others are micronutrients or trace elements, the requirements of which are minimal in humans [5]. However, both the deficiency and excess of minerals in food sources can exert harmful effects on humans. Moreover, minerals in excess can be lethal to aquatic organisms and cause biochemical, structural and functional disorders in species of fish. Studies on minerals are essential for understanding the effects associated with the consumption of fish meat by humans. Although the physiological importance is well documented for some animals, many aspects of ingestion, function and bioavailability need to be clarified [6]. Information on the nutritional micronutrient requirements of species of fish is also fragmentary, mainly because many micronutrients are only needed in very small quantities.

Species of fish can be used as biological indicators since they occupy the top of the food chain and accumulate metals, which can be passed on to humans through ingestion, leading to acute or chronic adverse health conditions. Residence time in polluted waters, age and size affect the concentration and bio-magnification of metals in aquatic organisms [7]. Species of fish in the lower course of the Itapecuru River in northeastern Brazil are an extremely important food source for river communities, as these organisms are a source of high quality proteins and minerals to meet nutritional needs as well as provide energy for the body and the maintenance of vital cell processes. Despite the recognized importance of fishing activities for these communities, little is known regarding the availability of minerals in the local diet. Among other species, *Plagioscion squamosissimus*, *Geophagus surinamensis*, *Curimata* sp. and *Prochilodus lacustris* are found in the lower Itapecuru River and have high economic value as well as recognized nutritional quality.

Despite the consensus that the consumption of fish meat is beneficial to humans, scientific records in Brazil on the mineral con-

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METAL LEVELS IN WATER AND THE MUSCLE TISSUE OF FISHES IN THE CACHORROS RIVER, SÃO LUÍS ISLAND, STATE OF MARANHÃO, BRAZIL

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Abstract. The present study evaluates physicochemical variables, perform a microbiological analysis as well as determine heavy metal concentrations in the water and muscle tissue of fishes from the Cachorros River. The analysis of metal concentrations in the estuarine water revealed high levels of Fe and Al, with values above the limits established by Brazilian legislation. The concentration of total coliforms and thermotolerant coliforms tended to be higher in the rainy season. Regarding metal concentrations in the muscle tissue of fishes, high levels of Pb and Cd were found, especially in carnivorous and detritivorous species, with values above the limits established by national legislation. Two-factor analysis of variance revealed that only Pb demonstrated a significant interaction between seasonality and the feeding habits of the fish fauna, with higher concentrations of this metal in the dry season among detritivorous species in comparison to herbivorous species. The present findings demonstrate the contamination pattern that has been occurring in the Cachorros River, as evidenced by the concentration of trace metals in both the water and muscle tissue of fishes, which are an important source of protein as well as an economic resource for the population of this river basin.
Keywords: *estuarine fish, metal levels, microbiological contamination, physicochemical variables, health risk*

Introduction

A large portion of the world's population lives in urban centers near estuarine coastlines, which places anthropogenic pressure on water resources due to the demands and wastes of such populations (Cunha et al., 2005; Carmo et al., 2011; Barbosa, 2006). It is estimated that approximately 75% of the world's population will be living within 160 km of a coastline by the year 2025 (Moura, 2009). Thus, urbanization and

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