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INSTITUTO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE

Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos

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ESTRUTURA FUNCIONAL DE COMUNIDADES DE PEIXES MARINHOS COSTEIROS DO ATLÂNTICO SUL OCIDENTAL

MACEIÓ - ALAGOAS

JUNHO/2024

DANIELE SOUTO VIEIRA

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Dissertação/Tese apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde. Universidade Federal de Alagoas, como requisito para obtenção do título de Mestre/Doutor em CIÊNCIAS BIOLÓGICAS, área de concentração em Conservação da Biodiversidade Tropical.

Orientador(a): Prof(a). Dr(a) NÍDIA NOEMI FABRÉ

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PROGRAMA DE PÓS-GRADUAÇÃO EM DIVERSIDADE BIOLÓGICA E CONSERVAÇÃO NOS TRÓPICOS

ATA DE DEFESA DE TESE DE DOUTORADO

DE PÓS-GRADUAÇÃO *STRICTO SENSU*

ATA Nº 24

Ata da sessão referente à defesa intitulada “*Estrutura funcional de comunidades de peixes marinhos do Atlântico Sul Ocidental*”, para fins de obtenção do título de Doutor em Ciências Biológicas na área de Biodiversidade, área de concentração Conservação da Biodiversidade Tropical e linha de pesquisa em Diversidade e ecologia de organismos tropicais**,** pelo(a) discente **Daniele Souto Vieira** (início do curso em 01/03/2020) sob orientação da Profa. Dra. Nídia Noemi Fabré/UFAL.
Ao vigésimo oitavo dia do mês de junho do ano de 2024 às 08 horas, online, reuniu-se a Banca Examinadora em epígrafe, aprovada pelo Colegiado do Programa de Pós-Graduação conforme a seguinte composição:

Dr.([a]) Presidente – Nídia Noemi Fabré/UFAL
Dr. ([a]) Lucas Augusto Kaminski
Dr. ([a]) Ronaldo Angelini
Dr. ([a]) Ezequiel Mabragaña
Dr. ([a]) Guilherme Ramos Demétrio Ferreira

Tendo o(a) senhor(a) Presidente declarado aberta a sessão, mediante o prévio exame do referido trabalho por parte de cada membro da Banca, o(a) discente procedeu a apresentação de seu Trabalho de Conclusão de Curso de Pós-graduação *stricto sensu* e foi submetido(a) à arguição e avaliação se o trabalho contém produção científica para gerar artigo em periódico P≥50 pela Banca Examinadora que, em seguida, deliberou sobre o seguinte resultado:

(X) **APROVADO**.

( ) **APROVADO CONDICIONALMENTE**, mediante o atendimento das alterações sugeridas pela Banca Examinadora, constantes em formulários em anexo a esta Ata.

( ) **REPROVADO**, conforme parecer circunstanciado, registrado no campo Observações desta Ata e/ou em formulários em anexo a esta Ata., elaborado pela Banca Examinadora.

Observações da Banca Examinadora (caso não inexistam, anular o campo):

Nada mais havendo a tratar, o(a) senhor(a) Presidente declarou encerrada a sessão de Defesa, sendo a presente Ata lavrada e assinada pelos(as) senhores(as) membros da Banca Examinadora e pelo(a) discente, atestando ciência do que nela consta.

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DEDICATÓRIA

Dedico esta tese aos meus pais e meu irmão em primeiro lugar. E dedico também aos meus amigos, que estiveram comigo durante o caminho.

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RESUMO

As comunidades de peixes marinhos costeiros desempenham um papel importante na produtividade, a estabilidade das cadeias alimentares e conectividade entre habitats, sendo fundamental na funcionalidade dos ecossistemas marinhos. No Atlântico Sul, a estrutura das comunidades é resultado de fatores como as dinâmicas de descarga dos rios, a precipitação e a disponibilidade de recursos, que pode influenciar não só a composição, mas a diversidade funcional dessas comunidades. Compreender a estrutura funcional dessas comunidades é essencial não apenas para a gestão sustentável dos recursos, mas também para a conservação eficaz dos ecossistemas costeiros. Nesse contexto, a pesquisa investiga a diversidade taxonômica e funcional e os fatores que influenciam as comunidades de peixes em ambientes costeiros lodosos no Atlantico Sudoeste Sul. Os resultados revelam diferenças significativas na composição taxonômica entre as áreas estudadas, explicadas em parte pela distribuição dos estuários da região. A presença de diferentes pools de espécies ao em áreas costeiras resulta em padrões diversos de biodiversidade de peixes, indo além da simples riqueza e abundância de espécies. Esses achados contribuem para uma melhor compreensão da estrutura e dinâmica das comunidades de peixes em ambientes costeiros lodosos. Além disso, a análise dos dados em escala regional demonstra padrões distintos de distribuição e composição das espécies ao longo das províncias do Sudoeste do Atlântico Sul, indicando a influência de fatores ambientais e biogeográficos na estrutura taxonômica e funcional das comunidades. Esses resultados podem contribuir significativamente para o conhecimento da ecologia marinha na região e fornecendo subsídios importantes para a conservação da biodiversidade marinha no na região.

Palavras-chave: peixes costeiros, estrutura funcional, ambientes tropicais

ABSTRACT

Coastal marine fish communities play an important role in productivity, food chains stability and connectivity between habitats, being fundamental in the marine ecosystems functioning. In the South Atlantic, the structure of communities is a result of river discharge dynamics, precipitation and resource availability, which can influence not only the composition, but the functional diversity of these communities. Understanding the functional structure of these communities is essential not only for sustainable resource management, but also for the effective conservation of coastal ecosystems. In this context, the research investigates the taxonomic and functional diversity and the factors that influence fish communities in muddy coastal environments in the South-West Atlantic. The results reveal significant differences in the taxonomic composition between the areas studied, explained in part by the distribution of the estuaries of the region. The presence of different pools of species in coastal areas results in different patterns of fish biodiversity, going beyond the simple richness and abundance of species. These findings contribute to a better understanding of the structure and dynamics of fish communities in muddy coastal environments. Furthermore, analysis of data on a regional scale demonstrates distinct patterns of species distribution and composition throughout the southwestern provinces of the South Atlantic, indicating the influence of environmental and biogeographic factors on the taxonomic and functional structure of communities. These results can significantly contribute to the knowledge of marine ecology in the region and provide important subsidies for the conservation of marine biodiversity in the region.

Key words: coastal fish, functional structure, tropical environments

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1. APRESENTAÇÃO

As comunidades ictiicas costeiras representam um componente essencial dos ecossistemas costeiros, pois desempenham um papel importante na composição da biodiversidade, estabilidade das cadeias alimentares, manutenção da cadeia pesqueira e funcionamento ecossistêmico marinho. No Atlantico Sul, a estrutura e composição funcional dessas comunidades é determinada pela interação de fatores bióticos e abióticos, ligadas principalmente às dinâmicas de descarga dos rios, precipitação e disponibilidade de recursos. Todas essas características somadas aos atributos funcionais das espécies, podem limitar a distribuição, a abundância e composição das comunidades. Por Isso, compreender essa estrutura é vital para a gestão sustentável dos recursos pesqueiros e para a conservação das funções ecossistêmicas. Tendo em vista a importância dessas comunidades, este estudo visa analisar a estrutura funcional das comunidades de peixes no Atlântico Sul, identificando os principais fatores ambientais geográficos e biológicos que moldam suas dinâmicas. A análise integrará dados ecológicos e funcionais para fornecer uma visão abrangente das interações ecológicas que caracterizam essas comunidades.

2. REVISÃO DA LITERATURA

2.1. Estudos biogeográficos

Estudos biogeográficos tentam explicar os padrões de diversidade e de distribuição de espécies atuais e extintas desde a escala local até a escala global (LOMOLINO, MARK V., RIDDLE, BRETT R., WHITTAKER, ROBERT J.; BROWN, 1998a). Para isso a biogeografia costuma atribuir padrões de distribuição de espécies ao processo de mudança de temperatura, salinidade, e disponibilidade de alimento (localmente), ou à eventos biogeográficos na escala temporal evolutiva, tais como movimentos tectônicos e formação de barreiras (regionalmente). Todos esses eventos em maior ou menor escala podem impedir ou facilitar outros eventos como variância e dispersão, levando a diversificação da composição e riqueza de espécies ao longo do globo. Apesar de parecer um tópico recente, a biogeografia começou a ser discutida a partir de alguns estudos geológicos e de distribuição de espécies do século 18 e foi impulsionada a partir de 1858 com as publicações de Darwin e Wallace (LOMOLINO, MARK V., RIDDLE, BRETT R., WHITTAKER, ROBERT J.; BROWN, 1998b). De fato, Wallace é considerado o pai da zoogeogeografia por ter dedicado sua vida a interpretar os conceitos da distribuição das espécies em um contexto evolutivo, tendo levantado hipóteses como: o clima tem efeitos na distribuição, fatores como predação e competição podem determinar a distribuição, assim como a dispersão e extinção de espécies de vários grupos. Além disso foi responsável por uma das primeiras divisões biogeográficas, incluindo algumas divisões batimétrica de alguns arquipélagos (WALLACE, 1878a).

Um dos primeiros trabalhos que buscou entender essas relações em ambientes marinhos foi de (BRIGGS, 1974), onde foram definidas zonas zoogeográficas e províncias marinhas a partir da taxa de endemismo dentro das províncias. Mais tarde, em 2007, SPALDIN utilizou dados mais recentes para limitar regiões biogeográficas marinhas em ambientes costeiros de plataforma continental baseado na identidade das espécies e levando em consideração a evolução, dispersão e isolamento. Assim, foram definidos reinos, províncias e ecorregiões como framework para a conservação de áreas marinhas protegidas (SPALDING et al., 2007a). Os reinos foram agrupados em polar, temperados e tropicais e subdivididos por bacias oceânicas de cada região, totalizando 12 reinos. Já as províncias foram definidas pela presença de biotas distintas com grande endemismo, e podem ser consideradas como unidade de isolamento evolutivo já que essas divergências decorrem das diferenças ambientais entre províncias. A menor unidade estabelecida são as ecorregiões, estas têm o propósito de serem usadas para fins de conservação e foram definidas pela similaridade da composição de espécies e os padrões ecológicos podem ser mais visíveis (SPALDING et al., 2007).

Apesar da importância das definições dessas regiões de endemismo e da consolidação do seu uso, estudos de biogeografia em ambientes marinhos podem ser dificultados pela falta de conhecimento biológico das espécies e das suas distribuições. Além disso, os fatores que influenciam as comunidades marinhas são diversos e nem sempre estão disponíveis nas bases de dados, como por exemplo, correntes, salinidade, profundidade, condição de fundo e barreiras (ACHA et al., 2004; MIRANDA; MARQUES, 2011). A dificuldade de definir barreiras que limitem a dispersão também pode ser um problema, especialmente porque as espécies respondem de forma diferente às condições ambientais, e o que limita uma espécie pode ser irrelevante para outra. Por exemplo, para espécies autótrofas, a falta de luz em grandes profundidades limita sua distribuição, mas não tem nenhum impacto em espécies bentônicas (PEREIRA; SOARES-GOMES, 2002). Assim como as variações de salinidade em ambientes estuarinos que podem limitar a entrada de espécies que não tenham tolerância às variações de salinidade (BARLETTA, 2004a).

2. 2 . Condições abióticas do Atlântico Sul

A região do sudeste do Atlântico Ocidental é caracterizada pelas porções tropicais, que inclui a plataforma Norte do Brasil e a plataforma tropical do Atlântico Sudoeste (área que corresponde a foz do Amazonas até Santa Catarina no sul do Brasil), e a porção quente e temperada que se estende de Santa Catarina no Brasil, até a Península de Valdez no sul da Argentina (BRIGGS; BOWEN, 2012a; HALPERN; FLOETER, 2008; SPALDING et al., 2007a) formando assim um gradiente ambiental. Nessa região encontram-se 4 províncias Plataforma Norte do Brasil, Atlântico Sudoeste Tropical, Atlântico Sudoeste temperado quente e parte da província Magellanica que segundo SPALDIN (2007) divergem em sua biota devido as diferenças nas características abióticas nas proximidades dos seus limites (ou seja, na área de separação entre províncias). E entender como essas características ambientais impactam a composição de espécies é importante para entender os padrões de distribuição atual.

A província ao norte, próxima ao equador, tende a ser mais quente, sob a influência de uma corrente quente (corrente do Norte do Brasil) somada a variabilidade na temperatura, precipitação e área de cobertura manguezal sessa região (VILAR et al., 2013a; VILAR; JOYEUX; SPACH, 2017), resultando no aumento na riqueza e abundância das assembleias ictiícas da costa brasileira. A entrada do grande volume das águas túrbidas do rio Amazonas também exerce influência nas comunidades estuarinas no Norte, onde se observa uma maior abundância de espécies únicas se comparada com outros estuários no Brasil (VILAR et al., 2013a). De forma semelhante, a presença da bacia amazônica é considerada o fator principal na taxa de endemismo de 25% na plataforma Norte do Brasil e nas diferenças na composição de espécies com o Caribe (BRIGGS; BOWEN, 2012b).

À medida que movemos em direção ao sul, a costa é marcada por uma plataforma continental estreita, uma corrente quente e fraca (corrente do Brasil) flui em direção ao sul. Além disso, a grande complexidade de habitats nos trópicos, incluindo manguezais, recifes de coral e florestas tropicais, oferece às espécies uma diversificação de micro-habitats e nichos, permitindo que elas coexistam (PIANKA, 1988, KOSTOLEV et al, 2005) e podendo aumentar a diversidade nessas áreas. A dinâmica estuarina, a grande descarga de nutrientes e processos de estuarinização também ajudam a sustentar essa diversidade em áreas costeiras (LONGHURST; PAULY, 1987a), mas existem outros fatores que são importantes para as comunidades. Essas regiões de transição entre as províncias e a descarga d'água nos estuários, ou encontro de massas de água com os oceanos formam o que chamamos de *fronts,* onde existem maiores variações de salinidade, densidade e turbidez podendo funcionar como barreiras para as espécies estuarinas (ACHA, EDUARDO M., ALBERTO PIOLA, OSCAR IRIRBARNE, 2015) e também para algumas espécies recifais que podem utilizar os estuários no seu ciclo de vida como Carangideos e Serranideos (FLOETER et al., 2008a).

A porção sul do Atlântico, que compreende a Argentina até a Terra do Fogo, possui uma das plataformas continentais mais amplas e exibe uma confluência oceanográfica entre a corrente do Brasil, que flui para o sul, e a corrente das Falklands/Malvinas, que traz água subantártica fria do Sul e prevalecem fundos arenosos com alta salinidade(COUSSEAU et al., 2020) . A temperatura diminui juntamente com a precipitação e a entrada de rios nessa região, causando um aumento da salinidade que pode limitar a distribuição da diversidade de várias espécies de peixes (BARLETTA, 2004b) e pode ser uma restrição para algumas espécies, reduzindo a biodiversidade.

2. 3. A diversidades taxonômica e funcional

A diversidade e riqueza de espécies têm sido usadas há décadas para entender os padrões e fatores que influenciam a distribuição de espécies. De forma direta, a riqueza é o número de espécies em uma comunidade e a diversidade é a função da frequência relativa das espécies (KEYLOCK, 2005). Diante da quantidade de estudos, foram definidos diversos padrões, tais como alta riqueza de espécies nos trópicos, baixa riqueza em grandes elevações e a relação da diversidade com fatores abióticos como temperatura, precipitação e salinidade (BARLETTA, 2004a; GASTON, 2000a). Em ambientes marinhos os padrões latitudinais também são observados e são influenciados também pela produtividade primária. Os ambientes costeiros tropicais são conhecidos pela produtividade e complexidade de habitats e abrigam grande diversidade de organismos estuarinos, recifais e marinhos (BARLETTA et al., 2010). Essa configuração taxonômica se reflete nas características ecológicas, onde normalmente se observa espécies de menor tamanho corporal e menor nível trófico em resposta ao maior número de indivíduos disputando recursos (HAYDEN et al., 2019).

A diversidade funcional é mensurada a partir de conjuntos de traços dos organismos que têm influência direta em alguns aspectos do funcionamento ecossistêmico, por isso, é considerada uma ferramenta importante para entender os processos das funções ecossistêmicas (TILMAN, 2001). Os traços são características morfológicas, fisiológicas e fenológicas que podem ser medidas em cada indivíduo e que interferem em como as espécies vão performar determinada função ecossistêmica (VIOLLE et al., 2007). As características morfológicas como o tamanho das espécies são importantes para entender as várias dimensões da sua ecologia, e por meio desses traços, é possível definir como as espécies se comportam, como se adaptam e de que forma utilizam os habitats e seus recursos (SIBBING; NAGELKERKE, 2000). Já os traços de história de vida estão ligados às estratégias de reprodução das espécies. Por isso, avaliar as características de fecundidade, comportamentos reprodutivos e cuidado parental, podem indicar questões ecológicas como abundância e resiliência das espécies (LADDS et al., 2018).

Assim, quanto maior a diversidade de espécies (e de traços) espera-se maior diversidade funcional (MICHELI; HALPERN, 2005). No entanto, as variações na diversidade funcional podem depender da identidade das espécies e do conjunto de seus traços, portanto comunidades com maior divergência nos seus traços são mais diversas que comunidades com mais espécies (HALPERN; FLOETER, 2008; VIOLLE et al., 2007). Em ambientes costeiros os padrões de diversidade estão relacionados com diversos fatores, tais como as diferenças nas condições abióticas, e as perdas de habitat e espécies (MOUILLOT et al., 2014a; PASSOS et al., 2016a).

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3. CAPÍTULO I: Biodiversity dimensions of fish communities inhabiting coastal muddy bottoms in the Tropical South Atlantic

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Abstract

This study provides insights into the intricate dynamics of coastal muddy bottoms within tropical regions spanning from the Amazon to the São Francisco River estuary. Through species analysis, distinct species pools distributed across the Tropical South Atlantic have been identified, revealing diverse patterns in fish biodiversity that transcend mere species richness and abundance, extending to their functional composition. More precisely, significant variations in taxonomic composition among the studied areas were observed, with differences in species composition and the presence of exclusive species contributing to the rise of unique patterns in functional diversity, partly attributed to differences in biogeographical provinces. Moreover, local processes such as salinization and estuarization also play crucial roles in shaping the taxonomic and functional diversity patterns within coastal muddy bottoms. By acknowledging the distinctive characteristics and ecological significance of these habitats, we can ensure the preservation of fish communities and uphold their crucial roles as vital nursery and fishing grounds.

Keywords: functional structuring, coastal habitats, fishery grounds

3.1. Introduction

Information about biodiversity patterns is crucial to our understanding of the functioning and conservation of ecosystems. The distribution and diversity of species in different regions are shaped by evolutionary processes, as well as biogeographic, climatic, and ecological processes (BANNAR-MARTIN et al., 2018; BARLETTA, 2004b; VILAR et al., 2013b). Investigating these patterns in specific habitats is crucial for comprehending the mechanisms underlying biodiversity and its implications for ecosystem dynamics, as well as anthropogenic stressor factors.

In the Tropical South Atlantic, for instance, the dynamics of biodiversity are particularly intriguing due to the presence of unique environmental conditions and biogeographic features (HENRIQUES et al., 2017b; SPALDING et al., 2007). The region is characterized by two distinct provinces (the Northern Brazil Shelf and Southwest Tropical Atlantic provinces), that exhibit contrasting climatic and geomorphological characteristics, as well as three recognized barriers: the Mid Atlantic Ridge, the discharge of the Amazon River, and the Benguela Current (FLOETER et al., 2008) . These barriers influence species dispersal, promoting allopatric speciation events, while occasionally allowing for connectivity and metapopulation formation(IBAÑEZ et al., 2022).

The Northern Brazil Shelf province experiences a hot and humid climate, and it is strongly influenced by the significant water influx from the Amazon River (GOUVEIA et al., 2019). This discharge leads to increased phytoplankton biomass and productivity, creating favorable conditions for fish species associated with muddy bottoms. These fish species have adapted to thrive in turbid waters, relying on the abundant organic matter and nutrients (BRIGGS; BOWEN, 2012c; VILAR et al., 2013b). In contrast, the Southwest Tropical Atlantic province has a narrow continental shelf, characterized by many smaller rivers that form estuarine systems with low biological productivity (EKAU; KNOPPERS, 1999). Phytoplankton biomass in this region is directly influenced by the flow of these small rivers, which fluctuates with seasonal variations and precipitation levels (NETO et al., 2014). Consequently, differences in productivity and isolation between these regions have a significant impact on the assembly of aquatic communities, especially in coastal areas.

Among the various habitats within these regions, coastal muddy bottoms hold particular ecological importance as they play essential roles as nursery and fishery grounds. Muddy bottoms are characterized by high levels of organic matter, fine sediments, and nutrient input derived from the animal’s excretion, bioturbation, and decomposition of organic material from rivers and estuaries(MCLUSKY; ELLIOTT, 2004). These environments support a diversified macrofauna and contribute greatly to coastal productivity. Furthermore, the detrital food chain operating in muddy bottoms enhances nutrient cycling (Caliman et al. 2011), leading to the presence of a variety of fish species associated with these environments (Loureiro et al. 2016; Ferreira et al. 2019).

Understanding the dimensions of biodiversity on coastal muddy bottoms is vital due to their crucial roles in providing shelter, food, and suitable conditions for reproduction and early development of numerous species (MARTINHO et al., 2007). These habitats contribute to the maintenance of fish populations and overall ecosystem functioning, while also supporting local fisheries by harboring commercially valuable species (AGUILAR-MEDRANO; VEGA-CENDEJAS, 2019; CAPEZZUTO et al., 2020). However, studying diversity patterns within presents many challenges, given the biogeographic differences discussed earlier. Variations in the total area of the study, and the diversity of fishing methods employed in each region can hamper the analysis and interpretation of biodiversity profiles (WIJERMANS et al., 2020). Nevertheless, overcoming these issues and unraveling the mechanisms driving community assembly in these habitats are critical for effective conservation and management strategies.

Therefore, the primary objective of this study is to investigate the patterns in the dimensions of biodiversity on coastal muddy bottoms within the Neotropical South Atlantic. Specifically, we aim to assess the different components of taxonomic and functional diversity (alpha and beta), focusing on understanding the effects of the regional species pool on trait composition and functional space within the community. By examining these patterns, we expect to obtain insights into the ecological processes shaping the biodiversity of these essential nursery and fishery grounds, assisting the development of effective conservation and management approaches.

3.2. Materials and methods

3.2.1. Study area

The study area encompasses the Neotropical South Atlantic, which is considered a highly productive area, influenced by a wide set of environmental and climatic factors. The North region is dominated by a humid tropical climate, where the actions of two ocean currents (the North Brazil Current and the Guiana Current), and significant tidal ranges are observed in its coastal environment (SILVA et al., 2021). The productivity of the area is mostly influenced by terrigenous inputs, with the discharge of the Amazon River forming a unique ecosystem along a large portion of the coast(SMITH; DEMASTER, 1996). The coastal bottom and its wide continental shelf are predominantly composed of sediments, mainly mud and sand, with few areas of gravel and calcareous algae (NITTROUER; DEMASTER, 1986).

In the Tropical Southwest Atlantic province, the dominant climate is tropical dry, with two well-defined seasons (dry and rainy) determined by the rainfall regime. This region is dominated by the Brazil Current, the southern branch of the South Equatorial Current (SILVA et al. 2021). The narrow continental shelf (between 20 and 50 km) found throughout the area is characterized by the presence of large reef barriers, with the substrate of the bottom dominated by terrigenous or organogenic sediments (sand and mud). The productivity of the area is considered moderate, with the drainage of continental waters influencing the narrow coastal strip (EKAU E KNOPPERS, 1999).

3.2.2. Data acquisition and species classification

A total of 29 sampling points were set throughout the Neotropical South Atlantic (Figure 1). Each station was sampled with the assistance of their corresponding fleets to ensure the representation of the captured fauna in the area. The fishing methods employed in these regions exhibit considerable diversity, encompassing a wide array of strategies and gear due to differences in the total area extent covered by each fishing ground, and the size of the catch obtained.

For instance, in the Northern Brazil Shelf province, industrial-scale fishing dominates, utilizing pair trawling techniques at depths ranging from 20 to over 60 meters. Conversely, artisanal fishing prevails in the Southwest Tropical Atlantic province, characterized by an extensive fleet of canoes, rafts, and small motorized vessels (up to 13 meters in length), working at depths ranging from 2 to 30 meters. Nonetheless, for the present study, only data from trawl nets used in shrimp species fisheries were included, as they are the main fishing strategy applied on muddy bottoms (see Supplementary Information – Table S1).

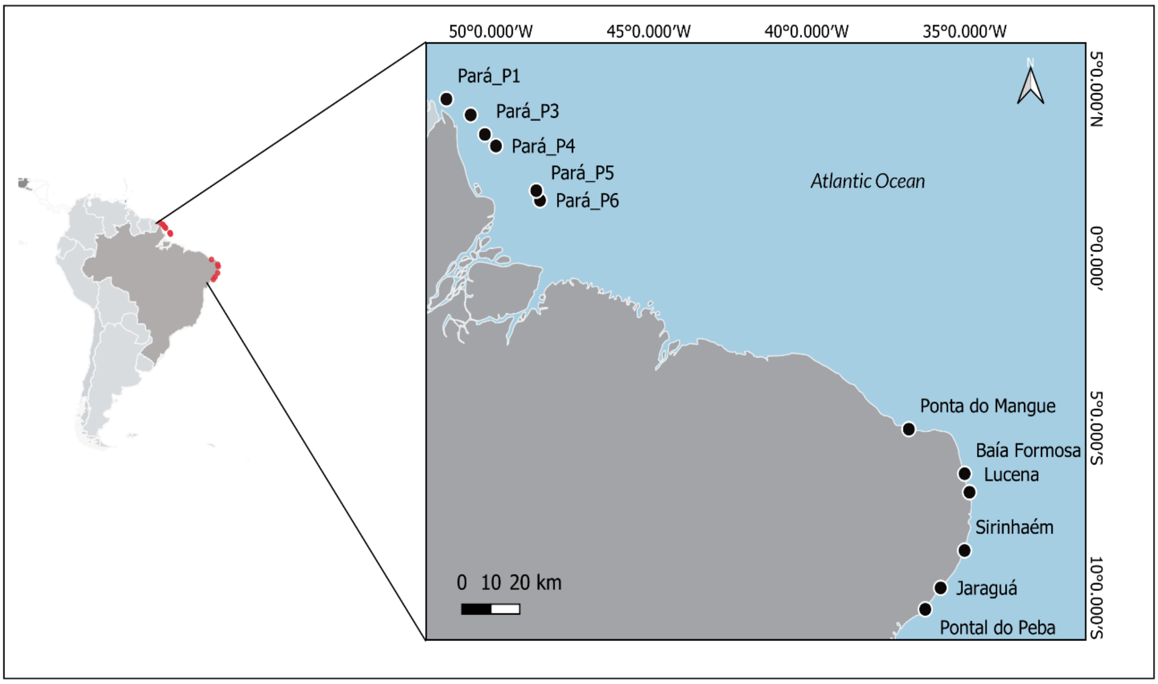

Figure 1. Map of the study area located in the Tropical Southwestern Atlantic, showing the sampling locations (black dots).Map of the study area located in the Tropical Southwestern Atlantic, showing the sampling locations (black dots).

All collected individuals were transported to laboratory facilities to undergo species identification and accurate morphometric recording. Subsequently, the fish species were subjected to further characterization based on a comprehensive set of eight functional traits (Table 1) associated with swimming efficiency, movement capacity, feeding behavior, and habitat utilization (SIBBING; NAGELKERKE, 2000; WATSON; BALON, 1984). To acquire this information, we used previously published works, as well as online databases (such as the FishBase), except for the calculation of the body shape index, which relied on the morphometric measurements obtained directly from the collected individuals. In order to facilitate subsequent functional analyses, a species-trait matrix was constructed using the compiled data.

Table 1. Description and interpretation of the traits used for the functional characterization of species collected throughout the Neotropical South Atlantic.

Functional traits		Variable type	Categories	Ecological meaning
Trophic	Mouth angle	Categorical	Bottom, top and terminal	Catchability of prey
	Type of dentition	Categorical	Flat, canine, conical, fused, incisor, molariform, nodular, triangular, tricuspid, villiform	Catchability of prey
	Trophic guild	Categorical	Herbivores, sessile invertebrates, mobile invertebrates, mobile invertebrates and detritus, mobile invertebrates and fish, piscivores and planktivores	Diet
Morphological	Aspect-ratio of caudal fin	Continuous	-	Swimming efficiency
	Body shape index	Continuous	-	Locomotion
	Maximum length	Continuous	-	Trophic position
Habitat use	Vertical use of the water column	Categorical	Benthic, benthopelagic, pelagic and reef	Habitat use and feeding strategy
	Horizontal use of the water column	Categorical	Coastal, neritic and oceanic	Habitat use and feeding strategy

3.2.3. Diversity measures and statistical analysis

Fish density for each haul was expressed as the total number of collected individuals per haul divided by the product of the swept area(GHODRATI SHOJAEI; AMIN TAGHAVI MOTLAGH, 2011). To analyze and identity patterns in species composition, two approaches were applied. First, a non-metric multidimensional scaling (NMDS) was performed using the "metaMDS" function (k = 2 dimensions and 100 iterations), based on Jaccard's distance as the dissimilarity measure (LEGENDRE; LEGENDRE, 2012). This iterative procedure, based on random start configurations, aimed to achieve a stable global solution for the ordination, as well as to mitigate the potential influences of different fishing gears applied during sampling. We also performed a clustering analysis for samples, using the Ward's method, and measured the indicator value (IndVal) of species to express species importance in community classifications (PODANI; CSÁNYI, 2010).

Following the examination of fish assemblages' composition, the next step was to analyze the observed patterns in sample aggregation using an analysis of dissimilarities, which was conducted using the "adonis" function available in the "vegan" package. This is a robust approach for conducting permutational multivariate analysis of variance with community ecology data, since dissimilarity patterns among fish assemblages can be thoroughly investigated while taking into account the underlying ecological factors that contribute to these variations (ANDERSON; WALSH, 2013).

Given the variability in size of fishing gear and sampling efforts, Hill numbers were applied to quantify the different diversity facets (taxonomic and functional) within each assemblage. The Hill number accounts for both species' richness and species abundance, providing a more comprehensive assessment of biodiversity. It offers several advantages as it is expressed in units of effective numbers of species, allowing for a more meaningful comparison of diversity across different assemblages in time or space (CHAO et al., 2014; CHIU; CHAO, 2014). This is particularly valuable when comparing communities with varying levels of rarity and commonness among the species, such as in this study.

Thus, we employed Taxonomic and Functional Hill numbers, following the approach outlined by Chiu and Chao (2014), to assess the different components of diversity (α and β-diversity) of studied assemblages by quantifying the effective number of equally abundant and functionally equally distinct species (CHIU; CHAO, 2014). Additionally, we incorporated the q factor to account for biomass effects, as described by (OHLMANN et al., 2019a). The q factor ranges from 0 to 2, where 0 represents species and/or functional richness, 1 represents the exponential Shannon entropy, and 2 generalizes Rao's quadratic entropy (OHLMANN et al. 2019).

Both taxonomic and functional β-diversity were calculated in a similar manner, converting the values into dissimilarity indices (β-Hill) that range from 0 (indicating samples with no shared species or trait composition) to 1 (representing identical samples). To compare taxonomic and functional diversity measures across regions, we conducted an analysis of covariance (ANCOVA) after confirming the normality and homoscedasticity of the data. We then used the “emmeans_test” function from the “rstatix” package, which performs a post-hoc pairwise comparisons between groups using the estimated marginal means for fitted models and profiles (KASSAMBARA, 2019).

3.3. Results

A total of 97,488 individuals belonging to 209 species were collected during the study period. Among these, 172 species were distributed throughout the Tropical Southwestern Atlantic, while 110 species were collected on the Northern Brazil Shelf. Clustering analysis based on the similarity of assemblage structures (Figure 2) revealed three distinct species pool among regions, which were subsequently confirmed by the PERMANOVA analysis (p=0.001).

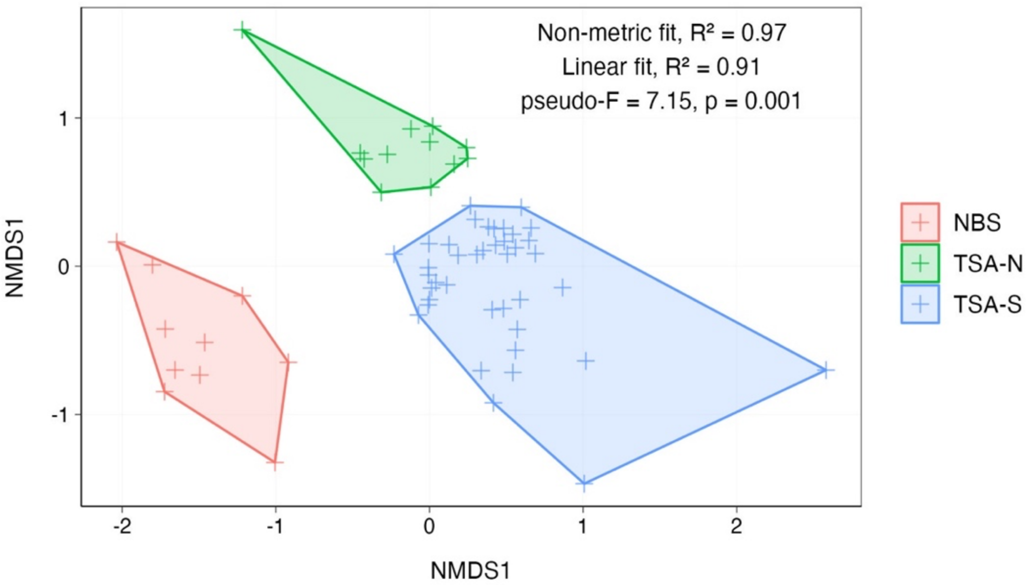

Figure 2. Multidimensional scaling (nMDS) applied to the similarity matrix of the collected species illustrating the significant differences in composition between three identified regions (NBS – Northern Brazil Shelf; TSA-N – North of the Southwestern Tropical Atlantic; TSA-S – South of the Southwestern Tropical Atlantic).

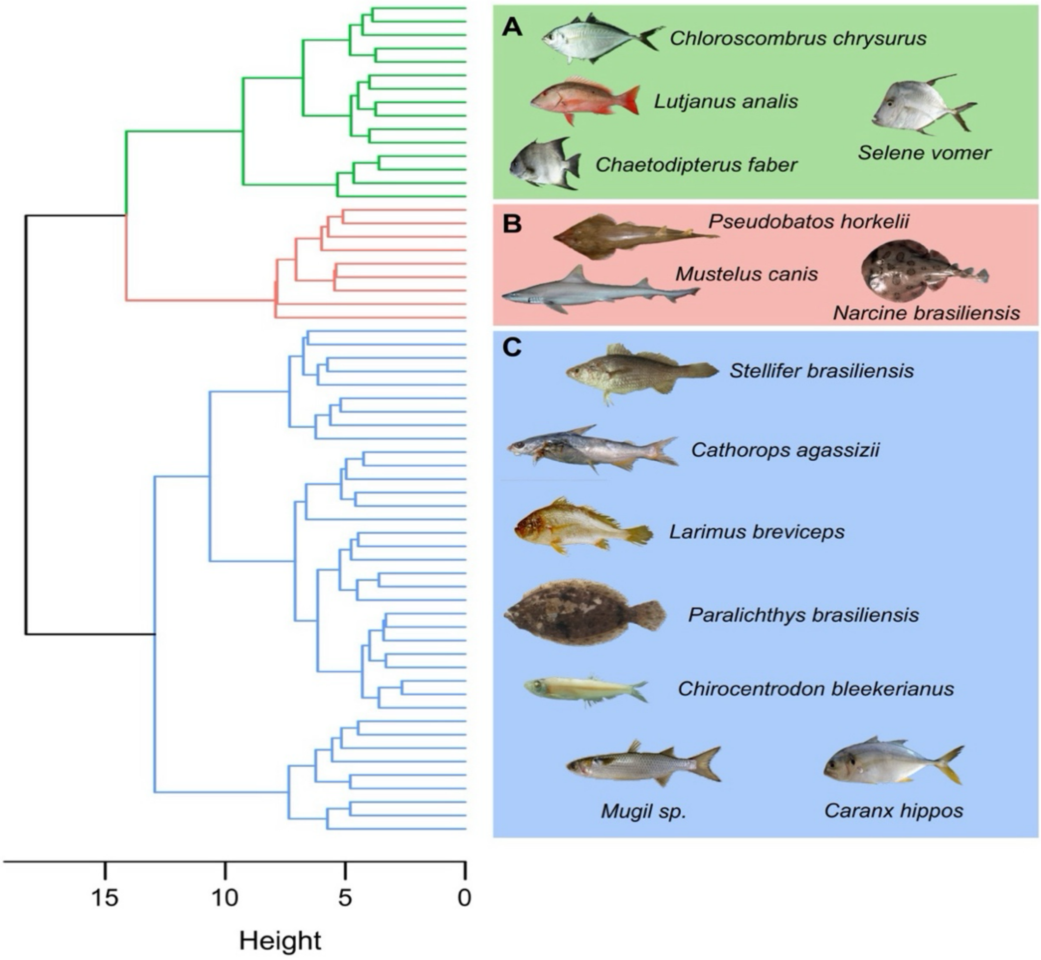

Figure 3. Analysis of similarity in species composition among samples, showing regional differences throughout the Neotropical Atlantic and the three regions identified in our study (A – North of the Southwestern Tropical Atlantic; B – Northern Brazil Shelf; and C – South of the Southwestern Tropical Atlantic).

The first group of species consisted of sampling points distributed along the Northern Brazil Shelf province (NBS), which were characterized by the presence of elasmobranchs and larger-sized fish, such as Mustelus canis, Pseudobatos horkelii and Narcine brasiliensis (see Table S2 for the whole list of species). The second group represented sampling points located north of the Southwestern Tropical Atlantic province (TSA-N) that featured many reef-associated species (i.e., Lujanus analis, Selene vomer, and Chaetodipterus faber), while the third one (TSA-S) comprised sampling points situated in the southern part of this province, mainly comprised for species predominantly belonging to coastal-estuarine environments, especially Cathorops agassizii, Larimus breviceps and Sciades herzbergii (Fig. 3).

The regions displayed significant variations in both taxonomic and functional alpha-diversity (Figure 4 and Table 2). However, the observed patterns were not congruent. Specifically, while meaningful differences in taxonomic diversity were only observed between TSA-N and TSA-S (ANCOVA, F= -2.992, p=0.012), it is noteworthy that TSA-N exhibited lower values of functional diversity even when compared to NBS (F=2.725, p=0.012), despite the absence of significant variation in species diversity between the two areas.

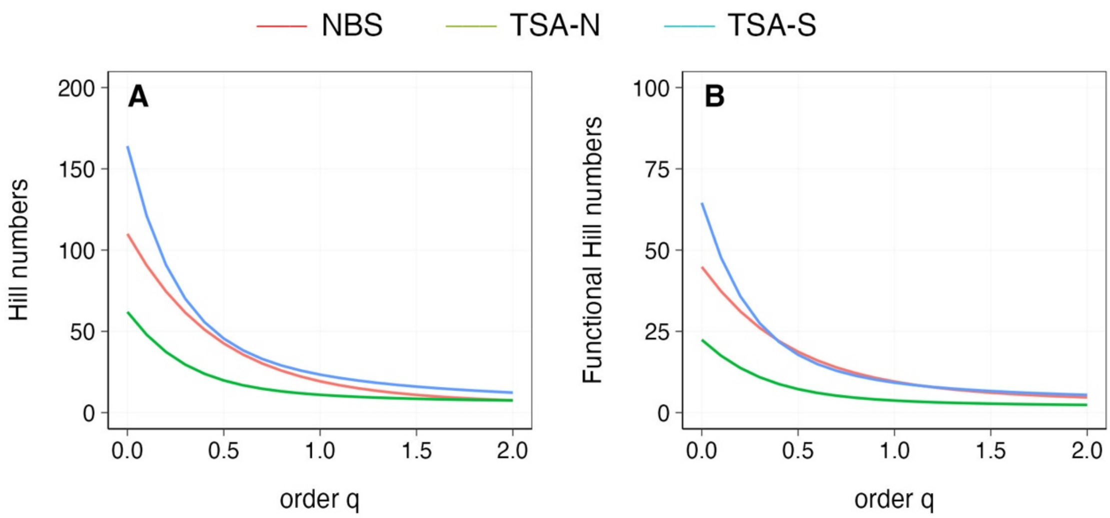

Figure 4. Diversity profiles as a function of order q for ordinary Hill numbers (A), and functional Hill numbers (B), where NBS – Northern Brazil Shelf; TSA-N – North of the Southwestern Tropical Atlantic; and TSA-S – South of the Southwestern Tropical Atlantic.

Table 2. Estimated marginal means (EMMs) applied as a post-hoc test to detect significant differences in biodiversity dimensions among identified regions (NBS – Northern Brazil Shelf; TSA-N – North of the Southwestern Tropical Atlantic; TSA-S – South of the Southwestern Tropical Atlantic).

Comparison	Taxonomic diversity		Functional diversity	
	Statistic	p-value	Statistic	p-value
NBS × TSA-N	1.919	0.089	2.725	0.012*
NBS × TSA-S	-1.176	0.244	-0.586	0.559
TSA-N × TSA-S	-2.992	0.012*	-3.231	0.006*

Examining the similarity in species composition within the study area, the analysis unveiled a small resemblance among regions (Fig. 5A). However, when delving into functional composition, we consistently observed higher β-Hill numbers across all three areas, indicating a significant level of redundancy (Fig. 5B). These results strongly suggest that multiple species within each region contribute to similar ecological functions, highlighting a noteworthy degree of functional convergence within the ecosystems under study.

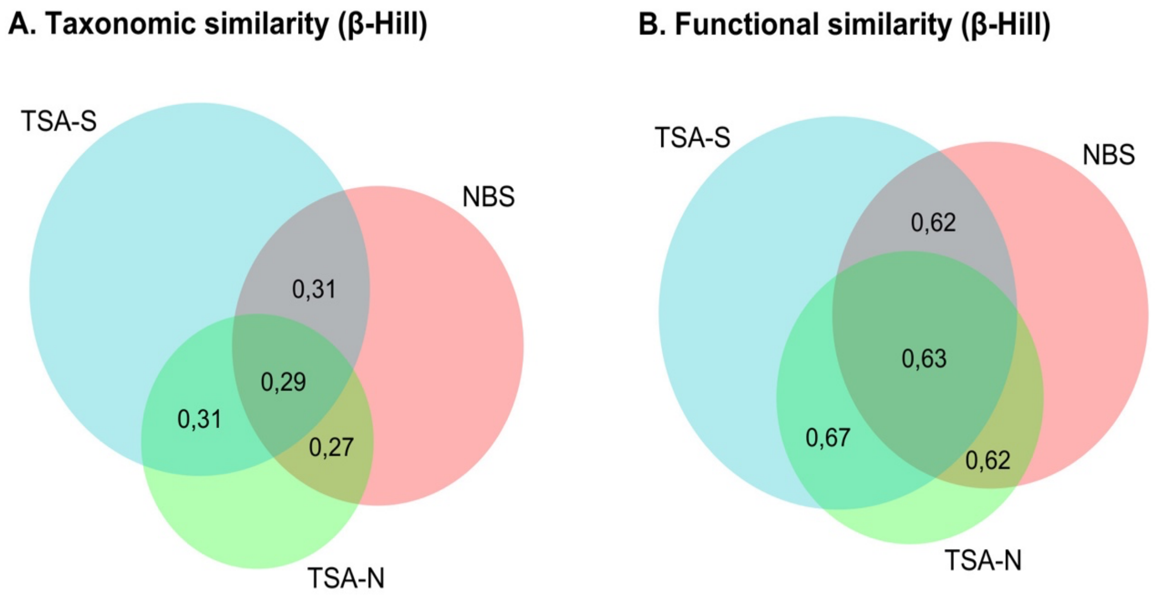

Figure 5. Similarity in species composition (A) and trait composition (B) of fish species inhabiting coastal muddy bottoms along the Neotropical South Atlantic (NBS – Northern Brazil Shelf; TSA-N – North of the Southwestern Tropical Atlantic; TSA-S – South of the Southwestern Tropical Atlantic).

3.4. Discussion

The findings presented in this study unveil the complex nature of coastal muddy bottoms in tropical regions. The taxonomic structuring shows the existence of distinct species pools that are dispersed across the study area, giving rise to diverse patterns across multiple dimensions of fish biodiversity. These patterns go beyond species richness and abundance, extending to the functional composition of the fish communities present.

For example, the taxonomic composition of muddy bottoms in the Tropical South Atlantic exhibited significant differences among studied areas, indicating the presence of three species pools influenced by regional biogeographic provinces. In the Northern Brazil Shelf (NBS) province, the influx of continental waters from major rivers such as the Orinoco and the Amazon enriches nutrient inputs, leading to increased productivity and species diversity (VILAR et al. 2013). These environments in the NBS coast exhibit high macrofauna density and richness, driven by a wide set of factors, such as habitat heterogeneity provided by vegetation and the complex local hydrodynamics, which contribute to the variation in macroinfaunal structure(KNEIB, 1984; RADER, 1984; SANTOS et al., 2020). This diverse community creates a favorable environment for a wide range of fish species, offering abundant benthonic food sources and enhancing ecological complexity, especially by the presence of elasmobranchs *Pseudobatos horkelii* and *Narcine brasiliensis* and larger-sized fish, such as *Mustelus canis* (CAVALCANTI-LIMA et al., 2023; MAGALHAES; PEREIRA; DA COSTA, 2015; SANTOS et al., 2020).

On the other hand, the coastline of the northern portion of the Tropical Southwestern Atlantic (TSA-N) presents a different scenario, as it serves as a significant transitional zone where the South Equatorial current bifurcates, dividing the area into two distinct fragments (PEREIRA et al., 2014; PETERSON; STRAMMA, 1991). This division creates a corridor, but also a barrier for the fish fauna (Silva and Kampel 2022), contributing to significant changes in the diversity of coastal species in the region, including the presence of a mix set of species that may inhabit different parts of the TSA-N (GARCIA JÚNIOR; NÓBREGA; OLIVEIRA, 2015).

For instance, many works have shown that while the dynamics of the region, along with the presence of many coral reef formations enable the presence of reef species in coastal areas, as seen in our study, these features also prevent the expansion of other species southwards, which could explain why the area has a distinct pool of species, and also the lowest values of taxonomic diversity among regions (FLOETER et al., 2001; JOHANSSON et al., 2013; MOUILLOT et al., 2014b).

Another possible explanation for the high incidence of reef species along the coast is the presence of hypersaline estuaries, which contribute to this pattern of occurrence (SALES et al., 2018).

In the TSA-S region, local landscape characteristics such as the presence of mangroves, seagrass, and reef formations may contribute to the structuring of assemblages and enhance species richness (DA SILVA et al., 2018; DA SILVA; DOLBETH; FABRÉ, 2021). The southern coast of the Tropical Southwestern Atlantic is marked by high influx of freshwater and sediments, which results in an estuarine-like condition that extends throughout many habitats along the coast, especially muddy bottoms (LONGHURST; PAULY, 1987b). This process, known as "estuarization", brings about significant changes in productivity levels and environmental factors such as salinity, turbidity, and dissolved oxygen (DA SILVA; DOLBETH; FABRÉ, 2021; KRUMME; HERBECK; WANG, 2012; PASSOS et al., 2016b). As a result, these alterations affect the overall structure of the habitats and have an impact on the composition of fish communities (SALES et al., 2016), allowing the occurrence of many coastal and estuarine species, as seen in our results.

Differences in species composition and the presence of exclusive species in each region may also have subsidized the distinct patterns of functional diversity found within these communities. For instance, in the NBS region, the presence of elasmobranchs and larger-sized species with higher mobility and trophic levels may be associated with increases in functional complexity (PAULY; PALOMARES, 2001). More precisely, elasmobranchs and larger-sized species found within the region might suggest a complex interplay of trophic interactions and functional diversity. The top-down control exerted by elasmobranchs and the ecological roles fulfilled by larger-sized species contribute to the functional complexity of the ecosystem (DESBIENS et al., 2021). Through predation and influencing resource availability, these species can shape the behavior, distribution, and abundance of other organisms within the community (DESBIENS et al., 2021).

For example, elasmobranch mesopredators, including batoids and small sharks, play a significant role in structuring the community in coastal marine habitats, as they may use them as feeding and reproductive areas (DA SILVA et al., 2018; PETERSON et al., 2001). Their predation on shellfish serves as a crucial link between apex predators and lower trophic levels, particularly in nearshore sandflats and seagrass beds(MYERS et al., 2007; VAUDO; HEITHAUS, 2011). Here, we provide evidence of this role, as species such *Mustelus canis*, *Pseudobatos horkelii* and *Narcine brasiliensis* enhanced functional diversity in the northern regions of the Amazon estuary, characterized by extensive muddy habitats resulting from the flow of the Amazon River. *Mustelus canis* has been highlighted as a major opportunistic predator of coastal habitats, feeding on a wide range of prey items and having a complex foraging ecology (MONTEMARANO; HAVELIN; DRAUD, 2016).

Meanwhile, in the TSA-S region, the collected species predominantly belong to coastal-estuarine environments, which can be related to the great number of small estuaries distributed along the whole coast, such as *Mugil sp.* and *Cathorops agassizii*. The species reported herein inhabit marine habitats, but use estuaries during their life cycle, potentially playing a functional connectivity role between coastal and neritic environments due to their high mobility (DA SILVA et al., 2022; MACEDO et al., 2021). In addition, the tropical coastal fish assemblages present in the region have been strongly associated to increases in functionality of coastal habitats. Specifically, higher functional diversity (FD) profiles have been reported in shallow areas than in deeper areas, especially during the rainy seasons (MACEDO et al., 2023, 2021; PASSOS et al., 2016b).

The pulse created by the rainfall favors connectivity and the exchange of organisms between estuaries and the coast habitats, creating seasonal changes in temperature, currents, and nutrient input (MACEDO et al., 2023, 2021). The ordered energy is greater in the rainy season, which means that in this season, an enormous amount of energy is concentrated in fewer paths than in the dry season, probably, due to the detritus from the river flow (MACEDO et al. 2023). These patterns align with the relaxation of niche filtering since deeper areas are located further from the land and have a much greater volume of water. As a result, they are less abiotically influenced by seasonal changes in terrestrial precipitation and associated run-off and discharge (MACEDO et al., 2023; PASSOS et al., 2016b).

On the other hand, in the TSA-N region, the dominance of fish that are predominantly associated with reef environments may explain why the area has the lowest values of functional diversity in comparison to the other regions (Sibbing and Nagelkerke 2000). These fish species have evolved to thrive in highly specialized ecological niches, presenting a similar set of traits that enhances functional redundancy, where multiple species perform similar ecological roles or functions within the ecosystem (NYSTRÖM, 2006). For instance, the body shape of these species has been linked to their feeding and migratory behaviors, as they primarily reside in structured environments where movement is characterized more by maneuvering than high speeds (Reis-Júnior et al., 2023).

3.5 . Conclusion

In conclusion, our study elucidates the intricate relationship among environmental variables, species assemblages, and functional diversity within coastal muddy bottoms, highlighting their key role as crucial habitats for fish species in coastal ecosystems. These habitats serve as vital nurseries for many species, while also playing a fundamental role in supporting complex food webs, which facilitate nutrient cycling, and sustain fisheries activities.

The highlighted differences in diversity profiles among regions prompts a deeper investigation into the underlying factors influencing species assembly. It suggests the presence of unique ecological dynamics or environmental pressures within that may disproportionately affect the distribution or functional roles of species, thus warranting further exploration and contextualization. Acknowledging the distinct attributes and ecological significance of these habitats on a spatial scale is imperative for the formulation of effective conservation and management strategies, which are essential for the preservation of fish communities and the enduring maintenance of these areas.

3.6. Acknowledgements

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4.CAPÍTULO II: Assessing functional composition patterns in fish communities along the South-Western Atlantic

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Abstract

Describe diversity patterns is an important mechanism to access community ecology, and functional diversity approach has been a useful tool to understand how dimensions of biodiversity and ecology interact through the ecosystems. In coastal ecosystem of South-Western Atlantic, the high diversity of fish and diversification of environmental and geological condition, could be an interesting area to access the dimensions of biodiversity through all four completely different provinces. Thus, this study aims to investigate biogeographic patterns in the species and functional composition of the South-Western Atlantic. We collected 10113 species of four provinces from fishbase. Then, we classified them in guilds regarding their feeding habits, habitat use, energy allocation to growth and reproduction, and used their traits to obtain a functional space of the communities. Our results showed that temperate province in the south is less diverse compared to warmer provinces in the north. Taxonomic similarity was low between faraway provinces, on the other hand functional similarity and redundancy were high. The proportion of big, generalist and with maternal care species seems to be higher in the south. In contrast, the north holds small and specialist group of species. The differences in diversity and life strategies

between provinces is a result of different environmental conditions such as river discharges, habitat complexity and productivity. Also, the niche compression in tropical habitats, help us to understand diversity of species and food items in the north provinces.

4.1. Introduction

Biodiversity is an intricate product of evolutionary and ecological processes, which goes beyond the mere species' identification and counting in a particular region (MAZEL et al., 2014). A comprehensive understanding of its patterns requires considerable attention to a broad spectrum of variables, including the distribution of species and traits, as well as the underlying processes driving them. For example, established patterns like the latitudinal biodiversity gradient and Bergmann's rule have provided insights into biodiversity dynamics. They indicate a trend of increased richness and diversity from the poles to the equator and noticeable variations in organism size, with smaller individuals in warmer climates and larger ones in colder climates and higher latitudes (BERGMANN, 1847; GASTON, 2000b).

Various mechanisms have been identified as contributors to these patterns, particularly in tropical regions. A classic example lies in the evolutionary history of regions characterized by climate stability during glaciations, which facilitated heightened speciation processes, resulting in greater diversity in the tropics compared to temperate zones (CARNAVAL; MORITZ, 2008; WALLACE, 1878b). Conversely, some authors emphasize natural gradients in environmental factors and existing barriers as significant drivers, including temperature, productivity, habitat geomorphology, and ocean currents (LONGHURST, 2010; LONGHURST; PAULY, 1987b). For instance, in the marine coastal areas, higher and stable temperatures, coupled with abundant river inputs in the Tropical South, sustain elevated primary production levels (LONGHURST; PAULY, 1987b). This, along with the intricate habitat structures such as mangroves, coral reefs, and seagrass beds, provides diverse micro-habitats and niches, facilitating species coexistence.(KOSTYLEV et al., 2005; PIANKA, 2011)

Species interactions, such as competition and predation, further shape species distribution and influence diversity patterns (MACARTHUR, 1984). Despite this understanding, knowledge gaps persist, particularly in coastal environments (HULTGREN et al., 2021; TEICHERT et al., 2018). Fish assemblages in the Southwestern Atlantic seem to be influenced by dispersal limitations and temperature, with trait composition being more closely associated with variables related to connectivity between estuaries and the ocean (HENRIQUES et al., 2017b, 2017a). However, comprehending how environmental gradients impact trait composition and functional diversity in coastal environments remains a challenge (MACEDO et al., 2021).

The Southwestern Atlantic is characterized by its complexity, with varied environmental conditions and distinct sea geology configurations, resulting in diverse biogeographic provinces and ecoregions along its coast (SPALDING et al., 2007b)., Each region's unique characteristics influence biodiversity dimensions differently, emphasizing the need for a comprehensive approach. This region is home to numerous species, particularly in coastal systems, making it an important hotspot of species richness (VASCONCELOS et al., 2015). Identifying the factors driving biodiversity dimensions along its length is crucial. Our hypothesis suggests that environmental and geomorphological gradients shape biodiversity in the Southwestern Atlantic. Specific objectives include investigating biogeographic patterns in species and functional composition and defining latitudinal patterns in parental care.

4.2. Materials and methods

4.2.1. Data acquisition and dataset creation

The study area encompassed four provinces in the South-western Atlantic according to Spalding (2007) (Figure 1). We selected these provinces based on their composition and environmental differences. Data on the occurrence of fish species in the coastal and marine regions of the South-western Atlantic were extracted from publicly available databases, including ORBIS and GBIF. The data were obtained using the ‘robis’ and ‘rgbif’ packages for the R statistical software. Initially, the dataset contained 1147 records, but filtering was conducted to remove duplicates and ensure the accuracy of taxonomic classification for all identified species. This filtering process involved removing records with incomplete or inconsistent data, as well as those flagged as outliers based on their geographic location. The taxonomic classification of each species was also verified using the most recent taxonomic literature available, through the ‘rfishbase’ package (BOETTIGER; LANG; WAINWRIGHT, 2012).

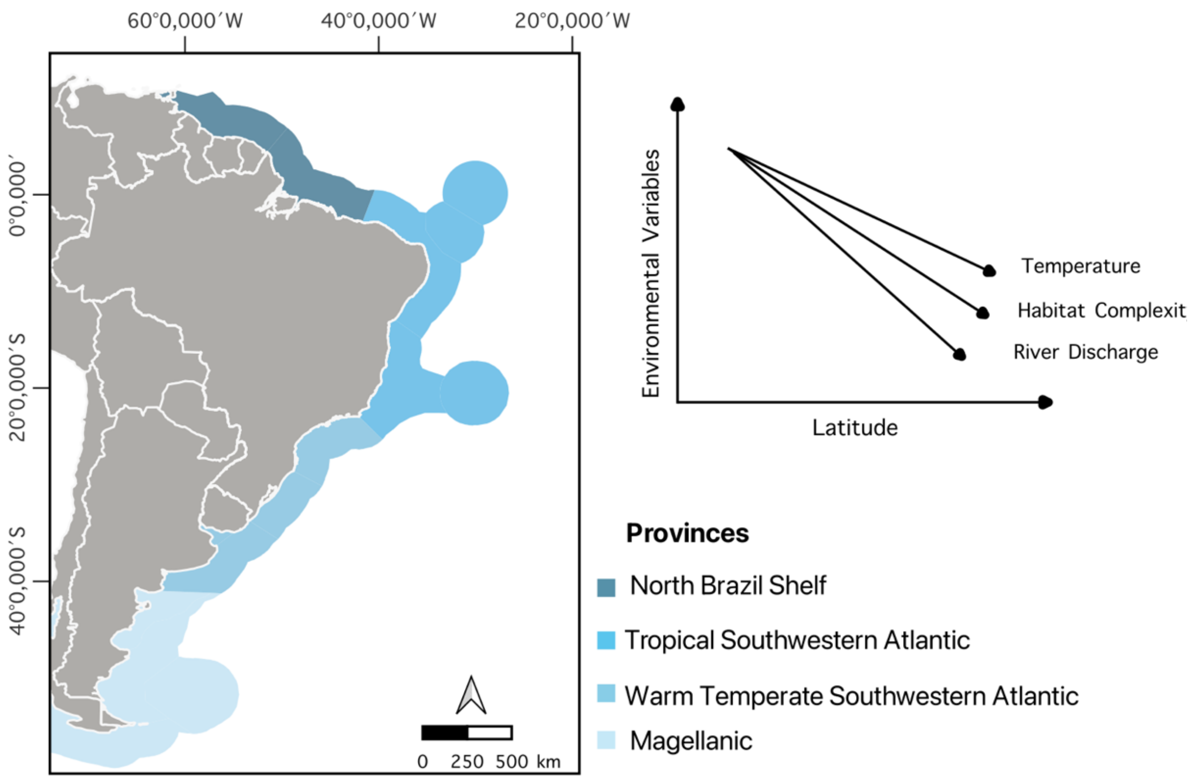

Figure 1. Study area showing Southwestern Atlantic coast with the provinces according Spalding et al. (2007). Also, the graphic shows environmental changes expected along the gradient in the area.

After correcting the database, the 'letsR' package was used to create a grid of 1x1 covering the entire study area (VILELA; VILLALOBOS, 2015). A matrix of species presence and absence was then generated, with each grid containing a binary representation of the occurrence of each species within. Our main goal was to create a database that comprises a comprehensive and up-to-date inventory of fish species occurring in the coastal and marine regions of South-Western Atlantic that would allow us to carry on a representative analysis of species and trait composition.

4.2.2. Functional traits of fish species

Functional traits were selected based on their well-known relationship with species performance in ecosystems, such as feeding habits, energy allocation to growth and reproduction, and habitat use (HENRIQUES et al., 2017a). We compiled a species-trait database with information retrieved from online databases(BEUKHOF et al., 2019; FROESE; PAULY, 2020) for four functional traits (Table 1). When data were not available from these sources, we conducted an online search for specific information and evaluated its reliability based on the reasonableness of reported values and the apparent credibility of the source. Because removing species with missing data could bias results for regional species assemblages (BRUM et al., 2017; NAKAGAWA; FRECKLETON, 2008), whenever information was not available for a particular species, we used existing data for the closest species in the same genus or family.

Parental care

Parental care refers to any investment, whether biological or behavioral, made by parents to ensure reproductive success by increasing the offspring's chance of survival (BAYLIS, 1981; GROSS, 2005a). In this study, we employed four categories as defined by (BALON, 1975) to characterize this life history trait: (a) non-guarders: these species exhibit no parental care, with external fertilization and zygotes not tended to by either parent. While this strategy may require less energy from parents, it often results in higher zygote mortality; (b) guarders: species in this category can identify and choose suitable spawning sites (such as under rocks, among plants, in caves, or nests), and the zygotes are cared for by one or both parents; (c) bearers:

fish in this group carry their zygotes, typically in the mouth, to protect the offspring and reduce predation risk; (d) maternal: involves internal fertilization in most species, with the zygotes carried inside the mother's body.

Salinity tolerance

(a)Freshwater and estuarine - species with low salinity tolerance and that able to move between freshwater and estuarine habitats; (b) Estuarine and estuarine - species are characterized by some tolerance to salinity changes, and depend on estuaries to complete their life cycle and/or feeding; (c) Estuarine and marine – species that moves easily between estuaries and marine environment, with tolerance to salinity change and (d) Marine – species strictly marine and high salinity tolerance.

Trophic guild

Since diet is related with species' position in the food chain**,** trophic guilds were organized bottom up in the following order: detritivores, Herbivorous, planktivorous, invertivores + herbivorous, invertivores, piscivores + invertivores, piscivores, piscivores. + Other vertebrates (birds, turtles).

Table 3. Functional traits used to estimate the functional diversity of fish species along the marine systems of the South-Western Atlantic.

Trait	Ecological meaning	Reference
Maximum body length (mm)	Generally associated with vertical position in the food web, energy allocation and life history	(HENRIQUES et al., 2017c)

	strategies, dispersal ability and home range	
Salinity tolerance	Physiological ability to deal with osmotic stress across the freshwater–marine ecotone	(HENRIQUES et al., 2017c)
Trophic guild	Role as consumer within the food web	(HENRIQUES et al., 2017c)
Parental care	Life history component generally associated with density-dependent population regulation	(LEFCHECK; DUFFY, 2015)

4.2.3. Statistical analysis

Taxonomic and Functional Hill numbers were employed to determine β-diversity following CHIU E CHAO (2014). We assessed species and trait distribution across each province by calculating the taxonomic and functional diversity of each grid. To accomplish this, we used the 'hillR' package to obtain Hill numbers. Taxonomic and Functional Hill numbers were used to quantify the effective number of functionally equally distinct species (CHIU; CHAO, 2014; OHLMANN et al., 2019a) and to assess abundance effects by weighting species dominance with a q factor (OHLMANN et al., 2019b). The calculation method for taxonomic and functional β-diversity had converted values into dissimilarity indices (β-Hill) that ranged from 0 (samples with no shared species) to 1 (identical samples). Comparisons between taxonomic and functional diversity measures for all provinces were carried out by an analysis of variance (ANOVA) since the normality and homoscedasticity of data were met.

To better understand patterns of distribution in both dimensions of diversity, we also calculated equivalent diversity measures for each grid, allowing for spatial comparisons. The taxonomic diversity component was expressed by the species richness (SR), which accounted for the total number of species found in each grid. Functional diversity was evaluated using the dendrogram length functional diversity (FD) proposed by (PETCHEY; GASTON, 2002), which is a non-abundance weighted diversity measure that incorporates small functional differences between species and simultaneously measures diversity at all hierarchical scales. While FD is expected to be correlated and have a significant relationship with SR, studies have shown that this relationship is weak at broader scales (ARNAN; CERDÁ; RETANA, 2017). Moreover, FD covary in different ways along geographic and environmental gradients (BERNARD-VERDIER et al., 2013; PURSCHKE et al., 2013) , making them suitable for studies that cross biogeographic regions. Heat maps using the estimated indexes were created using the “ggplot2” package.

4.3. Results

After correcting and filtering the database, we identified a total of 1,113 fish species distributed in coastal waters along the latitudinal gradient of the Southwestern Atlantic. Species richness varied significantly among the four provinces, with the highest number of species recorded in the Warm Temperate Southwestern Atlantic (WTSA) province (545 species), followed by the North Brazil Shelf (NBS) with 521 species, the Tropical Southwestern Atlantic (TSA) with 496 species, and the Magellanic (MAG) province with 143 species.

In terms of taxonomic composition, distinct patterns were identified, with the distance between provinces playing a significant role in estimating dissimilarity (Figure 2). In contrast, for the functional dimension, a pattern of redundancy was observed (Figure 2).

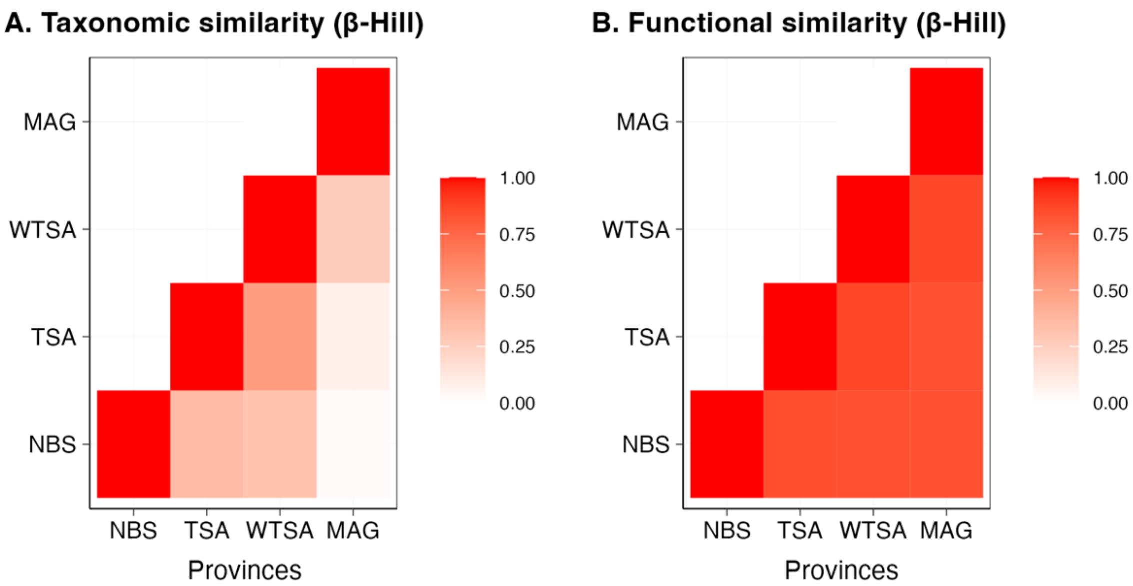

Figure 2. Similarity in taxonomic composition (A) and trait composition (B) of fish species among the four provinces along the latitudinal gradient of Southwestern Atlantic coastal waters.

Across all provinces, trends in fish traits unfolded systematically, reflecting variations in size, habitat use, parental care, and diet. Towards the northern regions, there was an increasing prevalence of small and medium-sized species, coupled with a greater diversity of habitat use guilds compared to the south (Figure 3). In addition, a broader array of feeding habits was also observed for the norther regions, resulting in a more complex dietary composition and a richer tapestry of trophic guilds and occupied niches. Conversely, in the southern reaches, larger and extra-large fishes were more common, suggesting a shift towards habitats conducive to their size and foraging behaviors. While most species across all provinces did not exhibit parental care behaviors, there was a notable increase in maternal care observed in the Magellanic province, particularly emblematic of southern regions.

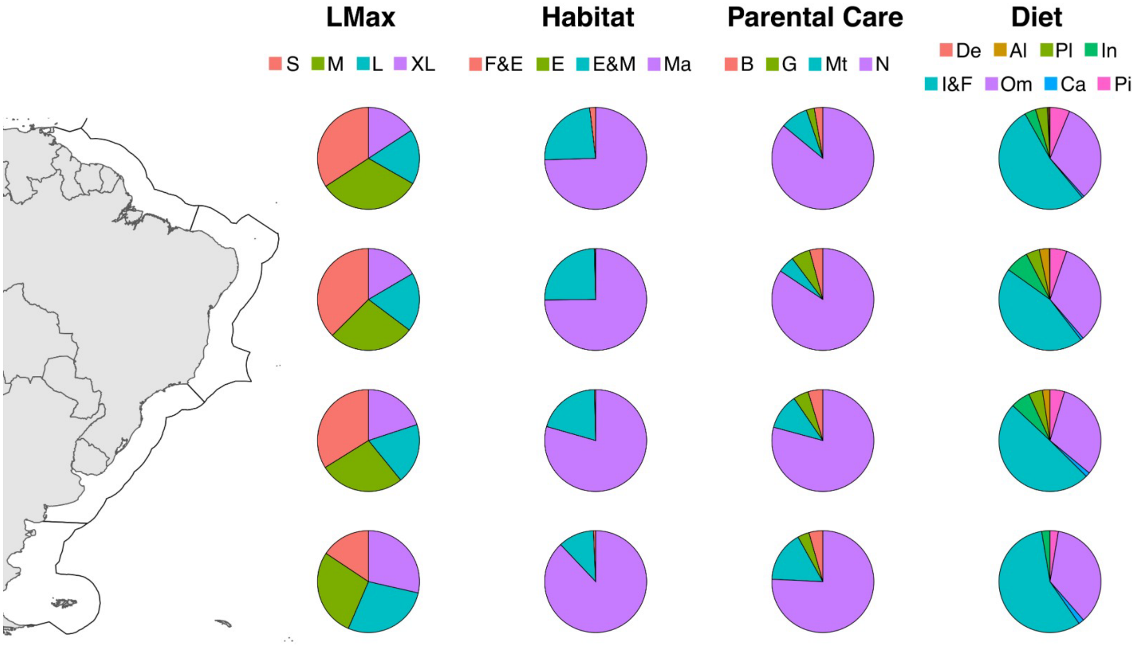

Figure 3. Proportions of traits represented in fish assemblages of coastal waters of four provinces in the Southwest Altantic..For maximum body length – S= small, M= medium, L= large, and XL = extra large; for habitat – F&E= fresh water and marine species; E= estuarine, E&M= estuarine and marine, M= marine; for parental care B= bearers, G= guarders, Mt= maternal care, N= no parental care; for diet – De= detritus, Al= algae, Pl= plankton, In= invertebrates, I&F= invertebrates and fish, Om= Invertebrates and plants, Ca= only fish, Pi= fish and other vertebrates (birds and turtles).

4.4 Discussion

Our study sheds light on the dimensions of fish diversity across the provinces of the Southwestern Atlantic. As expected, species richness exhibited a latitudinal gradient, with higher richness observed in tropical provinces, gradually decreasing towards the south. The similarity of fish communities and their diversity correlated with the proximity of provinces, with closer provinces sharing more species compared to those more distantly located. However, functional patterns were less predictable. While overall metrics of functional diversity indicated a redundancy pattern among regions, a closer examination of trait distribution revealed intriguing gradients in trait distribution across the study area.

In the North Brazil Shelf province, the pronounced diversity index and richness of species align with the latitudinal pattern of biodiversity (GASTON, 2000b). The region's biogeographical history, characterized by significant freshwater discharge from rivers such as the Orinoco and Amazonas, creates barriers to coastal dispersal for certain fish species (FLOETER et al., 2008c; ROCHA, 2003). This phenomenon likely contributes to regional patterns of endemism. Additionally, the presence of coral reefs along the coast, coupled with high productivity and habitat complexity, fosters greater species diversity in the area (ROCHA, 2003).

Conversely, in the Magellanic province, lower species diversity and limited species distributions along the coast may be influenced by variations in salinity and temperature. The region receives subantarctic water from the Antarctic convergence and discharges from ice melt originating from Tierra del Fuego, the Strait of Magellan, and rivers of Santa Cruz (COUSSEAU et al., 2020). Such factors lead to spatial variations in salinity, with coastal environments exhibiting lower tolerance to salinity changes compared to the open sea under the influence of the Falkland Current (BALECH; EHRLICH, 2008). Species occurrence in this region is contingent upon their ability to tolerate low temperatures and temporal and spatial fluctuations in salinity.

Provinces in close geographical proximity with similar environmental conditions are more likely to share similar species compositions (CHASE, 2003). For instance, the warm climate and presence of coral reefs in the North Brazil Shelf and Tropical

Southwestern Atlantic provinces contribute to the observed similarity in species composition. Coral reefs serve as specialized habitats for many marine species, particularly reef-associated fish, creating a common ecological niche and selecting for species adapted to coral reef environments.

The functional redundancy observed between provinces is consistent with previous studies on estuarine and reef fishes (BENDER et al., 2017; HENRIQUES et al., 2017d; MOUILLOT et al., 2014b). Tropical fish communities typically exhibit functional redundancy, with certain functional groups harboring a greater number of species due to phylogenetic trait conservatism. This redundancy enhances ecosystem functioning, stability, and resilience in the face of environmental change. However, rare species with unique functional trait configurations may play critical roles in ecosystem functions and may be particularly vulnerable to climate change (DA SILVA; FABRÉ, 2019).

In biogeographic regions exhibiting a pattern of redundancy, trait distributions tend to be homogeneous, characterized by two main combinations: large-bodied species with piscivorous diets and small-bodied species with omnivorous diets (BENDER et al., 2017). This pattern aligns with our findings and can explain the high proportion of small species with diverse feeding habits in the North Brazil Shelf province and the prevalence of large-bodied species feeding on fish and invertebrates in the Magellanic province. However, it is essential to recognize that trait distributions may be influenced by various ecological and environmental factors specific to each region, including temperature, salinity, and precipitation (HENRIQUES et al., 2017d). Therefore, it is important to take in consideration differences in trait distribution, even when faced with an apparent redundant patter.

For example, the Magellanic province exhibited a clear tendency towards larger body sizes, in line with Bergmann's rule, which suggests that organisms in colder environments tend to have larger body sizes. This may be attributed to metabolic efficiency in use and energy storage capabilities in cold environments, facilitating the success of large-bodied species such as pelagic species and sharks (DICKERSON, 1978; WALKER, 2005). Since energetic condition is what control parental investment in reproductive events (COOKE et al., 2006), larger body sizes in cold habitats may be associated with parental care strategies, as larger bodies individuals tend to have higher metabolic and lower fecundity rates, necessitating investment in parental care to ensure offspring survival (CARRIER; PRATT; CASTRO, 2004). Therefore, internal fertilization and maternal care are common strategies observed in the Magellanic province to safeguard offspring survival. Conversely, species in tropical provinces tend to be smaller and mature earlier (DICKERSON, 1978), which is associated with their lower metabolic rates (ALONSO-ALVAREZ; VELANDO, 2012; COOKE et al., 2006). Because of that, parental care seems to be energetically expensive to small body species, and they use other strategies to protect their brood such as small egg size, nesting and guarding behavior (COOKE et al., 2006; GROSS, 2005b; ZIĘBA et al., 2018).

In conclusion, our study reveals intricate patterns of fish diversity across the Southwestern Atlantic provinces. While we confirm the expected latitudinal gradient in species richness, we uncover nuanced variations in functional patterns. Factors such as freshwater discharge and habitat complexity drive biodiversity in certain provinces, while environmental gradients like salinity and temperature shape species distributions elsewhere. Proximity and environmental similarity facilitate species sharing among neighboring provinces, but the observed functional redundancy underscores the importance of considering trait distributions. Our findings underscore the need for a holistic understanding of ecological processes to inform effective conservation strategies amidst environmental change. Future research should focus on elucidating the mechanisms driving trait distributions and their implications for ecosystem resilience, while integrating climate change projections to anticipate and mitigate impacts on Southwestern Atlantic biodiversity.

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6. CONCLUSÃO

Em resumo, as comunidades de peixes do Atlântico Sul são fundamentais para a manutenção dos ecossistemas marinhos costeiros, e são influenciadas por diversos fatores bióticos e abióticos que afetam a distribuição e a abundância das espécies. Especialmente nos habitats considerados como berçário de diversas espécies de peixes, há uma forte correlação entre fatores ambientais, composição de espécies e diversidade funcional. Assim, os processos locais como salinização e estuarização ajudam a explicar a diversidade taxonômica e funcional em ambientes costeiros de fundos de lama.

Além disso, observamos um gradiente latitudinal já esperado na riqueza de espécies. Esse padrão de distribuição das espécies é resultado da influência de fatores como descarga de água doce e complexidade do habitat impulsionam a biodiversidade em certas províncias, enquanto gradientes ambientais como salinidade e temperatura influenciam outras comunidades.

No geral foi observado uma redundância funcional consistente tanto na escala local quanto na regional, a composição taxonômica e funcional são distintas, reforçando a importância de do pool de espécies locais para a manutenção da biodiversidade, na estabilidade das cadeias alimentares. Ademais, o funcionamento compreensão da estrutura funcional dessas comunidades é essencial para desenvolver estratégias de gestão sustentável dos recursos pesqueiros e para a conservação eficaz dos ecossistemas costeiros no Atlantico Sul.