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ICTIOFAUNA DE ESTUÁRIOS DA REGIÃO SEMIÁRIDA DO BRASIL: INVENTÁRIO DE ESPÉCIES, ASPECTOS FUNCIONAIS E INFLUÊNCIA DE EVENTO CLIMÁTICO

FORTALEZA
2023

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RESUMO

Muitos estuários da ecoregião marinha ‘Nordeste do Brasil’ são sazonalmente hipersalinos, e estão sujeitos a eventos climáticos extremos que podem modificar a composição da comunidade. É urgente entender as respostas das comunidades aos diferentes gradientes ambientais a fim de prever os efeitos das mudanças climáticas nos estuários influenciados pelo clima semi-árido da região Nordeste do Brasil. O presente estudo buscou fazer o inventário das espécies de peixes desses estuários (Capítulo 1), descrever as assembléias de peixes quanto à raridade e redundância funcional (Capítulo 2), e averiguar padrões taxonômicos e funcionais da ictiofauna com base nos diferentes gradientes de salinidade e épocas climáticas (Capítulo 3). A fauna de peixes foi amostrada de modo padronizado entre 2014 e 2020. As espécies foram classificadas quanto à dieta, uso do estuário, reprodução, posição na água e mobilidade. Medidas morfométricas também caracterizaram aquisição de alimento, locomoção e uso do hábitat. Foram calculadas raridades taxonômicas (restrição, R_i; escassez, S_i) e raridades funcionais (singularidade, U_i; distintividade, D_i) para cada espécie. Correlações entre as raridades averiguaram se espécies taxonomicamente raras também o são funcionalmente. Entidades funcionais (FEs) caracterizaram a redundância funcional das assembleias. A estrutura taxonômica foi comparada entre os estuários com NMDS e PERMANOVA. A estrutura funcional foi descrita por PCoA e caracterizada pelos índices de riqueza (FRic) e dispersão (FDis) funcionais. Simulações de perda de espécies foram realizadas a fim de averiguar como as espécies mais originais e especializadas contribuem para estrutura funcional dos estuários no tocante à FRic e FDis das assembleias. Foram coletadas 126 espécies de peixes em oito estuários ao longo da costa do Ceará. Os registros preenchem 224 lacunas de ocorrências nos estuários individuais. Muitas espécies foram regionalmente restritas, além de apresentarem baixa variação em U_i e D_i. As espécies foram inseridas em 44 FEs, das quais trinta abrigaram menos de três espécies, o que torna cerca de 30% das espécies com baixa redundância funcional. A composição taxonômica foi diferenciada entre grupos de estuários. Estuários em evento de seca prolongada perdem menos riqueza funcional à medida que as espécies mais originais e especializadas são excluídas. Em conclusão, os estuários possuem poucas espécies dominantes que são redundantes e muitas espécies raras que tendem a serem mais distintas funcionalmente. Além disso, são ambientes de elevada redundância funcional, mas ainda apresentam grande parte do conjunto de espécies com pouca ou nenhuma redundância em muitas FEs. Elevados níveis de salinidade modificam as estruturas taxonômica e funcional dos estuários, podendo ser conseqüência da marinização quando em eventos de seca extrema ou hipersalinidades. Isso pode trazer implicações para os efeitos das mudanças no clima nesses ecossistemas. Assim, o presente estudo providencia subsídios para futuras pesquisas e programas de conservação e manejo.

Palavras-chave: peixes estuarinos; ecologia funcional; semiárido; mudanças climáticas.

ABSTRACT

Most estuaries of the 'Northeast of Brazil' marine ecoregion are seasonally hypersaline, and are prone to extreme weather events that can modify community of the fish composition. It is urgent to understand community responses to different environmental gradients in order to predict the effects of climate change on estuaries influenced by the semi-arid climate of Northeast Brazil. The present study carried out an inventory of fish species in these estuaries (Chapter 1), described fish assemblages in terms of rarity and functional redundancy (Chapter 2), and investigated taxonomic and functional patterns based on different salinity gradients and climatic seasons Chapter 3). The fish fauna was sampled in a standardized way between 2014 and 2020. The species were classified according to diet, use of the estuary, reproduction, position in the water and mobility. Morphometric measures also characterized food acquisition, locomotion and habitat use. Taxonomic rarities (restriction, R_i; scarcity, S_i) and functional rarities (uniqueness, U_i; distinctiveness, D_i) were calculated for each species. Correlations between rarity indices verified whether taxonomically rare species are also functionally rare. Functional entities (FEs) characterized the functional redundancy of the assemblages. The taxonomic structure was compared between estuaries with NMDS and PERMANOVA. The functional structure was described by PCoA and characterized by functional richness (FRic) and dispersion (FDis) indices. Species loss simulations were carried out in order to find out how the most original and specialized species contribute to the functional structure of estuaries in terms of the FRic and FDis of the assemblages. A total of 126 species were collected in eight estuaries along the coast of Ceará. The records fill in 224 gaps for occurrences in individual estuaries. Many species were regionally restricted, in addition to presenting low variation in U_i and D_i. The species were inserted in 44 EFs, of which thirty had less than three species, which makes about 30% of the species with low functional redundancy. The taxonomic composition was differentiated between groups of estuaries. Estuaries in a prolonged drought event lose less functional richness as the most original and specialized species are excluded. In conclusion, estuaries have few dominant species that are redundant and many rare species that tend to be more functionally distinct. In addition, they are environments of high functional redundancy, but still present a large part of the species set with little or no redundancy in many EFs. High salinity levels modify the taxonomic and functional structures of estuaries, which may be a consequence of marinization during extreme drought or hypersalinity events. This may have implications for the effects of climate change on these ecosystems. Thus, the present study provides subsidies for future research and conservation and management programs.

Key-words: estuarine fish; functional ecology; semi-arid; climate changes.

SUMÁRIO

INTRODUÇÃO GERAL

Estuários são ecossistemas altamente produtivos que providenciam o sustento de grande biodiversidade e recursos genéticos por meio da alimentação, reprodução, abrigo e berçário para inúmeras espécies, incluindo espécies de importância comercial; regulam a ciclagem de nutrientes; filtram e assimilam poluentes; e capturam dióxido de carbono através de seus manguezais adjacentes (DAY Jr. *et al*., 2013). Estuários são ricos em biodiversidade de peixes (BLABER, 2000), no entanto, as pesquisas pretéritas sobre a ictiofauna realizadas nos estuários cearenses (BASÍLIO *et al*., 2009; OSÓRIO *et al*., 2011; BASÍLIO; GARCEZ, 2014; COSTA; LACERDA, 2014; PIMENTEL *et al*., 2016) apresentam informações pontuais, compreendendo organismos isolados ou a não avaliação de aspectos ecológicos em nível de assembleia. De fato, a costa nordeste brasileira tem sido reconhecida como uma área geográfica que requer inventários e estudos ecológicos para permitir uma apropriada e sustentável conservação e manejo dos seus recursos naturais (BRASIL, 2002). Estudos em estuários da costa semiárida do Brasil, que compreende a região entre os estados do Maranhão e Rio Grande do Norte (SOARES *et al*., 2021), ainda são escassos apesar de sua importância sócio-econômica para a pesca artesanal (BASÍLIO; GARCEZ 2014) e para uma diversidade de peixes e outros organismos (SALES *et al*., 2016).

Alguns estuários entre os estados do Maranhão e Rio Grande do Norte são peculiares. A maioria dos sistemas de rios nessa faixa costeira, de aproximadamente 1000 km, é pequeno e influenciado por regimes hídricos intermitentes, com domínio de manguezais e hipersalinos (VALENTIM *et al*., 2018; SOARES *et al*., 2021). Estuários negativos, também conhecidos como invertidos, são típicos de regiões onde o clima promove déficit hídrico nas bacias hidrográficas, geralmente agravado por barramentos, tornando o fluxo do rio muito fraco ou inexistente, havendo invasão da água oceânica continente adentro, pondendo gerar gradiente salino invertido, crescente à montante (POTTER *et al*., 2010). Nas últimas décadas uma redução na precipitação foi constatada na região da costa semiárida do Brasil (MARENGO *et al*., 2018), fazendo dessa zona costeira vulnerável às mudanças no clima, com aumentos de nível do mar e na freqüência de secas (UTIDA *et al*., 2019). Dessa forma, existe a possibilidade de alterações drásticas na salinidade estuarina, comprometendo a estrutura das assembleias de peixes (SOARES *et al*., 2021; GURGEL-LOURENÇO *et al*., 2022). Além disso, os estuários do Ceará têm sofrido agravamento histórico em diversos tipos de impactos ambientais (GORAYEB *et al*., 2005; SANTANA *et al*., 2015; FERREIRA; LACERDA, 2016). Muitos fatores prejudicam a qualidade ambiental como alastramento de zonas urbanas, de agriculturas e desenvolvimento industrial, outras formas de poluição, e sobrepesca (SANTANA *et al*., 2015). Isso pode acelerar a perda da biodiversidade, o que preocupa pelo valor intrínseco das espécies e pela perda de funções nos ecossistemas (VIOLLE *et al*., 2017). Assim, para propor medidas de conservação e proteção ambientais é necessário conhecer a biodiversidade e os compartimentos dos ecossistemas a fim de manejar e mitigar possíveis distúrbios provenientes das mais variadas atividades humanas.

A salinidade é um dos principais fatores que influenciam a estrutura das comunidades em estuários a partir das respostas fisiológicas dos organismos aquáticos às flutuações dessa variável (GILLANDERS *et al*., 2011; WHITFIELD, 2021). Secas severas tem mostrado modificar a estrutura da comunidade pela intrusão de água marinha (marinização) (PASQUAUD *et al*., 2012; LIMA *et al*., 2020; GURGEL-LOURENÇO *et al*., 2022). Além disso, barramentos de rios é outro fator considerável em alterar os níveis de salinidade dos estuários, por reterem o montante fluvial gerando desconexão com o mar, alterando ainda processos marinhos como deposição de sedimentos e aporte de nutrientes (CAVALCANTE *et al*., 2020). Pouco tem sido documentado sobre como a redução no fluxo de água doce impacta as assembleias de peixes estuarinas influenciadas por rios intermitentes, especialmente no Nordeste do Brasil. Entretanto, entender as respostas das comunidades aos diferentes gradientes ambientais ajuda a prever efeitos adversos das mudanças no clima global (SOARES *et al*., 2021).

Historicamente, estudos tem focado em abordagens taxonômicas, negligenciando os atributos funcionais das espécies, porém abordagens que focam na ecologia funcional têm ganhado atenção para descrever as comunidades combinada à taxonomia tradicional (FRANCO *et al*., 2008; VILLÉGER *et al*., 2008; LALIBERTÉ; LEGENDRE, 2010; MOUILLOT *et al*., 2013). Para esta tese, primeiro optamos por atualizar a base taxonômica com uma lista de espécies de peixes dos estuários (Capítulo 1, no qual foram levantadas as espécies de oito estuários). Essa lista forneceu a base taxonômica para os demais capítulos que abordam raridade, redundância e diversidade funcional (Capítulos 2 e 3).

Foram conduzidas amostragens padronizadas de peixes em estuários do Nordeste do Brasil, em alguns estuários durante a mais severa seca registrada nas últimas décadas e em outros estuários sob influência de pluviosidade acima da média histórica. De forma inédita, este estudo apresenta aspectos funcionais para a ictiofauna destes ambientes, na região, levando em consideração o total de espécies da assembleia, sendo possível evidenciar a imporância das espécies raras para a comunidade e a influência de condições de seca extrema sobre as estruturas taxonômica e funcional das assembleias de peixes estuarinas da costa semiárida do Brasil.

Desse modo, este documento pode trazer ferramentas para prever a distribuição dos peixes em estuários invertidos e uma base de informações para futuras comparações. Portanto, prevemos que o amplo número de espécies de peixes coletadas e adequadamente preservadas, assim como as informações abióticas obtidas, poderão fazer parte de novas pesquisas com este grupo faunístico e seus processos nos ecossistemas estuarinos locais. De fato, informações sobre a ictiofauna fornecidas nesta tese estão sendo úteis para grupos de pesquisa, fiscalização, conservação e manejo que atuam em regiões estuarinas e ecossistemas anexos, por exemplo, para os Planos de Manejo das APAs dos estuários dos rios Curu e Pacoti; do Parque Estadual do Cocó; e para a Lista Vermelha de espécies ameaçadas do Estado do Ceará.

A presente Tese está dividida em três Capítulos, sendo:

Capítulo 1: “Fish fauna from the estuaries of Ceará state, Brazil: a checklist in support of conservation of the Brazilian semiarid coast”. Artigo publicado na revista Check List (doi: 10.15560/19.1.63).

Capítulo 2: “Raridade e redundância funcional de assembleias de peixes de estuários sazonalmente hipersalinos do Nordeste do Brasil”. Manuscrito pré-formatado para submissão na revista Neotropical Ichthyology.

Capítulo 3: “Prolonged drought influences the taxonomic and functional structure of fish assemblages in estuaries along the Brazilian semiarid coast”. Artigo publicado na revista Hydrobiologia (doi: 10.1007/s10750-022-05059-5).

OBJETIVO GERAL

Listar as espécies de peixes, descrever a redundância funcional das assembleias de peixes e averiguar efeito de evento climático sobre a ictiofauna de estuários do estado do Ceará, Nordeste do Brasil.

OBJETIVOS ESPECÍFICOS

Listar as espécies de peixes de estuários da região semiárida compreendida pelo estado do Ceará, Nordeste do Brasil, a partir de amostragens in situ e de registros da literatura.

Caracterizar a redundância funcional de estuários da região semiárida compreendida pelo estado do Ceará, Nordeste do Brasil, por meio de índices de raridade funcional e por meio de entidades funcionais.

Verificar padrões taxômicos e funcionais das assembleias de peixes entre diferentes grupos de estuários com base na influência de seca prolongada e de precipitação acima da média.

CAPÍTULO 1

Fish fauna from the estuaries of Ceará state, Brazil: a checklist in support of conservation of the Brazilian semiarid coast [1]

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Abstract

We provide extensive surveys in eight estuaries along the coast of Ceará State in Northeastern Brazil, including local samples and data compiled from online data bases and literature. Samplings resulted in a checklist of the estuarine fish fauna, which recorded 126 fish species, and provides original information of some estuaries. Most of the sampled marine species are widely distributed and many are important commercial species for the artisanal fisheries. The addition of records from existing inventories and online collections increases the number of species to 245, of which 11 are threatened (critically endangered or vulnerable) and six are introduced. Our study provides an updated list of fish species of the estuaries along the semiarid coast of Brazil and is intended as a subsidy for further research, conservation and management efforts.

Keywords

Caatinga, estuarine fishes, ichthyofauna, inventory, mangrove, Northeastern Brazil

Introduction

The richness, composition and geographical distribution of species in an area are essential guide in taxonomy, systematics, ecological, biogeographic and conservation studies (Gotelli and Colwell 2001; Henriques et al. 2016), especially when addressing dynamic environments where assemblage and habitats are influenced in time and space by tides and annual seasonality (Day Jr et al. 2013; Silva et al. 2016, 2021). In estuaries, the effects of environmental fluctuations on the occurrence and distribution of fish species can hardly be overstated (Elliott et al. 2007; Neves et al. 2011; Potter et al. 2015). A good example is the semiarid coastal regions of Northeastern Brazil which comprises part of the Maranhão to the north of Rio Grande do Norte states (Soares et al. 2021), where most of the river systems are small and intermittent, with hypersaline mangroves and meadows (Valentim et al. 2018; Soares et al. 2021).

These estuaries are often neglected, despite their social-economic importance for artisanal fisheries (Basílio and Garcez 2014) and their role in providing microhabitats and nursery grounds for a varied of coastal and reef fishes (Sales et al. 2016). In recent decades, a reduction in precipitation has been observed (Marengo et al. 2018), and the Brazilian semiarid coast is now considered one of the most vulnerable to climate change in South America due to the sea level rise and increased frequency of droughts (Utida et al. 2019). Therefore, there is a possibly of drastic changes in estuarine salinity, decreased land-to-ocean matter flux, and acidification and therefore in the fish assemblages (Soares et al. 2021). This can potentially limit or extend the occurrence of fish species, depending on whether they are of continental or marine origin (Potter et al. 2015; Lauchlan and Nagelkerken 2020).

Tropical estuaries are rich in biodiversity, especially fishes (Blaber 2000), with an increasing number of inventories published in Northeastern Brazil over the past decades (Andrade-Tubino et al. 2008; Paiva et al. 2014; Lira et al. 2015; Costa et al. 2017; Guimarães-Costa et al. 2019; Medeiros et al. 2019; Lima et al. 2020). Published taxonomic surveys about fish fauna in estuaries of Ceará State are sparse in both space and time and often part of grey literature. One of the first surveys was conducted in the 1960s in four estuaries, covering the faunal and flora lists, registering 31 fish taxa (Menezes and Menezes 1968). An exclusive fish inventory had to wait for another decade, recording 86 species in the Jaguaribe estuary, the largest river basin in Ceará (Oliveira 1976). Another twenty years passed before the next survey was published, listing 85 species (Alves and Soares-Filho 1996). Araújo et al. (2000) issued a list of over 102 species by compiling unpublished studies on the ichthyofauna of three estuaries (Cocó, Jaguaribe and Pacoti rivers). Later, as part of the Ecological and Economic Zoning Program (EEZ), 17 estuaries were surveyed and subsistence fishermen were interviewed using photographs of fish species (EEZ 2005). Some new occurrences were reported by Basílio et al. (2009) in a study on the fish fauna of the Curu river estuary, and Soares-Filho et al. (2010) sampled and compiled the fish fauna of seven estuaries of the State. The most recent contributions are fish inventories from the Mundaú river basin (Teixeira et al. 2017) and the Timonha-Ubatuba estuary (Melo et al. 2021).

Most previous surveys have disagreements, as the outdated systematic nomenclature or the non-indication of voucher specimens in a fish official collection. This situation makes difficult for reliable identification and confirmation for new political managements of fishering and conservation. The estuarine regions of the Ceará State historically has showed aggravation of environmental impacts such as overexploitation, exotic species, shrimp farms and climatic changes in the last decades (Gorayeb et al. 2005; Santana et al. 2015; Ferreira and Lacerda 2016; Soares et al. 2021). Therefore we provide an ichthyological survey of eight estuaries from northern reaches of semiarid Northeastern Brazil, producing an extensive species list that provides subsidy to monitoring ichthyofauna changes, ecological studies, and management and conservation efforts.

Study Area

The sampled estuaries (Aracatiaçu, Aracatimirim, Choró, Cocó, Curu, Malcozinhado, Pacoti, and Pirangi rivers) are located in the marine ecoregion of Northeastern Brazil (Spalding et al. 2007) and in the continental ecoregion referred to as Mid-Northeastern Caatinga (Abell et al. 2008; Lima et al. 2017). According to the Köppen climate classification system (Alvares et al. 2014), the coastal region of Ceará has a type As climate, with a mean annual rainfall of 1,000-1,300 mm, but the climate is strongly influenced by the dynamics of the semiarid Caatinga (BSh climate) with its markedly seasonal precipitation of less than 800 mm, concentrated in the first semester. Thus, many estuaries in the northernmost part of Northeastern Brazil (the semiarid coast of Brazil) (Soares et al. 2021) display seasonal hypersalinity, with an inverted gradient in the second semester (Valentim et al. 2018; Soares et al. 2021). The fluvial discharge into these estuaries is strongly affected by water resource management (e.g., reservoirs along the river basins) and during the dry season may be reduced to less than 1 m³/s (Molisani et al. 2006; Valentim et al. 2018).

These estuaries are heavily impacted by human activities, including mangrove deforestation, fishing, fires, landfills, waste disposal, dam construction, shrimp farming, agricultural and urban runoff, domestic sewage, and unregulated tourism. In addition to the direct impacts, many of these activities involve the discharge of heavy metals, pesticides, pathogens, nutrients, surfactants and pharmacological residues into the environment (Gorayeb et al. 2005; Meireles et al. 2007; Lacerda et al. 2014; Santana et al. 2015; Ferreira and Lacerda 2016; Pimentel et al. 2016). Management plans are currently being drafted for the Environmental Protected Area (EPA) of the Pacoti estuary and the EPA of the Curu estuary, while the plan implemented for a third conservation unit (Cocó State Park) incorporates the present fish survey (SEMA 2020).

Methods

Fish were collected from estuaries along the semiarid coast of Ceará State between 2014 and 2021. We conducted six to eight bimonthly campaigns in each estuary, covering the entire estuarine area (Fig. 1), under license from ICMBio/SISBio (#43014, #57780, #64269). Samplings were carried out during ebb and flood tide in the daytime using a seine net (25 m long, 2 m high, 12 mm mesh size) at depths between 0.3 and 1.5 m, and casting nets (3 m high, 25 mm mesh size) in the main channel at depths between 0.5 and 3.5 m. In addition, to collect fish in areas with mangrove roots and in pools and inlets off the main channel we used sieve nets (0.2 m², 1 mm mesh size) and gillnets of varying mesh size (30-70 mm between opposite knots). The records were complemented by catches of local fishermen. The collected specimens were anesthetized in ice and subsequently fixated in 10% formalin for 48 hours, followed by preservation in 70% alcohol. Following the protocols of Malabarba and Reis (1987), batches of specimens were deposited in the fish collections of the Federal University of Rio Grande do

Norte (UFRN), the Federal University of Paraíba (UFPB), and the National Museum of the Federal University of Rio de Janeiro (MNRJ). In order to build a more comprehensive list, we compiled records from online collections (CRIA 2022, *species*Link) and publications of the study area (Menezes and Menezes 1968; Oliveira 1976; Alves and Soares-Filho 1996; Araújo et al. 2000; EEZ 2005; Freitas et al. 2006; Basílio et al. 2009; Soares-Filho et al. 2010; Costa and Lacerda 2014; Teixeira et al. 2017; Melo et al. 2021).

The collected species were identified to the lowest taxonomic category based on original descriptions, taxonomic reviews or dichotomous keys following Araújo et al. (2004), Britski et al. (1984), Carpenter (2002a, 2002b), Carvalho et al. (2020), Carvalho-Filho et al. (2019); Deckert and Greenfield (1987), Figueiredo and Menezes (1978, 1980, 2000), Fischer et al. (2011), Frable et al. (2013), Garcia Jr. et al. (2010), Géry (1977), Hui and Ng (2005), Loeb and Figueiredo (2014), Lourie et al. (2016), Marceniuk (2005), Marceniuk et al. (2012, 2019a, 2019b), Menezes and Figueiredo (1980, 1985), Menezes et al. (2015), Moura and Lindeman (2007), Pezold and Cage (2001), Tencatt et al. (2017), Vicente et al. (2020) and Sabaj et al. (2022) and adopting the systematic classification and nomenclature of valid names in Eschmeyer’s Catalog of Fishes (Fricke et al. 2022).

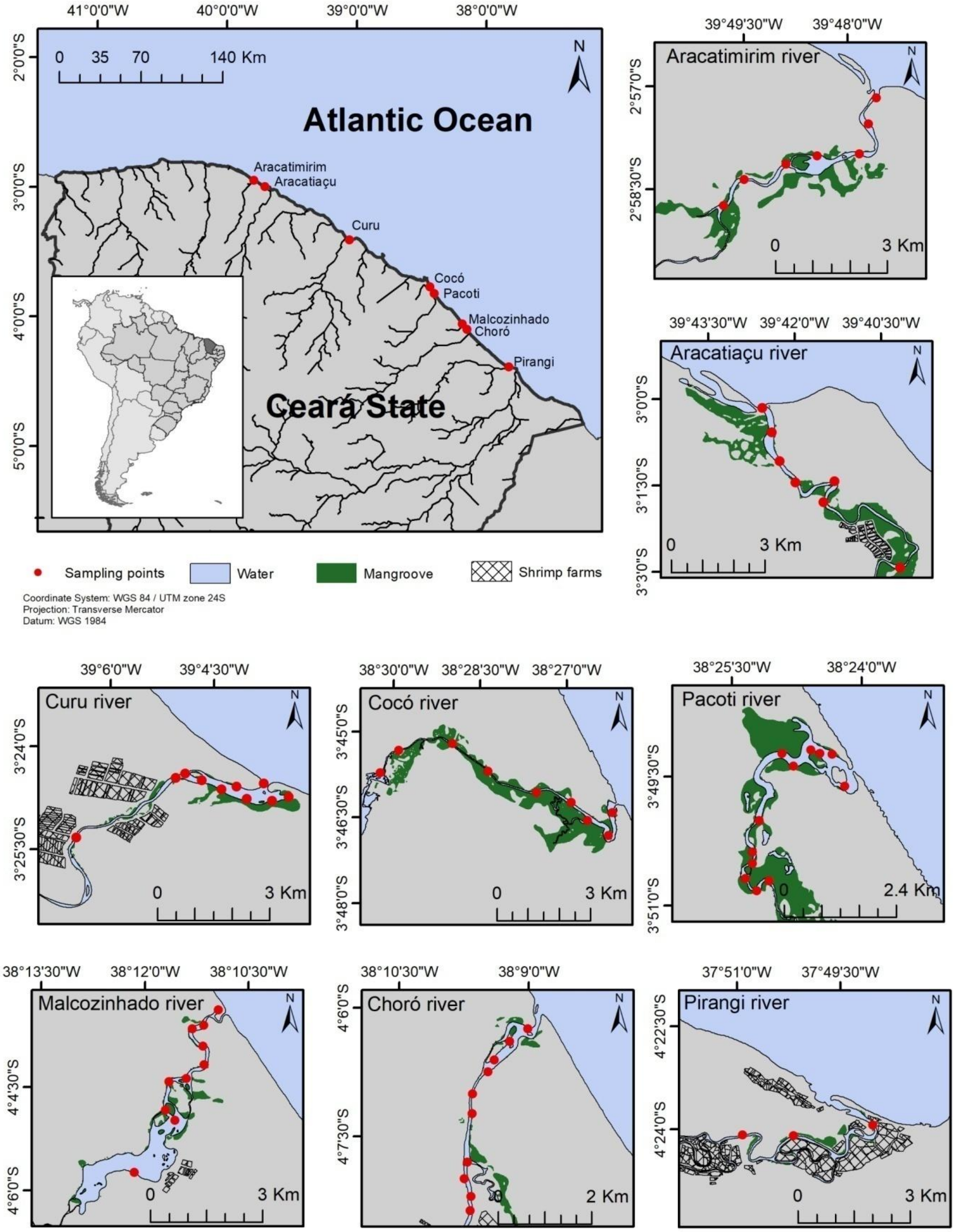

Figure 1. Sampling sites in eight estuaries of the State of Ceará (Aracatimirim, Aracatiaçu, Curu, Cocó, Pacoti, Malcozinhado, Choró, and Pirangi rivers).

The distribution of the species was categorized according to Floeter et al. (2008), Luiz Junior et al. (2008), Fricke et al. (2022) and Froese and Pauly (2022): Cosmopolitan; Circumtropical; Trans-Atlantic (both sides of the Atlantic); Western Atlantic (both hemispheres); Southwestern Atlantic (from Northern Brazil to Argentina); Greater Caribbean province (from Florida to Venezuela); Brazilian province (between the delta of the Orinoco river, Venezuela, and Santa Catarina, Brazil); and Eastern Pacific. Freshwater species were categorized as ‘continental freshwater’. Ordinance 445 of the Red List (BRASIL 2022) ascertained which species are classified as threatened with extinction in Brazil.

Results

We collected 126 species belonging to 92 genera, 56 families and 24 orders (Table 1). This included 224 new occurrences from individual estuaries. The most represented order was Acanthuriformes (seven families: 24 species, 19.0%), followed by Carangiformes (eight families: 23 species, 18.2%) and Clupeiformes (two families: 12 species, 9.5%). The most representative families were Gerreidae (eight species), Carangidae, Engraulidae, and Gobiidae (seven species each), and Clupeidae, Paralichthyidae, and Sciaenidae (five species each). Most species were marine and widely distributed (73 species associated with reefs, 57.9%). The result of the survey shows a mix of species with wide distribution, in some cases beyond the Western Atlantic (~48%), species occurring only in the provinces of the Greater Caribbean and/or Brazil (~30%), and a small number of continental freshwater species (n=15; ~12%).

If all the literature records from local estuaries are considered, the list increases by 119 species (Table 2), reaching a total richness of 245 species, 74 families and 28 orders. The proportion of species associated with reefs and the levels of distribution are similar to the shorter list of sampled species and the longer list of all reported species.

Four of the sampled species (Table 1) are classified in the Brazilian Red List (BRASIL 2022) as Vulnerable (*Hippocampus reidi*, *Megalops atlanticus*, *Mycteroperca bonaci*, and *Sciades parkeri*). Seven species are classified as Near-Threatened (*Aluterus monoceros, Cynoscion acoupa*, *Dormitator maculatus*, *Hyporhamphus unifasciatus*, *Lutjanus analis*, *L. jocu*, and *Mugil liza*) (SiBBr 2022). Others are classified as Data-Deficient: *Antennarius striatus*, *Archosargus probatocephalus*, *Menticirrhus martinicensis*, *Mugil curema*, *M. curvidens*, *M. rubrioculus*, *Sardinella aurita*, *Sciades proops*, and *Sphoeroides testudineus* (SiBBr 2022).

Considering the literature list, seven more species (Table 2) are classified as threatened on the Red List (BRASIL 2022): Critically Endangered (*Epinephelus itajara*, *Sphyrna tiburo*) and

Vulnerable (*Hippocampus erectus*, *Hypanus marianae*, *Lutjanus cyanopterus*, *Pseudobatos percellens*, *Sparisoma axillare*). Eight species are classified as Near-Threatened (*Balistes vetula*, *Carcharhinus leucas*, *C. limbatus*, *Gymnura micrura*, *Lutjanus synagris*, *Lutjanus vivanus*, *Ocyurus chrysurus*, and *Rhomboplites aurorubens*) (SiBBr 2022). Other species are classified as Data-Deficient: *Aetobatus narinari*, *Anisotremus surinamensis*, *Haemulon plumierii*, *Hemiramphus balao*, *Hypanus say*, *Menticirrhus cuiaranensis*, *Ophioscion punctatissimus*, *Pomacanthus arcuatus*, and *Rhizoprionodon porosus* (SiBBr 2022).

At least five introduced species were recorded: *Astronotus ocellatus*, *Betta splendens*, *Oreochromis niloticus*, *Poecilia reticulata*, and *P. sphenops*. All five were found in the Cocó estuary, while the other estuaries surveyed harbored up to two. One of the literature species is non-native: *Cichla ocellaris*.

Table 1. Fish species sampled in eight estuaries in the State of Ceará listed in geographical order, from west to east: Aracatimirim (AM), Aracatiaçu (AR), Curu (CU), Cocó (CO), Pacoti (PA), Malcozinhado (MC), Choró (CH) and Pirangi (PI). X: species sampled in the field. X^{NO}: species sampled in the field and reported for the first time in a given estuary. X^{L}: occurrence reported in the literature (Menezes and Menezes 1968; Araújo et al. 2000; ZEE 2005; Basílio et al. 2009; Soares-Filho et al. 2010; Osório et al. 2011). (NR): new record. (I): introduced species. (*): Species associated with reefs (Floeter et al. 2008; Chaves et al. 2013; Freitas and Lotufo 2015; Pinheiro et al. 2018; Freitas et al. 2019; Araújo et al. 2020; Froese and Pauly 2022). Red List (BRASIL 2022): NT: near threatened, VU: vulnerable, DD: data-deficient. Geographical distribution: C: cosmopolitan, CT: circumtropical, TA: trans-Atlantic, WA: Western Atlantic, SWA: Southwestern Atlantic, Ca: Greater Caribbean Province, Br: Brazilian Province, EP: Eastern Pacific, CF: continental freshwater. The order of the species follows Fricke et al. (2022).

TABLE 1

Taxa	**Distribution**	**AM**	**AR**	**CU**	**CO**	**PA**	**MC**	**CH**	**PI**	**Vouchers**
MYLIOBATIFORMES										
Dasyatidae										
Hypanus guttatus (Bloch & Schneider, 1801) (*)	Ca+Br	X	X^{L}	X^{L}	X^{L}	X	X	X	X^{L}	UFPB12050; UFRN4559; 4711
ELOPIFORMES										
Elopidae										
Elops saurus Linnaeus, 1766 (*)	WA	X	X	X^{L}	X	X	X	X	X^{L}	UFRN4545; 4817; 4697; 4498
Megalopidae										
Megalops atlanticus Valenciennes, 1847 (VU) (*)	TA			X^{L}	X	X^{L}	X^{NO}	X^{L}	X^{L}	UFRN4850
ALBULIFORMES										
Albulidae										
Albula cf. vulpes (Linnaeus, 1758) (*)	WA	X^{L}	X^{L}	X	X^{L}	X^{L}	X	X^{L}	X^{L}	UFRN4671
ANGUILLIFORMES										

Ophichthidae										
Myrichthys ocellatus (Lesueur, 1825) (*)	Ca+Br			X		X^{NO}		X^{NO}		UFRN4547; 4637; 4788
CLUPEIFORMES										
Engraulidae										
Anchoa hepsetus (Linnaeus, 1758)	WA	X	X	X^{L}	X^{L}	X^{L}	X	X	X^{L}	UFRN4603
Anchoa januaria (Steindachner, 1879)	SWA			X^{NO}				X^{NO}		UFRN4608; 4649
Anchovia clupeoides (Swainson, 1839)	Ca+Br	X	X	X	X^{L}	X	X	X	X	UFPB12055; 12056; 12057; UFRN4598; 4625; 4762; 4525
Anchoviella brevirostris (Günther, 1868)	Br						X^{NO}	X^{NO}		UFPB14023
Anchoviella lepidentostole (Fowler, 1911) (*)	Br								X^{NO}	URFN4517
Cetengraulis edentulus (Cuvier, 1829)	Ca+Br	X	X^{L}	X	X^{L}	X^{L}	X	X	X	UFPB12066; UFRN4607; 4657; 4535
Lycengraulis grossidens (Spix & Agassiz, 1829) (*)	Br+SWA	X	X	X	X	X	X	X	X	UFRN4609; 4849; 4628; 4770
Clupeidae										
Harengula clupeola (Cuvier, 1829)	WA						X^{NO}			UFPB12065
Lile piquitinga (Schreiner & Miranda Ribeiro, 1903) (*)	SWA	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	UFRN4601; 4843; 4641; 4768; 4531
Opisthonema oglinum (Lesueur, 1818) (*)	WA	X^{L}	X^{L}	X^{L}	X	X	X	X	X^{L}	UFRN4595; 4855; 4699
Rhinosardinia amazonica (Steindachner, 1879)	Br	X^{NO}	X^{NO}	X^{NO}	X^{L}	X	X^{NO}	X^{NO}	X^{NO}	UFRN4600; 4666; 4533
Sardinella aurita Valenciennes, 1847 (DD)	WA								X^{NO}	URFN4527
CHARACIFORMES										
Erythrinidae										
Hoplerythrinus unitaeniatus (Spix & Agassiz, 1829)	CF						X^{NO}			UFPB12058
Serrasalmidae										
Serrasalmus rhombeus (Linnaeus, 1766)	CF				X^{NO}			X^{NO}		UFRN4590; 4860
Curimatidae										
Steindachnerina notonota (Miranda Ribeiro, 1937)	CF		X^{NO}							UFPB12073
Prochilodontidae										
Prochilodus brevis Steindachner, 1875	CF						X^{NO}			UFPB12064
Characidae										
Astyanax bimaculatus (Linnaeus, 1758)	CF	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}			UFRN4821; 4616; 4763
Moenkhausia costae (Steindachner, 1907)	CF				X^{NO}	X^{NO}		X^{NO}		UFRN4567; 4851; 4694

SILURIFORMES										
Callichthyidae										
Megalechis thoracata (Valenciennes, 1840)	CF				X^{NO}					UFRN4814
Auchenipteridae										
Pseudauchenipterus nodosus (Bloch, 1794)	CF	X^{NO}								UFPB12075
Ariidae										
Cathorops spixii (Agassiz, 1829) (*)	Ca+Br	X^{NO}	X^{NO}	X	X^{L}	X	X^{NO}	X	X^{NO}	UFPB12047; UFRN4586; 4605; 4665; 4692; 4506
Sciades herzbergii (Bloch, 1794)	Ca+Br	X^{NO}	X^{NO}	X	X^{L}	X	X^{NO}	X^{NO}	X^{NO}	UFPB12051; UFRN5799; 4652; 5804; 4772; 4510
Sciades parkeri (Traill, 1832) (VU)	Br			X^{NO}		X^{L}	X^{NO}	X^{NO}		UFRN4597; 4669
Sciades proops (Valenciennes, 1840) (DD)	Ca+Br	X^{NO}	X^{NO}		X^{NO}		X^{NO}			UFRN5174; 4487
AULOPIFORMES										
Synodontidae										
Synodus bondi Fowler, 1939 (*)	Ca+Br	X^{NO}								UFPB12076
Synodus foetens (Linnaeus, 1766) (*)	WA	X^{NO}	X	X^{L}	X^{L}	X			X^{L}	UFRN4775
Synodus intermedius (Spix & Agassiz, 1829) (*)	WA							X^{NO}		UFRN4576
BATRACHOIDIFORMES										
Batrachoididae										
Batrachoides surinamensis (Bloch & Scheneider, 1801)	Ca+Br	X	X	X	X^{L}	X^{L}	X	X	X	UFPB12063; UFRN4578; 4635; 4509
Thalassophryne nattereri Steindachner, 1876 (*)	Ca+Br	X^{L}	X	X^{L}	X^{L}	X	X^{L}	X^{L}	X^{L}	UFRN4746
SCOMBRIFORMES										
Scombridae										
Scomberomorus brasiliensis Collette, Russo & Zavala-Camin, 1978 (*)	Ca+Br			X^{L}	X^{L}	X^{L}	X^{L}	X		UFRN4604
SYNGNATHIFORMES										
Dactylopteridae										
Dactylopterus volitans (Linnaeus, 1758) (*)	TA					X^{NO}				UFRN4675
Syngnathidae										
Bryx dunckeri (Metzelaar, 1919) (*)	Ca+Br			X^{NO}						MNRJ53260
Hippocampus reidi Ginsburg, 1933 (VU) (*)	WA	X^{L}	X^{NO}	X	X	X	X^{NO}	X	X^{L}	UFRN4580; 4621; 4740

Microphis lineatus (Kaup, 1856)	WA					X^{NO}				UFRN5179
Syngnathus pelagicus (Linnaeus, 1758)	WA	X^{NO}	X^{NO}	X^{NO}	X^{L}	X^{L}		X^{NO}		UFRN4588; MNRJ53261
GOBIIFORMES										
Eleotridae										
Dormitator maculatus (Bloch, 1792) (NT)	WA	X^{L}	X^{L}	X^{L}	X	X^{L}	X^{L}	X^{L}	X^{L}	UFRN4827; 4828
Eleotris pisonis (Gmelin, 1789)	Ca+Br				X^{NO}					UFRN4823; 4824
Gobiidae										
Bathygobius soporator (Valenciennes, 1837) (*)	TA	X^{NO}	X^{NO}	X	X	X	X	X^{NO}	X	UFRN4565; 4815; 4627; 4764; 4540
Ctenogobius boleosoma (Jordan & Gilbert, 1882) (*)	WA	X^{NO}	X^{NO}	X	X	X	X^{NO}	X^{NO}		UFRN4613; 4825; 4826; 4659; 4766
Ctenogobius smaragdus (Valenciennes, 1837)	WA	X^{NO}	X^{NO}		X^{L}	X^{L}	X^{NO}	X^{L}	X^{NO}	URFN4539
Ctenogobius stigmaticus (Poey, 1860)	Ca+Br			X^{NO}		X^{NO}	X^{NO}			UFRN4658; 4767
Evorthodus lyricus (Girard, 1858)	Ca+Br		X^{NO}		X	X				UFRN4816; 4744
Gobionellus oceanicus (Pallas, 1770)	WA	X^{NO}	X^{NO}	X^{NO}	X^{L}	X	X^{NO}	X	X^{NO}	UFRN4572; 4633; 4682; 4528
Gobionellus stomatus Starks, 1913	Br	X^{NO}		X	X^{L}	X	X^{NO}	X		UFRN4558; 4642; 4695; 4541
SYNBRANCHIFORMES										
Synbranchidae										
Synbranchus cf. *marmoratus* Bloch, 1795	CF				X^{NO}					UFRN5170
ANABANTIFORMES										
Osphronemidae										
Betta splendens Regan, 1910 (I)	CF				X^{NO}					UFRN5166; 5167
CARANGIFORMES										
Centropomidae										
Centropomus parallelus Poey, 1860	WA	X	X	X	X^{NO}	X^{NO}	X^{NO}	X	X^{NO}	UFRN4574; 4822; 4656; 4684
Centropomus undecimalis (Bloch, 1792) (*)	WA	X	X	X^{L}	X^{L}	X	X	X^{L}	X^{L}	UFRN4681; 4507
Sphyraenidae										
Sphyraena barracuda (Edwards, 1771) (*)	CT			X^{NO}	X	X	X^{NO}	X^{L}		UFRN4863; 4634; 4736
Sphyraena guachancho Cuvier, 1829 (*)	TA				X^{NO}		X^{NO}			UFRN4864
Polynemidae										
Polydactylus virginicus (Linnaeus, 1758)	WA				X^{L}	X				UFRN4456
Bothidae										

Bothus ocellatus (Agassiz, 1831) (*)	WA							X^{NO}		UFRN4561
Paralichthyidae										
Citharichthys arenaceus Evermann & Marsh, 1900 (*)	WA	X^{NO}	X^{NO}			X^{NO}		X^{NO}	X^{NO}	UFRN4714
Citharichthys spilopterus Günther, 1862 (*)	WA	X	X^{NO}	X	X	X	X^{NO}	X	X	UFRN4562; 4818; 4819; 4617; 4748; 4486
Citharichthys sp.	(?)							X^{NO}	X^{NO}	UFRN4585; 4522
Etropus crossotus Jordan & Gilbert, 1882 (*)	WA+EP	X	X^{L}	X^{L}	X^{L}	X		X^{L}	X^{L}	UFRN4689
Paralichthys brasiliensis (Ranzani, 1842) (*)	SWA	X^{NO}	X^{NO}	X^{NO}				X^{NO}	X^{NO}	UFRN4560; 4653
Achiridae										
Achirus achirus (Linnaeus, 1758)	WA	X^{NO}	X^{NO}	X	X^{L}	X	X^{NO}	X^{NO}	X^{NO}	UFPB12061; UFRN4587; 4654; 4761; 4421, 4515
Achirus declivis Chabanaud, 1940	WA		X^{L}	X^{L}	X^{L}	X^{L}			X	URFN4542
Achirus lineatus (Linnaeus, 1758) (*)	WA	X	X^{NO}	X	X^{L}	X	X^{NO}	X	X^{NO}	UFPB12062; UFRN4582; 4646; 4713
Trinectes paulistanus (Miranda Ribeiro, 1915)	Ca+Br	X^{NO}	X	X	X	X	X^{NO}	X^{NO}	X	UFPB12049; UFRN5803; 5171; 4648; 4735; 4530
Cynoglossidae										
Symphurus tessellatus (Quoy & Gaimard, 1824)	Ca+SWA	X^{NO}		X^{L}		X^{NO}		X^{NO}		UFRN4581; 4690
Carangidae										
Caranx latus Agassiz, 1831 (*)	TA	X	X	X	X	X	X	X	X	UFRN4606; 4812; 4813; 4655; 4683; 4534
Chloroscombrus chrysurus (Linnaeus, 1766) (*)	TA	X^{L}	X^{L}	X^{L}	X	X	X	X^{L}	X^{L}	UFRN5172
Oligoplites palometa (Cuvier, 1832) (*)	Ca+Br	X	X	X	X^{L}	X	X	X	X	UFRN4589; 4674; 4742
Oligoplites saurus (Bloch & Schneider, 1801) (*)	WA	X	X	X	X^{L}	X	X	X	X	UFRN4591; 4675; 4771; 4523
Selene vomer (Linnaeus, 1758) (*)	WA			X	X^{L}	X	X^{NO}	X	X	UFRN4570; 4663; 4773; 4502
Trachinotus carolinus (Linnaeus, 1766) (*)	WA			X^{L}			X^{NO}			UFPB12067
Trachinotus falcatus (Linnaeus, 1758) (*)	WA	X^{L}	X^{L}	X	X^{L}	X	X	X	X^{L}	UFPB12068; UFRN4602; 4629; 4776
CICHLIFORMES										
Cichlidae										
Astronotus ocellatus (Agassiz, 1831) (I)	CF				X^{NO}					UFRN5873
Oreochromis niloticus (Linnaeus, 1758) (I)	CF	X^{NO}	X^{NO}	X^{L}	X	X^{L}		X^{L}	X	UFRN4856; 4492
Pomacentridae										
Abudefduf saxatilis (Linnaeus, 1758) (*)	TA					X	X^{NO}			UFPB12059

ATHERINIFORMES										
Atherinopsidae										
Atherinella brasiliensis (Quoy & Gaimard, 1825) (*)	Ca+Br	X	X	X	X	X	X	X	X	UFRN4596; 4820; 4639; 4693; 4519
CYPRINODONTIFORMES										
Poeciliidae										
Poecilia reticulata Peters, 1859 (I)	CF				X^{NO}	X^{NO}				UFRN4858; 4745
Poecilia sphenops Valenciennes, 1846 (I) (NR)	CF				X^{NO}					UFRN5874
Poecilia vivipara Bloch & Schneider, 1801	CF			X^{NO}	X^{NO}	X^{NO}				UFRN4857; 4859; 4880; 5187; 4644; 5185; 5188
Anablepidae										
Anableps anableps (Linnaeus, 1758) (*)	Ca+Br			X^{NO}						UFRN4650
BELONIFORMES										
Belonidae										
Strongylura marina (Walbaum, 1792) (*)	WA	X	X	X	X^{L}	X	X^{NO}	X^{NO}	X	UFPB12053; UFRN4556; 4643; 4677; 4680
Strongylura timucu (Walbaum, 1792) (*)	WA	X^{NO}	X	X^{NO}	X	X	X	X	X^{NO}	UFPB12052; UFRN4543; 4876; 4877; 4878; 4615; 4716; 4496; 4497
Hemiramphidae										
Hyporhamphus unifasciatus (Ranzani, 1841) (NT) (*)	WA+EP	X	X^{NO}	X	X^{NO}	X	X	X	X^{NO}	UFRN4577; 4842; 4636; 5176; 4505
MUGILIFORMES										
Mugilidae										
Mugil curema Valenciennes, 1836 (DD) (*)	TA+EP	X	X	X	X	X	X	X	X	UFRN4575; 4852; 4622; 4679; 4738; 4739; 5181
Mugil curvidens Valenciennes, 1836 (DD) (*)	Ca+Br	X	X	X	X	X	X	X	X	UFRN4544; 4853; 4638; 5183
Mugil liza Valenciennes, 1836 (NT)	WA	X^{L}	X^{L}	X^{L}	X	X^{L}	X	X	X	UFRN4563; 4854; 4667; 4499; 4511; 4513
Mugil rubrioculus Harrison, Nirchio, Oliveira, Ron & Gavíria, 2007 (DD)	Ca+Br		X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	UFRN5192; 5190; 5184; 5186; 4504
PERCIFORMES										
Serranidae										
Mycteroperca bonaci (Poey, 1860) (VU) (*)	WA	X^{L}	X^{L}	X^{L}	X^{L}	X	X	X	X^{L}	UFRN4607
Scaridae										

Sparisoma radians (Valenciennes, 1840) (*)	Ca+Br		X^{NO}	X^{NO}		X^{NO}	X^{NO}	X^{NO}		UFRN4579; 4630; 4774
Triglidae										
Prionotus punctatus (Bloch, 1793)	Ca+SWA					X^{NO}		X^{NO}		UFRN4593; 4715
Scorpaenidae										
Scorpaena cf. plumieri Bloch, 1789 (*)	WA				X^{L}	X	X^{NO}	X^{NO}	X^{NO}	UFRN4553; 4685; 4500
ACANTHURIFORMES										
Lutjanidae										
Lutjanus alexandrei Moura & Lindeman, 2007 (*)	Br		X^{NO}	X	X^{NO}		X^{NO}	X^{NO}	X^{NO}	UFRN4612; 4844; 4619; 4769; 4526
Lutjanus analis (Cuvier, 1828) (NT) (*)	WA	X^{NO}	X^{NO}	X	X	X	X^{NO}	X	X	UFRN5801; 4845; 4614; 5177; 5178; 4524
Lutjanus jocu (Bloch & Schneider, 1801) (NT) (*)	TA	X	X^{L}	X	X^{L}	X^{L}	X^{L}	X	X^{L}	UFRN4546; 4673; 4491
Gerreidae										
Diapterus auratus Ranzani, 1842 (*)	WA	X	X	X	X	X	X	X	X	UFRN4551; 5169; 4661; 4712, 4749; 4508
Diapterus rhombeus (Cuvier, 1829) (*)	Ca+Br	X^{NO}		X	X^{L}	X	X^{NO}	X	X^{NO}	UFRN5191; 4660; 5175; 4501
Eucinostomus argenteus Baird & Girard, 1855 (*)	WA+EP	X^{NO}	X^{NO}	X	X	X	X^{NO}	X^{NO}	X^{NO}	UFRN4557; 4829; 4830; 4624; 5180
Eucinostomus gula (Quoy & Gaimard, 1824) (*)	WA	X^{NO}	X^{NO}	X	X^{L}	X	X^{NO}	X^{NO}	X^{NO}	UFRN5193; 4626; 4750; 5805; 4518
Eucinostomus havana (Nichols, 1912)	Ca+Br		X^{NO}	X^{NO}	X^{L}	X	X^{NO}	X^{NO}	X^{NO}	UFRN4550; 4662; 4698; 4512
Eucinostomus lefroyi (Goode, 1874) (*)	Ca+Br	X^{NO}	X^{NO}	X^{NO}		X^{NO}	X^{NO}	X^{NO}	X^{NO}	UFRN4584; 4668; 4777; 4536
Eucinostomus melanopterus (Bleeker, 1863) (*)	TA	X	X	X	X	X	X	X	X	UFRN4554; 4569; 4831; 4651; 4751; 4489; 4529
Eugerres brasilianus (Cuvier, 1830) (*)	WA	X^{NO}		X	X^{L}	X	X	X	X	UFPB12048; UFRN4573; 4623; 4688; 4490
Haemulidae										
Genyatremus luteus (Bloch, 1790) (*)	Ca+Br	X	X^{L}	X^{L}	X^{L}	X^{L}	X	X	X	UFRN4610; 4488
Haemulon parra (Desmarest, 1823) (*)	Ca+Br			X	X	X^{L}	X	X		UFRN4594; 5173; 4620
Haemulopsis corvinaeformis (Steindachner, 1868) (*)	Ca+SWA	X	X	X	X^{L}	X	X	X	X	UFRN5802; 4645; 4687; 4520
Orthopristis scapularis Fowler, 1915 (*)	Ca+Br					X^{NO}				UFRN4741

Sparidae										
Archosargus probatocephalus (Walbaum, 1792) (DD) (*)	WA			X	X^{L}	X^{L}		X	X^{L}	UFRN4672
Archosargus rhomboidalis (Linnaeus, 1758) (*)	WA		X^{NO}	X^{NO}		X^{NO}		X^{NO}		UFRN4599; 4647; 4747
Sciaenidae										
Cynoscion acoupa (Lacepède, 1801) (NT)	Ca+SWA	X^{L}	X^{L}	X^{L}	X^{L}	X	X^{L}	X^{L}	X^{L}	UFRN4752
Larimus breviceps Cuvier, 1830	Ca+Br	X^{NO}								UFPB12074
Menticirrhus martinicensis (Cuvier, 1830) (DD)	WA	X	X^{L}	X^{L}	X^{L}	X^{L}	X	X	X^{L}	UFRN4571; 4538
Micropogonias furnieri (Desmarest, 1823)	Ca+SWA	X^{L}	X^{L}	X	X^{L}	X	X^{L}	X	X^{L}	UFRN4611; 4664; 4743; 4495
Stellifer naso (Jordan, 1889)	Ca+Br	X^{NO}			X^{L}	X	X^{NO}			UFRN4691
Ephippidae										
Chaetodipterus faber (Broussonet, 1782) (*)	WA	X	X^{L}	X	X^{L}	X	X	X	X	UFRN4583; 4640; 4765; 4494
Acanthuridae										
Acanthurus bahianus Castelnau, 1855 (*)	WA			X^{L}	X	X^{L}	X^{NO}	X^{L}	X^{L}	UFPB12060; UFRN5168
LOPHIIFORMES										
Ogcocephalidae										
Ogcocephalus vespertilio (Linnaeus, 1758) (*)	Ca+SWA	X^{L}	X	X^{L}	X^{L}	X^{L}	X^{L}	X	X^{L}	UFRN4549
Antennariidae										
Antennarius striatus (Shaw, 1794) (DD) (*)	C		X^{NO}	X^{L}	X^{L}	X^{L}		X	X^{L}	UFRN4592
TETRAODONTIFORMES										
Diodontidae										
Chilomycterus antennatus (Cuvier, 1816) (*)	TA							X^{NO}		UFRN5189
Chilomycterus spinosus (Linnaeus, 1758) (*)	SWA			X^{L}	X^{L}	X		X^{L}		UFRN5182
Tetraodontidae										
Lagocephalus laevigatus (Linnaeus, 1766)	TA			X^{L}	X^{L}	X^{L}	X^{NO}	X	X^{L}	UFRN4548
Sphoeroides greeleyi Gilbert, 1900 (*)	Ca+Br	X^{NO}	X^{NO}	X	X^{NO}	X^{NO}	X^{NO}	X^{NO}	X^{NO}	UFRN4568; 4861; 4631; 4678; 4537
Sphoeroides cf. *spengleri* (Bloch, 1785) (*)	TA							X^{NO}	X^{NO}	UFRN4555; 4532

Sphoeroides testudineus (Linnaeus, 1758) (DD) (*)	WA	X	X	X	X	X	X	X	X	UFPB12046; UFRN4564; 4862; 4632; 4676; 4493
Monacanthidae										
Aluterus monoceros (Linnaeus, 1758) (NT) (*)	CT							X^{NO}		UFPB12070
New occurrences by estuary		31	32	19	19	19	43	35	26	
Total species by estuary		71	72	88	92	95	82	93	76	
Total species reef-associated	73									
Total species	126									

Table 2. Species registered for estuaries in the state of Ceará, Brazil, according to the literature. 1: Menezes and Menezes (1968), 2: Oliveira (1976), 3: Alves and Soares-Filho (1996), 4: Araújo et al. (2000), 5: EEZ (2005), 6: Freitas et al. (2006), 7: Basílio et al. (2009), 8: Soares-Filho et al. (2010), 9: Osório et al. (2011), 10: Costa and Lacerda (2014), 11: Teixeira et al. (2017), 12: Santana et al. (2020), 13: Melo et al. (2021). (I): introduced species. (*): Species associated with reefs (Floeter et al. 2008; Chaves et al. 2013; Freitas and Lotufo 2015; Pinheiro et al. 2018; Freitas et al. 2019; Araújo et al. 2020; Froese and Pauly 2022). Red List (BRASIL 2022): CR: critically endangered, NT: near threatened, VU: vulnerable, DD: data-deficient. Geographical distribution: C: cosmopolitan, CT: circumtropical, TA: trans-Atlantic (both sides of the Atlantic), WA: Western Atlantic (both hemispheres), SWA: Southwestern Atlantic (from Northern Brazil to Argentina), SSWA: South-Southwestern Atlantic (from Southeastern Brasil to Argentina), Ca: Greater Caribbean Province (from Florida to Venezuela), Br: Brazilian Province (between the delta of the Orinoco river, Venezuela, and Santa Catarina, Brazil), EP: Eastern Pacific, CF: continental freshwater. The taxonomic order followed Eschmeyer's Catalog of Fishes (Fricke et al. 2022).

TABLE 2

TÁXON	**Distribution**	**Literature record**	***Species*Link voucher**
CARCHARHINIFORMES			
Carcharhinidae			
Carcharhinus leucas (Müller & Henle, 1839) (NT) (*)	C	5	
Carcharhinus limbatus (Müller & Henle, 1839) (NT) (*)	C	7	
Rhizoprionodon porosus (Poey, 1861) (DD) (*)	Ca+SWA	7	
Sphyrnidae			
Sphyrna tiburo (Linnaeus, 1758) (CR) (*)	WA+EP	3,8	

RHINOPRISTIFORMES			
Rhinobatidae			
Pseudobatos percellens (Walbaum, 1792) (VU)	TA	5	
MYLIOBATIFORMES			
Dasyatidae			
Hypanus marianae (Gomes, Rosa & Gadig, 2000) (VU) (*)	Br	7	
Hypanus say (Lesueur, 1817) (DD)	WA	3,8	
Gymnuridae			
Gymnura micrura (Bloch & Schneider, 1801) (NT)	TA	2,5,7,8	
Aetobatidae			
Aetobatus narinari (Euphrasen, 1790) (DD) (*)	C	5,7,8	
ANGUILLIFORMES			
Ophichthidae			
Myrophis punctatus Lütken, 1852 (*)	WA	2,3,4,5,8	
Ophichthus gomesii (Castelnau, 1855) (*)	WA		OBIS_BR 1937
CLUPEIFORMES			
Engraulidae			
Anchoa spinifer (Valenciennes, 1848)	Ca+Br+EP	5	
Anchoa tricolor (Spix & Agassiz, 1829) (*)	SWA	7	
Lycengraulis batesii (Günther, 1868)	Ca+Br	13	
Clupeidae			
Rhinosardinia bahiensis (Steindachner, 1879)	Br	4,5	
Pristigasteridae			
Chirocentrodon bleekerianus (Poey, 1867)	Ca+Br	5,7	
CHARACIFORMES			
Erythrinidae			
Hoplias malabaricus (Bloch, 1794)	CF	1,2,3,5,7,8	
Serrasalmidae			
Pygocentrus nattereri Kner, 1858	CF	3,8	
Anostomidae			

Leporinus friderici (Bloch, 1794)	CF	3,8	
Schizodon dissimilis (Garman, 1890)	CF	2,3,5,8	
Triportheidae			
Triportheus signatus (Garman, 1890)	CF	2,3,5,8	
Characidae			
Hemigrammus marginatus Ellis, 1911	CF	2	
SILURIFORMES			
Loricariidae			
Hypostomus jaguribensis (Fowler, 1915)	CF	2,3,8	
Loricarichthys derbyi Fowler, 1915	CF	2,3,8	
Auchenipteridae			
Trachelyopterus galeatus (Linnaeus, 1766)	CF	2,3,5,7	
Heptapteridae			
Pimelodella sp. (not identified)	CF	2,3,8	
Ariidae			
Aspistor luniscutis (Valenciennes, 1840)	Br		OBIS_BR 179
Bagre filamentosus (Swainson, 1839)	Ca+Br	3,6,8,12	OBIS_BR 284
AULOPIFORMES			
Synodontidae			
Synodus poeyi Jordan 1887 (*)	Ca+Br		OBIS_BR 2630
HOLOCENTRIFORMES			
Holocentridae			
Holocentrus adscensionis (Osbeck, 1765) (*)	TA	10	
BATRACHOIDIFORMES			
Batrachoididae			
Amphichthys cryptocentrus (Vallenciennes, 1837) (*)	WA	13	
SCOMBRIFORMES			
Stromateidae			
Peprilus paru (Linnaeus, 1758)	WA	5	OBIS_BR 2051
Trichiuridae			
Trichiurus lepturus Linnaeus, 1758	CT	2,4,5,8	OBIS_BR 2696

SYNGNATHIFORMES			
Syngnathidae			
Hippocampus erectus Perry, 1810 (VU) (*)	WA	8	OBIS_BR 1424
Micrognathus crinitus (Jenyns, 1842)	Ca+Br		OBIS_BR 1678
Microphis brachyurus (Bleeker, 1853)	CT	5	
Syngnathus scovelli (Evermann & Kendall, 1896) (*)	Ca+Br		OBIS_BR 2590
GOBIIFORMES			
Eleotridae			
Erotelis smaragdus (Valenciennes, 1837)	Ca+Br		OBIS_BR 972, OBIS_BR 978
Guavina guavina (Valenciennes, 1837)	Ca+Br		OBIS_BR1296
Gobiidae			
Awaous tajasica (Lichtenstein, 1822)	Br		OBIS_BR 266
Ctenogobius shufeldti (Jordan * Eigenmann, 1887)	WA		OBIS_BR 1248
Gobioides broussonnetii (Lacepède, 1800)	WA	1,4,5	OBIS_BR 1205
Microgobius meeki Evermann & Marsh, 1899	Ca+Br		OBIS_BR 1690
CARANGIFORMES			
Centropomidae			
Centropomus ensiferus Poey, 1860	Ca+Br	3,4,5,7,8	OBIS_BR 413
Centropomus pectinatus Poey, 1860	Ca+Br	7	OBIS_BR 441
Paralichthyidae			
Paralichthys sp.	?	13	
Syacium micrurum Ranzani, 1842 (*)	WA	1,4,5,13	UESPIP 658
Achiridae			
Trinectes microphthalmus (Chabanaud, 1928)	Ca+Br		OBIS_BR 2718
Cynoglossidae			
Symphurus plagusia (Bloch & Schneider, 1801)	Ca+Br	2,4,5,8	OBIS_BR 2535
Carangidae			
Caranx crysos (Mitchill, 1815) (*)	TA	5	UESPIP 525
Caranx hippos (Linnaeus, 1766) (*)	TA	2,3,5,7,8	
Hemicaranx sp.	?	11	

Oligoplites saliens (Bloch, 1793) (*)	Ca+SWA	3,5,7,8	
Selene setapinnis (Mitchill, 1815) (*)	WA	5,8	
Trachinotus goodei Jordan & Evermann, 1896 (*)	WA	4,5,7	
Echeneidae			
Echeneis naucrates Linnaeus, 1758 (*)	CT	5,7	UESPIP 555
Remora remora (Linnaeus, 1758) (*)	CT	3,5,8	
CICHLIFORMES			
Cichlidae			
Cichla ocellaris (Bloch & Schneider, 1801) (I)	CF	3,5,8	
Cichlasoma orientale Kullander, 1983	CF	2,3,8	
Pomacentridae			
Stegastes variabilis (Castelnau, 1855) (*)	Br		OBIS_BR 2120
BELONIFORMES			
Belonidae			
Tylosurus crocodilus (Péron & Lesueur, 1821) (*)	CT	8	
Hemiramphidae			
Hemiramphus balao Lesueur, 1821 (DD) (*)	TA	3,5,8	
Hemiramphus brasiliensis (Linnaeus, 1758) (*)	TA		OBIS_BR 1376
Hyporhamphus roberti (Valenciennes, 1847)	Ca+Br		UESPIP 595
MUGILIFORMES			
Mugilidae			
Mugil brevirostris (Ribeiro, 1915) (*)	Br		OBIS_BR 1765
BLENNIIFORMES			
Labrisomidae			
Labrisomus nuchipinnis (Quoy & Gaimard, 1824) (*)	TA	6	OBIS_BR 1473
PERCIFORMES			
Serranidae			
Diplectrum radiale (Quoy & Gaimard, 1824) (*)	WA	2,3,4,5,7,8	OBIS_BR 857
Epinephelus itajara (Lichtenstein, 1822) (CR) (*)	WA	4,5,7,8	OBIS_BR 939
Rypticus randalli Courtenay, 1967	Ca+Br	2,4,5,7	OBIS_BR 2233
Serranus flaviventris (Cuvier, 1829) (*)	WA	8	OBIS_BR 2323

Scaridae			
Sparisoma axillare (Steindachner, 1878) (VU) (*)	Br+EA	6	OBIS_BR 21
Sparisoma rubripinne (Valenciennes, 1840) (*)	Ca+Br	13	
Uranoscopidae			
Astroscopus y-graecum (Cuvier, 1829) (*)	WA	13	
ACANTHURIFORMES			
Lutjanidae			
Lutjanus buccanella (Cuvier, 1828) (*)	Ca+Br	13	UESPIP 645
Lutjanus cyanopterus (Cuvier, 1828) (VU) (*)	Ca+Br	6,9,13	OBIS_BR 12, UESPIP 552
Lutjanus synagris (Linnaeus, 1758) (NT) (*)	WA	3,5,7,8,13	OBIS_BR 1578, UESPIP 662
Lutjanus vivanus (Cuvier, 1828) (NT) (*)	Ca+Br	8	
Ocyurus chrysurus (Bloch, 1791) (NT) (*)	WA		OBIS_BR 1894
Rhomboplites aurorubens (Cuvier, 1829) (NT) (*)	Ca+Br	10	
Gerreidae			
Gerres cinereus (Walbaum, 1792) (*)	Ca+Br	2,4,5,7	
Eugerres sp.	?	13	
Haemulidae			
Anisotremus surinamensis (Bloch, 1791) (DD) (*)	WA	5	
Anisotremus virginicus (Linnaeus, 1758) (*)	WA	5,6,7	OBIS_BR 129
Conodon nobilis (Linnaeus, 1758)	WA	5,8	OBIS_BR 573
Haemulon atlanticus Carvalho, Marceniuk, Oliveira & Wosiacki, 2020 (*)	Ca+Br	3,8	OBIS_BR 1364
Haemulon aurolineatum Cuvier, 1830 (*)	Ca+Br	6	OBIS_BR 1346
Haemulon flavolineatum (Desmarest, 1823) (*)	Ca+Br	5,8	
Haemulon cf. *plumierii* (Lacepède, 1801) (DD) (*)	Ca+Br		UESPIP 550
Paranisotremus moricandi (Ranzani, 1842) (*)	Ca+Br		OBIS_BR 117
Rhonciscus crocro (Cuvier, 1830) (*)	Ca+Br		OBIS_BR 2144
Sciaenidae			
Bairdiella goeldi Marceniuk, Molina, Caires, Rotundo, Wosiacki & Oliveira, 2019	Ca+Br	2,3,4,5,7,8	OBIS_BR 302
Cynoscion leiarchus (Cuvier, 1830)	Ca+Br	2,3,4,5,7,8	OBIS_BR 691
Cynoscion microlepidotus (Cuvier, 1830)	Br	2,4,5,7,8	OBIS_BR 710

Cynoscion virescens (Cuvier, 1830)	Ca+Br	5,8	OBIS_BR 749
Isopisthus parvipinnis (Cuvier, 1830)	Ca+Br	8	OBIS_BR 1461
Macrodon ancylodon (Bloch & Schneider, 1801)	Br+SSWA		OBIS_BR 1597
Menticirrhus cuiaranensis (Marceniuk, Caires, Rotundo, Cerqueira, Siccha-Ramirez, Wosiacki & Oliveira, 2020) (DD) (*)	WA	3,4,5,7,8	OBIS_BR 1651
Nebris microps Cuvier, 1830	Ca+Br		OBIS_BR 1882
Ophioscion punctatissimus Meek & Hildebrand, 1925 (DD)	Ca+Br	5	OBIS_BR 1970
Plagioscion squamosissimus (Heckel, 1840)	CF	2,10	
Paralonchurus brasiliensis (Steindachner, 1875)	WA	8	OBIS_BR 2030, UESPIP 705
Stellifer brasiliensis (Schultz, 1945)	Br		OBIS_BR 2393
Stellifer microps (Steindachner, 1864)	CA+Br		OBIS_BR 1958
Stellifer rastrifer (Jordan, 1889)	Br+SSWA	4,5	OBIS_BR 2432
Stellifer stellifer (Bloch, 1790)	Ca+Br		OBIS_BR 2453
Umbrina coroides Cuvier, 1830	Ca+Br	2,5,8	OBIS_BR 2765
Lobotidae			
Lobotes surinamensis (Bloch, 1790)	CT	2,4,5,7	OBIS_BR 1504
Pomacanthidae			
Pomacanthus arcuatus (Linnaeus, 1758) (DD) (*)	Ca+Br	5,8	OBIS_BR 2114
Acanthuridae			
Acanthurus chirurgus (Bloch, 1787) (*)	WA	6,9	OBIS_BR 24
Acanthurus coeruleus Bloch & Schneider, 1801 (*)	WA	4,5,7	
LOPHIIFORMES			
Ogcocephalidae			
Ogcocephalus nasutus (Cuvier, 1829) (*)	WA	13	
TETRAODONTIFORMES			
Diodontidae			
Chilomycterus antillarum Jordan & Rutter, 1897 (*)	Ca+Br	13	OBIS_BR 510, UESPIP 529
Diodon holocanthus Linnaeus, 1758 (*)	CT		OBIS_BR 833
Diodon hystrix Linnaeus, 1758 (*)	CT		OBIS_BR 839
Tetraodontidae			

Colomesus psittacus (Bloch & Schneider, 1801)	Ca+Br	2,5,7,8	OBIS_BR 558
Ostraciidae			
Lactophrys trigonus (Linnaeus, 1758) (*)	Ca+Br	8	
Monacanthidae			
Cantherhines macrocerus (Hollard, 1853) (*)	WA	13	
Balistidae			
Balistes vetula Linnaeus, 1758 (NT) (*)	TA		OBIS_BR 324
Melichthys niger (Bloch, 1786) (*)	CT	3,8	OBIS_BR 1624
Species reef-associated	62		
Species added from literature		92	
Species added from *Species*Link			67
Total species added	119		

Discussion

The observed pattern of family diversity is compatible with the results of Andrade-Tubino *et al.* (2008), which found four families (Sciaenidae, Gerreidae, Gobiidae, and Haemulidae) represented with the greatest number of species in Northeast Brazilian estuaries. Earlier estuarine fish fauna surveys from other regions of Northeastern Brazil (between the states of Rio Grande do Norte and Bahia) listed from 71 to 145 species (Lopes et al. 1998; Vasconcelos-Filho and Oliveira 1999; Paiva et al. 2008; Reis-Filho et al. 2010; Xavier et al. 2012; Oliveira and Pessanha 2014; Paiva et al. 2014; Reis-Filho and Santos 2014; Sales et al. 2016; Costa et al. 2017; Medeiros et al. 2019). Other compilations on fish diversity in Northeast Brazilian estuaries have included up to 190 species (Andrade-Tubino et al. 2008; Paiva and Araújo 2010), excluding synonyms and misidentifications.

It is possible that all the registered species, especially the marine and estuarine species, occur in each of the surveyed estuaries, with differences in abundance resulting from hydrological and geomorphological parameters, habitat and resource availability, and environmental impact levels (Baker et al. 2015; Pasquaud et al. 2015; Santana et al. 2015; Sheaves 2016). For example, *Chloroscombrus chrysurus* was only captured in Cocó estuary, but during the study period specimens were seen in the catches of fishermen exploiting other estuaries. Likewise, *Batrachoides surinamensis* was not captured in Pacoti estuary, but local fishermen reported the species during the rainy season. According to Potter et al. (2015), some fishes only enter estuaries sporadically or do not venture far beyond the lower or upper zone, leading to gaps in estuarine fish inventories.

Our survey revealed a predominance of marine fishes (111 species; 88%). A similar predominance of marine fishes may be observed in other estuaries from Northeastern to Southern Brazil (Vasconcelos-Filho and Oliveira 1999; Paiva et al. 2009; Reis-Filho et al. 2010; Vilar et al.

2011; Passos et al. 2013), indicating the relevance of these environments for the maintenance of marine species that use estuaries for reproduction, feed, growth, and shelter (Elliott et al. 2007). However, in our survey only 16 species (~13%) could be considered estuarine residents capable of completing their life cycle within this ecosystem (Paiva et al. 2009; Reis-Filho et al. 2010; Mai and Vieira 2013; Marceniuk et al. 2017b; Favero et al. 2019). Northern and Northeastern Brazil have similar percentages of resident estuarine species, as demonstrated by Vasconcelos-Filho and Oliveira (1999) (16.6%), Paiva et al. (2009) (14%), Carvalho-Neta et al. (2011) (10.5%), and Mourão et al. (2014), (16.4%), but in southward regions the percentage of resident species is higher (23-35%) (Reis-Filho et al. 2010; Hoeinghaus et al. 2011; Vilar et al. 2011; Passos et al. 2013; Pichler et al. 2015; Solari et al. 2015). Future studies are needed to prove this possible pattern; however this pattern may be the result of different sampling methodologies or species guild classification.

Seventy-five species recorded in this study are associated with reefs, reflecting the importance of estuaries as a stage in the life cycle of many fishes or as recruitment grounds (Xavier et al. 2012; Sales et al. 2016; Litvin et al. 2018). The large proportion of resident estuarine species associated with reefs (seven; 43%) suggests that part of their life cycle is extra-estuarine. More ecological research is necessary to understand the relative importance of different aquatic environments for these species at different stages of development (Bradley et al. 2019).

The small number of freshwater fishes recorded may be explained by the high salinity of the sampled estuaries or factors identified by Whitfield (2015), including strong competition and predation with marine species, the abundance of avian predators, the unavailability of upstream freshwater food sources, and habitat disconnectivity due to damming. Moreover, the observed continental freshwater fishes are physiologically secondary or peripheral and are known to tolerate moderate levels of salinity (Myers 1949). The freshwater families registered by Oliveira

(1976) and Alves and Soares-Filho (1996) in the estuary of the Jaguaribe river (Ceará) point to a richer freshwater ichthyofauna in the recent past. At many sampling sites, the assemblage may have changed as a result of local extinctions or rarity of sensible species. Furthermore, all the introduced species recorded in the literature or sampled in this study are of continental origin. Five non-native species were recorded in the sampled estuaries. At least four of these are exploited by the aquarium trade (*A. ocellatus*, *B. splendens*, *P. reticulata*, *P. sphenops*) and one is farmed (*O. niloticus*) (Leão et al. 2011; Brito et al. 2013). All five are found in several river basins in the Mid-Northeastern Caatinga, as shown by Rodrigues-Filho *et al.* (2016), Lima et al. (2017), Berbel-Filho et al. (2018), and Medeiros et al. (2019). *Poecilia sphenops* is reported from the Northeastern Atlantic Forest ecoregion, in Sergipe State (Brito et al. 2013; Lima et al. 2017), and this is the first record of this non-native species in the Mid-Northeastern Caatinga ecoregion. Lima et al. (2017) listed 12 non-native species in the Mid-Northeastern Caatinga; the new record of *P. sphenops* from Cocó river raises the number of non-native species in the Mid-Northeastern Caatinga ecoregion to 13 non-native species.

A greater and more consistent sampling effort (with voucher specimens) is required to effectively confirm some literature records. Nevertheless, it should be kept in mind that biological communities are subject to substantial fluctuations in time due to both natural and anthropic factors. We discuss here on selected species reported in the literature. In a large taxonomic study using molecular, cytogenetic and morphological methods, Menezes et al. (2015) reviewed the mullet species occurring in the Western Atlantic. The authors updated the distribution of mullets along the Brazilian coast and concluded that *Mugil trichodon* Poey, 1875 is limited to the Southern Caribbean, while the similar species occuring at the mouth of the Amazon river is *M. curvidens*, making it necessary to update earlier Brazilian reports of the former species. Menezes et al. (2015) also observed that *M. incilis* Hancock, 1830 occurs from Venezuela to Maranhão

(Northeastern Brazil) in close association with fresh water. The species was recorded by the EEZ program (2005) and by Basílio et al. (2009), but may be a case of misidentification. Basílio et al. (2009) also registered *M. platanus* Günther, 1880 (a synonym for *M. liza*) in the estuary of the Curu river. Accordingly, the mullet species sampled in the present study were identified as *M. curema*, *M. curvidens*, *M. liza*, *M. rubrioculus*, and *M. brevirostris*.

Lycengraulis batesii (Günther, 1868) was recorded by the EEZ program (2005), but its natural distribution is the coastal and interior waters of the Amazon and the Orinoco rivers (Fricke et al. 2022). The species was registered only through interviews, which can lead to spurious reports due to its great morphological similarity to *L. grossidens*. Thus, it may be another case of misidentification, as suggested by Basílio et al. (2009). *Genidens barbus* (Lacepède, 1803) was also registered by the EEZ program (2005), but since the distribution of this catfish is thought to be limited to Southern and Southeastern Brazil and Argentina, the interviewed fishermen may have mistaken it for another catfish species (e.g. *Sciades* spp.). Finally, Soares-Filho et al. (2010) reported *Notarius grandicassis* (Valenciennes, 1840), a species recently redescribed as *Notarius parmocassis* (Valenciennes, 1840). However, the latter has never been observed in estuaries (Marcenuik et al. 2017a).

Recent taxonomic reviews have substituted a number of local records. Marceniuk et al. (2019a) redescribed two species of the genus *Orthopristis* Girard, 1858, showing that *O. scapularis* occurs from Colombia to Northeastern Brazil, while *O. ruber* (Cuvier, 1830) is distributed along the shores of Southern and Southeastern Brazil. Marceniuk et al. (2019b) also demonstrated that the local taxon previously given as *Bairdiella rhonchus* (Cuvier, 1830) is a newly described species, *B. goeldi* Marceniuk, Molina, Caires, Rotundo, Wosiacki & Oliveira, 2019, which is distributed along the Brazilian coast, from Northern Pará to Santa Catarina, while *B. rhonchus* is a Caribbean species. Furthermore, Marceniuk et al. (2020) found *Menticirrhus americanus*

(Linnaeus, 1758) to be limited to the Northwestern Atlantic and revalidated the junior synonym *M. martinicensis* as a Southwestern Atlantic species. Likewise, *M. littoralis* (Holbrook, 1847) is now believed to be *M. cuiaranensis* (Marceniuk et al. 2020). Carvalho et al. (2020) redescribed *Haemulon steindachneri* (Jordan & Gilbert, 1882) as native to the East Pacific, while the species known from Costa Rica to Southern Brazil is *H. atlanticus*, a recently described species. Finally, Araujo et al. (2022) found disjunct populations of *Scorpaena plumieri* and *Sphoeroides spengleri* between Caribbean and Brazil, which lineages in the Brazilian Province likely represent species not formally recognized. Therefore, we designate the two species as *S.* cf. *plumieri* e *S.* cf. *spengleri*. According to Fricke et al. (2022), records of *Albula vulpes* from northern Brazil needs verification; previously supposed to be a circumglobal species in warm seas, but apparently is a species complex. Thus, we use *Albula* cf. *vulpes*.

Loricaria parnahybae Steindachner, 1907 was registered by Alves and Soares-Filho (1996) in the estuary of the Jaguaribe river, but the species is naturally distributed in the Maranhão-Piauí ecoregion (Lima et al. 2017) and may have been confounded with *Loricarichthys* Bleeker, 1862 ― probably *L. derbyi*, which occurs in the Mid-Northeastern Caatinga (Lima et al. 2017). The same may be the case of *Hypostomus plecostomus* (Linnaeus, 1758) and *Pimelodella cristata* (Müller & Troschel, 1849), which do not occur in this region: the former is probably *Hypostomus jaguribensis* while the latter appears to be *Pimelodella dorseyi* Fowler, 1941, which is native to the basin or ecoregion (Lima et al. 2017). These species were registered in a recent study on the fauna of the Jaguaribe river basin (Rodrigues-Filho et al. 2020).

In some cases, a species may be morphologically similar to another and far more abundant species, raising doubts about whether it has been correctly reported. For example, *Chirocentrodon bleekerianus* (Poey, 1867) was registered by the EEZ program (2005) in all local estuaries, but not a single specimen was obtained during the present study. The species in question can be difficult to distinguish from locally occurring engraulids. Likewise, *Anchoa tricolor*, which was registered by Basílio et al. (2009) in the Curu estuary, was maintained on our list of regional fishes (Appendix 3) despite the lack of voucher specimens to confirm its occurrence in estuaries. The occurrence of *Lutjanus cyanopterus* in the estuaries of Pacoti and Jaguaribe was based on underwater observations by Osório et al. (2011) and Freitas et al. (2006), respectively. This form of surveying can lead to misidentification, as in the case of *L. alexandrei* Moura & Lindeman, 2007, which was also reported by Osório et al. (2011) and collected in more recent studies. However, considering the natural distribution of *L. cyanopterus* (Western Atlantic, from Bermuda to Santa Catarina, Brazil, see Sanches et al. 2012), its occurrence in our region cannot be dismissed. The same is true for *Colomesus psittacus*, *Gerres cinereus*, and a number of carangids and sciaenids. As for seahorses, little is known about the distribution in Brazilian waters and the taxonomy is disputed. The only species recorded in the present study was *Hippocampus reidi*, but there is evidence that *H. erectus* also occurs on the Brazilian coast and is exploited by the aquarium trade (Gurjão and Lotufo 2018).

Due to the long period and large area covered by the study, the inventory of fishes from seasonally hypersaline estuaries in Northeastern Brazil increased considerably. In this study we provide an updated list of the fish species occurring in estuaries along the coast of Ceará, with taxonomic identities confirmed by experts. This is the most comprehensive survey of estuarine fish species from the semiarid coastal regions of Brazil, based on observations made at different times of the year and in different estuarine zones. Many species were added to the previous lists of this region, highlighting the importance of these ecosystems as shelter, feeding grounds and nurseries for marine and estuarine dependent fishes, some of which are commercially exploited. Many of the species occurring in the sampled estuaries are consumed, marketed by subsistence fishermen or sold in the aquarium trade (Barletta and Costa 2009; Basílio and Garcez 2014;

Gurjão and Lotufo 2018). This illustrates the role of estuaries as a source of income and animal protein for local populations. The study expands current knowledge of the fish fauna and subsidizes the management of conservation units covering three of the evaluated estuaries (EPA of the Pacoti estuary, EPA of the Curu estuary, and Cocó State Park).

In conclusion, a total of 245 species were recorded (126 species sampled and 119 species from the literature), comprising the majority of marine species and widely distributed in the Atlantic, with the Orders Acanthuriformes, Carangiformes and Clupeiformes most represented. The present study is highly relevant as it explores a region vulnerable to climate change, such as declining rainfalls, rising sea levels, decreased land-to-ocean matter flux, acidification, intensification of extreme events, eutrophication and hypoxia, and detrimental changes in biogeochemical processes (Ward et al. 2016; Lauchlan and Nagelkerken 2020; Soares et al. 2021). The current inventory fills important gaps in our knowledge of biodiversity in seasonally hypersaline estuaries in the semiarid coastal regions of Brazil and is intended as a point of departure for more comprehensive fish fauna research in the region.

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CAPÍTULO 2

Raridade e redundância funcional de assembleias de peixes de estuários sazonalmente hipersalinos do Nordeste do Brasil

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Abstract

This study described fish assemblages from estuaries in Northeastern Brazil in terms of functional redundancy through functional rarities and functional entities. The species were classified according to diet, estuary use, reproduction, position in the water column and mobility. Morphometric measurements were used to characterize functions of food acquisition, locomotion and habitat use. Taxonomic rarities (restrictedness, Ri and scarcity, Si) and functional rarities (uniqueness, Ui, distinctiveness, Di) were calculated for each species. Spearman correlations between indices verified whether taxonomically rare species are also functionally rare. Functional redundancy analyzes were performed from functional entities with categorical data. The estuaries were composed of many regionally restricted species, in addition to low variation in Ui and Di. The correlation between Ri and Ui was significant, where only *Hippocampus reidi* was both well distributed and functionally unique. There was a significant correlation between Si and Di, showing that locally rare species tend to be functionally distinct. Of the 44 functional entities (FEs), three showed high species richness. Thirty FEs harbored less than three species, which makes about 30% of the species with low or no functional redundancy. In conclusion, estuaries have few dominant species that are redundant and many rare species, which tend to be more functionally distinct. In general, an ichthyofauna with high functional redundancy, but showing a large part of the species pool with low or no redundancy in many FEs, bringing important implications for the management of these environments with current and future impacts.

Keywords: ichthyofauna, functional ecology, functional rarity, coastal ecosystems.

Resumo

O presente estudo descreveu as assembleias de peixes de estuários do Nordeste do Brasil quanto à redundância funcional por meio de raridades funcionais e entidades funcionais. As espécies foram classificadas quanto à dieta, uso do estuário, reprodução, posição na coluna d’água e mobilidade. Medidas morfométricas foram utilizadas para caracterizar funções de aquisição de alimento, locomoção e uso do hábitat. Foram calculadas raridades taxonômicas (restritividade, R_i e escassez, S_i) e raridades funcionais (singularidade, U_i, distintividade, D_i) para cada espécie de peixe. Correlações de Spearman entre os índices averiguaram se espécies taxonomicamente raras também o são funcionalmente. Análises de redundância funcional foram realizadas a partir de entidades funcionais com os dados categóricos. Os estuários foram compostos por muitas espécies de peixes regionalmente restritas, além de baixa variação em Ui e Di. A correlação entre R_i e U_i foi significativa, onde apenas *Hippocampus reidi* foi tanto bem distribuída como funcionalmente única. Houve correlação significativa entre S_i e D_i, mostrando que espécies de peixes localmente raras tendem a ser funcionalmente distintas. Das 44 entidades funcionais (FEs), três apresentaram elevada riqueza de espécies de peixes. Trinta FEs abrigaram menos de três espécies, o que torna cerca de 30% das espécies com baixa ou nenhuma redundância funcional. Em conclusão, os estuários possuem poucas espécies de peixes dominantes que são redundantes e muitas espécies raras, as quais tendem a serem mais distintas funcionalmente. No geral, uma ictiofauna com elevada redundância funcional, mas apresentam grande parte do conjunto de espécies com pouca ou nenhuma redundância em muitas FEs, trazendo implicações importantes para o manejo desses ambientes com os impactos atuais e futuros.

Palavras-chave: ictiofauna, ecologia funcional, raridade funcional, ecossistemas litorâneos.

Introdução

A perda acelerada da biodiversidade preocupa pelo valor intrínseco das espécies e pela perda de funções nos ecossistemas (Hooper *et al*., 2005; Violle *et al*., 2017). Um dos aspectos da ecologia funcional é a redundância funcional, quando espécies similares em atributos funcionais habitam um dado ecossistema, e sua importância se dá quando uma espécie é extinta e outra exerce a mesma função no ambiente, minimizando o impacto sobre o ecossitema (Naeem, 1998; Rosenfeld, 2002; Mouillot *et al*., 2013). Dessa forma, o entendimento de redundância funcional, assim como sua descrição em determinado ambiente, providencia oportunidades valiosas para a compreensão dos ecossistemas, pois a redundância funcional atua no amortecimento dos efeitos da perda de biodiversidade (Naeem, 1998; Rosenfeld, 2002; Loreau *et al*., 2003; Brandl *et al*., 2016). Historicamente, os estudos tem focado em abordagens taxonômicas, negligenciando os atributos funcionais das espécies (Rabinowitz, 1981; Prendergast *et al*., 1993), porém atualmente abordagens que focam na raridade filogenética e funcional têm ganhado atenção (Isaac *et al*., 2007; Cadotte, Davies, 2010; Mouillot *et al*., 2013; Violle *et al*., 2017).

A redundância funcional pode estar positivamente ligada à riqueza de espécies, onde ambientes mais ricos tenderiam de ser mais redundantes; assim como à equitabilidade funcional, onde comunidades que apresentam distribuição igualitária nas abundâncias das espécies entre os grupos funcionais seriam mais redundantes (Fonseca, Ganade, 2001; Jain *et al*., 2014). Autores também relatam que comunidades que possuem menos riqueza funcional (ou menos grupos funcionais) teriam maior redundância do que comunidades funcionalmente mais ricas (Fonseca, Ganade, 2001). Outra faceta da ecologia funcional é a raridade funcional, que é a característica de uma espécie possuir baixa abundância concomitante à características funcionais únicas (Violle *et al*., 2017). Espécies raras, ao possuírem pequenas populações, distribuição restrita e/ou nichos ambientais estreitos, são conhecidamente mais vulneráveis aos distúrbios do que espécies comuns (Rabinowitz, 1981; Gaston, 1994), e espécies mais distintas funcionalmente são conhecidamente mais vulneráveis à pressões como superexploração e mudança do clima (Mugier *et al*., 2021; Stewart *et al*., 2022). Além disso, espécies raras também contribuiriam menos do que espécies comuns para o funcionamento dos ecossistemas (Grime, 1998; Smith, Knapp, 2003; Pendleton *et al*., 2014; Dee *et al*., 2019), no entanto, estudos tem refutado essa premissa (Jain *et al*., 2014; Leitão *et al*., 2016; Chapman *et al*., 2018; Dee *et al*., 2019). Assim, considerar os atributos das espécies e suas abundâncias é uma etapa necessária para avaliar a vulnerabilidade funcional das comunidades aos distúrbios (Auber *et al*., 2022).

Nas regiões tropicais, estuários são ecossistemas conhecidos por apresentarem grande biodiversidade e elevada redundância funcional (Baptista *et al*., 2015; Dolbeth *et al*., 2016; Teichert *et al*., 2017; Silva, Fabré, 2019). Estuários geram bens e serviços e representam um dos mais produtivos ecossistemas com recursos para inúmeras espécies, as quais muitas são comerciais (Wolanski *et al*., 2011; Atwood *et al*., 2012), mas tem sofrido constantes distúrbios (Santana *et al*., 2015; Barletta *et al*., 2019; Barletta, Lima, 2019; Lauchlan, Nagelkerken, 2020). No entanto, também se têm mostrado que o conjunto de espécies nos estuários não é tão redundante assim, apesar da grande diversidade biológica (Henderson *et al*., 2020; Whitfield, Harrison, 2021). Logo, com a falta de concenso a respeito da redundância funcional das espécies estuarinas, ainda é pertinente estudos de caso que descrevam sobre esse aspecto ecológico, principalmente pelos ambientes estarem sujeitos a constantes distúrbios.

Estuários da parte mais setentrional da região Nordeste do Brasil (NEB) possuem uma rica assembleia de peixes até então pouco estudada, com literatura concentrada principalmente em inventários de espécies (Araújo *et al*., 2000; Basílio *et al*., 2009; Melo et al., 2021; Gurgel-

Lourenço *et al*., 2023). Assim, estuários da NEB são ricos em biodiversidade, mas ameaçados por diversos impactos intrínsecos às suas bacias e pelas mudanças no clima. Dessa forma, o presente estudo procura responder como a redundância funcional das assembleias de peixes dos estuários da costa semiárida do Brasil é distribuída entre as espécies e entidades funcionais. Esperamos que os estuários possuam elevada redundância funcional tanto em nível de espécies quanto para as entidades funcionais.

Material e métodos

Área de estudo. O clima da região costeira que compreende este estudo é "As" (zona tropical com verão seco), segundo classificação de Köppen (Alvares *et al.*, 2014), com deficiência hídrica moderada a baixa e valores médios entre 1000 e 1300 mm anuais, mas ainda com influência do clima semiárido "BSh" mais continental no aporte hídrico. Na NEB ocorrem estuários influenciados diretamente pelo clima semiárido da região, e apresentam muitas vezes sazonalidade na dinâmica de massas d'água onde podem se tornar hipersalinos, com gradiente de salinidade invertido, em função de eventos de seca e/ou devido aos barramentos dos rios (Moraes, Pinheiro, 2011; Valentim *et al*., 2018). Os estuários da costa cearense podem apresentar hipersalinização, em função da escassa contribuição de água doce de drenagem continental em grande parte do ano (período seco: junho a janeiro), produzindo maior concentração salina em relação ao oceano Atlântico adjacente (sensu Potter *et al.*, 2010; Valentim *et al.*, 2018). Tal condição se intensifica principalmente em anos de seca extrema ou por uma série de anos com déficit hídrico (Valentim *et al*., 2018). As vazões fluviais resultantes também são, em parte, determinadas pelos reservatórios ao longo de suas bacias hidrográficas (Molisani *et al.*, 2006; Moraes, Pinheiro, 2011).

Amostragem. Sete estuários da parte setentrional do Nordeste do Brasil tiveram sua fauna de peixes amostrada a partir de cinco a sete campanhas em cada estuário compreendendo intervalos bimestrais abrangendo todo o ciclo anual (Fig. 1). Os estuários dos rios Choró, Curu e Pacoti foram amostrados em 2014/2015 (Choró: 08/2014 a 08/2015; Curu: 11/2014 a 08/2015; Pacoti: 12/2014 a 09/2015). O estuário do rio Cocó foi amostrado em 2017/2018 (05/2017 a 05/2018). E os estuários dos rios Malcozinhado, Aracatimirim e Aracatiaçu foram amostrados em 2019/2020 (Aracatiaçu: 03/2019 a 12/2019; Aracatimirim: 03/2019 a 12/2019; Mal Cozinhado: 01/2019 a 02/2020).

As amostragens foram delineadas de modo a se configurar ao longo da extensão dos ecossistemas, desde a foz até pelo menos 5 km à montante, compreendendo de cinco a oito pontos amostrais. As capturas dos peixes foram padronizadas com rede de arrasto de praia de 25 m de comprimento e 2 m de altura de 1,2 cm de malha (três lances de arrastos por ponto), e tarrafa de 3 m de altura (10 m^2 de área total) com 2,5 cm de malha (20 a 30 minutos por ponto e contabilizados o número de arremessos). Os arrastos foram realizados em profundidades entre 0,3 m e 1,5 m. A amostragem com tarrafas foi realizada em áreas com maior amplitude de profundidade, entre 1,0 m e 3,5 m. Cada arrasto percorreu em torno de 200 m^2 de área estuarina de acordo com a equação: A= D x L, onde A é a área, D é a distância da margem (10 m) e L é o comprimento da rede efetivamente utilizado (20 m). Cada arremesso de tarrafa compreendeu uma abertura total de 10 m^2, correspondente a área circular ($\pi.r^2$). O número de indivíduos e a biomassa em gramas de cada espécie foram divididos pela área amostrada por cada ferramenta, obtendo valores em metros quadrados. Devido à seletividade dos aparelhos quanto às espécies e aos tamanhos dos indivíduos capturados, procurou-se reunir os dados padronizados provenientes das duas ferramentas e gerar unidades de densidade (indivíduos/100 m^2) e biomassa (g/100 m^2) conjuntas. Antes das amostragens de peixes, salinidades superficiais foram anotadas com refratômetro.

Todas as coletas foram realizadas em maré vazante (2,0 a 0,0) e maré enchente (0,0 a 2,0), compreendendo sempre horários diurnos (07:00 h a 17:00 h), e foram autorizadas pelo ICMBio/SISBio (Licenças: nº43014, 57780, 64269). Os peixes coletados foram condicionados em sacos plásticos em isopor com gelo e posteriormente fixados em formol 10% ao final das atividades em campo. Após 48h foram preservados em álcool 70% no Laboratório de Ecologia Aquática e Conservação (LEAC) da Universidade Federal do Ceará, onde as espécies tiveram suas identidades taxonômicas confirmadas segundo literatura especializada. Lotes de espécimes foram tombados em coleções oficiais da Universidade Federal da Paraíba e da Universidade Federal do Rio Grande do Norte (vouchers em Gurgel-Lourenço *et al*., 2023).

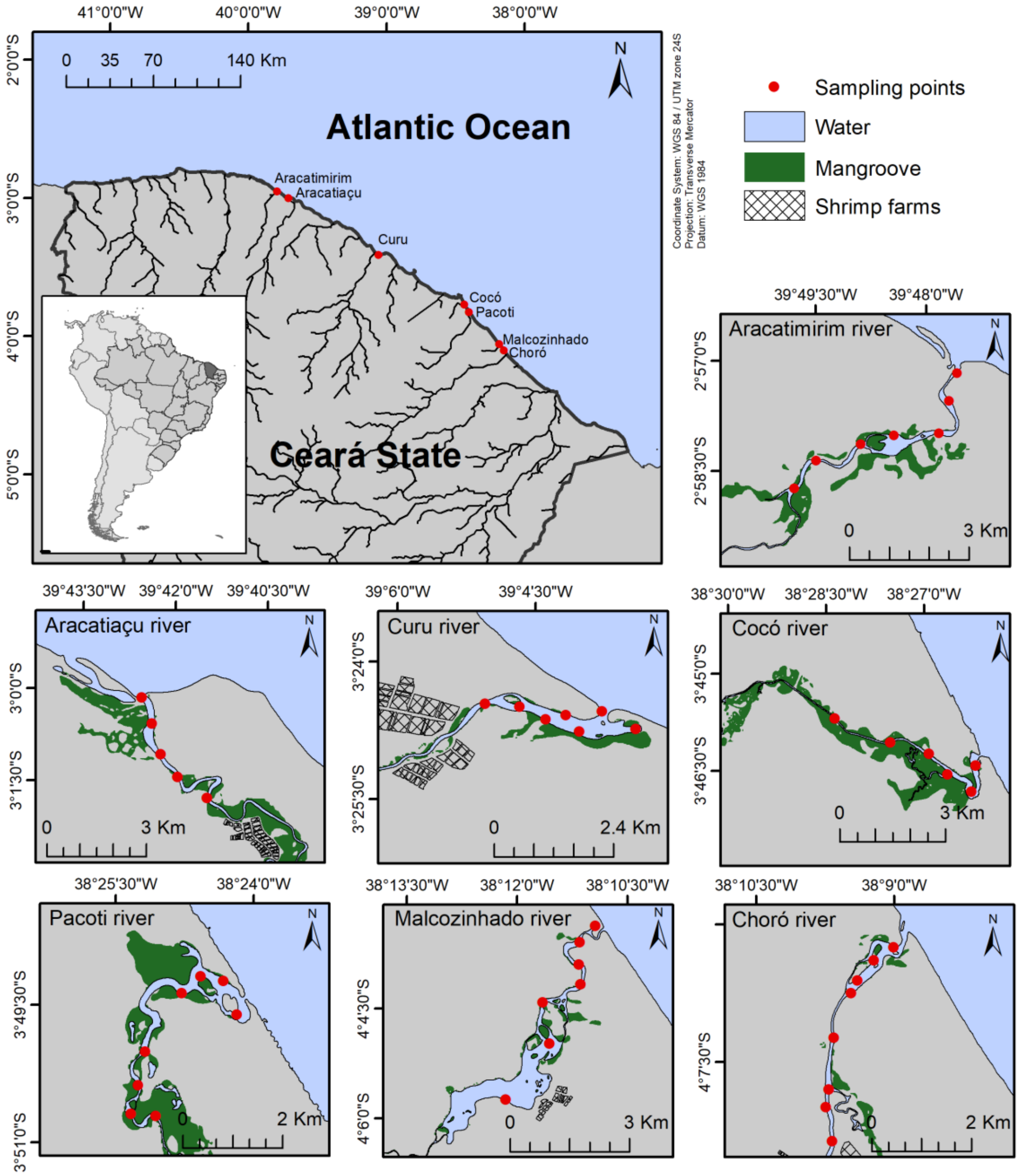

FIGURA 1 - Pontos de coleta para amostragem padronizada de peixes nos estuários dos rios Aracatimirim, Aracatiaçu, Curu, Cocó, Pacoti, Malcozinhado e Choró.

Dados funcionais das espécies. As espécies foram classificadas por guildas tróficas em detritívoras (Detri), planctívoras (Plank), herbívoras (Herb), invertívoras (Invert), macrocarnívoras (Macro) e onívoras (Oniv) a partir de Araújo *et al.* (2009; 2016), Barros *et al.* (2013), Brenner, Krumme (2007), Campos *et al.* (2015), Castillo Rivera *et al.* (2007), Chaves, Vendel (2008), Contente *et al.* (2012), Denadai *et al.* (2012), Denadai *et al.* (2013), Figueiredo, Pessanha (2016), Froese, Pauly (2019), Gay *et al*. (2002), Lopes (1999), Paiva *et al.* (2008), Passos *et al*. (2013), Pessanha *et al.* (2015), Ramos *et al.* (2014), Silva et al. (2001), Tonini et al. (2007) e Zahorcsak *et al.* (2000). Foi dada ênfase a literatura trófica em ambiente estuarino e com base nos tamanhos dos indivíduos coletados, visto que as espécies podem apresentar alterações no uso de recursos tróficos ao longo da ontogenia. As espécies também foram classificadas quanto à posição na coluna d'água em bentônicas (Bent), nectônicas (Nect) ou nectobentônicas (NectBent); em espécies móveis (MO) ou sedentárias (SE); e quanto à guilda reprodutiva em tipos de fecundação: fecundação externa (FE), fecundação externa com cuidado parental (FECP), fecundação interna (FI), e fecundação interna com desenvolvimento interno (FIDI) a partir de Froese, Pauly (2019), Garcia-Júnior *et al*. (2010). As espécies também foram classificadas de acordo com o modo de ocupação do ambiente estuarino com base na categorização de Potter *et al*. (2015) em marinhas visitantes (MS); marinhas migrantes, as quais incluem as marinhas estuarino-oportunistas e marinhas estuarino-dependentes (MM); estuarinas, que incluem estuarinas migrantes e estuarinas residentes (ES); diádromas (DI); e dulcícolas (FW). Dados binários também foram utilizados para assinalar a ocorrência das espécies em água doce, salobra e/ou salgada, segundo Froese, Pauly (2019). *Mugil* sp. foi tratada como uma espécie à parte devido seu tamanho diminuto (comprimento-padrão <40 mm) que impossibilitou sua identificação em nível de espécie. Atributos qualitativos estão disponíveis no Apêndice A.

Além dos atributos qualitativos, atributos quantitativos morfofuncionais também foram utilizados a fim de complementar a estrutura funcional das assembleias de peixes ao caracterizar três funções: aquisição de alimento, locomoção e uso do hábitat (Leitão *et al*., 2016). Massa corpórea e medidas morfométricas foram obtidas de um a cinco indivíduos de cada espécie (Fig. 2), dependendo da disponibilidade. As medidas morfométricas foram combinadas em 15 atributos funcionais (Tab. 1). A média de cada atributo obtido dos indivíduos foi calculada (Apêndice B). Os atributos medidos têm sido comumente utilizados para descrever a estrutura funcional da ictiofauna (Toussaint *et al*., 2016) e são especialmente úteis para regiões com grande riqueza de espécies onde o conhecimento básico sobre a ecologia das espécies é escasso (Villéger *et al*., 2017).

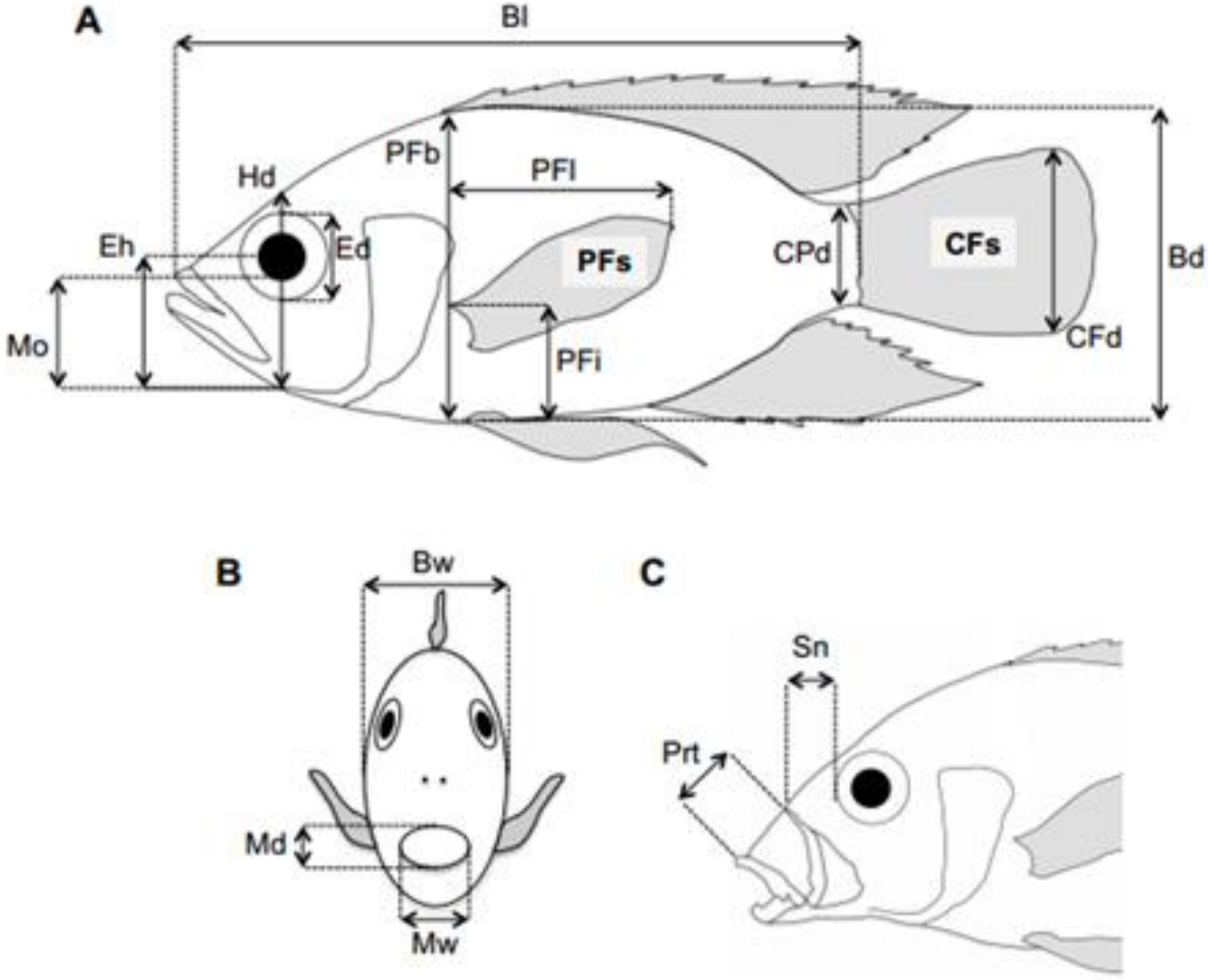

FIGURE 2 - Atributos funcionais medidos a partir de fotografias dos peixes (A): comprimento-padrão (Bl), altura do corpo (Bd), altura mínima do pedúnculo caudal (CPd), altura da nadadeira caudal (CFd), área da nadadeira caudal (CFs), distância entre a inserção da nadadeira peitoral ao fundo do corpo (PFi), altura do corpo ao nível da inserção da nadadeira peitoral (PFb), comprimento da nadadeira peitoral (PFl), área da nadadeira peitoral (PFs), altura da cabeça ao longo do eixo vertical do olho (Hd), diâmetro do olho (Ed), distância entre o centro do olho ao fundo da cabeça (Eh), distância do topo da boca ao fundo da cabeça ao longo do eixo da altura da cabeça (Mo); e com paquímetro (B, C): largura do corpo (Bw), altura do corpo (Md), largura da boca (Mw), comprimento do focinho (Sn), comprimento da protrusão (Prt). Retirada de Leitão *et al*. (2016).

TABLE 1 - Lista dos atributos funcionais quali e quantitativos das espécies de peixes dos estuários do presente estudo.

Atributos funcionais quantitativos	**Cálculo**	**Abreviação**	**Significado ecológico**	**Referência**
Massa corpórea	$\ln(Massa + 1)$	LogM	Metabolismo, resistência e capacidade de natação	Villéger *et al*. (2010)
Comprimento da protrusão da boca	$\frac{Prt}{Sn}$	Prt	Método de alimentação	Adaptado de Leitão *et al*. (2016)
Área da cavidade oral	$\frac{Mw * Md}{Bw * Bd}$	Osf	Tamanho dos itens alimentares capturados	Adaptado de Karpouzi, Stergiou (2003)
Forma da cavidade oral	$\frac{Md}{Mw}$	Osh	Método de captura de alimento	Karpouzi, Stergiou (2003)
Posição da cavidade oral	$\frac{Mo}{Hd}$	Ops	Método de alimentação na coluna d'água	Adaptado de Sibbing, Nagelkerke (2001)
Tamanho do olho	$\frac{Ed}{Hd}$	Edst	Detecção de presas	Adaptado de Boyle, Horn (2006)
Posição do olho	$\frac{Eh}{Hd}$	Eps	Posição vertical na coluna d'água	Gatz (1979)
Formato transversal do corpo	$\frac{Bd}{Bw}$	Bsh	Posição vertical na coluna d'água e hidrodinamismo	Sibbing, Nagelkerke (2001)
Área transversal do corpo	$\frac{\ln[(\frac{\pi}{4} * Bw * Bd) + 1]}{\ln(Massa + 1)}$	Bsf	Distribuição de massa ao longo do corpo para hidrodinamismo	Villéger *et al*. (2010)
Posição da peitoral	$\frac{PFi}{PFb}$	PFps	Uso da peitoral para manobrabilidade	Dumay *et al*., (2004)
Aspecto da peitoral	$\frac{PFl^2}{PFs}$	FPar	Uso da peitoral para propulsão	Adaptado de Fulton *et al*. (2001)
Tração do pedúnculo caudal	$\frac{CFd}{CPd}$	Cpt	Eficiência de propulsão caudal através da redução de resistência	Webb (1984)
Aspecto da caudal	$\frac{CFd^2}{CFs}$	CFar	Uso da nadadeira caudal para propulsão e/ou direção	Webb (1984)
Relação das áreas das nadadeiras	$\frac{2 * PFs}{CFs}$	Frt	Principal tipo de propulsão entre as nadadeiras caudal e peitoral	Villéger *et al*. (2010)
Relação entre superfície das nadadeiras e o tamanho do corpo	$\frac{(2 * PFs) + CFs}{\frac{\pi}{4} * Bw * Bd}$	Fsf	Eficiência de aceleração e/ou manobrabilidade	Villéger *et al*. (2010)
Atributos funcionais quantitativos		**Abreviação**	**Significado ecológico**	
Dieta				
	Detritívora	Detri	Espécies que se alimentam de detritos e/ou	

			microfitobentos
	Planctívora	Plank	Espécies que se alimentam de fitoplâncton e/ou zooplâncton
	Herbívora	Herb	Espécies que se alimentam de macroalgas/macrófitas
	Invertívora	Invert	Espécies que se alimentam principalmente de invertebrados bentônicos
	Macrocarnívora	Macro	Espécies que consomem principalmente peixes, mas podem predar invertebrados bentônicos
	Onívora	Oniv	Espécies que consomem de plantas a plâncton e/ou invertebrados bentônicos
Posição na coluna d'água			
	Bentônicas	Bent	Peixes que vivem mais associados ao substrato (ex: gobiideos)
	Nectobentônicas	NectBent	Peixes que utilizam a região pelágica e bentônica (ex: lutjanideos)
	Nectônicas	Nect	Peixes que vivem associados à região pelágica (ex: clupeideos)
Atividade			
	Móveis	MO	Peixes que se movimentam constantemente entre hábitats (ex: mugilideos)
	Sedentárias	SE	Peixes menos ativos em movimentação (ex: batrachoidideos)
Guilda reprodutiva			
	Fecundação externa	FE	Espécies de possuem fecundação externa
	Fecundação externa com cuidado parental	FECP	Espécies de possuem fecundação externa e apresentam algum nível de cuidado parental
	Fecundação interna	FI	Espécies de possuem fecundação interna
	Fecundação interna com desenvolvimento interno	FIDI	Espécies de possuem fecundação e desenvolvimento internos
Uso do estuário			
	Marinha visitante	MS	Espécies que ocorrem em baixos números e esporadicamente nos estuários
	Marinha migrante	MM	Espécies estuarino-oportunistas ou dependentes que usam o estuário para completar parte do ciclo de vida
	Estuarina	ES	Espécies capazes de completar todo o ciclo de vida nos estuários, mas não necessariamente o fazem. Incluem as estuarinas migrantes e as residentes
	Diádroma	DI	Espécies marinhas que necessitam de água doce para completar o ciclo de vida
	Dulcícola	FW	Espécies de água doce
Ocorrência			
	Água salgada	0/1	Ocorrência em águas com salinidade nula
	Água salobra	0/1	Ocorrência em salinidades intermediárias
	Água doce	0/1	Ocorrência em salinidades marinhas ou superiores

Análises estatísticas. A partir de Violle *et al*. (2017) foram calculadas as raridades taxonômicas e funcionais em níveis local e regional para cada espécie. O conjunto dos sete estuários foi considerado para o nível regional dos índices de raridades taxonômica (restritividade, R_i) e funcional (singularidade, U_i), e cada estuário foi considerado em nível local de raridades taxonômica (escassez, S_i) e funcional (distintividade, D_i). Todos os índices variam entre 0 e 1.

A Restritividade taxonômica (R_i) de uma espécie é mais alta quando a espécie ocorre em um ou dois estuários e mais baixa quando a espécie ocorre em todos os estuários, seguindo:

$$Ri = 1 - \frac{Ki}{Ktot},$$

onde K_i é o número de estuários onde a espécie *i* ocorre, e K_{tot} é o número total de estuários no conjunto de dados.

A singularidade funcional (U_i) é a distância de uma espécie focal *i* para o seu vizinho mais próximo no espaço funcional em um conjunto de assembleias (todas as espécies, todos os estuários), como segue:

$$Ui = \min(dij),$$

onde d_{ij} é a dissimilaridade funcional entre a espécie *i* e a espécie *j*, para pares de espécies da matriz espécie-estuário com $i \neq j$. Ela quantifica quão isolada uma espécie é no espaço funcional sem considerar as abundâncias, onde quanto maior o valor do índice, mais distante é uma espécie para o seu vizinho mais próximo (maior singularidade funcional) no espaço funcional.

A Escassez taxonômica (S_i) de uma dada espécie em uma assembleia (ou seja, em cada estuário) é próxima de zero quando a espécie focal é dominante em abundância, seguindo a equação:

$$Si = \exp[-N\ x \ln(2)\ x\ Ai],$$

onde *N* é o número de espécies e A_i é a abundância relativa (em densidade ou biomassa) da espécie *i* no estuário. Quando as espécies são igualmente abundantes na assembleia, com abundâncias relativas de 1/N, S_i é igual a 0,5.

A Distintividade funcional (D_i) é a diferença de atributos funcionais de uma espécie *i* em relação aos atributos das outras espécies em uma assembleia (em cada estuário), aqui ponderada pelas abundâncias relativas das espécies, como:

$$Di = \frac{\sum_{i=1,j\neq i}^{N} dijAj}{\sum_{j=1,j\neq i}^{N} Aj},$$

onde d_{ij} é a dissimilaridade funcional entre as espécies i e j, N é o número total de espécies em um dado estuário, A_j a abundância relativa da espécie j no estuário. D_i é padronizado entre zero, se uma espécie focal é idêntica a todas as outras espécies, e 1, quando a espécie focal é funcionalmente dissimilar em comparação às outras espécies.

Ao final dos cálculos dos índices de raridade, foram realizadas correlações de Spearman entre os mesmos a fim de investigar se espécies que são funcionalmente únicas/distintas também são taxonomicamente restritas/escassas (Grenié *et al*., 2017). Essas análises foram realizadas no software R 4.1.2 (R Core Team, 2021) com o pacote *funrar* (Grenié et al., 2017).

A redundância funcional de comunidades biológicas pode ser avaliada a partir do número de espécies nos grupos funcionais assim como por entidades funcionais. Entidades funcionais são espécies que possuem o mesmo conjunto de atributos funcionais. Os dados funcionais categóricos de dieta, uso do estuário, guida reprodutiva, posição na coluna d'água e mobilidade foram utilizados para as análises de redundância funcional. As espécies foram reunidas em entidades funcionais a partir das funções '*species_to_FE*' e '*FE_metrics*' em software R desenvolvidas por Sébastien Villéger (Mouillot *et al*., 2014).

Resultados

Um total de 40508 peixes foi amostrado nos sete estuários, compreendendo 115 espécies, 50 famílias e 22 ordens. Abundâncias em densidades e biomassas para cada espécie estão listadas nos Apêndices C e D. A maioria das espécies é invertívora, se alimentando de zoobentos, seguida pelas espécies macrocarnívoras e onívoras. Detritívoras, planctívoras e herbívoras constituem o menor número de espécies (Fig. 3A). A grande maioria das espécies compreende as marinhas migrantes, seguido pelas marinhas visitantes e estuarinas. Dulcícolas e diádromas constituem o menor número de espécies (Fig. 3B). A quase totalidade das espécies possui fecundação externa sem cuidado parental, seguido pelas espécies que o fazem; e poucas espécies com fecundação interna (Fig. 3C). Nectobentônicas e nectônicas compreendem a maioria das espécies, seguidas pelas bentônicas (Fig. 3D). Por fim, as assembleias são bem mais representadas por organismos móveis do que por espécies sedentárias (Fig. 3E).

Os estuários apresentaram correlação positiva entre salinidade e riqueza de espécies de peixes, sendo os estuários dos rios Choró (salinidade: 33,6 ± 11,83), Pacoti (31,7 ± 12,70) e Curu (34,4 ±

5,56) os mais salinos; Malcozinhado (22,9 ± 13,65), Aracatimirim (13,7 ± 13,40) e Aracatiaçu (15,2 ± 12,37) foram estuários com valores intermediários de salinidade; e o Cocó o estuário menos salino (6,8 ± 8,85). Estuários mais salinos apresentaram maiores números de espécies detritívoras, planctívoras, invertívoras e macrocarnívoras, de espécies marinhas visitantes e marinhas migrantes, de espécies nectônicas e nectobentônicas, e espécies mais ativas. Espécies onívoras e espécies dulcícolas foram mais comuns em estuários menos salinos (Apêndice H).

Os estuários foram compostos por considerável número de espécies de peixes (39 espécies, ~34%) regionalmente restritas ($R_i > 0,70$). Apenas cerca de 36% das espécies (42 espécies) são bem distribuídas regionalmente ($R_i < 0,30$) (Apêndice E). Os estuários são compostos por espécies com baixa variação nos valores de singularidade funcional (U_i: menos de 0,001 a 0,179). Das 115 espécies, apenas 12 (~10%) apresentaram valores de U_i acima de 0,09, das quais sete espécies também apresentaram valores mais altos de R_i (> 0,70): *A. saxatilis*, *D. volitans*, *P. nodosus*, *S. brasiliensis*, *S. rhombeus*, *S. bondi* e *S. foetens* (Apêndice E). A correlação entre R_i e U_i foi baixa, apesar de significativa (densidade: rho = 0,212; $p = 0,022$; biomassa: rho = 0,221; $p = 0,017$), com apenas uma espécie, *Hippocampus reidi*, bem distribuída e funcionalmente única (Fig. 4). Ao retirar *H. reidi* das análises, as quantidades e as identidades das espécies mais funcionalmente únicas e os resultados das correlações praticamente não mudam (não apresentados). As demais 107 espécies, independentemente da restritividade taxonômica, possuem valores muito baixos de singularidade funcional (Fig. 4).

Distintividade (D_i) e singularidade (U_i) funcionais foram positivamente correlacionadas (densidade: rho = 0,350; $p < 0,001$; biomassa: rho = 0,324; $p < 0,001$), indicando que espécies de peixes que são regionalmente únicas tenderam a ser localmente distintas (Fig. 5). Mesmo que a correlação entre as raridades funcionais regional e local tenha sido significativa, a fraca correlação implica que a raridade deva ser estimada em ambas as escalas para melhor caracterização das assembleias.

Houve correlação significativa entre escassez taxonômica (S_i) e distintividade funcional (D_i), mostrando uma tendência de que espécies de peixes localmente raras são funcionalmente distintas (densidade: rho = 0,279; $p = 0,002$; biomassa: rho = 0,202; $p = 0,03$; Fig. 6). Muitas espécies são raras localmente, onde 85 espécies (~74%) possuem valores médios de $S_i > 0,80$ (Apêndice F). Valores médios de distintividade funcional (D_i) variaram de 0,119 a 0,373, valores relativamente baixos para um índice de 0 a 1. Vinte e uma espécies de peixes (~18%) possuem os maiores valores médios de Di (> 0,30), das quais 20 também foram localmente mais raras ($S_i > 0,80$): syngnathideos (*B. dunckeri*, *H. reidi, S. pelagicus*, *Syngnathus* sp.), batrachoidideos (*B. surinamensis, T. nattereri*), alguns gobiideos (*B. soporator*, *C. stigmaticus*, *E. lyricus*), alguns linguados (*B. ocellatus, P. brasiliensis*, *S. tessellatus*), algumas espécies de água doce (*P. reticulata*, *P. nodosus, S. rhombeus*, *S. notonota*) e outras marinhas (*A. bahianus, H. guttatus, O. vespertilio, S. plumieri*) (Apêndice F). Os estuários não apresentaram diferença nos valores de singularidade e distintividade funcionais (Fig. 7).

As 115 espécies de peixes foram distribuídas em 44 entidades funcionais, onde três entidades apresentaram elevada riqueza de espécies (Tab. 2). A FE1 foi composta por 13 espécies invertívoras, marinhas migrantes, com fecundação externa, nectobentônicas e maior mobilidade, além de possuírem morfotipos semelhantes. Por outro lado, a FE2 compreendeu espécies semelhantes quanto às categorias funcionais (macrocarnívoras, marinhas migrantes fecundação externa, nectônicas, móveis), porém morfologicamente diferenciadas, com carangídeos, sphyraenideos e belonídeos, entre outros. O mesmo ocorreu na FE3, com categorias semelhantes (invertívoros, marinhas migrantes, fecundação externa, bentônicas, sedentárias) mas morfologia diferenciada, comportando linguados e alguns gobiideos. Várias entidades compreenderam espécies filogeneticamente aparentadas como FE4 (lutjanideos), FE5 (mugilideos), FE7 (ariideos), FE14 (poeciliideos) e FE15 (characideos) (Tab. 2).

Vinte e duas entidades funcionais comportaram de duas a cinco espécies de peixes, enquanto outras 19 entidades funcionais compreenderam apenas uma espécie (Tab. 2). No geral, espécies mais raras e distintas (S_i e D_i elevados) fizeram parte de FEs de baixa redundância, corroborando os resultados de raridades funcionais; porém, outras espécies que não se destacaram nas análises de raridade também figuraram nessas FEs: *A. striatus*, *A. vulpes, D. volitans, M. ocellatus* e *S. radians*. No entanto, seis FEs com apenas uma espécie contêm uma espécie dominante (baixo S_i: *A. brasiliensis*) e espécies menos distintas (baixo D_i: *A. rhomboidalis, A. saxatilis, E. saurus, O. niloticus* e *O. scapularis*) (Tab. 2). Em suma, cerca de 30% das espécies ficaram inseridas em

FEs com uma ou duas espécies, ou seja, com baixa ou nenhuma redundância funcional. Mesmo refazendo a análise ao excluir um dos cinco grupos funcionais, todos os resultados apresentaram muitas entidades com nenhuma redundância (Apêndice G).

Ao analisarmos entidades funcionais para cada estuário separadamente seguindo gradiente de riqueza de espécies de peixes, vemos que todos os estuários apresentam poucas FEs com muitas espécies e muitas FEs com pouca ou nenhuma redundância (Tab. 3), com média de 45% das espécies englobando FEs com apenas uma ou duas espécies. Isso mostra que mesmo estuários mais ricos em espécies possuem baixa redundância funcional em muitas entidades.

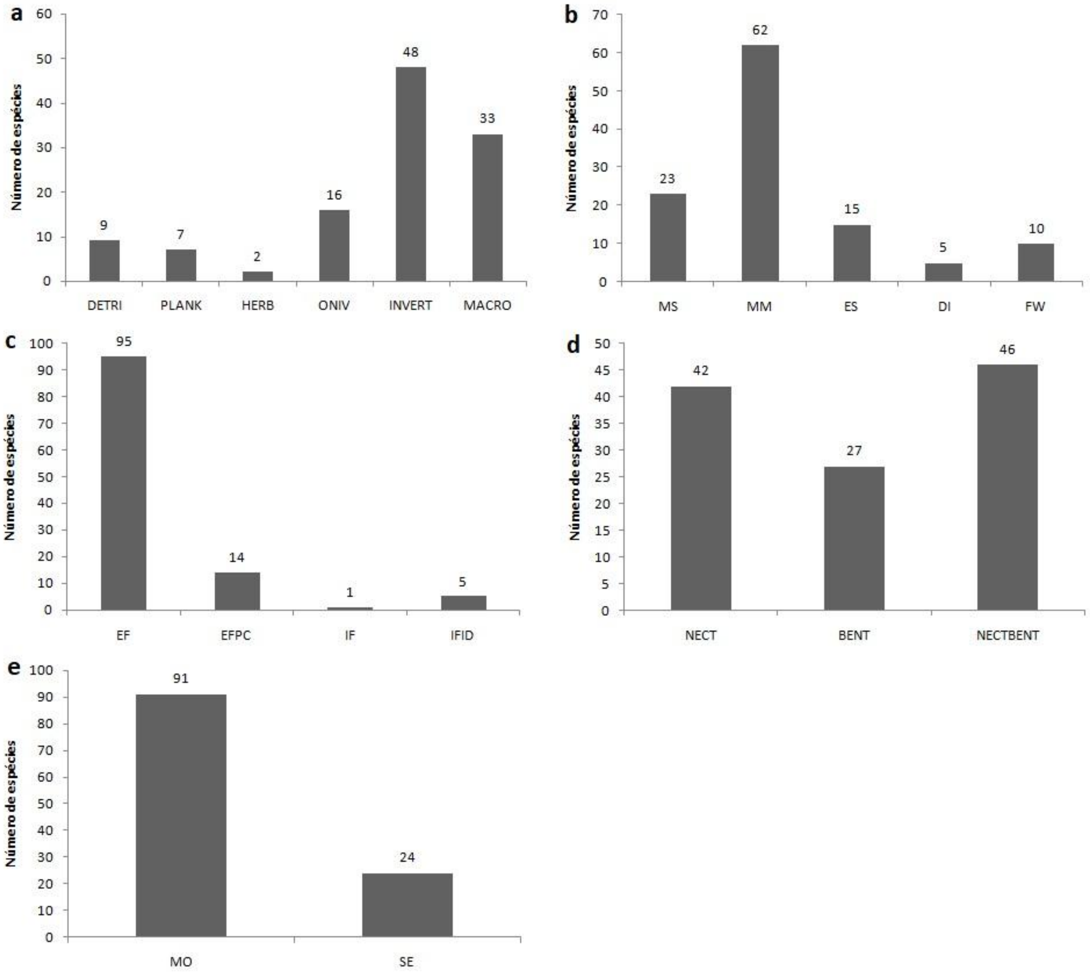

FIGURA 3 - Caracterização em guildas ecológicas da ictiofauna de sete estuários do Nordeste do Brasil quanto à dieta (a), uso do estuário (b), reprodução (c), posição na coluna d’água (d) e mobilidade (e). Abreviaturas das características (eixo x) estão descritas na tabela 1.

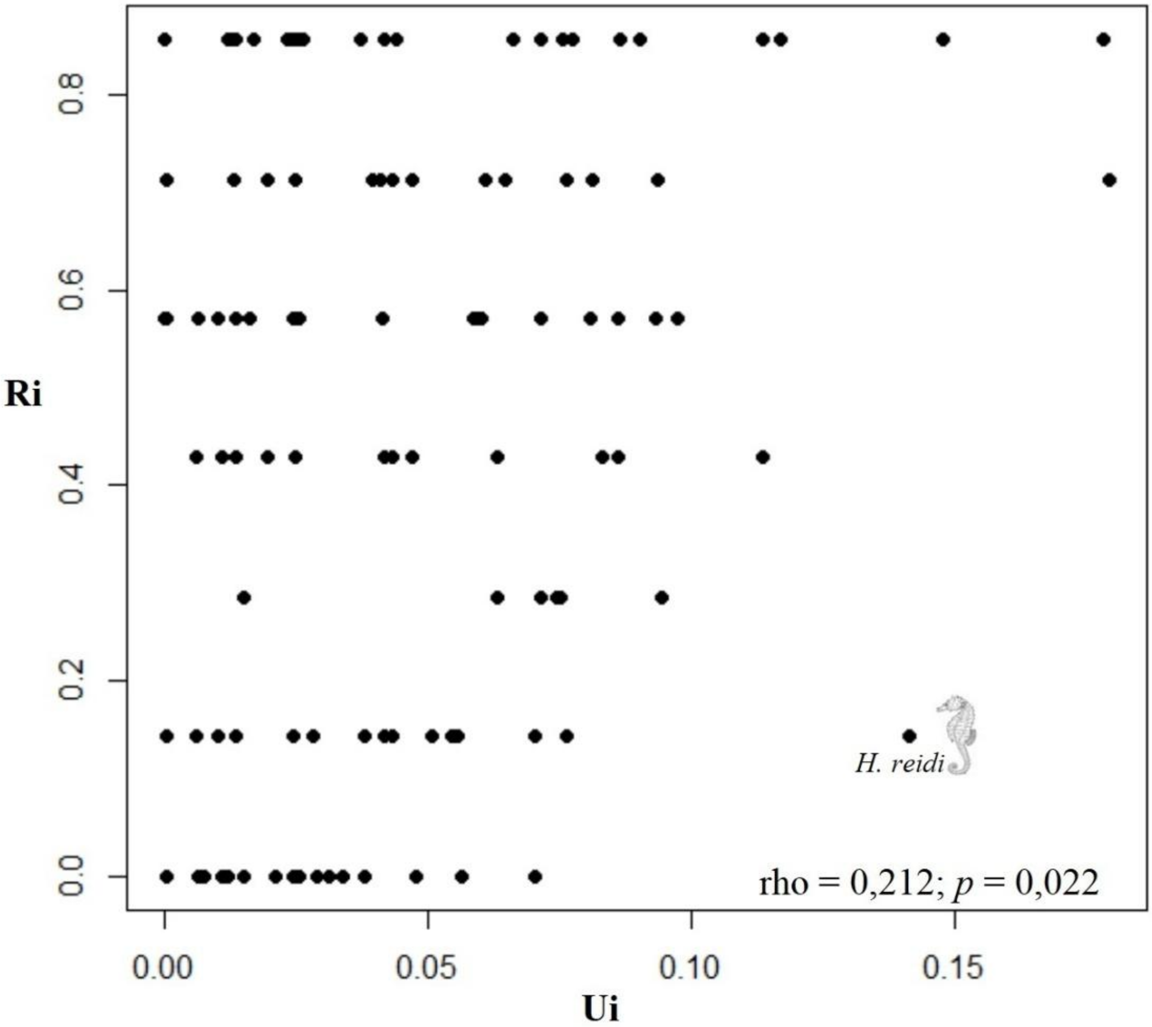

FIGURA 4 - Correlação de Spearman entre os índices de restritividade taxonômica (R_i) e singularidade funcional (U_i).

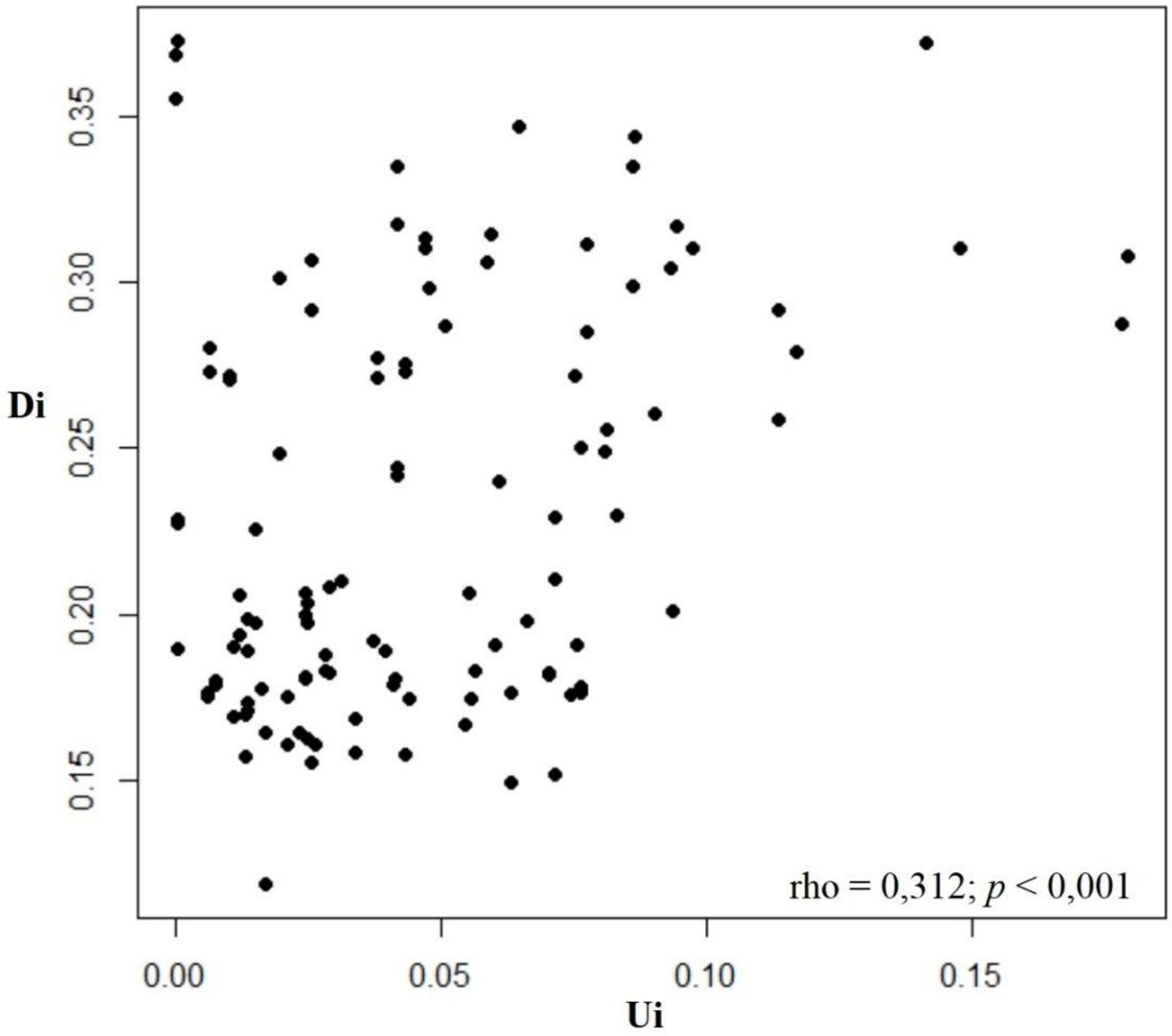

FIGURA 5 - Correlação de Spearman entre os índices de distintividade funcional (D_i) e singularidade funcional (U_i).

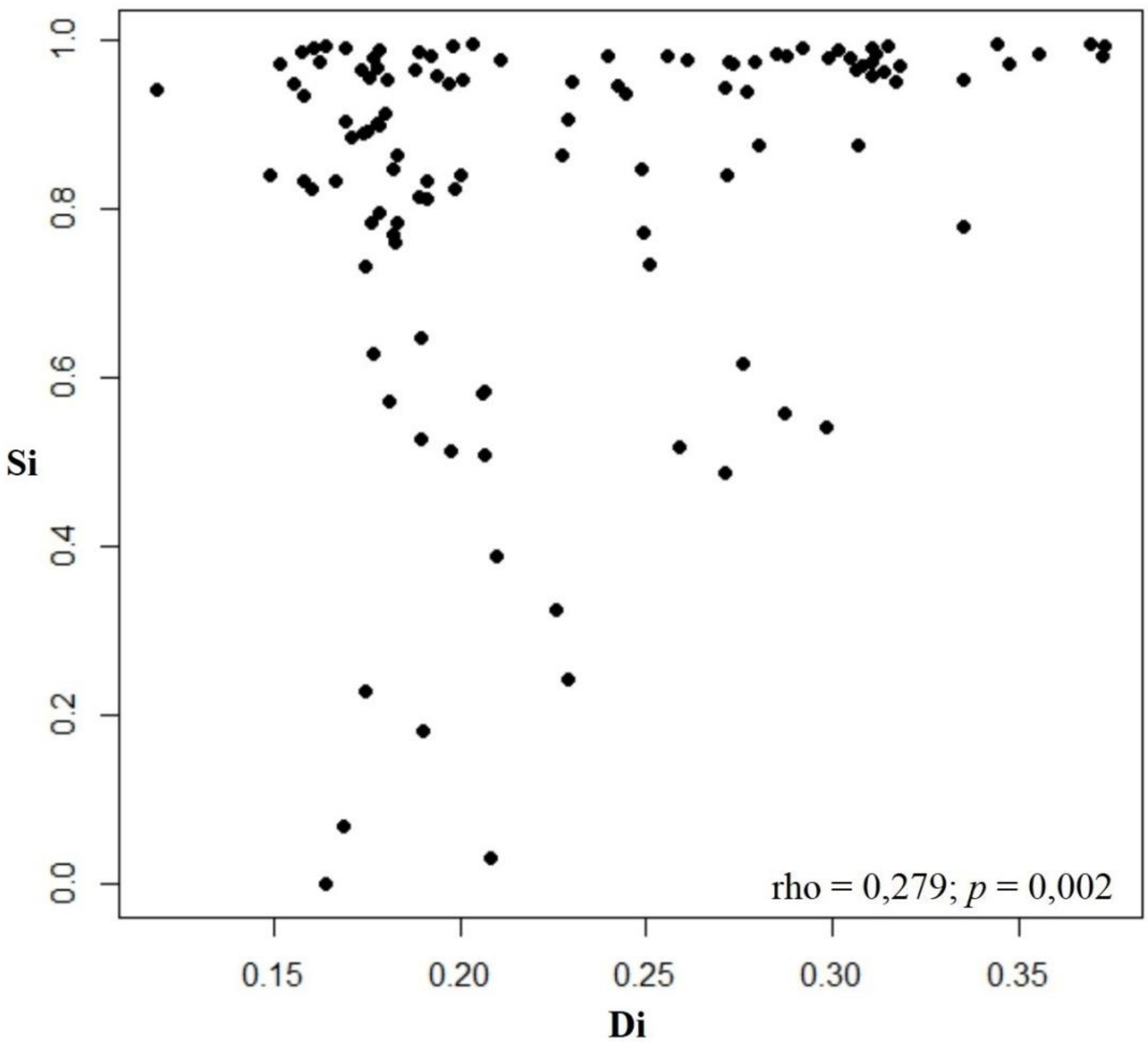

FIGURA 6 - Correlação de Spearman entre os índices de escassez taxonômica (S_i) e distintividade funcional (D_i).

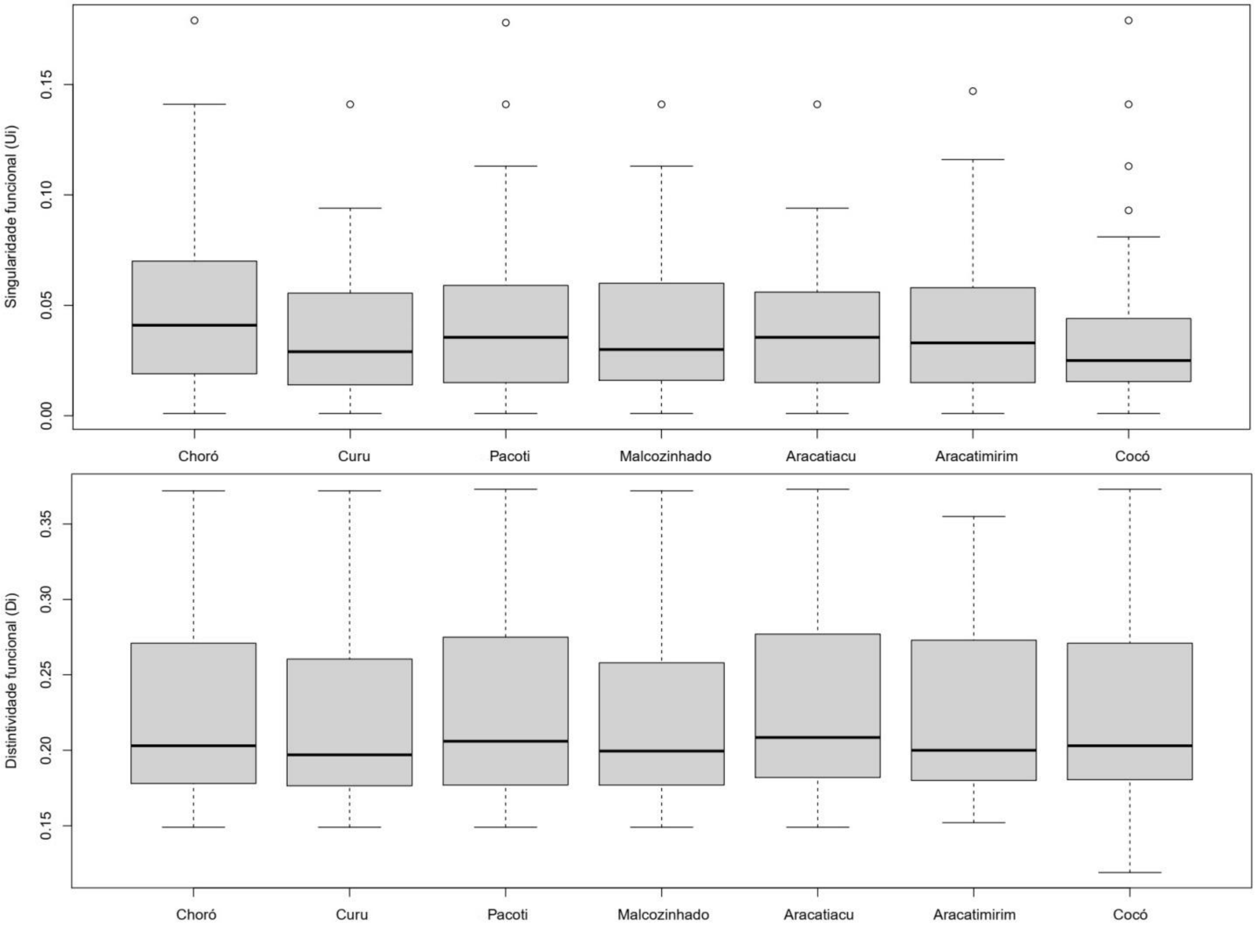

FIGURA 7 - Boxplots de valores de singularidade funcional (Ui: *Kruskal-Wallis* = 3,84; gl= 6; *P* = 0,70) e distintividade funcional das espécies (Di: *Kruskal-Wallis* = 2,10; gl= 6; *P* = 0,91) para os estuários.

TABELA 2 - Entidades funcionais do conjunto de espécies dos sete estuários com cinco atributos funcionais categóricos (dieta, uso do estuário, guilda reprodutiva, posição na coluna d'água e mobilidade). FE: entidade funcional. N: número de espécies na entidade funcional. Códigos dos atributos na tabela 1.

FE	Atributos categóricos	Espécies	N
1	Invert, MM, FE, NectBent, MO	*Diapterus auratus*, *D. rhombeus*, *Eugerres brasilianus*, *Eucinostomus gula*, *E. havana*, *E. lefroyi*, *Genyatremus luteus*, *Haemulopsis corvinaeformis*, *Haemulon parra*, *Lutjanus alexandrei*, *Micropogonias furnieri*, *Menticirrhus martinicensis*, *Stellifer naso*	13
2	Macro, MM, FE, Nect, MO	*Cynoscion acoupa*, *Caranx latus*, *Lycengraulis grossidens*, *Lagocephalus laevigatus*, *Oligoplites palometa*, *O. saurus*, *Sphyraena barracuda*, *S. guachancho*, *Strongylura marina*, *S. timucu*, *Selene vomer*	11
3	Invert, MM, FE, Bent, SE	*Achirus achirus*, *A. lineatus*, *Cithatichthys arenaceus*, *C. spilopterus*, *Ctenogobius boleosoma*, *C. smaragdus*, *C. stigmaticus*, *Etropus crossotus*, *Symphurus tessellatus*, *Trinectes paulistanus*	10
4	Macro, MM, FE, NectBent, MO	*Lutjanus analis*, *L. apodus*, *L. griseus*, *L. jocu*, *Mycteroperca bonaci*	5
5	Detri, MM, FE, Nect, MO	*Mugil curema*, *M. curvidens*, *M. liza*, *M. rubrioculus*, *Mugil* sp.	5
6	Invert, MS, FE, NectBent, MO	*Archosargus probatocephalus*, *Prionotus punctatus*, *Polydactylus virginicus*, *Sphoeroides spengleri*	4
7	Invert, ES, FECP, NectBent, MO	*Cathorops spixii*, *Sciades herzbergii*, *S. parkeri*, *S. proops*	4
8	Macro, MS, FE, Nect, MO	*Larimus breviceps*, *Scomberomorus brasiliensis*, *Trachinotus carolinus*, *T. falcatus*	4
9	Plank, MM, FE, Nect, MO	*Anchovia clupeoides*, *Cetengraulis edetulus*, *Opisthonema oglinum*	3
10	Invert, MM, FE, Nect, MO	*Anchoa hepsetus*, *A. spinifer*, *Chaetodipterus faber*	3
11	Invert, ES, FECP, Bent, SE	*Bathygobius soporator*, *Eleotris pisonis*, *Hippocampus reidi*	3
12	Macro, DI, FE, Nect, MO	*Centropomus parallelus*, *C. undecimalis*, *Megalops atlanticus*	3
13	Macro, MM, FE, Bent, SE	*Paralichthys brasiliensis*, *Scorpaena plumieri*, *Thalassophryne nattereri*	3
14	Oniv, FW, FIDI, Nect, MO	*Poecilia reticulata*, *P. vivipara*, *Poecilia* sp.	3
15	Oniv, FW, FE, Nect, MO	*Astyanax bimaculatus*, *Moenkhausia costae*	2
16	Plank, MS, FE, Nect, MO	*Anchoviella brevirostris* , *Harengula* sp.	2

17	Invert, MS, FE, Bent, SE	*Bothus ocellatus*, *Ogcocephalus vespertilio*	2
18	Oniv, MM, FE, Nect, MO	*Chloroscombrus chrysurus*, *Hyporhamphus unifasciatus*	2
19	Oniv, MM, FE, NectBent, MO	*Eucinostomus argenteus*, *E. melanopterus*	2
20	Detri, ES, FE, Bent, SE	*Gobionellus oceanicus*, *G. stomatus*	2
21	Plank, ES, FE, Nect, MO	*Lile piquitinga*, *Rhinosardinia amazonica*	2
22	Detri, FW, FE, NectBent, MO	*Prochilodus brevis*, *Steindachnerina notonota*	2
23	Macro, MS, FE, Bent, MO	*Synodus bondi*, *S. foetens*	2
24	Invert, ES, FE, NectBent, MO	*Sphoeroides greeleyi*, *S. testudineus*	2
25	Invert, MM, FECP, NectBent, MO	*Syngnathus pelagicus*, *Syngnathus* sp.	2
26	Oniv, MS, FIDI, NectBent, MO	*Anableps anableps*	1
27	Herb, MS, FE, NectBent, MO	*Acanthurus bahianus*	1
28	Oniv, ES, FE, Nect, MO	*Atherinella brasiliensis*	1
29	Oniv, MS, FE, NectBent, MO	*Archosargus rhomboidalis*	1
30	Oniv, MS, FECP, NectBent, MO	*Abudefduf saxatilis*	1
31	Macro, MS, FE, Bent, SE	*Antennarius striatus*	1
32	Invert, DI, FE, NectBent, MO	*Albula vulpes*	1
33	Invert, MS, FECP, NectBent, MO	*Bryx dunckeri*	1
34	Macro, MM, FECP, Bent, SE	*Batrachoides surinamensis*	1
35	Invert, MS, FE, NectBent, SE	*Dactylopterus volitans*	1
36	Oniv, ES, FECP, Bent, SE	*Evorthodus lyricus*	1
37	Macro, DI, FE, NectBent, MO	*Elops saurus*	1
38	Invert, MM, FIDI, Bent, MO	*Hypanus guttatus*	1
39	Invert, MS, FE, Bent, MO	*Myrichthys ocellatus*	1
40	Oniv, FW, FECP, NectBent, MO	*Oreochromis niloticus*	1
41	Macro, MS, FE, NectBent, MO	*Orthopristis scapularis*	1
42	Oniv, FW, FI, NectBent, MO	*Pseudauchenipterus nodosus*	1
43	Herb, MM, FE, NectBent, MO	*Sparisoma radians*	1
44	Macro, FW, FE, Nect, MO	*Serrasalmus rhombeus*	1

TABELA 3 - Número de entidades funcionais com respectivos números de espécies para cada estuário seguindo gradiente de riqueza de espécies.

Choró		**Malcozinhado**		**Pacoti**	
(78 espécies)		(74 espécies)		(70 espécies)	
n FEs	n espécies	n FEs	n espécies	n FEs	n espécies
1	12	1	12	1	10
1	8	1	10	2	9
1	7	1	7	1	4
2	5	1	5	1	3
3	3	2	4	10	2
9	2	1	3	15	1
14	1	8	2		
		13	1		
31 FEs no total		28 FEs no total		30 FEs no total	

Curu		**Aracatimirim**		**Aracatiaçu**	
(63 espécies)		(61 espécies)		(54 espécies)	
n FEs	n espécies	n FEs	n espécies	n FEs	n espécies
1	10	2	9	1	7
1	8	1	6	2	6
1	6	1	4	1	4
1	4	2	3	2	3
2	3	7	2	5	2
7	2	13	1	15	1
15	1				
28 FEs no total		26 FEs no total		26 FEs no total	

Cocó	
(43 espécies)	
n FEs	n espécies
1	5
1	4
4	3
6	2
10	1
22 FEs no total	

Discussão

A elevada biodiversidade de peixes, além do elevado número de espécies raras, é consistente com o padrão de diversidade em ambientes tropicais (Longhurst, Pauly, 2007) e pode ser explicado pelas flutuações ambientais dinâmicas associadas com grande diversidade de habitats e elevada produtividade desses ambientes (Blaber, 2000; Vilar *et al*., 2013; Vasconcelos *et al*., 2015). Poucas espécies representam a quase totalidade das abundâncias (em densidade e em biomassa, Apêndices C e D): *Atherinella brasiliensis*, *Diapterus auratus*, *Eucinostomus argenteus*, *Lile piquitinga*, *Mugil curema* e *Sphoeroides testudineus*. No estuário do rio Cocó, 86% das espécies apresentaram abundância relativa menor do que 1%, e nos demais estuários de 70% a 78% das espécies apresentaram abundância relativa menor do que 1%. Os estuários apresentaram assembleia de peixes com baixos valores em singularidade e distintividade funcionais para todas as espécies, o que indica considerável redundância funcional.

O conjunto de espécies de peixes nos sete estuários compreendeu assembleia regional bastante redundante para quanto a singularidade funcional (U_i: <0,001 - 0,179). Assembleias locais também foram redundantes para o índice de distintividade funcional (D_i: 0,119 - 0,373). Ambientes estuarinos são conhecidos por considerável redundância funcional (Baptista *et al*., 2015; Dolbeth *et al*., 2016; Teichert *et al*., 2017; Silva, Fabré, 2019), o que faz deles ecossistemas com maior resiliência a distúrbios a partir do amortecimento que ocorre quando uma espécie é extinta (Mouillot et al., 2013).

A escassez taxonômica e a distintividade funcional foram positivamente correlacionadas, havendo uma tendência de que espécies mais raras sejam funcionalmente mais distintas nesses estuários, corroborando o aumento da diferenciação de nicho exercida por essas espécies nesses ambientes (Silva, Fabré, 2019). Mesmo se tratando de uma tendência, isso poderia mostrar que espécies raras são tão importantes quanto às espécies mais comuns que influenciam bastante no funcionamento do ecossistema a partir de sua maior representatividade via abundâncias (Chapman *et al*., 2018). Logo, nesses estuários as espécies raras, além de possuírem atributos diferenciados, poderiam contribuir significativamente para o funcionamento desses ecossistemas por apresentarem elevado número de espécies. De fato, *Hippocampus reidi* foi a única espécie que apresentou maior distribuição regional além de elevada singularidade funcional. Isso se deu pelo conjunto de atributos categóricos e obviamente devido ao seu morfotipo característico. Isso pode significar que *H. reidi* possui funções importantes ou demandas diferenciadas no ambiente e precisa de grande atenção para sua preservação já que configura atualmente como espécie Vulnerável na lista de espécies ameaçadas de extinção (Brasil, 2022).

A baixa variação nos índices de raridade funcional pode ser explicada pela grande quantidade de espécies generalistas ou que apresentam atributos morfológicos semelhantes independentemente do parentesco evolutivo (Villéger *et al*., 2012). O ambiente estuarino é enriquecido com tipos funcionais provenientes dos representantes marinhos (Gurgel-Lourenço *et al*., 2022), diminuindo o poder de detecção de padrões funcionais sobre atributos relacionados à locomoção (Mouchet *et al*., 2013), e quando as condições marinhas prevalecem no período seco, o filtro ambiental pode ser mais forte para atributos relacionados à dieta oportunista, com grande contribuição de espécies que se alimentam dos bentos (Mouchet *et al*., 2013). De fato, quase metade das espécies do presente estudo são invertívoras, na qual seus representantes possuem uma miríade de atributos funcionais relativamente contrastantes.

Por outro lado, muitas entidades funcionais compreenderam poucas espécies. Os resultados mostraram que os ambientes estuarinos apresentaram cerca de 30% das espécies em entidades funcionais com baixa ou nenhuma redundância, e independente da riqueza de espécies os estuários apresentaram muitas entidades funcionais com apenas uma ou duas espécies. Mouillot *et al*. (2014) mostraram que mesmo ecossistemas recifais do Indo-Pacífico com mais de 3500 espécies de peixes, 38% das entidades funcionais compreenderam apenas uma espécie, podendo aumentar a diferenciação de nicho, com papéis cruciais para o funcionamento do ecossistema (Silva, Fabré, 2019), e concluindo que mesmo a enorme biodiversidade tropical pode conter muitas vulnerabilidades (Mouillot *et al*., 2014).

Dentre as 19 espécies isoladas em FEs, apenas duas espécies são dominantes na comunidade. *Atherinella brasiliensis* é dominante em todos os estuários e *Oreochromis niloticus* é dominante no Cocó. Henderson *et al*. (2020) mostraram baixa redundância funcional, mesmo em estuários altamente diversos, com uma única espécie dominante significativamente responsável pela função carniceira ("*scavenger*"). Já *O. niloticus* é um caso de espécie introduzida, o que poderia explicar sua abundância e o seu isolamento na FE. Com exceção de *A. brasiliensis* e *O. niloticus*, todas as demais espécies isoladas em FEs são raras na comunidade, corroborando em parte as análises de raridade funcional.

Tem sido freqüentemente mostrado que assembleias de peixes são organizadas com forte seleção do hábitat (filtragem de nicho) onde espécies morfologicamente semelhantes coexistem (Whitfield, 1999; Oliveira *et al*., 2005; Willis *et al*., 2005; Hoagstrom; Berry, 2008; Mouchet *et al*., 2013). Ecossistemas estuarinos são muito dinâmicos temporal e espacialmente (Wolanski *et al*., 2011), provavelmente permitindo a coexistência ou a complementaridade funcional de uma rica fauna de peixes em termos taxonômicos e funcionais (Brown *et al*., 2015). A maioria das espécies ocupa amplo intervalo espacial nesses estuários (Gurgel-Lourenço, dados não publicados). Características do hábitat podem influenciar a estrutura da comunidade e ter papel na distribuição das espécies, de modo que a coexistência em muitas assembleias de peixes pode se dar pela diferenciação morfológica ou pela segregação espacial (Azevedo *et al*., 2006; Boyle, Horn, 2006; Sampaio *et al*., 2013; Ramos *et al*., 2014; 2016).

A fauna estuarina compartilha um grande número de espécies marinhas e escassez de espécies de água doce (Barletta, Blaber, 2007; Paiva *et al*., 2008; Reis-Filho *et al*., 2010; Barbanti *et al*., 2013; Pichler *et al*., 2015; Whitfield, 2015), o que não foi diferente para os estuários aqui estudados. Estuários australianos, onde a salinidade é relativamente uniforme, a biomassa de peixes é dominada por espécies marinhas, enquanto estuários amazônicos apresentam assembleias dominadas por espécies tipicamente estuarinas (Barletta, Blaber, 2007; Giarrizzo, Krumme, 2008). A escassez de espécies dulcícolas pode ser explicada pela alta salinidade, assim como elevado número de predadores, teia trófica e recursos diferenciados, além da desconexão por meio de barramentos (Whitfield, 2015). Além disso, é conhecido que a fauna de peixes de águas interiores do semi-árido brasileiro é menos rica em relação às outras regiões compreendidas em diferentes biomas (Rodrigues-Filho *et al*., 2018; Albert *et al*., 2020).

Os estuários estudados apresentaram diferentes riquezas em espécies de peixes, provavelmente relacionado aos conjuntos de impactos ambientais característicos de cada um e pelas diferentes dinâmicas de salinidades ao longo do ano (Gurgel-Lourenço *et al*., 2022). O número de espécies por guilda seguiu o mesmo padrão de riqueza de espécies dos estuários, o que poderia indicar simples relação entre redundância e diversidade (Whitfield; Harrison, 2021) para detritívoros, planctívoros, invertívoros e macrocarnívoros, marinhas migrantes, fecundação externa, bentônicas, nectobentônicas, móveis e sedentárias. Por outro lado, o número de espécies em outras guildas pode estar mais relacionado às características ambientais. Por exemplo, espécies onívoras foram mais representadas no Cocó, o estuário mais impactado, com gradiente positivo por todo o ano com grande contribuição do escoamento urbano, apresentando muitos trechos com baixos níveis de oxigênio dissolvido (dados não publicados). A onivoria pode ser característica comum em ambientes perturbados por ser um hábito alimentar oportunista (Gillespie, 2017). Outro exemplo é o número de espécies marinhas visitantes e dulcícolas, que foram menor e maior nesse estuário, respectivamente, relacionado à dinâmica temporal de salinidades (dados não publicados).

Todos os estuários apresentaram muitas espécies de peixes raras e foi observada uma tendência positiva para raridade funcional acompanhar a raridade taxonômica. Abordando a raridade funcional, os estuários apresentaram assembleia de peixes com considerável redundância funcional. Porém, ao abordar somente atributos categóricos por meio de entidades funcionais, os estuários se apresentam muito redundantes para somente três entidades funcionais, enquanto na maioria das entidades há poucas espécies. Podemos concluir que os estuários possuem assembleias onde espécies raras tendem a ser mais distintas funcionalmente, e que, no geral, são ambientes de elevada redundância funcional, mas que ainda apresentam parte do conjunto de espécies com pouca ou nenhuma redundância. Logo, mesmo sendo, no geral, ambientes de considerável redundância funcional, ainda apresentam muitas exceções na comunidade, trazendo implicações importantes para o futuro desses ambientes com os constantes distúrbios atuais e os que devem surgir no futuro.

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Apêndice A - Valores dos atributos funcionais qualitativos para as espécies de peixe dos estuários. 0/1: ocorrência em águas doce, salobra e salgada; Nect: nectônica; NectBent: nectobentônica; Bent: bentônica; Detri: detritívora; Herb: herbívora; Plank: planctívora; Invert: invertívora; Macro: macrocarnívora; Oniv: onívora; EF: fecundação externa; EFPC: fecundação externa com cuidado parental; FI: fecundação interna; FIDI: fecundação interna com desenvolvimento interno; MO: móvel; SE: sedentária. MS: marinhas visitantes; MM: marinhas migrantes; ES: estuarinas; DI: diádromas; FW: dulcícolas.

Espécie	Água doce	Água salobra	Água marinha	Posição na água	Dieta	Guilda reprodutiva	Mobilidade	Uso estuário
A sax	0	0	1	NectBent	Oniv	EFPC	MO	MS
A bah	0	0	1	NectBent	Herb	EF	MO	MS
A ach	1	1	1	Bent	Invert	EF	SE	MM
A lin	0	1	1	Bent	Invert	EF	SE	MM
A vul	0	1	1	NectBent	Invert	EF	MO	DI
A ana	1	1	1	NectBent	Oniv	FIDI	MO	MS
A hep	0	1	1	Nect	Invert	EF	MO	MM
A spi	1	1	1	Nect	Invert	EF	MO	MM
A clu	0	1	1	Nect	Plank	EF	MO	MM
A bre	1	1	1	Nect	Plank	EF	MO	MS
A str	0	1	1	Bent	Macro	EF	SE	MS
A pro	0	1	1	NectBent	Invert	EF	MO	MS
A rho	0	1	1	NectBent	Oniv	EF	MO	MS
A bim	1	0	0	Nect	Oniv	EF	MO	FW
A bra	0	1	1	Nect	Oniv	EF	MO	ES
B sop	1	1	1	Bent	Invert	EFPC	SE	ES
B sur	0	1	1	Bent	Macro	EFPC	SE	MM
B oce	0	0	1	Bent	Invert	EF	SE	MS
B dun	0	0	1	NectBent	Invert	EFPC	MO	MS
C lat	1	1	1	Nect	Macro	EF	MO	MM
C spx	0	1	1	NectBent	Invert	EFPC	MO	ES
C ede	0	1	1	Nect	Plank	EF	MO	MM
C par	1	1	1	Nect	Macro	EF	MO	DI
C und	1	1	1	Nect	Macro	EF	MO	DI
C fab	0	1	1	Nect	Invert	EF	MO	MM
C chr	0	1	1	Nect	Oniv	EF	MO	MM
C are	0	0	1	Bent	Invert	EF	SE	MM
C spi	1	1	1	Bent	Invert	EF	SE	MM
C bol	1	1	1	Bent	Invert	EF	SE	MM
C sma	1	1	1	Bent	Invert	EF	SE	MM
C sti	0	0	1	Bent	Invert	EF	SE	MM
C aco	1	1	1	Nect	Macro	EF	MO	MM
D vol	0	1	1	NectBent	Invert	EF	SE	MS
D aur	0	1	1	NectBent	Invert	EF	MO	MM
D rho	0	1	1	NectBent	Invert	EF	MO	MM
E pis	1	1	1	Bent	Invert	EFPC	SE	ES
E sau	1	1	1	NectBent	Macro	EF	MO	DI
E cro	0	1	1	Bent	Invert	EF	SE	MM
E arg	1	1	1	NectBent	Oniv	EF	MO	MM
E gul	1	1	1	NectBent	Invert	EF	MO	MM
E hav	0	1	1	NectBent	Invert	EF	MO	MM
E lef	0	1	1	NectBent	Invert	EF	MO	MM
E mel	1	1	1	NectBent	Oniv	EF	MO	MM
E bra	0	0	1	NectBent	Invert	EF	MO	MM
E lyr	1	1	1	Bent	Oniv	EFPC	SE	ES
G lut	0	1	1	NectBent	Invert	EF	MO	MM
G oce	1	1	1	Bent	Detri	EF	SE	ES
G sto	0	1	0	Bent	Detri	EF	SE	ES
H par	0	0	1	NectBent	Invert	EF	MO	MM

H cor	1	1	1	NectBent	Invert	EF	MO	MM
H_sp	0	1	1	Nect	Plank	EF	MO	MS
H rei	0	1	1	Bent	Invert	EFPC	SE	ES
H gut	0	0	1	Bent	Invert	FIDI	MO	MM
H uni	0	1	1	Nect	Oniv	EF	MO	MM
L lae	0	1	1	Nect	Macro	EF	MO	MM
L bre	0	1	1	Nect	Macro	EF	MO	MS
L piq	0	1	1	Nect	Plank	EF	MO	ES
L ale	0	0	1	NectBent	Invert	EF	MO	MM
L ana	0	1	1	NectBent	Macro	EF	MO	MM
L apo	0	1	1	NectBent	Macro	EF	MO	MM
L gri	1	1	1	NectBent	Macro	EF	MO	MM
L joc	1	1	1	NectBent	Macro	EF	MO	MM
L gro	1	1	1	Nect	Macro	EF	MO	MM
M atl	1	1	1	Nect	Macro	EF	MO	DI
M mar	0	1	1	NectBent	Invert	EF	MO	MM
M fur	0	1	1	NectBent	Invert	EF	MO	MM
M cos	1	0	0	Nect	Oniv	EF	MO	FW
M cur	1	1	1	Nect	Detri	EF	MO	MM
M cuv	1	1	1	Nect	Detri	EF	MO	MM
M liz	1	1	1	Nect	Detri	EF	MO	MM
M rub	0	1	1	Nect	Detri	EF	MO	MM
M_sp	1	1	1	Nect	Detri	EF	MO	MM
M bon	0	0	1	NectBent	Macro	EF	MO	MM
M oce	0	0	1	Bent	Invert	EF	MO	MS
O ves	0	0	1	Bent	Invert	EF	SE	MS
O pal	1	1	1	Nect	Macro	EF	MO	MM
O sau	0	1	1	Nect	Macro	EF	MO	MM
O ogl	0	0	1	Nect	Plank	EF	MO	MM
O nil	1	1	0	NectBent	Oniv	EFPC	MO	FW
O sca	0	1	1	NectBent	Macro	EF	MO	MS
P bra	0	1	1	Bent	Macro	EF	SE	MM
P ret	1	1	0	Nect	Oniv	FIDI	MO	FW
P viv	1	1	0	Nect	Oniv	FIDI	MO	FW
P_sp	1	1	0	Nect	Oniv	FIDI	MO	FW
P vir	0	1	1	NectBent	Invert	EF	MO	MS
P pun	0	1	1	NectBent	Invert	EF	MO	MS
P bre	1	0	0	NectBent	Detri	EF	MO	FW
P nod	1	1	0	NectBent	Oniv	FI	MO	FW
R ama	1	1	0	Nect	Plank	EF	MO	ES
S her	1	1	1	NectBent	Invert	EFPC	MO	ES
S par	0	1	1	NectBent	Invert	EFPC	MO	ES
S pro	1	1	1	NectBent	Invert	EFPC	MO	ES
S bra	0	0	1	Nect	Macro	EF	MO	MS
S plu	0	0	1	Bent	Macro	EF	SE	MM
S vom	0	1	1	Nect	Macro	EF	MO	MM
S rho	1	0	0	Nect	Macro	EF	MO	FW
S rad	0	0	1	NectBent	Herb	EF	MO	MM
S gre	0	1	1	NectBent	Invert	EF	MO	ES
S spe	0	1	1	NectBent	Invert	EF	MO	MS
S tes	0	1	1	NectBent	Invert	EF	MO	ES
S bar	0	1	1	Nect	Macro	EF	MO	MM
S gua	0	1	1	Nect	Macro	EF	MO	MM
S not	1	0	0	NectBent	Detri	EF	MO	FW
S nas	0	1	1	NectBent	Invert	EF	MO	MM
S mar	1	1	1	Nect	Macro	EF	MO	MM
S tim	1	1	1	Nect	Macro	EF	MO	MM
S tss	0	1	1	Bent	Invert	EF	SE	MM
S pel	0	0	1	NectBent	Invert	EFPC	MO	MM

*S*_sp	0	0	1	NectBent	Invert	EFPC	MO	MM
S bon	0	0	1	Bent	Macro	EF	MO	MS
S foe	0	1	1	Bent	Macro	EF	MO	MS
T nat	0	1	1	Bent	Macro	EF	SE	MM
T car	0	1	1	Nect	Macro	EF	MO	MS
T fal	0	1	1	Nect	Macro	EF	MO	MS
T pau	1	1	1	Bent	Invert	EF	SE	MM

Apêndice B - Valores médios dos atributos morfofuncionais para cada espécie de peixes dos estuários. LogM: Massa corpórea; Prt: Comprimento da protrusão da boca; Osf: Área da cavidade oral; Osh: Forma da cavidade oral; Ops: Posição da cavidade oral; Edst: Tamanho do olho; Eps: Posição do olho; Bsh: Formato transversal do corpo; Bsf: Área transversal do corpo; PFps: Posição da peitoral; FPar: Aspecto da peitoral; Cpt: Tração do pedúnculo caudal; CFar: Aspecto da caudal; Frt: Relação das áreas das nadadeiras; Fsf: Relação entre superfície das nadadeiras e o tamanho do corpo.

Espécie	LogM	Prt	Osf	Osh	Ops	Edst	Eps	Bsh	Bsf	PFps	FPar	Cpt	CFar	Frt	Fsf
A sax	3,743	0,588	0,065	1,067	0,481	0,323	0,608	2,498	1,806	0,338	2,795	1,645	1,515	1,242	1,063
A bah	3,640	0	0,039	0,528	0,298	0,236	0,727	2,727	1,793	0,406	1,726	2,276	1,402	1,135	1,376
A ach	2,598	0	0,086	1,717	0,453	0,567	0,869	0,104	2,033	1,000	3,389	1,462	1,229	0,053	1,767
A lin	2,535	0	0,071	1,732	0,481	0,577	0,861	0,119	2,096	1,000	4,963	1,470	1,239	0,049	1,536
A vul	2,980	0	0,236	1,278	0,501	0,509	0,665	1,783	1,844	0,175	4,302	3,433	2,247	0,448	1,801
A ana	3,430	0,831	0,262	0,659	0,408	0,485	0,744	0,843	1,665	0,226	2,988	1,618	0,937	1,084	3,023
A hep	0,977	0	0,449	3,338	0,408	0,521	0,572	2,534	4,110	0,159	3,130	2,109	2,102	0,659	2,862
A spi	0,837	0	0,501	3,239	0,419	0,556	0,618	2,769	4,557	0,130	2,857	2,425	1,951	0,511	3,519
A clu	1,344	0	0,619	3,467	0,512	0,531	0,629	3,482	3,446	0,137	2,663	2,742	2,994	0,512	2,884
A bre	0,270	0	0,530	3,376	0,446	0,497	0,585	2,796	9,619	0,181	2,533	2,274	2,534	0,814	3,786
A str	4,676	0,647	0,248	0,797	0,825	0,135	0,753	1,214	1,577	0,159	2,010	2,090	0,888	1,244	0,806
A pro	2,451	0,503	0,116	1,178	0,272	0,397	0,633	3,078	2,280	0,314	3,817	2,005	1,463	1,204	1,799
A rho	2,576	0,482	0,125	1,221	0,315	0,379	0,659	3,208	2,212	0,332	4,568	2,149	1,786	1,148	1,825
A bim	1,445	0	0,172	1,220	0,633	0,398	0,599	2,942	3,268	0,138	2,980	2,854	2,932	0,597	1,673
A bra	2,437	0,473	0,164	0,996	0,571	0,579	0,584	1,621	2,136	0,720	3,085	2,534	2,172	1,064	2,785
B sop	2,437	0,567	0,386	0,943	0,482	0,293	0,783	1,023	2,274	0,647	2,052	1,499	0,966	1,599	2,470
B sur	3,381	0	0,715	0,540	0,702	0,190	0,832	0,657	1,815	0,736	1,721	1,624	0,775	2,968	1,858
B oce	2,313	0,237	0,072	2,137	0,456	1,031	0,831	0,114	2,527	1,000	4,988	1,826	1,273	0,479	1,514
B dun	0,247	0	0,097	1,501	0,638	0,266	0,430	1,295	7,803	0	0	1,963	0,858	0	1,500
C lat	2,773	0,430	0,244	1,925	0,417	0,383	0,628	3,142	2,109	0,378	5,422	7,182	3,207	1,019	1,757
C spx	2,814	0	0,202	0,805	0,331	0,436	0,638	1,151	2,076	0,174	5,600	3,494	2,907	0,416	1,324
C ede	2,457	0	0,313	3,132	0,344	0,578	0,572	2,497	2,183	0,172	3,649	2,112	2,286	0,455	1,493
C par	3,255	0,154	0,730	2,010	0,444	0,545	0,677	2,099	1,729	0,346	3,154	3,601	2,889	0,450	3,729
C und	3,258	0,152	0,734	2.014	0,442	0,546	0,671	2.095	1.735	0,348	3,158	3,609	2,884	0,455	3,740
C fab	2,424	0,313	0,099	1,168	0,293	0,248	0,602	4,910	3,718	0,324	1,905	1,780	1,479	1,403	1,037
C chr	1,486	0,656	0,217	2,126	0,703	0,367	0,678	5,069	3,245	0,510	6,044	6,112	3,362	1,197	1,972
C are	3,176	0	0,141	3,996	0,430	0,738	0,877	0,131	1,806	1,000	3,822	1,469	1,139	0,340	1,847
C spi	2,812	0	0,225	4,640	0,424	0,878	0,868	0,122	1,892	1,000	3,882	1,485	1,114	0,341	2,258
C bol	0,565	0,080	0,570	0,829	0,333	0,242	0,796	1,813	5,158	0,584	2,588	2,114	0,982	1,014	7,757
C sma	0,763	0,094	0,483	0,944	0,317	0,314	0,782	1,327	4,947	0,595	2,603	1,513	0,550	0,832	3,549
C sti	1,138	0,463	0,683	0,837	0,418	0,304	0,777	1,749	3,342	0,582	3,544	1,463	0,636	0,899	5,475
C aco	3,112	0,395	0,343	1,397	0,399	0,466	0,695	1,874	1,883	0,355	3,545	2,267	1,034	0,647	2,046
D vol	5,430	0,758	0,250	1,076	0,222	0,462	0,674	0,719	1,300	0,392	1,570	5,906	1,656	15,256	21,270
D aur	2,964	1,298	0,074	1,123	0,273	0,454	0,500	3,590	2,021	0,325	5,138	3,377	3,299	0,767	1,895
D rho	2,998	1,280	0,081	1,405	0,347	0,488	0,555	3,650	2,011	0,330	4,904	3,457	3,336	0,785	1,826
E pis	2,356	0,381	0,275	1,047	0,630	0,299	0,810	1,227	2,288	0,613	2,836	1,748	1,140	0,721	1,567
E sau	2,933	0	0,848	2,215	0,454	0,516	0,680	1,960	1,824	0,150	4,022	3,526	3,106	0,413	3,189
E cro	2,049	0,554	0,065	1,681	0,426	0,682	0,826	0,090	2,307	1,000	4,807	1,444	1,077	0,323	2,256
E arg	1,960	1,217	0,100	1,214	0,399	0,510	0,605	2,464	2,634	0,331	6,389	2,761	2,570	0,786	1,678
E gul	2,225	1,202	0,077	1,307	0,436	0,517	0,587	3,038	2,393	0,331	4,416	3,001	3,064	1,114	2,074
E hav	2,194	1,020	0,083	1,123	0,456	0,544	0,629	2,542	2,419	0,354	4,244	3,106	3,024	0,970	1,932
E lef	2.101	0,982	0,094	1,044	0,503	0,513	0,609	2,252	2,497	0,395	4,409	3,272	3,028	0,886	1,662
E mel	2,652	1,134	0,107	1,101	0,451	0,572	0,586	2,833	2,105	0,350	3,873	3,432	3,374	0,775	1,913
E bra	3,329	1,174	0,104	1,230	0,269	0,485	0,549	3,251	1,900	0,314	4,683	3,325	2,820	0,707	2,129
E lyr	0,920	0,161	0,334	0,861	0,339	0,267	0,736	1,512	4,337	0,590	3,098	1,413	0,871	1,199	2,996
G lut	1,717	0,543	0,107	1,231	0,270	0,496	0,625	2,822	5,360	0,352	2,665	2,068	1,563	1,317	1,679
G oce	2.630	0,473	0,410	1,359	0,418	0,265	0,834	1,477	1,935	0,590	2,023	1,273	0,564	0,961	4,055
G sto	1,603	0,434	0,544	0,969	0,265	0,298	0,786	1,742	2,729	0,656	2,134	1,701	0,636	1,196	5,564
H par	2,568	0,615	0,257	1,670	0,209	0,454	0,643	2,350	2,289	0,398	3,399	2,637	1,979	0,915	1,649
H cor	2,282	0,525	0,194	1,437	0,270	0,485	0,661	2,028	2,336	0,329	3,485	2,247	1,720	0,882	1,717
*H*_sp	2,868	0	0,184	1,975	0,749	0,488	0,678	2,306	2,004	0,144	4,109	2,833	3,208	0,706	1,426
H rei	1,964	0	0,006	1,366	0,366	0,390	0,627	13,955	3,356	0,953	1,096	0	0	0	0,046
H gut	5,034	0	0,050	0,719	0	0,257	0,672	0,082	1,530	0	0	0	0	0	0
H uni	2,511	0	0,311	1,148	0,683	0,653	0,596	1,653	1,942	0,760	2,986	3,593	2,169	0,900	3,748
L lae	0,912	0	0,101	0,810	0,443	0,433	0,696	1,392	4,547	0,532	1,501	2,966	0,985	1,225	1,379
L bre	0,571	0,538	0,393	1,723	0,527	0,439	0,675	2,284	6,340	0,455	5,806	1,788	0,246	0,237	4,141
L piq	2,458	0	0,107	1,949	0,771	0,567	0,645	2,378	2,201	0,114	3,433	2,692	2,933	0,526	1,686
L ale	2.725	0,266	0,262	1,533	0,381	0,421	0,751	2,520	2,269	0,330	3,194	1,925	1,502	1,144	1,874
L ana	2,881	0,313	0,323	1,634	0,309	0,393	0,735	2,592	2,032	0,314	3,440	2,317	1,782	0,939	2,079

L apo	2,849	0,302	0,275	1,614	0,279	0,418	0,710	2,424	2,048	0,311	3,534	2,032	1,509	1,059	1,895
L gri	3,286	0,326	0,251	1,659	0,287	0,381	0,744	2,307	1,887	0,344	4,028	2,072	1,689	0,973	1,698
L joc	1,327	0,439	0,240	2,012	0,330	0,484	0,686	2,430	3,608	0,332	2,971	1,626	1,233	1,306	1,466
L gro	2,722	0	0,445	3,263	0,450	0,515	0,657	2,698	1,961	0,181	4,018	2,454	2,672	0,469	2,610
M atl	3,974	0	0,389	2,304	0,820	0,471	0,702	3,181	1,613	0,144	3,342	2,469	1,965	0,842	3,179
M mar	2,808	0,476	0,228	1,127	0,279	0,376	0,708	1,713	2,037	0,290	3,793	2,137	1,334	0,854	2,321
M fur	2.978	0,528	0,196	1,040	0,221	0,368	0,697	2.543	1,967	0,373	5,197	2,923	1,171	0,706	2,001
M cos	1,550	0	0,097	1,670	0,708	0,422	0,554	3,102	3,093	0,128	3,995	2,509	2,572	0,637	1,376
M cur	3,557	0,874	0,202	1,164	0,466	0,502	0,578	1,716	1,756	0,711	3,047	3,278	2,956	0,591	2,348
M cuv	3,226	0,954	0,151	1,178	0,414	0,533	0,603	1,563	1,852	0,769	3,304	2,495	2,122	0,697	1,607
M liz	3,963	0,622	0,151	0,978	0,455	0,480	0,622	1,369	1,617	0,713	3,508	2,299	1,817	0,538	1,812
M rub	3,967	0,936	0,167	1,023	0,441	0,545	0,572	1,733	1,696	0,711	3,615	2,549	2,379	0,614	1,677
*M*_sp	0,706	0,853	0,158	0,803	0,639	0,504	0,604	1,875	5,611	0,704	3,638	2,945	1,841	0,430	2,256
M bon	3,136	0,385	0,444	1,944	0,416	0,383	0,733	2,281	1,854	0,397	2,915	1,875	1,217	1,041	2,548
M oce	3,796	0	0,455	0,988	0,254	0,293	0,657	1,140	1,267	0	0	0	0	0	0
O ves	3,382	0,504	0,109	0,794	0,237	0,137	0,750	0,408	1,956	1,000	1,261	2,667	1,149	1,265	0,887
O pal	2,049	0	0,424	2,158	0,650	0,472	0,611	3,354	2,595	0,432	3,566	5,324	2,634	0,581	2,311
O sau	2,092	0	0,405	2,447	0,676	0,489	0,624	3,558	2,361	0,444	3,770	4,703	2,367	0,496	2,304
O ogl	2,207	0	0,119	2,538	0,757	0,455	0,709	2,656	2,369	0,187	5,469	2,649	2,454	0,496	1,351
O nil	3,929	0,526	0,150	1,197	0,620	0,419	0,719	2,299	1,677	0,293	4,688	1,339	1,027	1,795	1,571
O sca	3,453	0,464	0,183	1,289	0,318	0,468	0,745	2,423	1,800	0,376	1,833	2,545	1,141	0,949	2,467
P bra	3,831	0	0,314	3,285	0,402	0,632	0,891	0,141	1,580	1,000	2,891	2,016	1,537	0,298	2,941
P ret	0,543	0,100	0,795	0,658	0,159	0,858	0,630	1,519	7,484	0,514	3,455	1,524	1,053	0,404	1,638
P viv	1,257	0,689	0,091	0,467	0,674	0,590	0,632	1,596	3,765	0,482	4,092	1,004	0,902	0,539	1,337
*P*_sp	1,235	0,741	0,094	0,724	0,711	0,622	0,550	1,671	3,852	0,410	2,823	1,086	1,082	0,888	1,414
P vir	2,949	0	0,497	1,507	0,287	0,643	0,749	2,624	1,900	0,129	5,209	2,753	2,669	0,449	2,877
P pun	2,240	0,291	0,754	0,866	0,331	0,455	0,780	1,021	2,315	0,204	1,255	3,358	0,365	3,701	17,395
P bre	2,248	0	0,304	0,821	0,673	0,427	0,530	3,130	2,326	0,155	5,213	3,055	3,143	0,320	1,708
P nod	0,658	0	0,456	0,927	0,283	0,403	0,430	1,386	5,901	0,083	7,223	2,226	1,423	0,170	1,241
R ama	1,202	0	0,143	1,868	0,745	0,489	0,652	3,144	3,479	0,159	3,406	2,292	2,623	0,587	2,780
S her	3,012	0	0,252	0,708	0,392	0,423	0,693	1,058	1,930	0,126	4,140	3,340	2,558	0,629	1,605
S par	2,894	0	0,326	0,641	0,434	0,398	0,694	1,021	2,049	0,165	6,007	3,170	2,272	0,676	1,487
S pro	3,295	0	0,334	0,720	0,288	0,390	0,708	0,884	1,892	0,114	4,111	3,786	2,312	0,632	1,414
S bra	1,399	0	0,700	3,073	0,450	0,488	0,715	2,396	2,915	0,607	0,501	4,344	0,426	0,551	11,038
S plu	3,612	0,473	0,374	1,016	0,473	0,241	0,804	1,589	1,833	0,382	2,577	2,075	1,031	2,074	2,340
S vom	2,730	0	0,082	3,803	0,288	0,152	0,595	7,493	2,216	0,486	4,804	7,865	4,378	1,231	1,936
S rho	4,709	0	0,190	1,175	0,615	0,350	0,721	3,479	1,520	0,177	4,541	5,933	4,618	0,394	1,198
S rad	3,263	0	0,097	1,246	0,571	0,297	0,781	2,285	1,858	0,334	2,538	1,915	1,475	1,100	1,711
S gre	2,475	0	0,103	0,850	0,449	0,216	0,773	0,915	2,215	0,417	1,506	2,437	1,067	0,832	1,411
S spe	2,407	0	0,093	0,919	0,486	0,218	0,709	0,849	2,259	0,434	1,118	2,506	1,125	1,125	1,300
S tes	3,975	0	0,094	0,845	0,419	0,229	0,810	0,869	1,678	0,437	2,139	2,689	1,149	0,581	1,640
S bar	2,979	0	0,617	2,578	0,610	0,491	0,686	1,674	1,805	0,416	3,261	2,650	2,047	0,466	2,493
S gua	2,919	0	0,555	2,482	0,476	0,536	0,607	1,872	1,771	0,379	3,801	3,008	2,509	0,474	2,401
S not	2,293	0	0,921	0,414	0,112	0,862	0,564	1,898	2,277	0,140	4,389	1,712	1,190	0,358	1,232
S nas	2,485	0,635	0,171	1,085	0,262	0,461	0,640	1,871	2,281	0,366	4,535	1,946	1,132	0,712	1,835
S mar	3,861	0	1,120	3,558	0,618	0,626	0,632	1,003	1,400	0,715	3,837	4,174	1,792	1,151	3,855
S tim	3,830	0	1,115	3,549	0,627	0,635	0,621	1,012	1,412	0,724	3,848	4,163	1,781	1,162	3,843
S tss	2,572	0	0,111	2,100	0,545	0,483	0,903	0,197	2,264	1,000	0	1,066	0,658	0	0,154
S pel	0,247	0	0,098	1,500	0,637	0,265	0,429	1,296	7,802	0	0	1,964	0,859	0	1,501
*S*_sp	0,246	0	0,100	1,511	0,629	0,269	0,440	1,310	7,813	0	0	1,955	0,870	0	1,550
S bon	2,456	0	0,877	1,517	0,474	0,361	0,745	0,640	2,022	0,594	3,861	2,219	1,401	0,718	1,468
S foe	3,050	0	0,922	1,349	0,405	0,422	0,705	0,873	1,744	0,434	3,198	3,538	2,330	0,657	2,054
T nat	3,378	0,245	0,316	0,323	1,000	0,199	0,913	0,495	1,875	1,000	1,963	2,698	1,406	2,121	2,165
T car	1,751	0,385	0,175	1,977	0,578	0,426	0,654	3,846	2,929	0,366	3,347	3,692	2,450	0,671	1,500
T fal	3,514	0,667	0,086	1,374	0,278	0,355	0,524	4,232	1,871	0,404	3,037	5,069	3,050	0,667	1,233
T pau	3,704	0	0116	1,149	0,458	0,530	0,855	0,132	1,665	1,000	4,431	1,478	1,252	0,012	1,603

Apêndice C - Abundância em densidade das espécies (indivíduos por 100 m²) para cada estuário. Em negrito os valores que correspondem a densidades relativas acima de 1% na assembleia de cada estuário.

		Densidade (ind/100m²)						
Espécie	Cod	Choró	Curu	Pacoti	Cocó	Malcozinhado	Aracatiaçu	Aracatimirim
Abudefduf saxatilis	Asax	---	---	---	---	0,67	---	---
Acanthurus bahianus	Abah	---	---	---	0,25	0,67	---	---
Achirus achirus	Aach	10,45	12,63	**17,72**	---	**28,57**	**15,59**	**68,35**
Achirus lineatus	Alin	14,88	**24,41**	13,44	---	13,73	3,17	**30,10**
Albula vulpes	Avul	---	0,33	---	---	0,33	---	---
Anableps anableps	Aana	---	10,00	---	---	---	---	---
Anchoa hepsetus	Ahep	13,32	---	---	---	0,25	---	6,17
Anchoa spinifer	Aspi	15,25	0,75	---	---	---	---	---
Anchovia clupeoides	Aclu	**68,96**	11,90	11,50	---	**52,33**	**8,25**	11,00
Anchoviella brevirostris	Abre	---	---	---	---	0,67	---	---
Antennarius striatus	Astr	0,59	---	---	---	---	0,25	---
Archosargus probatocephalus	Apro	---	1,95	---	---	---	---	---
Archosargus rhomboidalis	Arho	1,70	9,49	0,25	---	---	0,63	---
Astyanax bimaculatus	Abim	---	1,67	0,17	0,50	1,42	0,42	1,34
Atherinella brasiliensis	Abra	**264,42**	**318,07**	**157,18**	**191,34**	**430,71**	**133,33**	**82,31**
Bathygobius soporator	Bsop	9,94	4,28	8,84	6,02	4,50	1,42	0,75
Batrachoides surinamensis	Bsur	0,48	0,17	---	---	0,50	0,26	5,92
Bothus ocellatus	Boce	0,91	---	---	---	---	---	---
Bryx dunckeri	Bdun	---	0,25	---	---	---	---	---
Caranx latus	Clat	14,75	11,62	13,49	2,67	7,05	6,49	3,59
Cathorops spixii	Cspx	8,94	11,33	5,83	---	3,33	**23,33**	**328,23**
Cetengraulis edentulus	Cede	8,74	1,19	---	---	2,42	---	0,88
Centropomus parallelus	Cpar	---	---	**33,50**	17,08	---	---	---
Centropomus undecimalis	Cund	2,17	13,77	0,27	---	**40,98**	**41,98**	**52,71**
Chaetodipterus faber	Cfab	4,84	0,50	1,08	---	0,58	---	0,25
Chloroscombrus chrysurus	Cchr	---	---	---	1,50	---	---	---
Citharichthys arenaceus	Care	1,74	---	3,72	---	---	5,53	**15,01**
Citharichthys spilopterus	Cspi	**53,69**	19,44	**47,51**	3,17	14,42	**8,59**	**19,09**
Ctenogobius boleosoma	Cbol	0,99	0,17	0,50	56,25	14,71	1,17	3,50
Ctenogobius smaragdus	Csma	---	---	---	---	1,00	0,67	0,25
Ctenogobius stigmaticus	Csti	---	0,25	0,33	---	0,25	---	---
Cynoscion acoupa	Caco	---	---	3,94	---	---	---	---
Dactylopterus volitans	Dvol	---	---	0,63	---	---	---	---
Diapterus auratus	Daur	**38,40**	**72,99**	**161,84**	10,00	**60,76**	**12,11**	**47,04**
Diapterus rhombeus	Drho	**47,44**	**63,98**	**48,18**	---	2,41	---	3,75
Eleotris pisonis	Epis	---	---	---	2,00	---	---	---
Elops saurus	Esau	1,54	---	12,68	20,09	3,41	4,10	3,67
Etropus crossotus	Ecro	---	---	0,38	---	---	---	1,25
Eucinostomus argenteus	Earg	**271,39**	**669,35**	**291,46**	**360,25**	**207,06**	**61,51**	**151,89**
Eucinostomus gula	Egul	**25,49**	**30,58**	3,20	---	14,73	1,11	1,82
Eucinostomus havana	Ehav	1,60	2,00	8,67	---	3,61	---	---
Eucinostomus lefroyi	Elef	3,75	9,22	3,00	---	**16,92**	1,00	**16,50**
Eucinostomus melanopterus	Emel	14,17	**27,01**	7,73	2,00	**18,79**	1,00	5,08
Eugerres brasilianus	Ebra	**18,23**	**36,55**	8,95	---	4,81	3,77	1,67
Evorthodus lyricus	Elyr	---	---	0,67	4,00	---	0,33	---
Genyatremus luteus	Glut	1,80	---	---	---	0,50	---	1,85
Gobionellus oceanicus	Goce	**32,88**	**32,87**	**18,46**	---	**101,49**	0,25	4,00
Gobionellus stomatus	Gsto	2,08	6,84	6,33	---	11,92	---	3,25
Haemulon parra	Hpar	0,45	4,43	---	0,77	3,73	---	---
Haemulopsis corvinaeformis	Hcor	9,60	7,42	4,77	---	**15,23**	0,77	0,42
Harengula sp.	H_sp	---	---	---	---	0,75	---	---
Hippocampus reidi	Hrei	1,00	2,43	0,17	0,25	0,25	0,25	---
Hypanus guttatus	Hgut	0,92	---	2,21	---	2,07	---	0,83
Hyporhamphus unifasciatus	Huni	0,50	13,50	9,34	23,66	11,38	1,83	4,67
Lagocephalus laevigatus	Llae	0,38	---	---	---	0,25	---	---

Larimus breviceps	Lbre	---	---	---	---	---	---	0,50
Lile piquitinga	Lpiq	**64,13**	**337,54**	**229,75**	2,25	**86,49**	**36,71**	**113,83**
Lutjanus alexandrei	Lale	3,55	2,71	1,50	8,00	2,41	0,88	---
Lutjanus analis	Lana	9,54	4,70	3,65	0,67	1,41	0,25	2,41
Lutjanus apodus	Lapo	0,75	1,04	2,99	2,27	7,49	2,88	4,97
Lutjtanus griseus	Lgri	4,39	9,93	4,19	12,83	13,39	**9,43**	10,32
Lutjanus jocu	Ljoc	0,45	3,25	---	---	---	---	0,25
Lycengraulis grossidens	Lgro	**105,10**	**29,13**	**29,35**	4,17	8,59	**10,09**	9,24
Megalops atlanticus	Matl	---	---	---	9,93	---	---	---
Menticirrhus martinicensis	Mmar	0,50	---	---	---	1,44	---	0,92
Micropogonias furnieri	Mfur	1,37	0,67	9,41	---	---	---	---
Moenkhausia costae	Mcos	0,25	---	0,25	34,50	---	---	---
Mugil curema	Mcur	**145,55**	**406,59**	**127,04**	**168,36**	**63,55**	**30,27**	4,35
Mugil curvidens	Mcuv	11,51	**29,24**	0,33	1,92	11,39	2,21	0,75
Mugil liza	Mliz	3,53	---	---	5,91	0,48	---	---
Mugil rubrioculus	Mrub	10,33	11,67	1,87	---	2,44	3,06	---
Mugil sp. (juvenis)	M_sp	**34,75**	---	0,50	**3089,00**	6,79	4,58	1,92
Mycteroperca bonaci	Mbon	0,17	---	---	---	1,00	---	---
Myrichthys ocellatus	Moce	1,50	0,63	0,17	---	---	---	---
Ogcocephalus vespertilio	Oves	0,50	---	---	---	---	0,63	---
Oligoplites palometa	Opal	1,08	1,50	**38,13**	---	1,13	0,63	0,25
Oligoplites saurus	Osau	2,29	1,29	2,33	---	0,58	0,25	0,25
Opisthonema oglinum	Oogl	**54,34**	---	**33,63**	8,37	**16,41**	---	---
Oreochromis niloticus	Onil	---	---	---	**75,58**	---	**6,83**	0,59
Orthopristis scapularis	Osca	---	---	0,25	---	---	---	---
Paralichthys brasiliensis	Pbra	0,33	1,91	---	---	---	0,78	1,53
Poecilia reticulata	Pret	---	---	0,17	---	---	---	---
Poecilia vivipara	Pviv	---	---	---	**2145,50**	---	---	---
Poecilia sp.	P_sp	---	---	---	13,00	---	---	---
Polydactylus virginicus	Pvir	---	---	0,48	---	---	---	---
Prionotus punctatus	Ppun	0,33	---	0,63	---	---	---	---
Prochilodus brevis	Pbre	---	---	---	---	0,50	---	---
Pseudauchenipterus nodosus	Pnod	---	---	---	---	---	---	0,25
Rhinosardinia amazonica	Rama	40,75	6,17	---	---	**114,83**	**79,94**	**101,34**
Sciades herzbergii	Sher	**24,15**	12,76	10,14	---	0,75	0,26	1,60
Sciades parkeri	Spar	**17,51**	1,93	---	---	0,25	---	---
Sciades proops	Spro	---	---	---	1,00	8,83	4,83	5,21
Scomberomorus brasiliensis	Sbra	0,25	---	---	---	---	---	---
Scorpaena plumieri	Splu	3,06	---	0,17	---	0,67	---	---
Selene vomer	Svom	2,33	0,33	3,34	---	0,77	---	---
Serrasalmus rhombeus	Srho	0,50	---	---	10,00	---	---	---
Sparisoma radians	Srad	9,01	6,16	4,25	---	4,00	---	---
Sphoeroides greeleyi	Sgre	**30,47**	**39,24**	**98,36**	19,58	**22,37**	1,17	4,49
Sphoeroides spengleri	Sspe	1,33	---	---	---	---	---	---
Sphoeroides testudineus	Stes	**69,23**	**55,50**	**110,71**	9,67	**18,14**	**19,97**	**22,54**
Sphyraena barracuda	Sbar	---	1,38	4,66	0,50	1,39	---	---
Sphyraena guachancho	Sgua	---	---	---	0,3	0,25	---	---
Steindachnerina notonota	Snot	---	---	---	---	---	0,25	---
Stellifer naso	Snas	---	---	7,21	---	0,25	---	4,36
Strongylura marina	Smar	4,92	5,50	3,67	---	4,79	0,25	1,42
Strongylura timucu	Stim	0,33	3,15	9,34	2,76	4,08	**8,16**	2,75
Symphurus tessellatus	Stss	1,58	---	1,50	---	---	---	0,25
Syngnathus pelagicus	Spel	0,83	0,50	---	---	---	---	0,25
Syngnathus sp.	S_sp	---	---	0,17	0,50	---	0,17	---
Synodus bondi	Sbon	---	---	---	---	---	---	0,71
Synodus foetens	Sfoe	2,59	---	---	---	---	---	0,25
Thalassophryne nattereri	Tnat	---	---	0,67	---	---	0,50	---
Trachinotus carolinus	Tcar	---	---	---	---	0,25	---	---
Trachinotus falcatus	Tfal	0,37	3,02	0,17	---	0,42	---	---
Trinectes paulistanus	Tpau	2,85	0,17	1,29	0,50	0,50	3,26	2,33
TOTAL (ind/100m^2)		1636,73	2410,93	1650,16	6328,69	1507,16	565,53	1177,56
Riqueza de espécies	115	78	63	70	43	74	54	61

Apêndice D - Abundância em biomassa das espécies (gramas por 100 m^2) para cada estuário. Em negrito os valores que correspondem a biomassas relativas acima de 1% na assembléia de cada estuário.

		Biomassa (g/100m^2)						
Espécie	Cod	Choró	Curu	Pacoti	Cocó	Malcozinhado	Aracatiaçu	Aracatimirim
Abudefduf saxatilis	Asax	---	---	---	---	25,02	---	---
Acanthurus bahianus	Abah	---	---	---	0,20	24,45	---	---
Achirus achirus	Aach	**212,53**	8,26	74,16	---	81,77	**51,05**	**247,24**
Achirus lineatus	Alin	94,92	61,03	50,68	---	57,56	5,60	**146,19**
Albula vulpes	Avul	---	4,02	---	---	0,17	---	---
Anableps anableps	Aana	---	49,33	---	---	---	---	---
Anchoa hepsetus	Ahep	18,62	---	---	---	0,04	---	1,66
Anchoa spinifer	Aspi	12,87	0,35	---	---	---	---	---
Anchovia clupeoides	Aclu	**272,90**	17,29	81,59	---	64,99	25,98	13,58
Anchoviella brevirostris	Abre	---	---	---	---	0,17	---	---
Antennarius striatus	Astr	16,55	---	---	---	---	29,76	---
Archosargus probatocephalus	Apro	---	21,07	---	---	---	---	---
Archosargus rhomboidalis	Arho	20,03	76,59	1,23	---	---	9,70	---
Astyanax bimaculatus	Abim	---	7,37	0,49	0,70	1,73	1,31	5,15
Atherinella brasiliensis	Abra	**928,23**	**962,38**	**597,58**	**734,58**	**1516,00**	**841,84**	**266,27**
Bathygobius soporator	Bsop	92,29	58,53	52,77	64,56	71,63	4,74	3,95
Batrachoides surinamensis	Bsur	4,11	24,52	---	---	15,79	2,48	**144,20**
Bothus ocellatus	Boce	10,68	---	---	---	---	---	---
Bryx dunckeri	Bdun	---	0,05	---	---	---	---	---
Caranx latus	Clat	64,42	37,58	38,88	5,36	50,95	21,30	18,42
Cathorops spixii	Cspx	104,08	60,88	91,72	---	21,85	**137,64**	**1666,66**
Cetengraulis edentulus	Cede	72,93	11,20	---	---	5,32	---	4,94
Centropomus parallelus	Cpar	---	---	**547,92**	81,11	---	---	---
Centropomus undecimalis	Cund	64,20	**432,30**	16,16	---	**719,47**	**633,52**	**801,29**
Chaetodipterus faber	Cfab	42,44	24,41	4,92	---	0,92	---	0,04
Chloroscombrus chrysurus	Cchr	---	---	---	6,78	---	---	---
Citharichthys arenaceus	Care	18,05	---	49,88	---	---	40,07	**111,63**
Citharichthys spilopterus	Cspi	**354,59**	163,38	**309,11**	16,57	74,96	**67,16**	**94,77**
Ctenogobius boleosoma	Cbol	0,17	0,12	0,09	14,81	1,70	0,28	0,66
Ctenogobius smaragdus	Csma	---	---	---	---	1,50	1,04	0,16
Ctenogobius stigmaticus	Csti	---	2,84	0,32	---	0,56	---	---
Cynoscion acoupa	Caco	---	---	45,65	---	---	---	---
Dactylopterus volitans	Dvol	---	---	86,50	---	---	---	---
Diapterus auratus	Daur	**210,15**	**789,32**	**1270,84**	5,41	**178,52**	37,78	**176,96**
Diapterus rhombeus	Drho	**371,09**	**373,70**	**661,24**	---	37,47	---	24,03
Eleotris pisonis	Epis	---	---	---	10,89	---	---	---
Elops saurus	Esau	39,92	---	134,77	**379,22**	**104,13**	28,94	21,66
Etropus crossotus	Ecro	---	---	1,20	---	---	---	8,30
Eucinostomus argenteus	Earg	**1201,08**	**3479,34**	**1246,84**	**450,16**	**769,26**	**367,60**	**587,53**
Eucinostomus gula	Egul	**189,89**	**384,24**	20,23	---	81,06	5,24	17,37
Eucinostomus havana	Ehav	12,46	24,98	95,00	---	29,47	---	---
Eucinostomus lefroyi	Elef	9,00	74,07	5,45	---	50,94	2,73	8,24
Eucinostomus melanopterus	Emel	94,90	236,39	56,26	11,20	62,43	1,24	33,56
Eugerres brasilianus	Ebra	**202,73**	**696,01**	**180,40**	---	**96,01**	26,28	7,07
Evorthodus lyricus	Elyr	---	---	0,57	4,32	---	0,62	---
Genyatremus luteus	Glut	21,26	---	---	---	0,28	---	34,41
Gobionellus oceanicus	Goce	**397,03**	**622,87**	**162,31**	---	**968,80**	1,73	15,27
Gobionellus stomatus	Gsto	22,63	70,41	39,70	---	27,15	---	4,65

Haemulon parra	Hpar	6,03	47,08	---	9,09	59,94	---	---
Haemulopsis corvinaeformis	Hcor	103,37	190,22	69,57	---	**96,31**	7,28	3,07
Harengula sp.	H_sp	---	---	---	---	8,97	---	---
Hippocampus reidi	Hrei	6,04	7,56	0,35	0,84	0,83	0,83	---
Hypanus guttatus	Hgut	86,98	---	**364,64**	---	**265,53**	---	**80,51**
Hyporhamphus unifasciatus	Huni	3,10	258,69	**197,38**	**142,72**	72,17	14,00	30,09
Lagocephalus laevigatus	Llae	33,89	---	---	---	0,36	---	---
Larimus breviceps	Lbre	---	---	---	---	---	---	0,28
Lile piquitinga	Lpiq	**209,22**	**1420,54**	**598,41**	12,64	**320,25**	**149,73**	**148,43**
Lutjanus alexandrei	Lale	19,80	33,69	7,56	27,91	30,15	39,08	---
Lutjanus analis	Lana	118,75	63,71	19,07	3,80	80,83	13,85	8,63
Lutjanus apodus	Lapo	3,77	11,88	94,82	26,93	57,70	40,63	**66,38**
Lutjtanus griseus	Lgri	35,07	118,78	34,38	26,82	**215,09**	**230,04**	**157,72**
Lutjanus jocu	Ljoc	4,44	2,73	---	---	---	---	0,72
Lycengraulis grossidens	Lgro	**158,28**	75,30	59,29	7,70	50,52	**121,66**	**89,45**
Megalops atlanticus	Matl	---	---	---	**3430,33**	---	---	---
Menticirrhus martinicensis	Mmar	14,43	---	---	---	26,04	---	16,22
Micropogonias furnieri	Mfur	18,80	2,61	101,28	---	---	---	---
Moenkhausia costae	Mcos	0,56	---	0,58	80,34	---	---	---
Mugil curema	Mcur	**2702,02**	**12372,46**	**2109,36**	**830,09**	**1134,60**	**360,04**	55,73
Mugil curvidens	Mcuv	**210,52**	**849,00**	2,72	43,62	**158,58**	**50,48**	19,58
Mugil liza	Mliz	**205,80**	---	---	**151,88**	4,26	---	---
Mugil rubrioculus	Mrub	**253,47**	**803,13**	131,29	---	**142,82**	**65,37**	---
Mugil sp. (juvenis)	M_sp	5,08	---	0,07	**590,85**	7,65	0,48	0,24
Mycteroperca bonaci	Mbon	0,04	---	---	---	23,11	---	---
Myrichthys ocellatus	Moce	33,14	24,78	5,36	---	---	---	---
Ogcocephalus vespertilio	Oves	6,03	---	---	---	---	18,93	---
Oligoplites palometa	Opal	4,82	23,04	61,41	---	11,68	4,91	0,85
Oligoplites saurus	Osau	14,49	5,97	6,00	---	2,15	2,68	1,60
Opisthonema oglinum	Oogl	**353,16**	---	**279,75**	64,92	**99,21**	---	---
Oreochromis niloticus	Onil	---	---	---	**1227,63**	---	**102,16**	35,05
Orthopristis scapularis	Osca	---	---	7,65	---	---	---	---
Paralichthys brasiliensis	Pbra	24,60	41,67	---	---	---	48,18	30,53
Poecilia reticulata	Pret	---	---	0,10	---	---	---	---
Poecilia vivipara	Pviv	---	---	---	**2223,10**	---	---	---
Poecilia sp.	P_sp	---	---	---	15,11	---	---	---
Polydactylus virginicus	Pvir	---	---	8,61	---	---	---	---
Prionotus punctatus	Ppun	2,24	---	6,53	---	---	---	---
Prochilodus brevis	Pbre	---	---	---	---	5,50	---	---
Pseudauchenipterus nodosus	Pnod	---	---	---	---	---	---	0,26
Rhinosardinia amazonica	Rama	109,28	9,92	---	---	**157,50**	**137,55**	**159,21**
Sciades herzbergii	Sher	**873,78**	**827,54**	100,51	---	15,36	3,49	28,58
Sciades parkeri	Spar	**223,98**	18,96	---	---	1,33	---	---
Sciades proops	Spro	---	---	---	**269,93**	**191,31**	24,73	53,61
Scomberomorus brasiliensis	Sbra	0,76	---	---	---	---	---	---
Scorpaena plumieri	Splu	64,96	---	2,36	---	12,22	---	---
Selene vomer	Svom	14,69	0,39	37,44	---	11,31	---	---
Serrasalmus rhombeus	Srho	0,30	---	---	**769,90**	---	---	---
Sparisoma radians	Srad	**165,91**	54,35	58,60	---	76,05	---	---
Sphoeroides greeleyi	Sgre	**245,41**	232,99	**449,62**	62,84	**103,42**	15,65	25,53
Sphoeroides spengleri	Sspe	14,28	---	---	---	---	---	---
Sphoeroides testudineus	Stes	**3458,99**	**3778,76**	**3816,14**	27,18	**344,62**	**680,20**	**901,29**
Sphyraena barracuda	Sbar	---	15,26	88,92	0,08	33,27	---	---

Sphyraena guachancho	Sgua	---	---	---	4,80	4,70	---	---
Steindachnerina notonota	Snot	---	---	---	---	---	1,87	---
Stellifer naso	Snas	---	---	47,50	---	0,98	---	33,28
Strongylura marina	Smar	61,64	82,56	59,14	---	64,81	5,04	30,05
Strongylura timucu	Stim	9,60	155,17	137,11	29,75	62,09	**364,39**	**93,89**
Symphurus tessellatus	Stss	30,49	---	16,92	---	---	---	0,54
Syngnathus pelagicus	Spel	0,03	0,06	---	---	---	---	0,07
Syngnathus sp.	S_sp	---	---	0,03	0,12	---	0,01	---
Synodus bondi	Sbon	---	---	---	---	---	---	8,25
Synodus foetens	Sfoe	88,08	---	---	---	---	---	2,58
Thalassophryne nattereri	Tnat	---	---	16,51	---	---	15,20	---
Trachinotus carolinus	Tcar	---	---	---	---	1,19	---	---
Trachinotus falcatus	Tfal	3,53	136,69	3,11	---	5,66	---	---
Trinectes paulistanus	Tpau	43,11	12,03	12,03	0,19	24,71	**135,60**	31,56
TOTAL (g/100m²)		15223,07	30452,30	14936,53	11864,99	9125,02	4999,66	6579,60
Riqueza de espécies	115	78	63	70	43	74	54	61

Apêndice E - Índices de raridades taxonômica (Ri) e funcional (Ui) de nível regional para cada espécie referentes às densidades (ind/100m^2). Em negrito os valores mais elevados.

Espécie	R_i	U_i	Espécie	R_i	U_i	Espécie	R_i	U_i	Espécie	R_i	U_i
A sax	**0,857**	**0,090**	*C sma*	0,571	0,006	*L ana*	0	0,007	*P nod*	**0,857**	**0,147**
A bah	**0,714**	0,019	*C sti*	0,571	0,059	*L apo*	0	0,007	*R ama*	0,286	0,071
A ach	0,143	0,038	*C aco*	**0,857**	0,044	*L gri*	0	0,070	*S her*	0,143	0,013
A lin	0,143	0,043	*D vol*	**0,857**	**0,178**	*L joc*	0,571	0,071	*S par*	0,571	0,024
A vul	**0,714**	0,013	*D aur*	0	0,015	*L gro*	0	0,024	*S pro*	0,429	0,013
A ana	**0,857**	0,075	*D rho*	0,286	0,015	*M atl*	**0,857**	0,024	*S bra*	**0,857**	**0,113**
A hep	0,571	0,060	*E pis*	**0,857**	0,025	*M mar*	0,571	0,016	*S plu*	0,571	**0,097**
A spi	**0,714**	0,076	*E sau*	0,143	0,070	*M fur*	0,571	0,016	*S vom*	0,429	0,082
A clu	0,143	0,055	*E cro*	**0,714**	0,043	*M cos*	0,571	0,010	*S rho*	**0,714**	**0,179**
A bre	**0,857**	0,071	*E arg*	0	0,029	*M cur*	0	0,021	*S rad*	0,429	0,019
A str	**0,714**	0,081	*E gul*	0,143	0,055	*M cuv*	0	0,021	*S gre*	0	0,019
A pro	**0,857**	0,013	*E hav*	0,429	0,006	*M liz*	0,571	0,025	*S spe*	**0,857**	0,012
A rho	0,429	0,043	*E lef*	0,143	0,006	*M rub*	0,286	0,063	*S tes*	0	0,031
A bim	0,143	0,010	*E mel*	0	0,029	*M*_sp	0,143	0,076	*S bar*	0,429	0,024
A bra	0	0,033	*E bra*	0,143	0,076	*M bon*	**0,714**	0,060	*S gua*	**0,714**	0,024
B sop	0	0,025	*E lyr*	0,571	**0,093**	*M oce*	0,571	0,086	*S not*	**0,857**	0,077
B sur	0,286	**0,094**	*G lut*	0,571	0,041	*O ves*	**0,714**	0,064	*S nas*	0,571	0,013
B oce	**0,857**	0,041	*G oce*	0,143	0,050	*O pal*	0,143	0,028	*S mar*	0,143	<0,001
B dun	**0,857**	<0,001	*G sto*	0,286	0,075	*O sau*	0,143	0,028	*S tim*	0	<0,001
C lat	0	0,056	*H par*	0,429	0,041	*O ogl*	0,429	**0,113**	*S tss*	0,571	0,058
C spx	0,143	0,024	*H cor*	0,143	0,054	*O nil*	0,571	0,081	*S pel*	0,571	<0,001
C ede	0,429	0,010	*H*_sp	**0,857**	0,024	*O sca*	**0,857**	0,023	*S*_sp	0,571	<0,001
C par	**0,714**	<0,001	*H rei*	0,143	**0,141**	*P bra*	0,429	0,047	*S bon*	**0,857**	**0,116**
C und	0,143	<0,001	*H gut*	0,429	0,086	*P ret*	**0,857**	0,086	*S foe*	**0,714**	**0,093**
C fab	0,286	0,074	*H uni*	0	0,033	*P viv*	**0,857**	0,016	*T nat*	**0,714**	0,047
C chr	**0,857**	0,066	*L lae*	**0,714**	0,040	*P*_sp	**0,857**	0,016	*T car*	**0,857**	0,026
C are	0,429	0,041	*L bre*	**0,857**	0,037	*P vir*	**0,857**	0,013	*T fal*	0,429	0,063
C spi	0	0,047	*L piq*	0	0,011	*P pun*	**0,714**	0,039	*T pau*	0	0,038
C bol	0	0,006	*L ale*	0,143	0,041	*P bre*	**0,857**	0,077			

Apêndice F - Índices de raridades taxonômica (S_i) e funcional (D_i) de nível local para cada espécie em cada estuário referentes às densidades (ind/100m²). Em negrito os valores mais elevados.

	Choró		Curu		Pacoti		Cocó		Malcozinhado		Aracatiaçu		Aracatimirim		Média	
Espécie	S_i	D_i	S_i	D_i	S_i	D_i	S_i	D_i	S_i	D_i	S_i	D_i	S_i	D_i	S_i	D_i
A sax	---	---	---	---	---	---	---	---	0,977	0,260	---	---	---	---	**0,977**	0,260
A bah	---	---	---	---	---	---	0,999	0,373	0,977	0,265	---	---	---	---	**0,988**	**0,301**
A ach	0,708	0,266	0,795	0,276	0,594	0,271	---	---	0,378	0,257	0,365	0,273	0,086	0,282	0,486	0,271
A lin	0,611	0,276	0,642	0,287	0,673	0,270	---	---	0,626	0,269	0,810	0,280	0,339	0,271	0,617	0,275
A vul	---	---	0,994	0,164	---	---	---	---	0,989	0,175	---	---	---	---	**0,991**	0,169
A ana	---	---	0,834	0,191	---	---	---	---	---	---	---	---	---	---	**0,834**	0,191
A hep	0,644	0,192	---	---	---	---	---	---	0,991	0,183	---	---	0,801	0,197	**0,812**	0,191
A spi	0,604	0,178	0,986	0,177	---	---	---	---	---	---	---	---	---		0,795	0,178
A clu	0,102	0,209	0,806	0,206	0,713	0,207	---	---	0,168	0,200	0,579	0,194	0,673	0,220	0,507	0,206
A bre	---	---	---	---	---	---	---	---	0,977	0,210	---	---	---	---	**0,977**	0,210
A str	0,980	0,253	---	---	---	---	---	---	---	---	0,983	0,258	---	---	**0,982**	0,256
A pro	---	---	0,965	0,173	---	---	---	---	---	---	---	---	---	---	**0,965**	0,173
A rho	0,945	0,161	0,842	0,149	0,992	0,150	---	---	---	---	0,959	0,170	---	---	**0,935**	0,157
A bim	---	---	0,970	0,281	0,995	0,293	0,997	0,226	0,952	0,276	0,972	0,262	0,953	0,292	**0,973**	0,272
A bra	<0,001	0,167	0,003	0,159	0,010	0,162	0,406	0,174	<0,001	0,176	<0,001	0,168	0,052	0,174	0,067	0,169
B sop	0,720	0,307	0,925	0,313	0,771	0,309	0,972	0,308	0,858	0,297	0,910	0,310	0,973	0,299	**0,875**	**0,306**
B sur	0,984	0,315	0,997	0,332	---	---	---	---	0,983	0,305	0,983	0,316	0,808	0,313	**0,951**	**0,316**
B oce	0,970	0,317	---	---	---	---	---	---	---	---	---	---	---	---	**0,970**	**0,317**
B dun	---	---	0,995	0,369	---	---	---	---	---	---	---	---	---	---	**0,995**	**0,369**
C lat	0,614	0,179	0,810	0,163	0,672	0,187	0,987	0,186	0,786	0,180	0,733	0,169	0,879	0,215	0,783	0,183
C spx	0,744	0,204	0,814	0,196	0,842	0,187	---	---	0,892	0,210	0,213	0,222	<0,001	0,219	0,584	0,206
C ede	0,749	0,169	0,978	0,164	---	---	---	---	0,921	0,160	---	---	0,969	0,183	**0,904**	0,169
C par	---	---	---	---	0,373	0,195	0,922	0,182	---	---	---	---	---	---	0,648	0,189
C und	0,931	0,181	0,779	0,175	0,992	0,192	---	---	0,248	0,184	0,062	0,176	0,150	0,227	0,527	0,189
C fab	0,852	0,179	0,990	0,180	0,968	0,173	---	---	0,980	0,173	---	---	0,991	0,172	**0,956**	0,175
C chr	---	---	---	---	---	---	0,993	0,198	---	---	---	---	---	---	**0,993**	0,198
C are	0,944	0,336	---	---	0,896	0,330	---	---	---	---	0,693	0,343	0,583	0,331	0,779	**0,335**
C spi	0,169	0,298	0,703	0,302	0,247	0,303	0,985	0,308	0,612	0,279	0,566	0,294	0,504	0,301	0,541	0,298
C bol	0,967	0,280	0,997	0,291	0,985	0,286	0,767	0,276	0,606	0,269	0,925	0,279	0,882	0,279	**0,876**	0,280
C sma	---	---	---	---	---	---	---	---	0,966	0,266	0,956	0,277	0,991	0,277	**0,971**	0,273
C sti	---	---	0,995	0,328	0,990	0,307	---	---	0,991	0,307	---	---	---	---	**0,992**	**0,314**
C aco	---	---	---	---	0,890	0,174	---	---	---	---	---	---	---	---	**0,890**	0,174
D vol	---	---	---	---	0,981	0,287	---	---	---	---	---	---	---	---	**0,981**	0,287
D aur	0,281	0,216	0,266	0,200	0,008	0,205	0,954	0,293	0,126	0,230	0,448	0,234	0,184	0,201	0,324	0,226
D rho	0,208	0,209	0,313	0,191	0,242	0,184	---	---	0,921	0,213	---	---	0,874	0,188	0,512	0,197
E pis	---	---	---	---	---	---	0,990	0,291	---	---	---	---	---	---	**0,990**	0,291
E sau	0,950	0,172	---	---	0,688	0,176	0,909	0,197	0,890	0,176	0,762	0,169	0,876	0,200	**0,846**	0,182
E cro	---	---	---	---	0,989	0,274	---	---	---	---	---	---	0,956	0,271	**0,972**	0,273
E arg	<0,001	0,211	<0,001	0,192	<0,001	0,214	0,183	0,192	<0,001	0,214	0,017	0,211	0,004	0,220	0,029	0,208
E gul	0,431	0,177	0,574	0,148	0,910	0,170	---	---	0,605	0,184	0,929	0,188	0,936	0,180	0,731	0,174
E hav	0,948	0,181	0,964	0,168	0,775	0,163	---	---	0,884	0,188	---	---	---	---	**0,893**	0,175
E lef	0,883	0,180	0,846	0,168	0,915	0,162	---	---	0,562	0,188	0,936	0,193	0,553	0,164	0,782	0,176
E mel	0,626	0,181	0,613	0,146	0,796	0,180	0,990	0,191	0,527	0,190	0,936	0,190	0,833	0,199	0,760	0,182
E bra	0,547	0,254	0,515	0,245	0,768	0,233	---	---	0,849	0,265	0,779	0,269	0,941	0,235	0,733	0,250
E lyr	---	---	---	---	0,980	0,328	0,981	0,271	---	---	0,978	0,313	---	---	**0,980**	**0,304**
G lut	0,942	0,189	---	---	---	---	---	---	0,983	0,193	---	---	0,935	0,159	**0,953**	0,180
G oce	0,337	0,285	0,551	0,291	0,581	0,289	---	---	0,031	0,284	0,983	0,280	0,866	0,291	0,558	0,286
G sto	0,933	0,270	0,883	0,284	0,830	0,274	---	---	0,666	0,259	---	---	0,890	0,270	**0,840**	0,271
H par	0,985	0,220	0,922	0,217	---	---	0,996	0,302	0,880	0,229	---	---	---	---	**0,946**	0,242
H cor	0,728	0,167	0,874	0,149	0,869	0,164	---	---	0,595	0,173	0,950	0,176	0,985	0,169	**0,833**	0,166
*H*_sp	---	---	---	---	---	---	---	---	0,974	0,162	---	---	---	---	**0,974**	0,162
H rei	0,967	0,365	0,957	0,378	0,995	0,360	0,999	0,399	0,991	0,359	0,983	0,370	---	---	**0,982**	**0,372**
H gut	0,970	0,342	---	---	0,937	0,332	---	---	0,932	0,345	---	---	0,970	0,320	**0,952**	**0,335**
H uni	0,983	0,154	0,783	0,154	0,760	0,161	0,894	0,178	0,679	0,142	0,886	0,141	0,845	0,176	**0,833**	0,158
L lae	0,987	0,183	---	---	---	---	---	---	0,991	0,173	---	---	---	---	**0,989**	0,178
L bre	---	---	---	---	---	---	---	---	---	---	---	---	0,982	0,192	**0,982**	0,192
L piq	0,120	0,178	0,002	0,192	0,001	0,194	0,989	0,215	0,052	0,173	0,088	0,173	0,016	0,204	0,181	0,190
L ale	0,889	0,230	0,952	0,231	0,956	0,216	0,963	0,308	0,921	0,238	0,943	0,242	---	---	**0,937**	0,244
L ana	0,729	0,170	0,918	0,163	0,898	0,159	0,996	0,244	0,953	0,172	0,983	0,175	0,917	0,175	**0,914**	0,180
L apo	0,975	0,168	0,981	0,161	0,915	0,157	0,989	0,242	0,774	0,171	0,826	0,175	0,836	0,172	**0,900**	0,178
L gri	0,865	0,175	0,835	0,159	0,884	0,175	0,941	0,207	0,634	0,180	0,535	0,180	0,690	0,196	0,769	0,182
L joc	0,985	0,150	0,942	0,136	---	---	---	---	---	---	---	---	0,991	0,169	**0,973**	0,152
L gro	0,031	0,186	0,590	0,174	0,421	0,191	0,980	0,170	0,746	0,174	0,512	0,160	0,717	0,212	0,571	0,181
M atl	---	---	---	---	---	---	0,954	0,180	---	---	---	---	---	---	**0,954**	0,180
M mar	0,983	0,181	---	---	---	---	---	---	0,952	0,187	---	---	0,967	0,164	**0,967**	0,177
M fur	0,955	0,186	0,988	0,178	0,758	0,168	---	---	---	---	---	---	---	---	**0,900**	0,177
M cos	0,991	0,284	---	---	0,992	0,297	0,850	0,231	---	---	---	---	---	---	**0,945**	0,270
M cur	0,081	0,176	<0,001	0,167	0,023	0,186	0,452	0,156	0,115	0,171	0,134	0,165	0,855	0,201	0,227	0,175
M cuv	0,683	0,159	0,588	0,141	0,990	0,169	0,991	0,143	0,678	0,160	0,864	0,153	0,973	0,195	**0,824**	0,160
M liz	0,890	0,160	---	---	---	---	0,972	0,145	0,984	0,159	---	---	---	---	**0,948**	0,155
M rub	0,711	0,153	0,809	0,144	0,946	0,151	---	---	0,920	0,148	0,816	0,150	---	---	**0,840**	0,149
*M*_sp	0,317	0,180	---	---	0,985	0,194	<0,001	0,147	0,793	0,171	0,738	0,162	0,933	0,203	0,628	0,176
M bon	0,994	0,237	---	---	---	---	---	---	0,966	0,242	---	---	---	---	**0,980**	0,240
M oce	0,951	0,298	0,988	0,310	0,995	0,288	---	---	---	---	---	---	---	---	**0,978**	0,299
O ves	0,983	0,342	---	---	---	---	---	---	---	---	0,959	0,352	---	---	**0,971**	**0,347**
O pal	0,965	0,178	0,973	0,175	0,326	0,196	---	---	0,962	0,174	0,959	0,159	0,991	0,213	**0,862**	0,183
O sau	0,927	0,186	0,977	0,186	0,933	0,188	---	---	0,980	0,180	0,983	0,177	0,991	0,209	**0,965**	0,188
O ogl	0,166	0,248	---	---	0,372	0,244	0,961	0,297	0,572	0,245	---	---	---	---	0,518	0,258
O nil	---	---	---	---	---	---	0,700	0,220	---	---	0,636	0,264	0,979	0,264	0,772	0,249
O sca	---	---	---	---	0,992	0,164	---	---	---	---	---	---	---	---	**0,992**	0,164
P bra	0,989	0,308	0,965	0,320	---	---	---	---	---	---	0,949	0,308	0,946	0,317	**0,963**	**0,313**
P ret	---	---	---	---	0,995	0,344	---	---	---	---	---	---	---	---	**0,995**	**0,344**
P viv	---	---	---	---	---	---	<0,001	0,164	---	---	---	---	---	---	<0,001	0,164
*P*_sp	---	---	---	---	---	---	0,940	0,119	---	---	---	---	---	---	**0,940**	0,119
P vir	---	---	---	---	0,986	0,157	---	---	---	---	---	---	---	---	**0,986**	0,157
P pun	0,989	0,199	---	---	0,981	0,179	---	---	---	---	---	---	---	---	**0,985**	0,189

P bre	---	---	---	---	---	---	---	---	0,983	0,285	---	---	---	---	**0,983**	0,285
P nod	---	---	---	---	---	---	---	---	---	---	---	---	0,991	0,310	**0,991**	**0,310**
R ama	0,260	0,224	0,894	0,218	---	---	---	---	0,020	0,225	0,005	0,217	0,026	0,260	0,241	0,229
S her	0,450	0,192	0,793	0,175	0,742	0,189	---	---	0,974	0,195	0,983	0,198	0,944	0,184	**0,814**	0,189
S par	0,560	0,200	0,965	0,193	---	---	---	---	0,991	0,205	---	---	---	---	**0,839**	0,200
S pro	---	---	---	---	---	---	0,995	0,204	0,740	0,200	0,726	0,203	0,829	0,187	**0,823**	0,199
S bra	0,991	0,291	---	---	---	---	---	---	---	---	---	---	---	---	**0,991**	0,292
S plu	0,904	0,313	---	---	0,995	0,308	---	---	0,977	0,310	---	---	---	---	**0,958**	**0,310**
S vom	0,926	0,232	0,994	0,229	0,906	0,229	---	---	0,974	0,230	---	---	---	---	**0,950**	0,230
S rho	0,983	0,307	---	---	---	---	0,953	0,308	---	---	---	---	---	---	**0,969**	**0,308**
S rad	0,742	0,249	0,894	0,251	0,882	0,237	---	---	0,872	0,255	---	---	---	---	**0,848**	0,248
S gre	0,365	0,198	0,491	0,200	0,055	0,189	0,911	0,267	0,467	0,202	0,925	0,206	0,851	0,176	0,581	0,206
S spe	0,957	0,193	---	---	---	---	---	---	---	---	---	---	---	---	**0,957**	0,193
S tes	0,101	0,203	0,365	0,200	0,038	0,189	0,955	0,274	0,539	0,203	0,266	0,214	0,445	0,183	0,387	0,209
S bar	---	---	0,975	0,187	0,871	0,187	0,997	0,234	0,953	0,179	---	---	---	---	**0,949**	0,197
S gua	---	---	---	---	---	---	0,998	0,231	0,991	0,175	---	---	---	---	**0,995**	0,203
S not	---	---	---	---	---	---	---	---	---	---	0,983	0,311	---	---	**0,983**	**0,311**
S nas	---	---	---	---	0,809	0,165	---	---	0,991	0,187	---	---	0,855	0,160	**0,885**	0,170
S mar	0,850	0,224	0,905	0,223	0,897	0,237	---	---	0,849	0,219	0,983	0,205	0,950	0,261	**0,906**	0,228
S tim	0,989	0,224	0,944	0,223	0,759	0,238	0,987	0,217	0,870	0,219	0,582	0,207	0,906	0,261	**0,863**	0,227
S tss	0,949	0,311	---	---	0,956	0,306	---	---	---	---	---	---	0,991	0,300	**0,965**	**0,306**
S pel	0,973	0,363	0,991	0,369	---	---	---	---	---	---	---	---	0,991	0,333	**0,985**	**0,355**
*S*_sp	---	---	---	---	0,995	0,354	0,997	0,394	---	---	0,989	0,369	---	---	**0,994**	**0,373**
S bon	---	---	---	---	---	---	---	---	---	---	---	---	0,975	0,279	**0,975**	0,279
S foe	0,918	0,192	---	---	---	---	---	---	---	---	---	---	0,991	0,208	**0,954**	0,200
T nat	---	---	---	---	0,980	0,308	---	---	---	---	0,967	0,312	---	---	**0,974**	**0,310**
T car	---	---	---	---	---	---	---	---	0,991	0,160	---	---	---	---	**0,991**	0,160
T fal	0,987	0,180	0,946	0,171	0,995	0,174	---	---	0,986	0,179	---	---	---	---	**0,979**	0,176
T pau	0,910	0,272	0,997	0,280	0,962	0,275	0,997	0,296	0,983	0,261	0,805	0,277	0,919	0,276	**0,939**	0,277

Apêndice G - Número de entidades funcionais com respectivos números de espécies que as compõem após exclusão de um dos grupos funcionais da análise em ordem de número de categorias.

Sem Mobilidade
(2 categorias)

Número de Entidades	Número de Espécies
1	13
1	11
1	10
3	5
2	4
8	3
9	2
16	1

41 entidades

Sem Posição na Água
(3 categorias)

Número de Entidades	Número de Espécies
2	16
1	10
1	7
2	5
3	4
5	3
7	2
15	1

36 entidades

Sem Guilda Reprodutiva
(4 categorias)

Número de Entidades	Número de Espécies
1	15
1	11
1	10
1	6
4	5
2	4
5	3
9	2
12	1

36 entidades

Sem Uso do Estuário
(5 categorias)

Número de Entidades	Número de Espécies
1	20
1	19
1	12
3	7
2	5
1	4
4	3
5	2
7	1

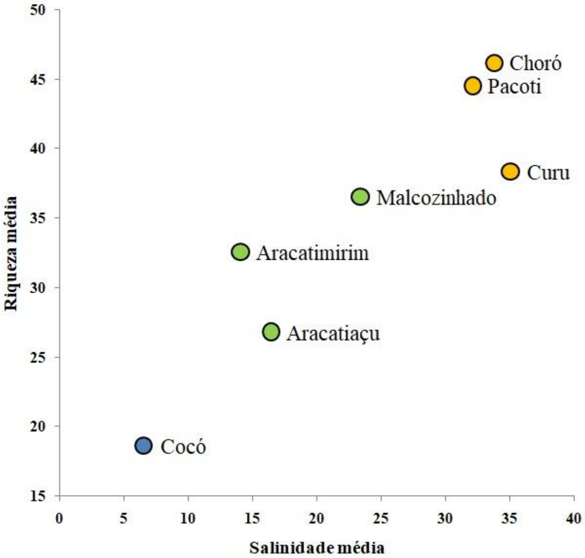
25 entidades

Sem Dieta
(6 categorias)

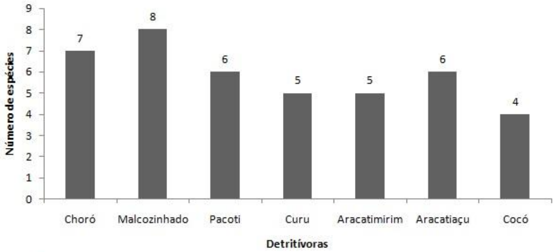
Número de Entidades	Número de Espécies
1	24
1	21
1	13
1	7
1	6
2	4
6	3
6	2
6	1

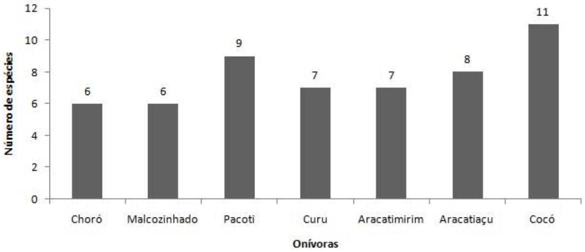
25 entidades

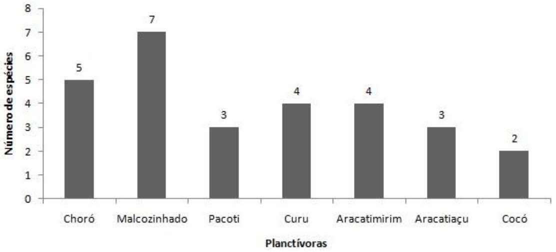
Apêndice H – Correlação entre salinidade média e riqueza média de espécies, e número de espécies por grupo funcional para cada estuário seguindo gradiente de riqueza de espécies.

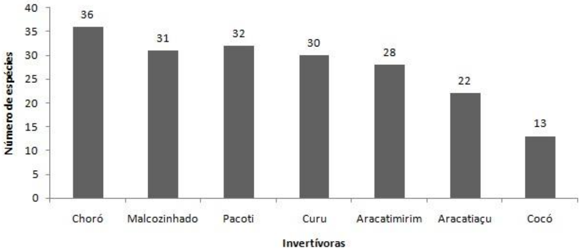


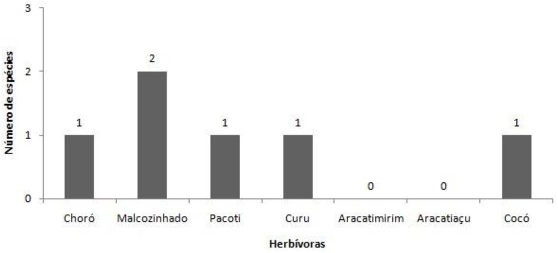
DIETA

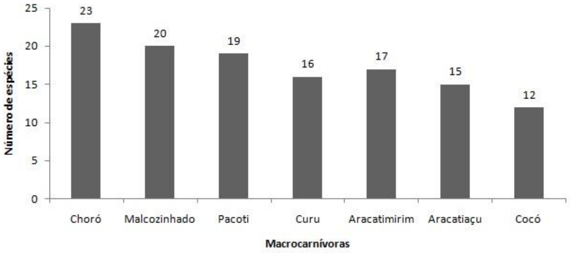




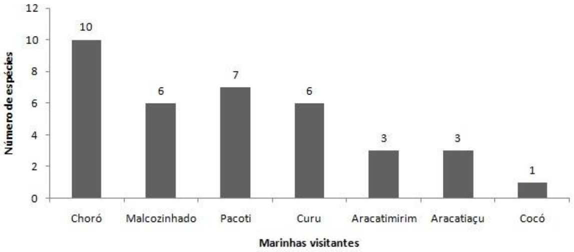


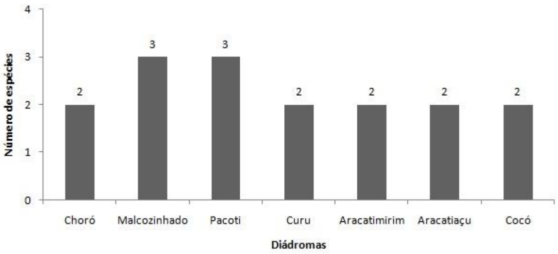


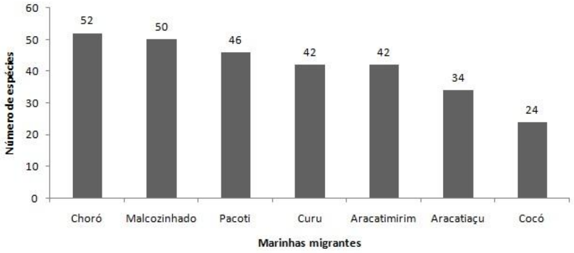


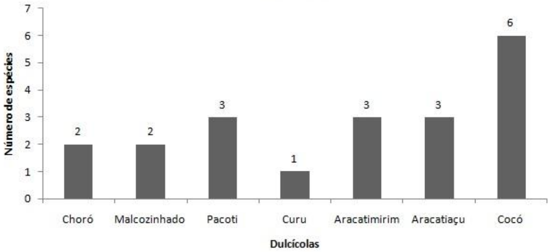


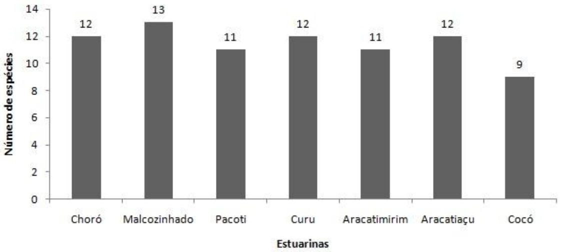
USO DO ESTUÁRIO



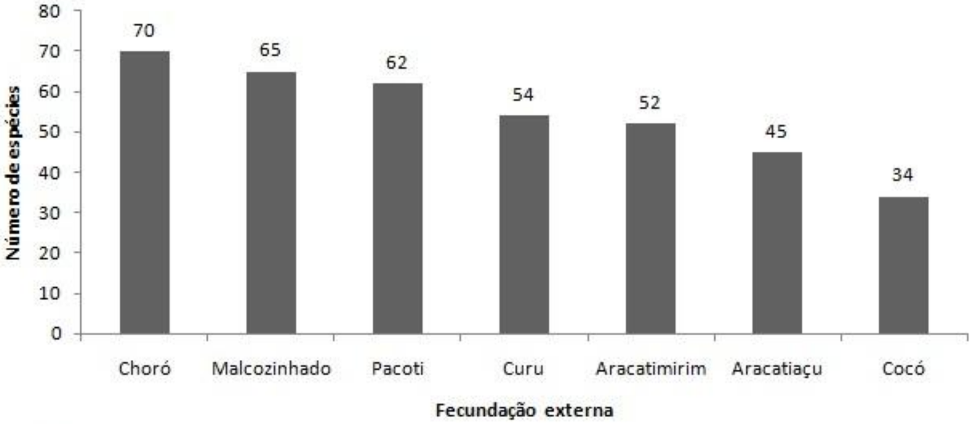


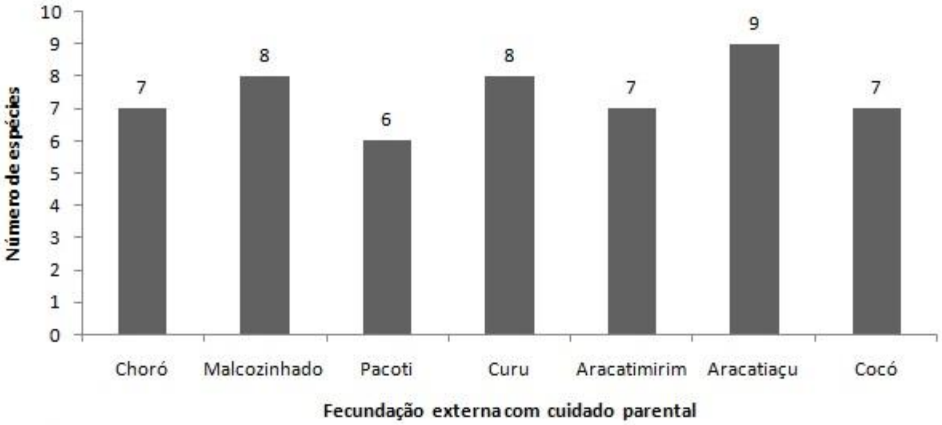


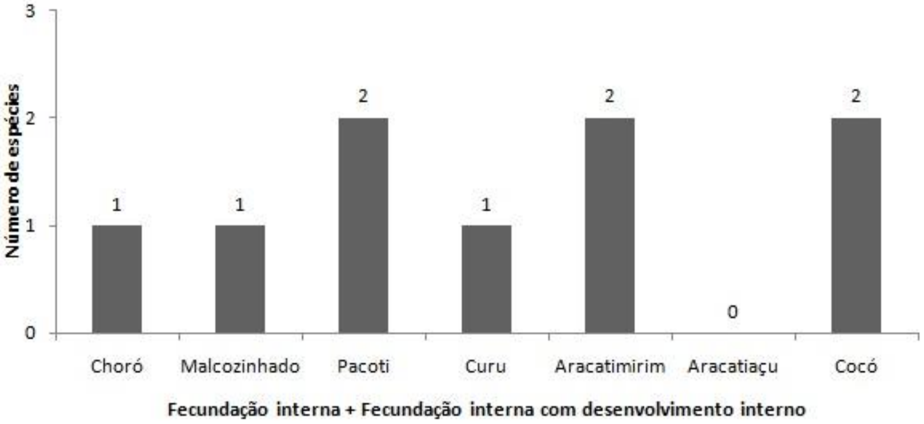




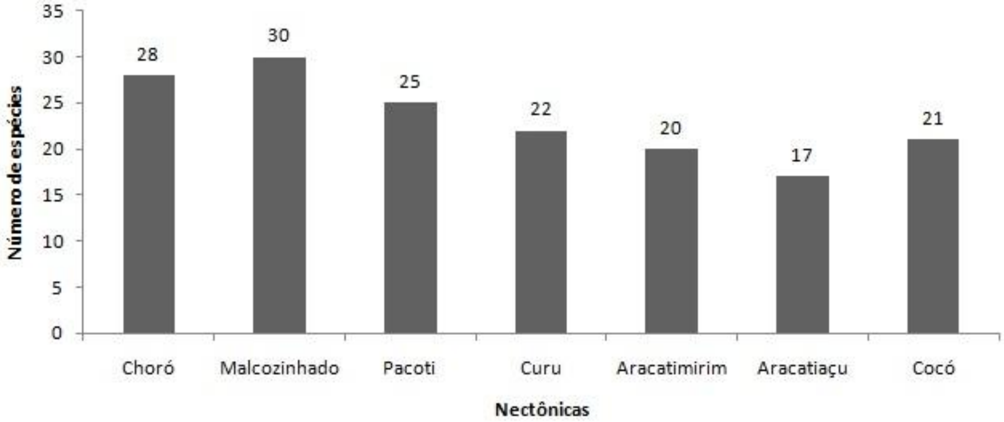
REPRODUÇÃO

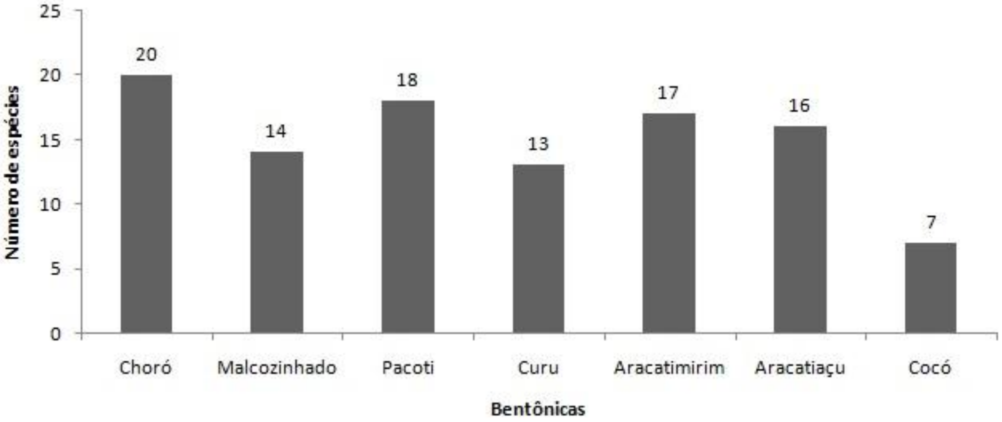

Número de espécies
0
10
20
30
40
50
60
70
80
70
65
62
54
52
45
34
Choró
Malcozinhado
Pacoti
Curu
Aracatimirim
Aracatiaçu
Cocó
Fecundação externa

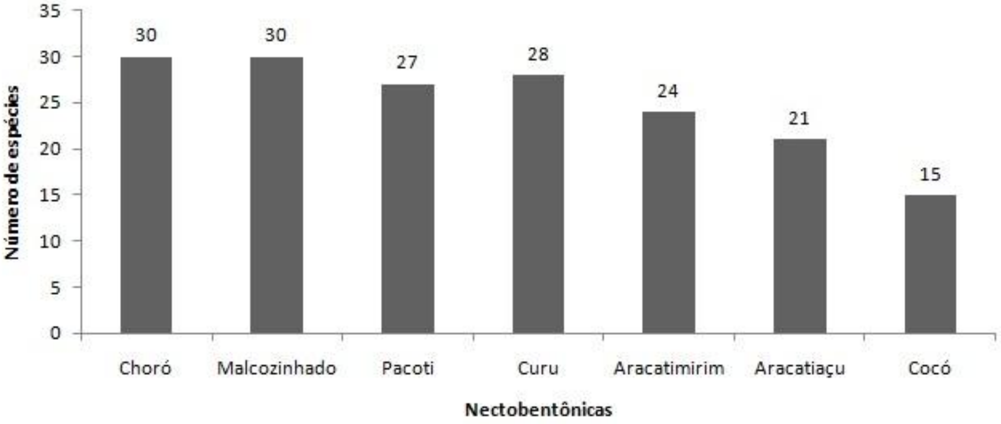

Número de espécies
0
1
2
3
4
5
6
7
8
9
10
7
8
6
8
7
9
7
Choró
Malcozinhado
Pacoti
Curu
Aracatimirim
Aracatiaçu
Cocó
Fecundação externa com cuidado parental


Número de espécies
0
1
2
3
1
1
2
1
2
0
2
Choró
Malcozinhado
Pacoti
Curu
Aracatimirim
Aracatiaçu
Cocó
Fecundação interna + Fecundação interna com desenvolvimento interno

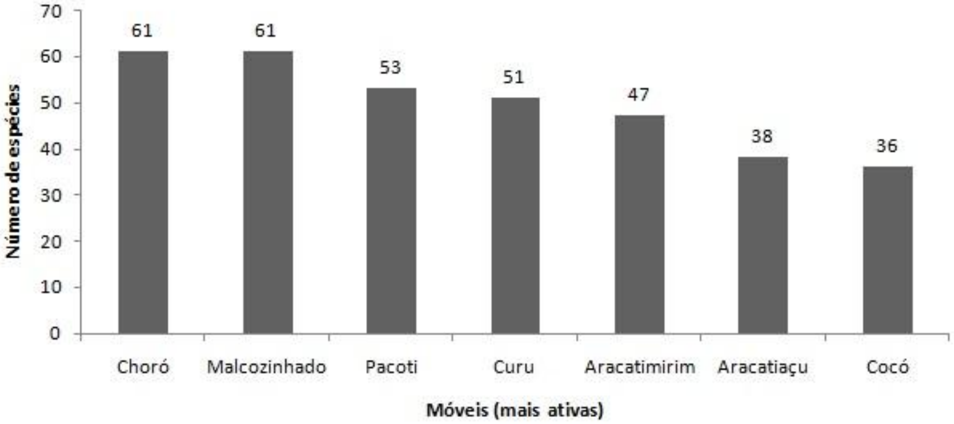
POSIÇÃO NA COLUNA D’ÁGUA

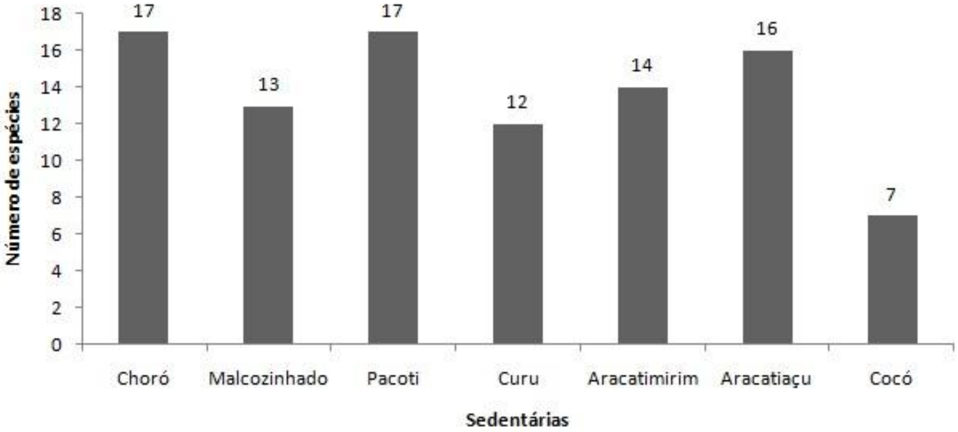






MOBILIDADE


70
60
50
40
30
20
10
0
Número de espécies
61
61
53
51
47
38
36
Choró
Malcozinhado
Pacoti
Curu
Aracatimirim
Aracatiaçu
Cocó
Móveis (mais ativas)


18
16
14
12
10
8
6
4
2
0
Número de espécies
17
13
17
12
14
16
7
Choró
Malcozinhado
Pacoti
Curu
Aracatimirim
Aracatiaçu
Cocó
Sedentárias

CAPÍTULO 3

Prolonged drought influences the taxonomic and functional structure of fish assemblages in estuaries along the Brazilian semiarid coast[2]

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Abstract

We evaluated how fish assemblages in estuaries on the semiarid coast of Brazil are impacted taxonomically and functionally under two contrasting events: prolonged drought vs. ample precipitation. The fish fauna of six local estuaries was sampled, three under each event. The species composition of the two groups was compared using non-metric multidimensional scaling, permutational multivariate analysis of variance and similarity percentages analysis. The functional structure was described using principal coordinate analysis and expressed as functional richness (FRic) and functional dispersion (FDis). We also ran extinction simulations to estimate how the most functionally original (FOri) and specialized (FSpe) species contributed to functional structure (FRic, FDis). Estuaries exposed to prolonged drought displayed greater abundance of marine stragglers and marine migrants and higher FRic values than did estuaries exposed to ample precipitation. They also suffered smaller losses in FRic when the most original and specialized species were removed. No clear pattern was discernible for FDis. In short, prolonged drought was associated with changes in the taxonomic and functional structure of the fish fauna in the sampled estuaries through the process of ‘marinization’. Monitoring these ecosystems can predict changes in salinity associated with long-term global climate trends and their effects on the fish fauna.

Keywords: Marinization. Hypersalinity. Climate change. Estuarine fishes. Northeastern Brazil.

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Author contributions

All authors contributed to the study conception and design. Data collection was performed by RCGL and LMP. Data analyses were performed by RCGL and CASRF. The first draft of the manuscript was written by RCGL and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability

Supplementary data included.

Code availability

Not applicable.

Declarations

Confict of interest

The authors have not disclosed any competing interests.

Consent to participate

N/a.

Ethical approval

ICMBio/SISBio licences #43014 and #64269 for sampling fishes.

Introduction

Functional ecology has been combined with traditional taxonomy to describe communities (Franco et al., 2008; Mouillot et al., 2013), including the use of novel diversity metrics based on species traits (Villéger et al., 2008; Laliberté & Legendre, 2010; Mouillot et al., 2013). The approach focuses on the association between diversity, ecosystem functioning and species' response to environmental disturbances (Mouillot et al., 2013; Brandl et al., 2016; Dolbeth et al., 2016; Silva-Júnior et al., 2017). Climate variability (especially extreme events) modulates biotic and abiotic factors and is therefore an essential determinant of the availability of freshwater, nutrients and organic matter in estuaries (Scavia et al., 2002; Paerl et al., 2006; Abrantes et al., 2015). Estuaries are temporally dynamic transitional ecosystems with steep environmental gradients, determined by river flow and interactions with the ocean. Their peculiar physical, chemical and biological properties permit the development of aquatic life forms and provide subsistence for local communities (Pimm et al., 2014; Saunders et al., 2014; Guannel et al., 2016; Claudet et al., 2020). However, estuaries are highly susceptible to impacts from their respective catchment areas and to adverse climatic factors (Santana et al., 2015; Barletta et al., 2019; Barletta & Lima, 2019; Lauchlan & Nagelkerken, 2020), making it necessary to adopt urgent and effective planning and management measures, especially in socioecologically vulnerable areas (Bennett et al., 2016; Keys et al., 2019), to mitigate nonrandom taxonomic and functional changes in biological communities (Mouillot et al., 2013).

Disturbances caused by extreme weather events tend to be particularly destructive in arid regions, potentially leading to desertification (Pickett & White, 1985; Nóbrega et al., 2016). Northeastern Brazil (NEB) has a typically semiarid climate characterized phytogeographically by Caatinga shrubland (Moro et al., 2015). Many of the estuaries in NEB display considerable seasonal variations in horizontal salinity profile, reflecting the two annual seasons (Zanella, 2005; Valle-Levinson & Schettini, 2016; Soares et al., 2021). During the rainy season (February to May), the estuaries of the semiarid coastal areas of NEB (Soares et al., 2021) display greater freshwater flow and a positive salinity gradient. At the onset of the dry season, as a result of reduced rainfalls and high rates of evaporation, salinity tends to become homogeneous throughout the estuary. During longer cycles of drought, the salinity gradient may become inverted, frequently exceeding 40 in salinity (Valle-Levinson & Schettini, 2016; Valentim et al., 2018). The effects of seawater intrusion are enhanced by the excessive number of dams in the catchment area and by extended water residence, aggravating the drought scenario (Molisani et al., 2006; Moraes & Pinheiro, 2011; Lacerda et al., 2020). Although these phenomena are relatively common, few studies have been conducted in NEB to evaluate how seasonal salinity impacts the taxonomic and functional composition of regional estuarine fish assemblages and, to our knowledge, no previous study has focused on functional changes caused by extreme weather events in the region (Dolbeth et al., 2016; Silva-Júnior et al., 2017; Silva & Fabré, 2019; Silva et al., 2021).

In the future, longer and more severe periods of hypersalinity may be expected in small and shallow estuaries of NEB (Soares et al., 2021). Projections made by the Intergovernmental Panel on Climate Change for arid zones point to increased temperatures, rainfall abnormalities and more frequent droughts (IPCC, 2014; Robins et al., 2016). This is compatible with the growing freshwater scarcity observed in NEB (Marengo et al., 2017; Marengo et al., 2018) and with the prolonged drought of 2012-2016 (the most severe since the 1960s) (Marengo et al., 2018), with serious impacts on the salinity of local estuaries (Valle-Levinson & Schettini, 2016; Barroso et al., 2018; Valentim et al., 2018), and estuarine biota is likely affected by changes in the global climate (Gillanders et al., 2011; Lauchlan & Nagelkerken, 2020).

Salinity is one of the factors which most influence community structure in estuaries (Gillanders et al., 2011; Neves et al., 2011; Menegotto et al., 2019; Whitfield, 2021). The physiological response of aquatic organisms to fluctuations in salinity (Elliott et al., 2007; Gillanders et al., 2011) is reflected in their use of the environment (Elliott et al., 2007; Potter et al., 2015). Estuaries have steep salinity gradients, producing a zoning pattern, with species distributed according to tolerance: the upstream waters of estuaries are often colonized by freshwater species, while marine species tend to remain in zones with high salinity; and estuarine species capable of tolerating greater environmental variations (Sosa-López et al., 2007; Lauchlan & Nagelkerken, 2020). Severe droughts have been shown to modify community structure through a process of seawater intrusion referred to as ‘marinization’ (Pasquaud et al., 2012; Lima et al., 2020). Little has been published about how reduced freshwater flow impacts estuarine fish assemblages influenced by intermittent rivers, especially in NEB. However, understanding the response of biological communities to different environmental gradients in local estuaries exposed to extreme weather events helps predict adverse effects of changes in the global climate (Soares et al., 2021).

Knowledge of the interplay between extreme weather conditions and the dynamics of biological communities in estuaries is crucial to environmental management. Thus, many authors have reported that elevated salinity in estuaries (>50) leads to loss of diversity or abundance and to the predominance of a few highly tolerant species, while mesohaline salinity is associated with more diversified assemblages (Montagna et al., 2002; Whitfield et al., 2006; Montagna et al., 2008; Tweedley et al., 2019; Silva et al., 2021). Because estuaries with a positive salinity gradient display greater interaction between continental and marine waters, allowing for the occurrence of species adapted to each level of salinity between the extremes of freshwater and seawater (Sosa-López et al., 2007; Lauchlan & Nagelkerken, 2020), such systems are expected to display a high level of functional specialization. The latter promotes significant changes in functional structure because specialized species tend to occupy the boundaries of functional space (combination of extreme traits) and to be farther apart in the functional space (high levels of originality). On the other hand, when the salinity is elevated throughout the entire estuary, the environmental gradient is flatter and one would expect greater functional redundancy due to a reduction in the number of freshwater and estuarine species (Sosa-López et al., 2007; Lauchlan & Nagelkerken, 2020), leading to smaller changes in functional structure associated with lower levels of originality and specialization (higher redundancy). Since the most specialized taxa are likely the first to be excluded under conditions of homogeneous salinity, extreme weather events are a possible cause of loss of functional diversity.

Four major premises were considered in the formulation of our hypotheses: (1) salinity is the key determinant of estuarine fish assemblages, (2) estuaries in NEB display marked seasonality in their horizontal salinity profiles, (3) estuaries in NEB are frequently impacted by severe droughts associated with global climate events (El Niño Southern Oscillation, the Atlantic dipole), and (4) specialized taxa are more vulnerable than generalist taxa to variations in salinity. Thus, the following hypotheses were formulated: (i) salinity influences the taxonomic and functional structure of estuarine fish assemblages in semiarid coastal regions of Brazil; (ii) estuaries impacted by severe drought display smaller functional richness and functional diversity; and (iii) the removal of the most original and specialized species causes greater functional erosion in estuaries exposed to ample precipitation (steeper salinity gradients) than in estuaries impacted by severe drought. To test these hypotheses, we conducted a standardized sampling of the fish fauna in six estuaries in the northernmost part of NEB, three of which during the most severe local drought recorded in six decades, and three with rainfall indices above the historical mean. This made it possible to observe the influence of particularly adverse drought conditions on taxonomic and functional structure, shedding light on the interplay between weather events and fish assemblages in estuaries on Brazilian semiarid coast.

Material and methods

Study area

According to the Köppen classification (Alvares et al., 2014), the climate in the area covered by the study is "As" (tropical zone with dry summers) with moderate to low hydric deficit (annual mean rainfall: 1000-1300 mm) directly influenced by the continental semiarid climate ("BSh"), with a pluviometric amplitude of <50 mm (dry season, June-January) to 900 mm (rainy season, February-May) (Alvares et al., 2014). The displacement of the Intertropical Convergence Zone (ITCZ) over the Atlantic creates a pattern of greater rainfalls in the coastal regions (Zanella, 2005; Marengo et al., 2018). The ITCZ is responsible for the onset of the rainy season in February as it moves across the southern hemisphere. Likewise, rainfalls decline in May as the ITCZ moves back into the northern hemisphere (Zanella, 2005). In the hinterlands, rainfalls are unevenly distributed throughout the year as a result of global climate events like El Niño Southern Oscillation (ENSO) and the Atlantic dipole (Nóbrega et al., 2016). Droughts interspersed by shorter periods of ample precipitation are a characteristic of the semiarid regions of NEB. Of special interest to our sampling strategy, the period from 2012 to 2016 saw the most severe drought in over half a century; this was followed by precipitation at the historical average (2017/2018) and above the historical average (2019/2020) (Fig. S2.1 and Fig. S2.2 of Online Appendix 2).

In this study we investigated the fish communities of six estuaries along the semi-arid coast of Brazil: Choró, Curu, Pacoti, Malcozinhado, Aracatirimim and Aracatiaçu rivers. This included the collection of environmental data for each estuary. Google Earth images were used to estimate the length of the continental shelf, the area of the drainage basins, and the area occupied by shrimp farms. The delimitation of the channels was performed visually based on textures and colors. The mangrove area was estimated from the classification of Landsat 8 satellite images, with a resolution of 30 meters. Georeferenced points representing areas with mangrove vegetation in each estuary were used as input to train decision tree models. The classified image was later vectorized and the area representing the mangrove was measured. The sampled estuaries displayed relatively similar geomorphologic characteristics (Table 1), having shallow and well-mixed systems without vertical salinity stratification (Schettini al., 2017; Soares et al., 2021). For example, the average depth in the estuaries of Malcozinhado and Pacoti was 1.3 and 1.5 m, respectively (Pinheiro et al., 2006). Even regional estuaries larger than the systems sampled for this study (e.g., the Jaguaribe river) have been shown to be well-mixed (Dias et al., 2009).

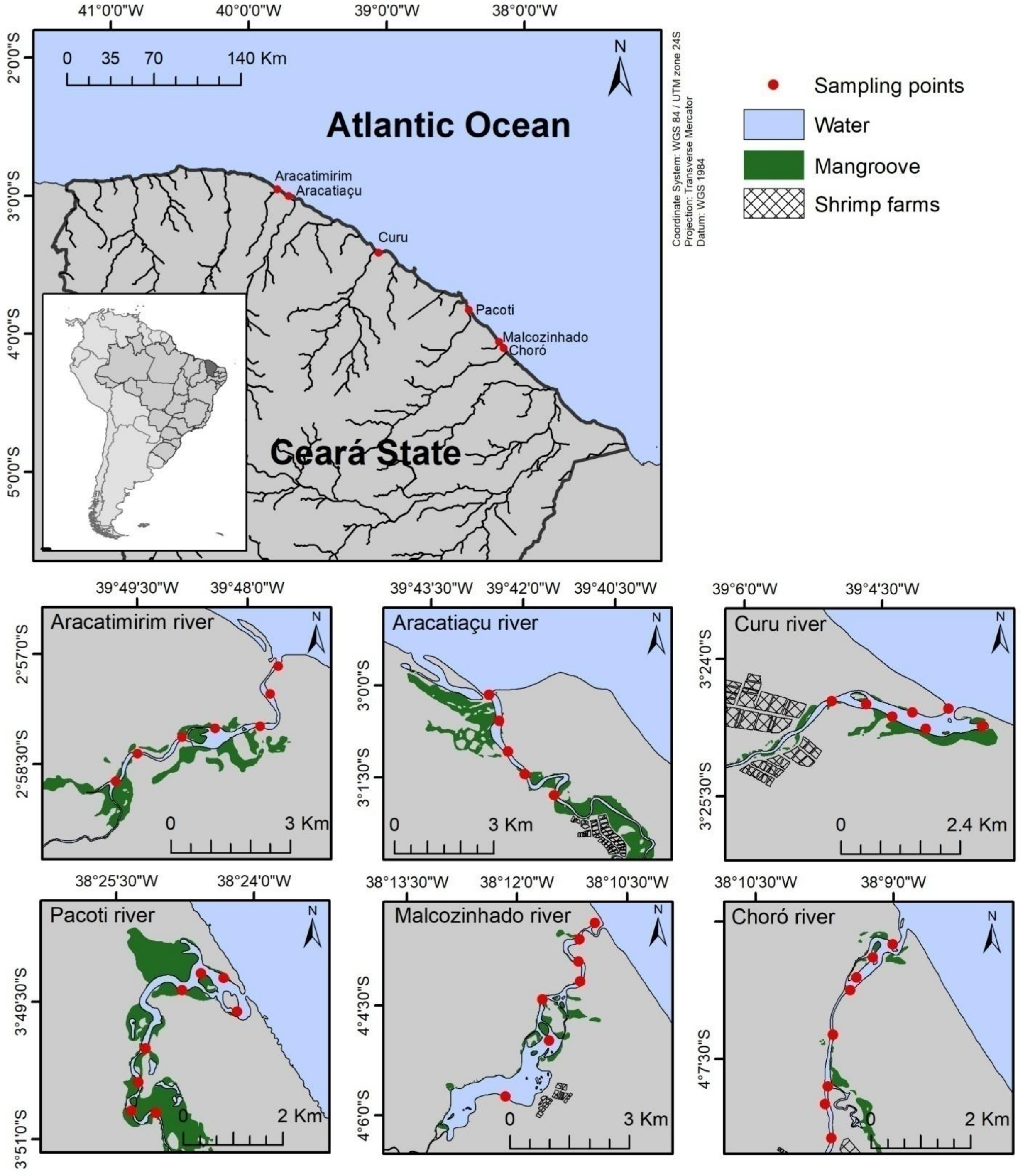

Fig. 1 Sites of standardized fish sampling in the estuaries of Aracatimirim, Aracatiaçu, Curu, Pacoti, Malcozinhado and Choró, on Brazilian semiarid coast

Table 1 - Environmental characteristics of the six estuaries of the present study.

	Prolonged drought (group 1)			**Ample precipitation (group 2)**			**group 1**	**group 2**
	Choró	**Curu**	**Pacoti**	**Malcozinhado**	**Aracatimirim**	**Aracatiaçu**	Mean ± sd	Mean ± sd
Continental shelf length (km)	553.9	416.2	548.3	551.9	475.7	452.3	516.1 ± 77.9	493.3 ± 52.1
Drainage basin area (km^2)	4757.3	8571.5	1281.7	396.1	1568.4	3454.2	4870.2 ± 3646.2	1806.3 ± 1542.9
Estuary length (km)	~13.8	~14.1	~17.0	~12.2	~15.6	~26.4	14.9 ± 1.8	18.0 ± 7.4
Estuary mouth width (m)	~68	~52	~59	~123	~151	~82	59.6 ± 7.7	118.6 ± 34.8
Average (and sd) river width (m)*	116.9 ± 58.36	184.6 ± 113.15	130.4 ± 72.05	171.1 ± 180.38	242.7 ± 183.21	120.4 ± 41.78	143.9 ± 20.7 (**)	178.1 ± 35.4 (**)
Mangrove area (km^2)	0.72	0.93	4.68	0.86	2.60	7.55	2.11 ± 2.2	3.67 ± 3.5
Shrimp farms area (km^2)	3.51	4.36	0.07	0.17	0.16	1.87	2.65 ± 2.3	0.73 ± 1.0

* Values measured at fish sampling points considering high tide. ** standard-error (se)

Sampling

Each estuary was sampled 5-7 times at different sites in the ecosystem and at bimonthly intervals, covering approximately one annual cycle (Fig. 1). Three of the estuaries were sampled in 2014/2015 during a prolonged drought (Choró 08/2014–08/2015; Curu 11/2014–08/2015; Pacoti 12/2014–09/2015), while the three other estuaries were sampled in 2019/2020, with rainfalls above the historical average (Aracatiaçu 03/2019–12/2019; Aracatimirim 03/2019–12/2019; Malcozinhado 01/2019–02/2020). The fish sampling was standardized using beach seines measuring 25 m in length and 2 m in height, with a mesh size of 12 mm (three hauls per site), and casting nets measuring 3 m in height, with a mesh size of 25 mm (20-30 min per site, counting the number of throws). The hauls were carried out at depths between 0.3 m and 1.5 m, while the throws were made in areas with greater depth amplitude (between 1.0 m and 3.5 m). Each haul covered approximately 200 m² of estuary bottom, according to the equation: A= D x L, where A is the area, D is the distance from the shore (10 m) and L is the length of effectively used net (20 m). Each throw of the casting net covered a circular area of 10 m² ($\pi . r^2$). The number of individuals and the biomass (g) of each species were divided by the area (m^2) sampled. Due to the selectivity of the gear with regard to species and individual size, the data collected with the two types of gear were standardized and pooled into overall units of density (individuals/100 m²) and biomass (g/100 m²). Surface salinity was measured with a refractometer. The samplings were conducted during ebb tide (2.0–0.0) and flood tide (0.0–2.0), in daylight (between 7 am and 5 pm), under a license from ICMBio/SISBio (#43014; #64269). The collected fish were stored in plastic bags in an ice box during field work, then fixated in 10% formaldehyde. After another 48 hours, the specimens were preserved in 70% alcohol, and each was identified taxonomically in accordance with the literature. The specimens were archived in batches in official ichthyological collections (see vouchers in Online Appendix 1).

Functional data

Using the classification of Potter et al. (2015), the species were identified according to their use of the ecosystem: marine stragglers (MS), marine migrants (MM, marine estuarine-opportunists and marine estuarine-dependents), estuarine species (ES, estuarine migrants and estuarine residents), diadromous fishes (DI), and freshwater fishes (FW, freshwater estuarine-opportunists and freshwater stragglers). Binary data were used to indicate the occurrence of a species in freshwater, brackish water and/or seawater, as done by Froese and Pauly (2021). The species were also classified into trophic guilds: detritivores (Detri), planktivores (Plank), herbivores (Herb), invertivores (Invert), macrocarnivores (Macro) and omnivores (Omniv) based on the literature on estuarine ecology and taking into account the size of the collected specimens. Moreover, the species were classified according to their position in the water column: benthic (Bent), nektonic (Nekt) or nektobenthic (NektBent); according to their activity: active (MO) or sedentary (SE); and according to their form of fertilization: external fertilization (EF), external fertilization with parental care (EFPC), internal fertilization (IF), and internal fertilization with internal development (IFID), as done by Froese and Pauly (2021). Specimens of *Mugil* sp. (standard length <40 mm) were treated as a separate species due to their small size, which makes it impossible to identify individuals at the species level. The qualitative traits are listed in Table S3.2 of Online Appendix 3.

In addition to qualitative traits, we used quantitative ecomorphological traits (proxies for food acquisition, locomotion and habitat use) to describe the functional structure of the fish assemblages (Villéger et al., 2017). Body mass and morphometric measures obtained from 1-5 individuals of each species (Fig. S3 of Online Appendix 3) were combined into 15 ecomorphological traits (Table S3.1 of Online Appendix 3) for which averages were calculated (Table S3.3 of Online Appendix 3). Such measurements are commonly used in the assessment of functional diversity, especially in regions rich in species for which the basic ecology is relatively unknown (Toussaint et al., 2016; Villéger et al., 2017).

Functional structure

The functional structure of the fish assemblage of each estuary and each climate event (prolonged drought=2014/2015 vs. ample precipitation=2019/2020, three estuaries each) were characterized in terms of functional richness (FRic) and functional dispersion (FDis). FRic (which does not take species abundance into account) expresses the amount of functional space occupied by the community, calculated as the volume of the minimum convex hull including all the species in a given community, that is, the functional volume of the synthetic niche space encompassed by the outermost vertices of the assemblage (the most functionally differentiated species) (Cornwell et al., 2006). Species with less extreme functional traits occupy the interior of the polygon, while species with more extreme traits are plotted on the vertices (Villéger et al., 2008). FDis, a measure of functional diversity, is expressed by the mean distance from the individual species to the centroid of all species within the multidimensional trait space. The more species are distant from the centroid, the greater the functional dispersion (Laliberté & Legendre, 2010). Thus, while FRic is directly dependent on local species richness, FDis bears no relation to it.

We also calculated indices of functional originality (FOri) and functional specialization (FSpe) for each species. FOri is the mean distance of a species from its closest neighbor in the functional space, and FSpe is the mean distance of a species from the centroid of the assemblage (Mouillot et al., 2013). It should be kept in mind that FOri and FSpe were calculated taking into account the entire species pool of the six estuaries.

Data analyses

The species abundance data matrix was standardized by the total number of individuals from each campaign. The species composition of the estuaries groups was compared with distance-based permutational multivariate analysis of variance (PERMANOVA, $\alpha < 0.05$) using a Bray-Curtis distance matrix because it is the most recommended distance metric for species abundances (Anderson et al., 2001). Similarity percentages analysis (SIMPER; $\alpha < 0.05$) revealed which species contributed most to the difference observed between the two groups. A non-metric multidimensional scaling (NMDS) analysis was done to visualize the results. The mean values of the 15 continuous fish traits were standardized and scaled to a mean of 0 and standard deviation 1 and, along with the categorical traits, submitted to principal coordinates analysis (PCoA) using Gower's distance. The number of dimensions retained for interpretation of the axes was based on a comparison of the distances between the species and the distances between the species in the functional space (Marie et al., 2015). Finally, we selected five PCoA axes with high-quality functional information.

Using these five axes of functional space, we evaluated the contribution of freshwater fishes (FW) and marine stragglers (MS) to the functional space. These guilds would be the most influenced by climatic events as they represent the extremes of the estuarine gradient. The contribution of these two groups was quantified based on the volume occupied inside the functional space (FRic; Cornwell et al., 2006). A large volume suggests that a group of species is important in the functional space. However, observed patterns must be contrasted with patterns expected by chance to determine to what extent they reflect differences in species richness. To do so, we made a null model that randomly selected the same number of species observed in the two groups (FW and MS). The process was repeated 999 times and at each permutation the volume occupied in the functional space was recalculated. Actual values were expected to differ by 95% from random scenarios.

To determine how the functional structure of the estuaries was influenced by functional trait diversification (FOri and FSpe) we ran a set of simulations of loss of species (all species of each estuary). For each estuary, we evaluated how the removal of the most original (FOri) and specialized (FSpe) species impacted FRic and FDis values. A decreasing ranking of species was made from the values of FOri and FSpe for the species removal sequence. Thus, species were sequentially removed and the resulting decrease in FRic and FDis values was recorded. To verify whether the observed changes in functional structure were different from random scenarios, we calculated 999 null models from which species were removed at random. We then plotted the actual values against the expected values, adopting a 95% confidence interval. Regions with values within the 95% interval were considered non-significant; regions with values outside the 95% interval were deemed significant.

Results

The estuaries of Choró, Curu and Pacoti displayed marked variations in salinity throughout the year, with a positive salinity gradient in part of the rainy season as a result of the increased river flow, and an inverted salinity gradient during part of the dry season. Most of the time, the salinity in these estuaries was similar to or higher than in the adjacent coastal seawater, with an increase towards the continent. The only exceptions were March and May, when the salinity increased towards the mouth of the river. The seasonality of the salinity profile in the estuaries of Malcozinhado, Aracatiaçu and Aracatimirim was less marked. The gradient was positive in the rainy season, with higher salinities in the dry season, usually at moderate levels and/or homogeneous throughout the estuary. Among these three estuaries, only Malcozinhado displayed an inverted salinity gradient (at the end of the dry season) (Table 2 and Fig. S4.1 of Online Appendix 4). In the estuaries of Malcozinhado, Aracatiaçu and Aracatimirim, most sampling points displayed salinity between 0 and 30, while salinity was predominantly between 31 and 40 at sampling points in Choró, Curu and Pacoti, suggesting a positive association between prolonged drought and marinization (Table 2).

Table 2 - Different periods of the year sampled in each campaign and description of the salinity profiles of the estuaries, showing the values from the mouth to the most upstream point sampled, and average values per point and per campaign, and distance in kilometers from the sampling point to the sea. Further down, the number of points sampled with salinity ranges 0-30, 31-40 and >40, and their respective percentages.

		Downstream						Upstream		
Estuary	**Season**	**Pt1**	**Pt2**	**Pt3**	**Pt4**	**Pt5**	**Pt6**	**Pt7**	**Pt8**	**Mean±sd**
Choró	Distance (km)	0.68	1.04	1.45	1.98	3.92	4.20	4.61	5.13	
November/2014	Dry	37	34	38	40	42	42	40	41	39.2±2.7
January/2015	Transition	39	40	--	39	40	43	39	40	40.0±1.4
March/2015	Rainny	35	--	26	8	6	11	0	0	12.3±13.3
June/2015	Transition	37	36	37	36	35	35	31	38	35.6±2.1
August/2015	Dry	35	35	36	37	40	45	43	43	39.2±4.0
Mean±sd		36.6±1.6	36.3±2.6	34.3±5.5	32.0±13.5	32.6±15.1	33.5±15.6	31.0±17.9	32.2±18.1	
Curu	Distance (km)	0.61	1.05	1.59	1.66	2.75	3.39	4.10		
November/2014	Dry	38	--	38	--	40	40	36		38.4±1.6
January/2015	Transition	36		39	37	38	38	36		37.1±1.4
March/2015	Rainny	35	37	38	31	31	33	33		34.0±2.7
May/2015	Rainny	35	35	32	37	35	20	15		29.9±8.7
August/2015	Dry	35	37	36	37	36	--	33		35.7±1.5
Mean±sd		35.8±1.3	36.3±1.1	36.6±2.8	35.4±2.6	36.0±3.4	32.8±9.0	30.6±8.8		
Pacoti	Distance (km)	0.26	0.78	1.20	1.73	3.60	4.75	5.23	6.03	
December/2014	Dry	--	40	41	--	44	45	--	50	44.0±3.9
February/2015	Rainny	--	--	--	--	--	40	43	47	43.3±3.5
March/2015	Rainny	36	--	33	26	25	--	--	--	30.0±5.3
May/2015	Rainny	30	25	17	15	13	2	0	0	11.3±11.5
June/2015	Transition	40	40	40	40	--	36	32	29	36.7±4.5
September/2015	Dry	35	35	35	35	--	36	35	33	34.8±0.9
Mean±sd		35.3±4.1	35±7.0	33.2±9.6	29.0±11.0	27.3±15.6	32.6±15.4	27.5±18.9	29.2±20.1	
Malcozinhado	Distance (km)	0.13	0.76	1.80	2.27	3.51	4.74	6.60		
January/2019	Transition	--	35	32	35	34	35	--		33.5 ±1.9
March/2019	Rainny	21	17	0	0	0	0	0		4.8 ±8.8
May/2019	Rainny	25	24	15	11	3	0	0		10.5±10.3
July/2019	Dry	29	29	28	26	22	21	16		23.9 ±5.6
October/2019	Dry	30	32	34	34	31	31	29		31.6 ±1.9
December/2019	Dry	39	40	40	40	39	41	43		40.3 ±1.4
February/2020	Rainny	24	16	16	16	16	16	12		16.6 ±3.6
Mean±sd		28±6.3	27.6±9.0	23.6±13.9	23.1±14.6	18.0±15.45	21.5±30.4	14.3±11.9		
Aracatiaçu	Distance (km)	0.41	1.33	2.20	3.08	5.49				
March/2019	Rainny	20	0	5	0	0				4.2 ±8.0
May/2019	Rainny	0	0	0	0	0				0.0 ±0.0
August/2019	Dry	23	21	21	21	16				20.4 ±2.6
October/2019	Dry	26	29	31	31	24				28.2 ±3.1
December/2019	Dry	30	30	29	26	26				28.2 ±2.0
Mean±sd		19.8±11.6	16±15.0	17.2±14.0	15.6±14.6	13.2±12.6				
Aracatimirim	Distance (km)	0.30	1.31	2.49	3.09	4.30	5.50	6.80		

March/2019	Rainny	0	0	0	0	0	0	0	0.0 ±0.0
May/2019	Rainny	9	1	0	0	0	0	0	1.4 ±3.3
August/2019	Dry	21	21	19	19	5	0	0	12.1 ±9.9
October/2019	Dry	29	28	29	29	27	25	23	27.1 ±2.3
December/2019	Dry	28	29	31	31	29	30	30	29.7 ±1.1
Mean±sd		17.4±11.2	15.8±12.8	15.8±13.5	15.8±13.5	12.2±13.0	11.0±13.5	13.3±13.5	

		Number of sample points in each salinity range				Percentage of sample points in each salinity range		
Climate	**Estuary**	**Salinity (0-30)**	**Salinity (31-40)**	**Salinity (> 40)**	**Grand total of samples**	**Salinity (0-30)**	**Salinity (31-40)**	**Salinity (> 40)**
Prolonged drought	Choró	6	25	7	38	15.8	65.8*	18.4
Prolonged drought	Curu	2	29	0	31	6.5	93.5*	0.0
Prolonged drought	Pacoti	11	17	6	34	32.4	50.0*	17.6
Ample precipitation	Malcozinhado	30	15	2	47	63.8*	31.9	4.3
Ample precipitation	Aracatiaçu	23	2	0	25	92.0*	8.0	0.0
Ample precipitation	Aracatimirim	33	2	0	35	94.3*	5.7	0.0

*At least 50% of all points.

A total of 26,264 specimens were sampled, covering 110 species, 48 families and 22 orders. Species richness was positively correlated with salinity (Fig. 2a); thus, estuaries with longer periods of marinization displayed higher average species richness, such as Choró (46.2 ± 4.3 species per campaign; total=78), Pacoti (44.5 ± 4.7; total=70) and Curu (38.4 ± 4.2; total=63). Average species richness was somewhat lower in the estuaries of Malcozinhado (36.6 ± 7.1; total=74), Aracatimirim (32.6 ± 2.8; total=61) and Aracatiaçu (26.8 ± 7.0; total=54) (ANOVA $F_{5,30}$= 8.60; p<0.001; Tukey's test: Aracatiaçu differs significantly from Choró, Curu and Pacoti; and Aracatimirim differs significantly from Choró and Pacoti; Fig. 3). FRic was not correlated with salinity (Fig. 2b), despite the positive relationship between species richness and FRic (Fig. S4.2 of Online Appendix). Nevertheless, FRic values were higher in estuaries sampled during prolonged drought than in estuaries with lower salinities and rainfalls above the historical average (Fig. 4).

Shannon-Weaver diversity was positively correlated with salinity, at least with regard to abundance expressed as density (Fig. 2c and Fig. 2e). Shannon-Weaver indices were higher in estuaries with longer periods of marinization, such as Choró (2.81 ± 0.17), Pacoti (2.71 ± 0.12) and Curu (2.31 ± 0.25). On average, Shannon-Weaver diversity was relatively lower in Malcozinhado (2.42 ± 0.41), Aracatimirim (2.28 ± 0.36) and Aracatiaçu (2.13 ± 0.38), but the statistical difference between the groups was small (ANOVA $F_{5,30}$= 3.32; p=0.02; Tukey's test: Aracatiaçu differs significantly only from Choró; Fig. 3). Functional diversity (FDis) was not correlated with salinity (Fig. 2d and Fig. 2f). No clear pattern was observed for FDis, whether density or biomass was considered (Fig. 4), despite the positive relationship between species richness and FDis expressed as density (Fig. S4.2 of Online Appendix).

The seven most abundant species in all six estuaries were *Atherinella brasiliensis* (Quoy & Gaimard, 1825), *Citharichthys spilopterus* Günther, 1862, *Diapterus auratus* Ranzini, 1842, *Eucinostomus argenteus* Baird & Girard, 1855, *Lile piquitinga* (Schreiner & Miranda Ribeiro, 1903), *Mugil curema* Valenciennes, 1836, and *Sphoeroides testudineus* (Linnaeus, 1758) (Table S4.1, Table S4.2 of Online Appendix 4). The twenty most abundant species accounted for approximately 90% of the total abundance in the estuaries, with regard to density and biomass. Overall, abundances were higher in estuaries influenced by prolonged drought where the density of the twenty most abundant species ranged from 1,232.20 ind/100 m² (*E. argenteus*) to 41.08 ind/100 m² (*Mugil curvidens* Valenciennes, 1836), as opposed to densities from 646.35 ind/100 m² (*A. brasiliensis*) to 20.54 ind/100 m² (*Citharichthys arenaceus* Evermann & Marsh, 1900) in estuaries exposed to ample precipitation (Fig. S4.3 of Online Appendix 4). A similar pattern was observed for biomass: in the estuaries influenced by prolonged drought, the biomass of the twenty most abundant species ranged from 17,183.84 g/100 m² (*M. curema*) to 451.62 g/100 m² (*Hypanus guttatus* (Bloch & Schneider, 1801)), compared to biomasses from 2,624.11 g/100 m² (*A. brasiliensis*) to 208.19 g/100 m² (*Mugil rubrioculus* Harrison, Nirchio, Oliveira, Ron & Gaviria, 2007) in estuaries exposed to ample precipitation (Fig. S4.3 of Online Appendix 4).

The estuaries differed in species composition according to climate events (prolonged drought vs. ample precipitation) in density (pseudo-$F_{1,30}$ = 5.33; p<0.001) and in biomass (pseudo-$F_{1,30}$ = 7.82; p<0.001) (Fig. 5). As for the ranking of the most abundant species, the two groups of estuaries differed with regard to the density of *Cathorops spixii* (Agassiz, 1829), *Rhinosardinia amazonica* (Steindachner, 1879), *Centropomus undecimalis* (Bloch, 1792), *Achirus achirus* (Linnaeus, 1758) (higher ranking in estuaries with ample precipitation), and *M. curema*, *Diapterus rhombeus* (Cuvier, 1829), *Opisthonema oglinum* (Lesueur, 1818), and *Eugerres brasilianus* (Cuvier, 1830) (higher ranking in estuaries with prolonged drought). The biomass of *C. undecimalis*, *C. spixii*, *R. amazonica*, *A. achirus*, *Lutjanus griseus* (Linnaeus, 1758), and *Strongylura timucu* (Walbaum, 1792) ranked higher in estuaries with ample precipitation, and the biomass of *M. curema*, *D. auratus*, *D. rhombeus*, *E. brasilianus* and *Sciades herzbergii* (Bloch, 1794) ranked higher in estuaries with prolonged drought (Fig. S4.3 of Online Appendix 4). The SIMPER analysis showed significant differences in abundance for 35 species when comparing the groups, with prolonged drought benefiting mainly marine stragglers and marine migrant species, while ample precipitation benefited only three species, one of which diadromous (*C. undecimalis*) (Table 3 and Fig. S4.3 of Online Appendix 4). In other words, during severe drought periods, the abundance of diadromous fishes decreased and the abundance of marine migrants and marine stragglers increased (Table 3).

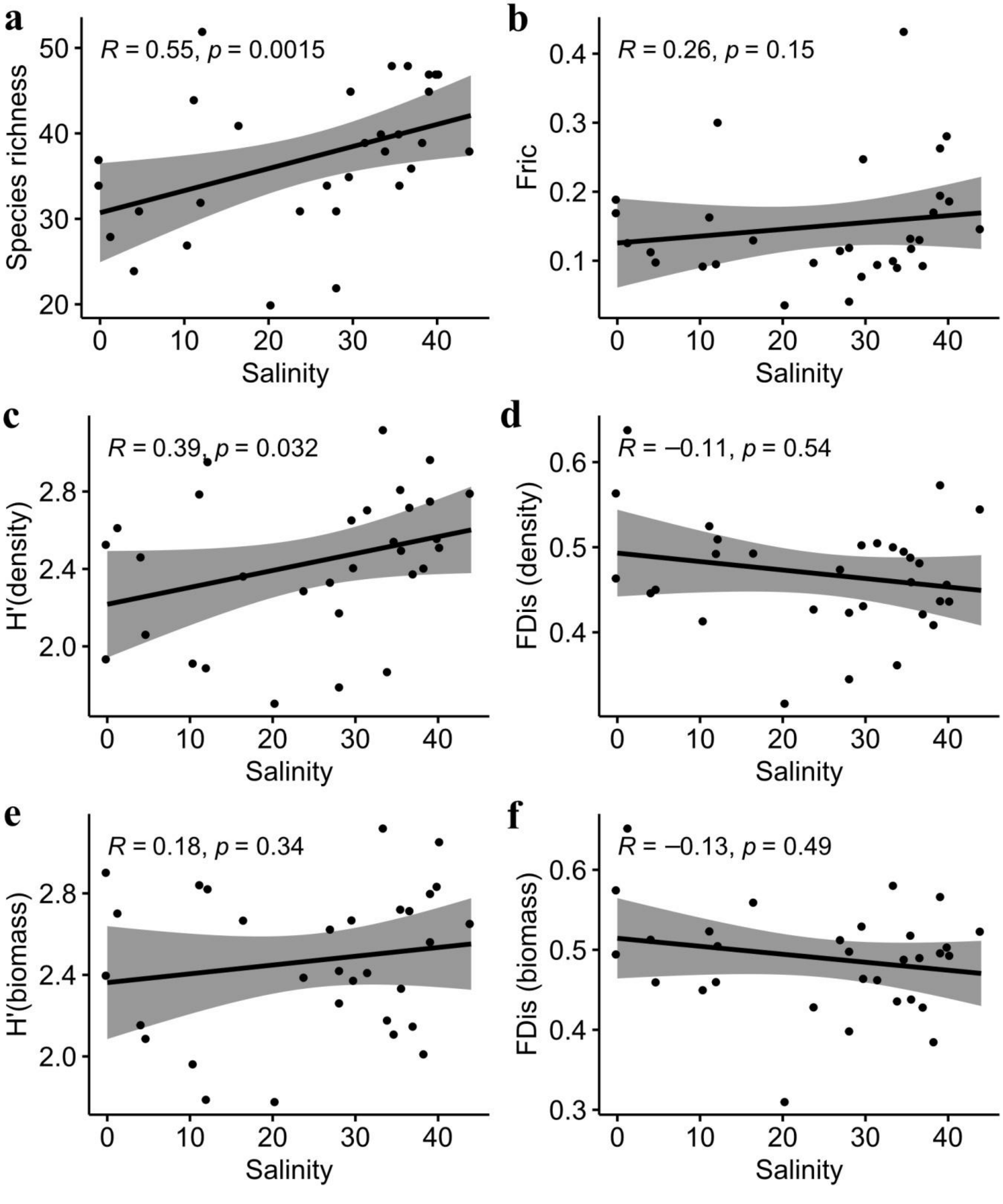

Fig. 2 Spearman's correlations between salinity and species richness (a), FRic (b), Shannon-Weaver diversity and FDis in density (c, d) and biomass (e, f), respectively, for the set of six estuaries

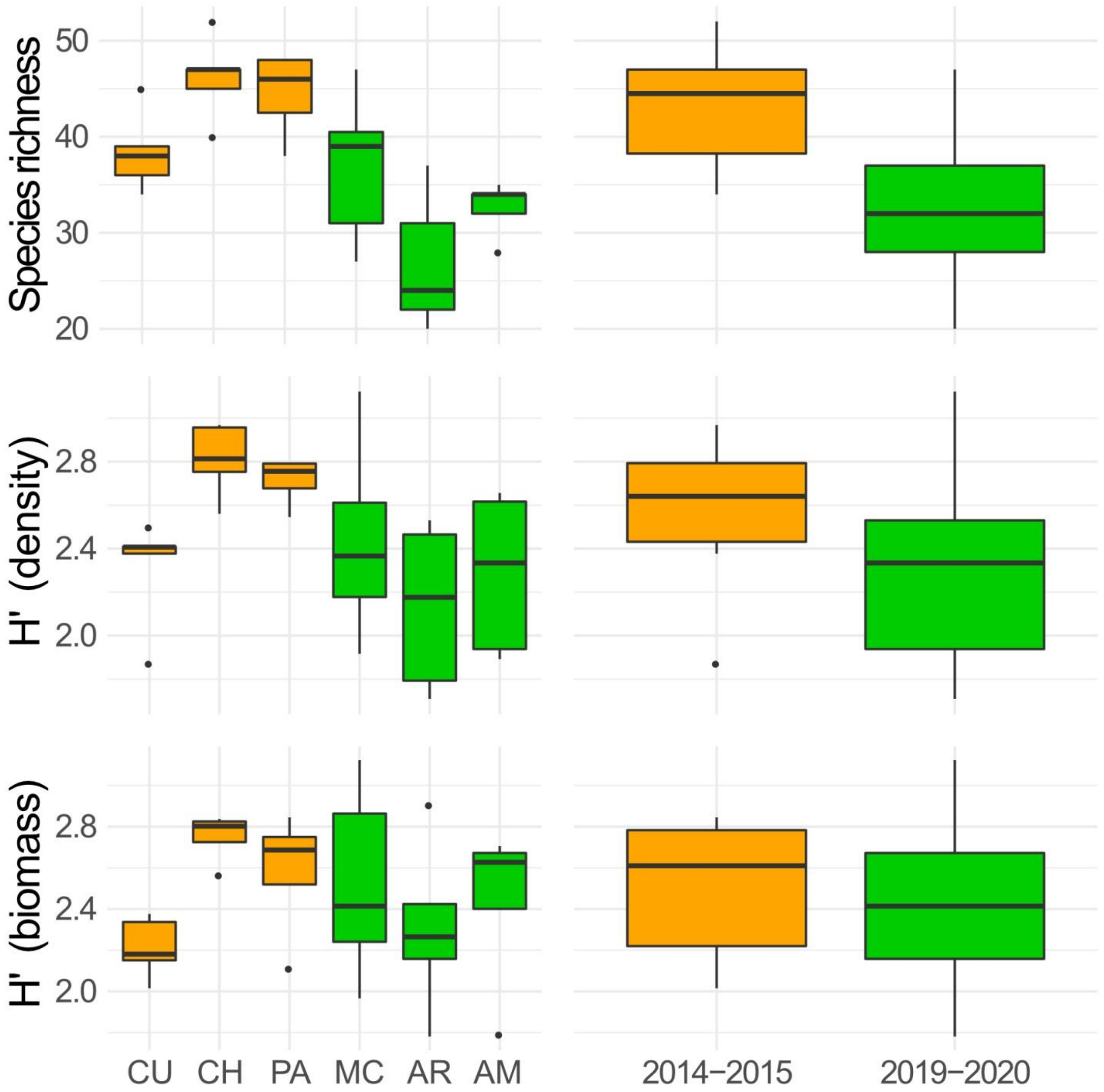

Fig. 3 Species richness and species diversity (Shannon-Weaver, H’) in density and biomass, respectively, in each estuary (CU = Curu, CH = Choró, PA = Pacoti, MC = Malcozinhado, AR = Aracatiaçu, AM = Aracatimirim) and climate event (2014/2015 = prolonged drought; 2019/2020 = ample precipitation)

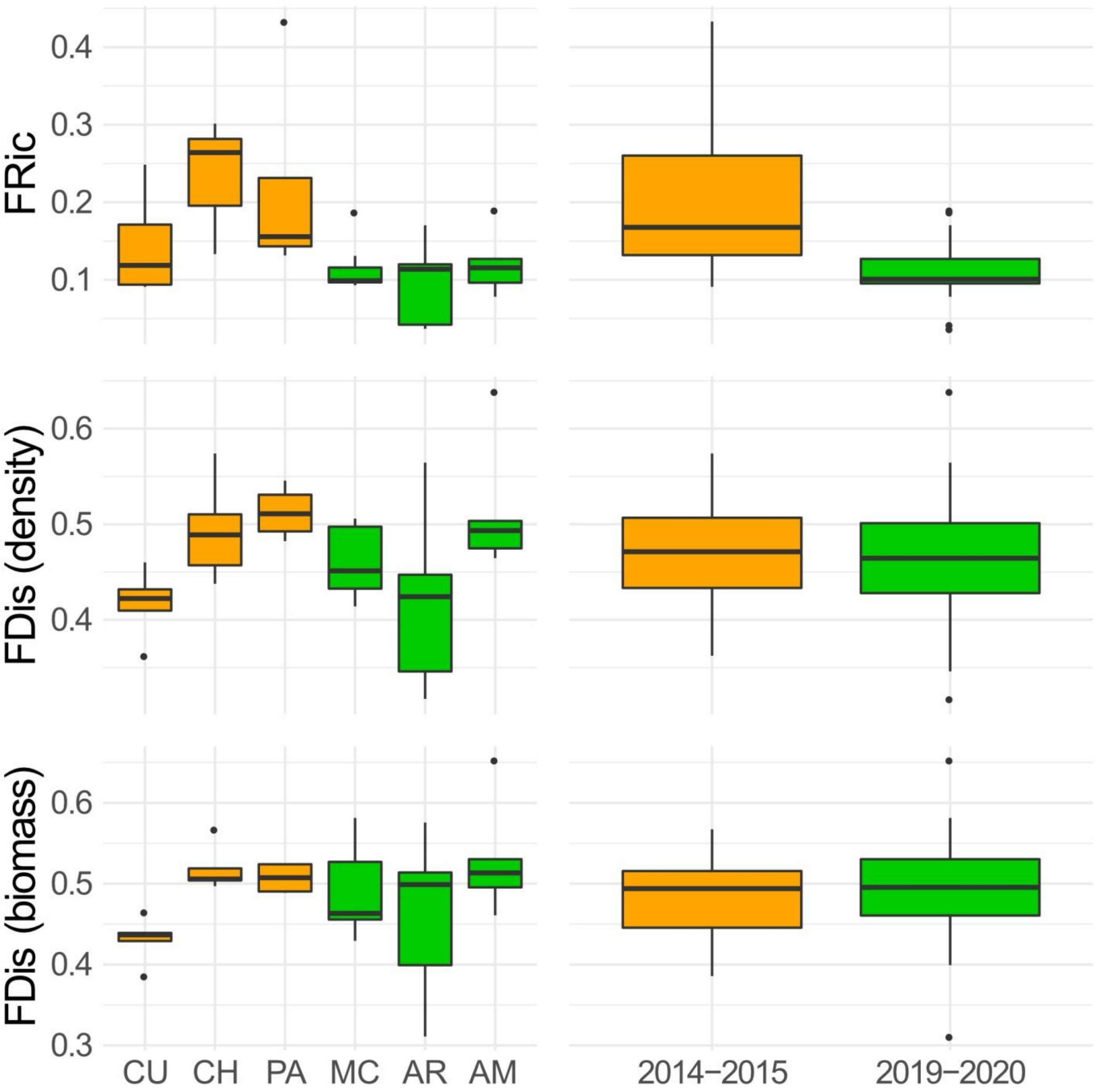

Fig. 4 Functional richness (FRic) and functional dispersion (FDis) in density and biomass, respectively, in each estuary (CU = Curu, CH = Choró, PA = Pacoti, MC = Malcozinhado, AR = Aracatiaçu, AM = Aracatimirim) and climate event (2014/2015 = prolonged drought; 2019/2020 = ample precipitation)

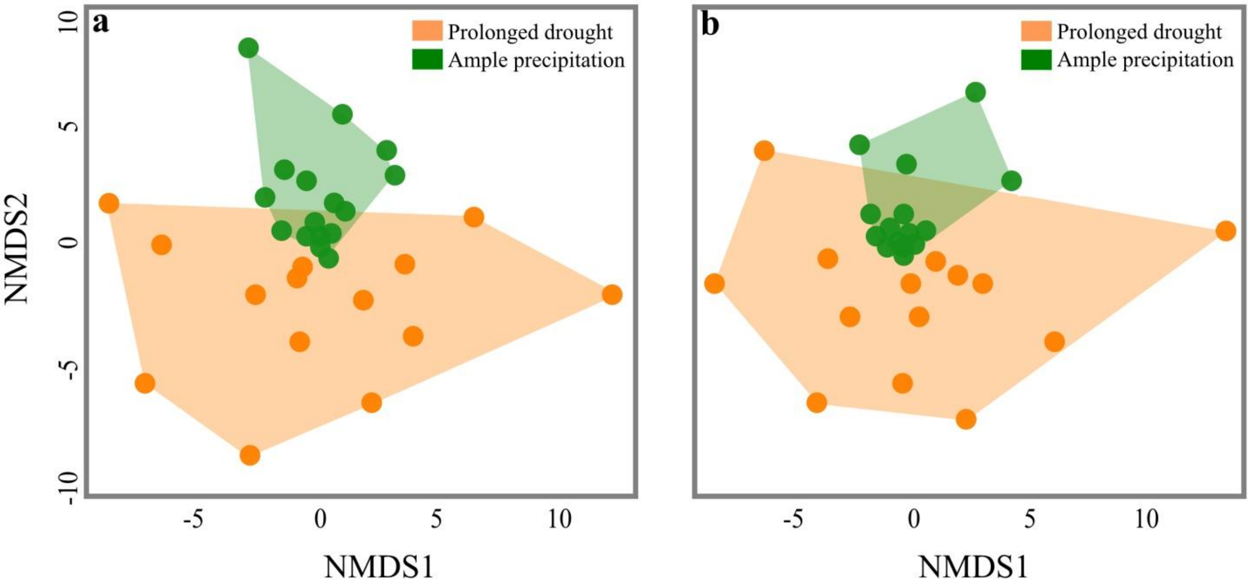

Fig. 5 NMDS analysis of the taxonomic composition in estuaries influenced by prolonged drought (Choró, Curu, Pacoti) vs. estuaries exposed to ample precipitation (Malcozinhado, Aracatiaçu, Aracatimirim) for (a) density and (b) biomass

Table 3 - Similarity percentage analysis (SIMPER) showing species significantly ($p<0.05$) more abundant under each climate event, expressed as density and biomass. EU: estuary use guild (MS: marine straggler; MM: marine migrant; ES: estuarine; DI: diadromous; FW: freshwater). Species p-values in the table S4.1 and table S4.2 of Online Appendix 4.

Abundance (Density)				**Abundance (Biomass)**			
Prolonged drought	**EU**	**Ample precipitation**	**EU**	**Prolonged drought**	**EU**	**Ample precipitation**	**EU**
Anableps anableps	MS	*Ctenogobius boleosoma*	MM	*Anableps anableps*	MS	*Ctenogobius boleosoma*	MM
Archosargus probatocephalus	MS	*Lutjanus griseus*	MM	*Archosargus probatocephalus*	MS	*Lutjanus griseus*	MM
Archosargus rhomboidalis	MS	*Centropomus undecimalis*	DI	*Archosargus rhomboidalis*	MS	*Centropomus undecimalis*	DI
Bothus ocellatus	MS			*Bothus ocellatus*	MS		
Bryx dunckeri	MS			*Bryx dunckeri*	MS		
Dactylopterus volitans	MS			*Dactylopterus volitans*	MS		
Myrichthys ocellatus	MS			*Myrichthys ocellatus*	MS		
Orthopristis scapularis	MS			*Orthopristis scapularis*	MS		
Polydactylus virginicus	MS			*Polydactylus virginicus*	MS		
Prionotus punctatus	MS			*Prionotus punctatus*	MS		
Scomberomorus brasiliensis	MS			*Scomberomorus brasiliensis*	MS		
Sphoeroides spengleri	MS			*Sphoeroides spengleri*	MS		
Anchoa spinifer	MM			*Anchoa spinifer*	MM		
Chaetodipterus faber	MM			*Chaetodipterus faber*	MM		
Citharichthys spilopterus	MM						
Cynoscion acoupa	MM			*Cynoscion acoupa*	MM		
Diapterus rhombeus	MM			*Diapterus rhombeus*	MM		
Eucinostomus argenteus	MM			*Eucinostomus gula*	MM		
Eugerres brasilianus	MM			*Eugerres brasilianus*	MM		
Lutjanus analis	MM						
Lycengraulis grossidens	MM						
Micropogonias furnieri	MM			*Micropogonias furnieri*	MM		
Mugil curema	MM			*Mugil curema*	MM		
Oligoplites saurus	MM						
Selene vomer	MM						
Sparisoma radians	MM						
Symphurus tessellatus	MM			*Symphurus tessellatus*	MM		
Sciades herzbergii	ES			*Sciades herzbergii*	ES		
Sciades parkeri	ES			*Sciades parkeri*	ES		
Sphoeroides greeleyi	ES			*Sphoeroides greeleyi*	ES		
Sphoeroides testudineus	ES			*Sphoeroides testudineus*	ES		
Moenkhausia costae	FW			*Moenkhausia costae*	FW		
Poecilia reticulata	FW			*Poecilia reticulata*	FW		
Serrasalmus rhombeus	FW			*Serrasalmus rhombeus*	FW		

The sampled species displayed diversified morphology, diet and habitat use. The negative PCO1 aggregated species with compressed or fusiform body and large eyes, most of which were highly active nektonic species using the peduncle and caudal fin for propulsion, with highly diversified diets and varying tolerance of salinity (including all freshwater species). The positive PCO1 included species with greater morphological variation, all of which marine, benthic and sedentary, with eyes high on the head, reduced caudal fins and mostly invertivore habits (Fig. S4.4 of Online Appendix 4). The negative PCO2 clustered nektobenthic species, most of which invertivores, with protrusive jaws and greater mass distribution along the body for hydrodynamism. Finally, the positive PCO2 included typically macrocarnivores with large, upturned mouths, making frequent use of the pectoral fins for maneuverability (Fig. S4.4 of Online Appendix 4).

The actual functional contribution of freshwater species was smaller than the contribution of the random combinations (*p*=0.001; Fig. 6a and b), despite appearing as a differentiated group in the functional space. In contrast, marine stragglers contributed about four times more to the functional space, though the contribution was non-significant in relation to the random combinations, suggesting functional redundancy (*p*=0.142; Fig. 6a and b). Estuaries with long periods of marinization displayed greater abundances of marine stragglers, while estuaries exposed to ample precipitation displayed greater abundances of freshwater fishes (Fig. 6c). FRic values decreased significantly when functionally more original and specialized species were removed, regardless of the estuary (Fig. 7). However, the loss of functional richness was less severe in estuaries influenced by prolonged drought than in estuaries with ample precipitation (Table 4, Fig. 7 and Fig. S4.5 of Online Appendix 4). No clear pattern was observed for FDis. When specialized species were removed, FDis decreased significantly in only two of the estuaries, one from each group (Choró and Malcozinhado) (Fig. 7 and Fig. S4.6 of Online Appendix 4).

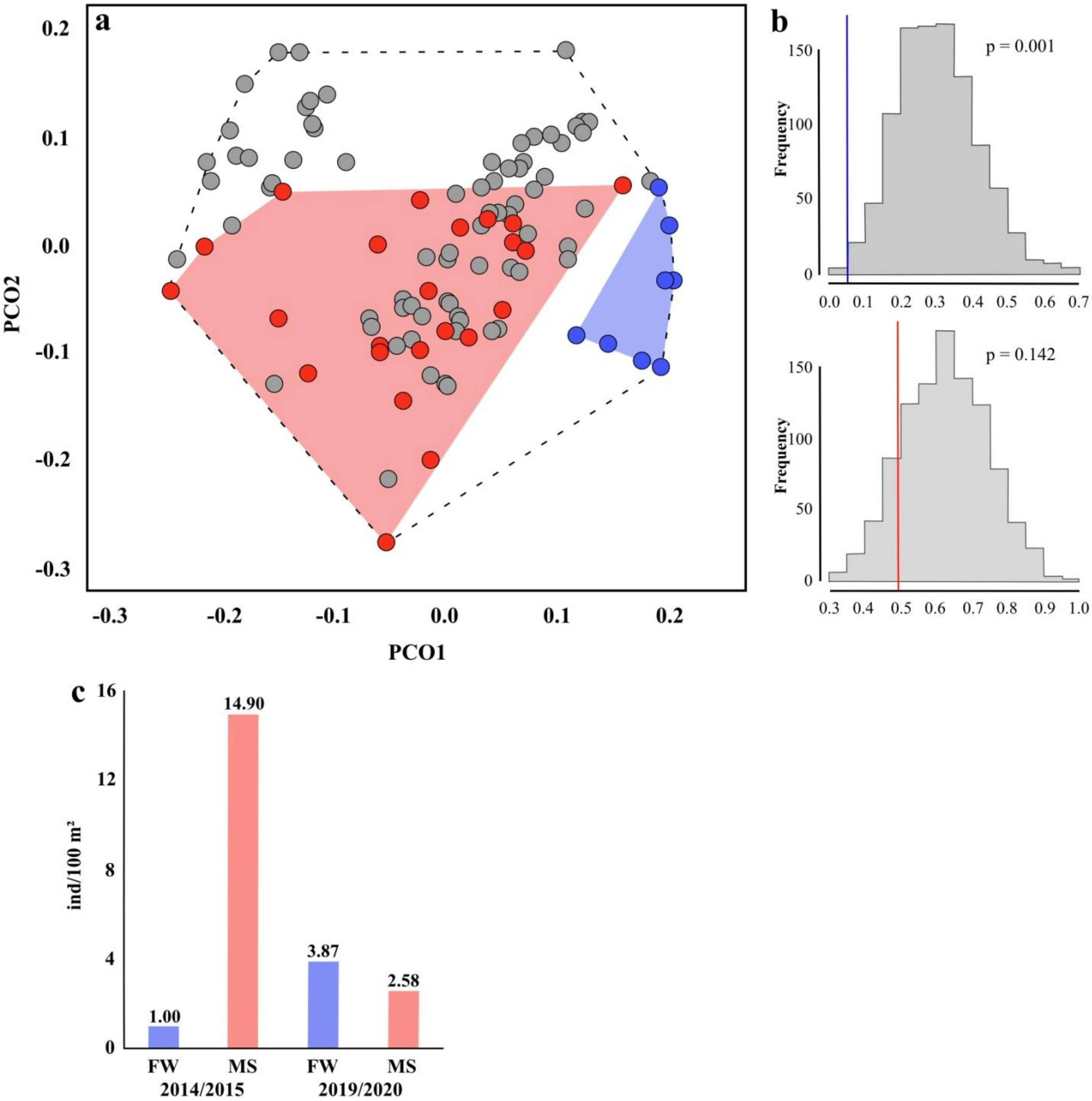

Fig. 6 (a) Functional space occupied by freshwater fishes (FW, blue) and marine stragglers (MS, red); (b) null model with 999 polygons with random species compared to the polygons for freshwater fishes and marine stragglers; and (c) average density (ind/100 m²) of freshwater fishes and marine stragglers in estuaries under the two climate events (Choró, Curu, Pacoti [2014-2015] vs. Malcozinhado, Aracatiaçu, Aracatimirim [2019-2020]).

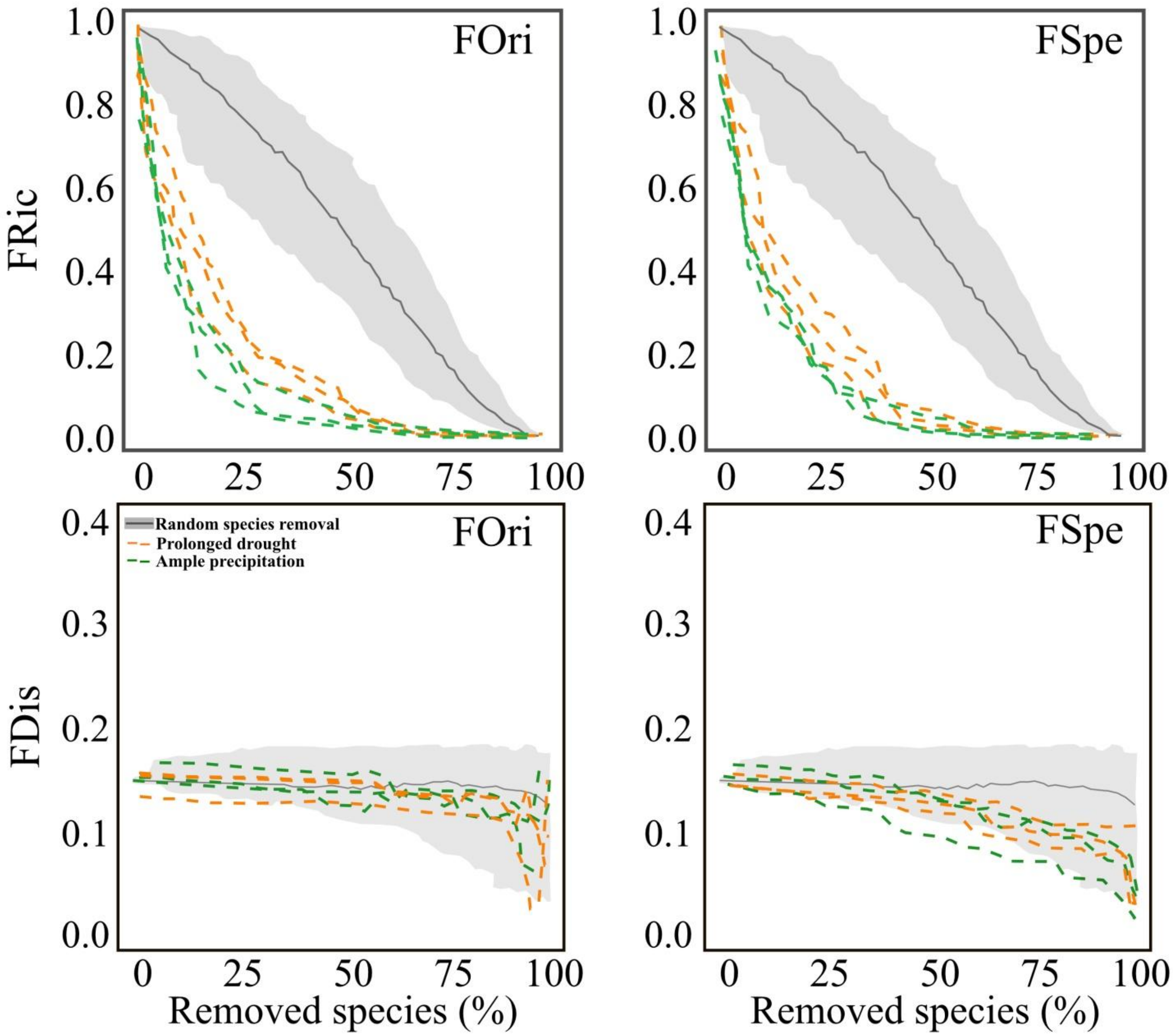

Fig. 7 Effect of the removal of original (FOri) and specialized (FSpe) species on functional richness (FRic) and functional dispersion (FDis, calculated by density) in each estuary.

Table 4 Functional richness (FRic) values upon removal of 10%, 25% and 50% of the most specialized (FSpe) and original (FOri) species of each estuary.

Time	**Estuary**	**Species loss (FSpe)**			**Species loss (FOri)**		
		10% loss	**25% loss**	**50% loss**	**10% loss**	**25% loss**	**50% loss**
Prolonged drought	Choró (**FRic loss**)	50.1%	25%	10%	51%	30%	8%
Prolonged drought	Curu	45%	18%	5%	42%	19%	3%
Prolonged drought	Pacoti	57%	24%	5%	45%	20%	3%
Ample precipitation	Malcozinhado	40.2%	18%	4%	40.4%	19%	3%
Ample precipitation	Aracatiaçu	32%	12%	2%	31%	13%	3%
Ample precipitation	Aracatimirim	38.5%	8%	3%	38%	14%	2%
Mean ±sd (%)	Prolonged drought	50.7 ± 6.02	22.3 ± 3.79	6.7 ± 2.89	46.0 ± 4.58	23.0 ± 6.08	4.7 ± 2.89
Mean ±sd (%)	Ample precipitation	36.9 ± 4.33	12.7 ± 5.03	3.0 ± 1.00	36.5 ± 4.88	15.3 ± 3.21	2.7 ± 0.58

Discussion

As expected, the fish assemblages of the sampled estuaries were taxonomically and functionally impacted by climate events. The short and shallow estuaries of NEB display little variation in water temperature and vertical salinity profile, basically behaving like mixed systems of which the tides are the main hydrodynamic force (Dias et al., 2009; Schettini et al., 2017; Barroso et al., 2018). Compared to estuaries in other regions, the small size of these systems make them particularly susceptible to adverse climate events (Prandle & Lane, 2015; Scanes et al., 2020). The reduction in rainfalls and the retainment of freshwater by damning decreased the river flow in the sampled estuaries, allowing for greater seawater intrusion at the height of the drought and creating a gradient of homogeneous or inverted salinity during most of the annual cycle. Seasonal rainfalls caused considerable variations in salinity in the upstream sections of estuaries like Choró, Curu and Pacoti, as opposed to estuaries with positive gradients and persistent inflow (Neves et al., 2011; Schettini et al., 2017).

The composition and abundance of estuarine fishes reflect changes in salinity; in fact, salinity and diversity are often claimed to be inversely related (Whitfield et al. 2006; Bucater et al., 2013; Brookes et al., 2015). Nevertheless, in our study the group of estuaries influenced by prolonged drought displayed greater species richness, especially marine stragglers, and greater abundance of marine stragglers and migrants. This supports the hypothesis of 'marinization' (Pasquaud et al., 2012; Lima et al., 2020), according to which a stronger marine influence on estuaries favors occupation by these groups of fishes. High salinity attracts marine stragglers which otherwise appear only sporadically (Potter et al., 2015) and provides nursery grounds for a greater variety of reef marine migrants (Sales et al., 2018). Baptista et al. (2010) made similar observations for marine stragglers, but in their study assemblages were more abundant in non-drought years and at lower salinities (Mann et al., 2002; Baptista et al., 2010; Tweedley et al., 2019).

The most abundant species in estuaries influenced by prolonged drought were marine migrants, followed by species tolerant of brackish or near-eurihaline environments. For example, *Micropogonias furnieri* (Desmarest, 1823) spawns on the coast and the juveniles enter estuaries concomitantly with the seawater intrusion (Costa et al., 2015), *Lycengraulis grossidens* (Spix & Agassiz, 1829) and *Sphoeroides* spp. display predominantly marine and estuarine resident habits in this region (Fávaro et al., 2009; Mai et al., 2014), as do mullets (*Mugil* spp.) — marine migrants with great osmoregulatory ability which depend on estuaries for their ontogeny (Avigliano et al., 2021; Krispyn et al., 2021). In contrast, estuaries exposed to ample precipitation displayed greater abundances of *A. achirus*, *C. spixii*, *C. undecimalis*, *L. griseus*, *R. amazonica* and *S. timucu*. These species prefer fresh and brackish water for spawning and growout, especially *C. undecimalis* and *R. amazonica* (Adams et al., 2009; Clark & Pessanha, 2015; Daros et al., 2016), and were frequently observed upstream during the study.

Seawater intrusion tends to increase salinity upstream and may even invert the salinity gradient (Valle-Levinson & Schettini, 2016; Valentim et al., 2018; Lauchlan & Nalgelkerke, 2020). When this happens, marine migrants and freshwater fishes move upstream while marine stragglers become more abundant downstream, affecting the food web and predator-prey relationships (Livernois et al., 2021), in some cases leading to mass mortality, as documented for hypersaline systems (Tweedley et al., 2019). Salinity plays a role in the structuring of estuarine communities, especially in closed estuaries, with some species capable of surviving at salinities over 50 or in frequently hypersaline systems (Gonzalez, 2012; Wedderburn et al., 2016). Few species tolerate salinities over 70 (Tweedley et al., 2019), a situation reported for at least two estuaries on the semiarid coast of NEB (Valle-Levinson & Schettini, 2016; Barroso et al., 2018). The fish fauna in small hypersaline estuaries is often impoverished and dominated by a handful of highly abundant species (Tweedley et al., 2019). The estuaries sampled for this study had communities dominated by a few species: over 70% of the species in all six estuaries had a relative abundance of less than 1%, and the most abundant species were marine migrants and estuarine fishes (up to 19 species with >1% abundance, depending on the estuary). Nevertheless, the assemblages were not impoverished in terms of diversity.

Diadromous fishes were more abundant in estuaries exposed to ample precipitation than in estuaries influenced by prolonged drought. Hypersalinity affects diversity, abundance and productivity according to the tolerance and life history of the species. This is especially evident for diadromous fishes in the case of loss of connectivity between the river and the estuary or between the river and the sea (Zampatti et al., 2010; Bucater et al., 2013; Wedderburn et al., 2016). Snooks (*Centropomus* spp.) were less abundant in estuaries influenced by prolonged drought, and other species may be undergoing local exclusion, such as *Albula vulpes* (Linnaeus, 1759) and *Megalops atlanticus* Valenciennes, 1847, all of which were rare or absent from our samples. Considered an endangered species (Batista et al., 2020), *M. atlanticus* was not observed in this study, despite being abundant in another local estuary (Cocó river) not sampled for this study (unpublished data). Cocó differs from other local systems in that it receives a permanent inflow of freshwater from urban sources (Schettini et al., 2017). Overall, freshwater species displayed the lowest diversity and abundance under both climate events, despite differences in abundance between the groups. Thus, differences in salinity gradients were crucial to the few freshwater fishes observed.

The differences in functional structure between estuaries under different climate events may be explained by the occurrence of more marine species, causing an increase in functional richness during prolonged droughts. This contradicts our hypothesis that estuaries exposed to rainfalls above the historical average ought to display greater functional richness due to a steeper salinity gradient, and may be due to the direct association between functional and taxonomic richness (Villéger et al., 2008; Laliberté & Legendre, 2010). In fact, estuaries influenced by prolonged drought suffered less functional erosion, as posited by our third hypothesis, probably because of greater functional redundancy. On the one hand, functional richness was greater in estuaries influenced by prolonged drought, mitigating functional erosion in the simulations removing the most original and specialized species. On the other hand, the freshwater fish fauna consisted of a few functionally redundant species with no significant contribution to functional erosion. This suggests that prolonged droughts favor the occurrence of a larger number of marine species in the estuary through the process of ‘marinization’ (Baptista et al., 2010; Pasquaud et al., 2012), introducing new sets of functional traits or increasing the functional redundancy. However, no clear pattern of functional dispersion was found for estuaries or climate events, perhaps because the estuarine ecosystems are temporally and spatially dynamic enough to support a rich fish fauna. This may have prevented more robust predictions based on the analyzed traits, where the high functional redundancy of these ecosystems could play a fundamental role (Villéger et al., 2010; Silva et al., 2021). However, to fill extant gaps in our understanding of functional dispersion, analyses should include life history characteristics and body variables associated with ecological activities in microhabitats (Poff, 1997; Pease et al., 2012).

Hydrological, geomorphological and biological factors (river forcing, waves, tides, river mouth width, substrate type, estuary area, mangrove area) account for an array of differences in estuarine fish assemblages (Ley, 2005; Pasquaud et al., 2015; Vasconcelos et al., 2015). Along the Australian coast, the area covered by mangrove varies from estuary to estuary (Baker et al., 2015), matching our own observations. Temperature, depth, dissolved oxygen and turbidity also play a decisive role (Blaber, 2002; Lunt & Smee, 2014; França & Cabral, 2015). In their evaluations of the contribution of niche filtering and limiting similarity to the functional structure of assemblages in coastal ecosystems, Mouillot et al. (2007) and Mouchet et al. (2013) found environmental filters to have the greatest impact, with more functionally similar species coexisting than would be expected by chance. On the other hand, Sheaves (2016) looked at how unpredictable factors affect estuarine assemblages, such as the contribution of marine currents to larval migration, depending on the distance between the coastal spawning areas and the river mouth. Moreover, the relationship between environmental variables and fish fauna is modulated by anthropic pressures (Whitfield, 1999; Barletta et al., 2019; Barletta & Lima, 2019). The six estuaries sampled for this study are subject to a range of anthropic impacts from deforestation and discharge of urban wastewater and solid waste, causing damage at varying levels (Gorayeb et al., 2005a; Gorayeb et al., 2005b; Lacerda et al., 2008; Cavalcante et al., 2009; Santana et al., 2015). The estuaries of Choró, Aracatimirim and Acaratiaçu are criss-crossed by motorized boats involved in daily fishing or tourist activities, and all six estuaries are to some extent contaminated with solid waste (Lacerda et al., 2008; Cavalcante et al., 2009). In the present study, assemblages were strongly influenced by salinity, but the role potentially played by other variables and stochastic processes should not be overlooked. However, the groups did not differ with regard to geomorphological variables such as continental shelf length (~500 km ± 59), estuary length and river width. The other environmental variables in the present study did not seem to affect fish communities as might be expected (Table 1 and Fig. S4.7 of Online Appendix 4) since the estuaries influenced by prolonged drought (with greater taxonomic and functional richness and greater abundances: Choró, Curu and Pacoti) also had narrower river mouths, smaller mangrove cover and larger areas dedicated to shrimp farming.

In view of the different levels of pressure and the intrinsic environmental conditions, the sampled systems present characteristics which, if carefully analyzed, may explain differences in the assemblages of the estuaries. Evidently, comparing the same estuary under different climate events would yield more robust results, but the groups employed in this study appear to be representative of the seasonality of the salinity profiles and the contrasting weather events. The 2012-2016 drought was particularly severe (Marengo et al., 2018), making it possible to observe the effect of weather events on estuarine fish assemblages along the semiarid coast of Northeastern Brazil, a region in which most estuaries are seasonally hypersaline. In this study we standardized sampling to ensure robust comparisons and identify possible effects of contrasting weather events. Our results, however, are limited to assemblages in shallow waters (i.e., mostly juveniles). Future investigations should conduct samplings at night and evaluate other components of the fish fauna, such as larger individuals occupying the main channel (Dantas & Barletta, 2016; Ramos et al., 2011; Reis-Filho et al., 2011).

Can the increase in abundance and functional richness associated with marinization, as observed in this study, be sustained in the long run in the face of persistent extreme weather events? Events like ENSO and the Atlantic dipole reduce rainfalls below the historical average (Nóbrega et al., 2016) and due to their frequency and intensity have a strong impact on the region (Marengo et al., 2018). During drought periods, the sea surface temperature (SST) gradient in the tropical Atlantic is positive and abrupt, and the ITCZ remains further to the north, while the SST of the tropical eastern Pacific tends to be abnormally warm (Marengo et al., 2013; Marengo & Bernasconi, 2015; Nobre et al. 2006). Droughts are the result of natural fluctuations in the climate, but weather events are expected to become increasingly adverse in the future (Marengo & Bernasconi, 2015; Marengo et al., 2017). In fact, rainfalls in the NEB have declined since the 1970s, posing a risk to the environment and local water and power security (Marengo et al., 2013). Projections suggest temperatures in NEB could increase by 2°C until 2040 and by over 4°C until 2100 (Marengo & Bernasconi, 2015). Also, rainfalls and air humidity are predicted to decrease by 5% and 15%, respectively, directly impacting continental runoff (Marengo & Bernasconi, 2015). Over time, these changes can harm the soil and crop productivity, reduce rainfalls further, raise temperatures and render droughts more frequent and severe (Marengo et al., 2009; IPCC, 2014; Marengo et al., 2017). One of the main climate concerns in NEB, rainfalls are expected to continue declining, affecting water flow and residence time, and promoting hypersalinity. Predictions of adverse climate events also include rising sea levels, coastal erosion, inland expansion of mangroves, silting up of sand bars at river mouths, acidification, enhancement of extreme weather, eutrophication, hypoxia, and disruptions of biogeochemical processes (Lacerda et al., 2020; Soares et al., 2021).

We believe total abundance in the sampled fish assemblages is likely to decrease in the long run, along with global changes, especially considering the decreasing input of organic matter and nutrients to the estuary and coast and the structural changes in habitats (Gillanders et al., 2011; Tweedley et al., 2019; Lauchlan & Nagelkerken, 2020). High salinities cause physiological stress and increase the trophic overlap between species (Wedderburn et al., 2016; Hossain et al., 2017). In times of drought, the food web is often primarily sustained by autochthonous pelagic and benthic primary production (Lamontagne et al., 2016). The fact that many benthic invertebrates are intolerant of high salinities can affect fish indirectly by locally reducing or eliminating macrobenthic taxa, without replacement by alternative benthic prey (Montagna et al., 2002; Tweedley et al., 2019). In contrast, certain plankton components may proliferate under hypersaline conditions (Barroso et al., 2018), modifying the food web. The prey least affected under this scenario are microphytobenthos and detritus, favoring the occurrence of detritivorous species in the fish community (Tweedley et al., 2019). The lack of connectivity with freshwater and the limited communication with the ocean also affect the dispersal of fish larvae (Bucater et al., 2013), and droughts can enhance the effects of overfishing (Ferguson et al., 2013). These trends, along with the observations of this study, raise concerns about the future integrity of the regional estuarine fish fauna.

Our results should be interpreted in light of the peculiar semiarid climate of NEB and the community dynamic that flows from it. Assemblages could be said to be impacted rather by rainfalls than by droughts; i.e., due to excessive damning and reduced river flow most of the year, the fish fauna in shallow estuaries becomes depleted of freshwater species and rich in marine species (Whitfield, 2015), creating a dynamic specific for the region, at least for the northernmost coastline (Soares et al., 2021) with its brief and unevenly distributed rainfalls. This would explain the greater functional richness and greater overall abundance during drought years, intensified during extreme weather events, at least at the current stage. Similar observations were made for phytoplankton biomass in the estuary of Pirangi (NEB), showing that rainfalls, and not drought, were the source of disturbance in the community (Barroso et al., 2018). However, it should be pointed out that as adverse weather events escalate and river flow lessens even further, as predicted by global models, a salinity plateau may be reached which limits response in the form of increasing functional diversity, inverting the process and eventually reducing overall functional diversity through an environmental filter (Henriques et al., 2017). This highlights the importance of developing predictive models to anticipate how salinity will fluctuate in the coming decades and how the local fish fauna will respond to these changes in the long run.

Conclusion

Small estuaries play a crucial role for local communities and fishing activities in semiarid Northeastern Brazil. These ecosystems are exposed to severe environmental impacts, especially changes in salinity associated with prolonged droughts, modifying the taxonomic and functional structure of fish assemblages by making marine species more abundant and attracting functionally more original and specialized species, while excluding freshwater species. The marine species attracted by the saline environment increase functional redundancy into the estuarine community, if compared to less saline estuaries exposed to ample precipitation. Referred to as ‘marinization’, this process has serious implications for fish assemblages and the functioning of ecosystems.

Our study provides initial subsidies for future analyses of the effects of extreme weather events on the fish fauna of seasonally hypersaline estuaries along the Brazilian semiarid coast and highlights the importance of including adverse climate events as a determining factor in management efforts. By comparing the effect of contrasting climate scenarios on the local fish fauna, the observed response of the sampled estuaries may be used as a model to understand the dynamics of minor tropical estuaries in semiarid regions. Further studies, ideally designed to include a wider set of components of the food web, are necessary to identify the cumulative effects of extreme weather events in these ecosystems.

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Supplementary material

Prolonged drought influences the taxonomic and functional structure of fish assemblages in estuaries along the Brazilian semiarid coast

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Appendix 1

Voucher specimens of species sampled for six estuaries in Northeastern Brazil (Aracatimirim, Aracatiaçu, Choró, Curu, Malcozinhado, and Pacoti). UFRN = fish collection at the Laboratory of Systematic and Evolutionary Ichthyology (LISE) of the Federal University of Rio Grande do Norte. UFPB = fish collection at the Federal University of Paraíba.

Abudefduf saxatilis (UFPB12059); *Achirus achirus* (UFPB12061; UFRN4587; 4654; 4761; 4421, 4515); *Achirus lineatus* (UFPB12062; UFRN4582; 4646; 4713); *Albula vulpes* (UFRN4671); *Anableps anableps* (UFRN4650); *Anchoa hepsetus* (UFRN4603); *Anchoa spinifer* (UFRN4608; 4649); *Anchovia clupeoides* (UFPB12055; 12056; 12057; UFRN4598; 4625; 4762; 4525); *Anchoviella brevirostris* (UFPB); *Anchoviella lepidentostole* (URFN4517); *Antennarius striatus* (UFRN4592); *Archosargus probatocephalus* (UFRN4672); *Archosargus rhomboidalis* (UFRN4599; 4647; 4747); *Astyanax bimaculatus* (UFRN4821; 4616; 4763); *Atherinella brasiliensis* (UFRN4596; 4820; 4639; 4693; 4519); *Bathygobius soporator* (UFRN4565; 4815; 4627; 4764; 4540); *Batrachoides surinamensis* (UFPB12063; UFRN4578; 4635; 4509); *Bothus ocellatus* (UFRN4561); *Bryx dunckeri* (MNRJ53260); *Caranx latus* (UFRN4606; 4812; 4813; 4655; 4683; 4534); *Cathorops spixii* (UFPB12047; UFRN4586; 4605; 4665; 4692; 4506); *Centropomus parallelus* (UFRN4574; 4822; 4656; 4684); *Centropomus undecimalis* (UFRN4681; 4507); *Cetengraulis edentulus* (UFPB12066; UFRN4607; 4657; 4535); *Chaetodipterus faber* (UFRN4583; 4640; 4765; 4494); *Citharichthys arenaceus* (UFRN4714); *Citharichthys spilopterus* (UFRN4562; 4818; 4819; 4617; 4748; 4486); *Ctenogobius boleosoma* (UFRN4613; 4825; 4826; 4659; 4766); *Ctenogobius smaragdus* (URFN4539); *Ctenogobius stigmaticus* (UFRN4658; 4789); *Cynoscion acoupa* (UFRN4752); *Dactylopterus volitans* (UFRN4675); *Diapterus auratus* (UFRN4551; 5169; 4661; 4712, 4749; 4508); *Diapterus rhombeus* (UFRN5191; 4660; 5175; 4501); *Elops saurus* (UFRN4545; 4817; 4697; 4498); *Etropus crossotus* (UFRN4689); *Eucinostomus argenteus* (UFRN4557; 4829; 4830; 4624; 5180); *Eucinostomus gula* (UFRN5193; 4626; 4750; 5805; 4518); *Eucinostomus havana* (UFRN4550; 4662; 4698; 4512); *Eucinostomus lefroyi* (UFRN4584; 4668; 4777; 4536); *Eucinostomus melanopterus* (UFRN4554; 4569; 4831; 4651; 4751; 4489; 4529); *Eugerres brasilianus* (UFPB12048; UFRN4573; 4623; 4688; 4490); *Evorthodus lyricus* (UFRN4816; 4744); *Genyatremus luteus* (UFRN4610; 4488); *Gobionellus oceanicus* (UFRN4572; 4633; 4682; 4528); *Gobionellus stomatus* (UFRN4558; 4642; 4695; 4541); *Haemulon parra* (UFRN4594; 5173; 4620); *Haemulopsis corvinaeformis* (UFRN5802; 4645; 4687; 4520); *Harengula* sp. (UFPB12065); *Hippocampus reidi* (UFRN4580; 4621; 4740); *Hoplerythrinus unitaeniatus* (UFPB12058); *Hypanus guttatus* (UFPB12050; UFRN4559; 4711); *Hyporhamphus unifasciatus* (UFRN4577; 4842; 4636; 5176; 4505);

Lagocephalus laevigatus (UFRN4548); *Larimus breviceps* (UFPB12074); *Lile piquitinga* (UFRN4601; 4843; 4641; 4768; 4531); *Lutjanus alexandrei* (UFRN4612; 4844; 4619; 4769; 4526); *Lutjanus analis* (UFRN5801; 4845; 4614; 5177; 5178; 4524); *Lutjanus apodus* (UFRN4566; 4846; 4686; 4503); *Lutjanus griseus* (UFRN4552; 4847; 4767); *Lutjanus jocu* (UFRN4546; 4673; 4491); *Lycengraulis grossidens* (UFRN4609; 4849; 4628; 4770); *Megalechis thoracata* (UFRN4814); *Menticirrhus martinicensis* (UFRN4571; 4538); *Microphis lineatus* (UFRN5179); *Micropogonias furnieri* (UFRN4611; 4664; 4743; 4495); *Moenkhausia costae* (UFRN4567; 4851; 4694); *Mugil curema* (UFRN4575; 4852; 4622; 4679; 4738; 4739; 5181); *Mugil curvidens* (UFRN4544; 4853; 4638; 5183); *Mugil liza* (UFRN4563; 4854; 4667; 4499; 4511; 4513); *Mugil rubrioculus* (UFRN5192; 5190; 5184; 5186; 4504); *Mycteroperca bonaci* (UFRN4607); *Myrichthys ocellatus* (UFRN4547; 4637; 4788); *Ogcocephalus vespertilio* (UFRN4549); *Oligoplites palometa* (UFRN4589; 4674; 4742); *Oligoplites saurus* (UFRN4591; 4675; 4771; 4523); *Opisthonema oglinum* (UFRN4595; 4855; 4699); *Oreochromis niloticus* (UFRN4856; 4492); *Orthopristis scapularis* (UFRN4741); *Paralichthys brasiliensis* (UFRN4560; 4653); *Poecilia reticulata* (UFRN4858; 4745); *Polydactylus virginicus* (UFRN4456); *Prionotus punctatus* (UFRN4593; 4715); *Prochilodus brevis* (UFPB12064); *Pseudauchenipterus nodosus* (UFPB12075); *Rhinosardinia amazonica* (UFRN4600; 4666; 4533); *Sciades herzbergii* (UFPB12051; UFRN5799; 4652; 5804; 4772; 4510); *Sciades parkeri* (UFRN4597; 4669); *Sciades proops* (UFRN5174; 4487); *Scomberomorus brasiliensis* (UFRN4604); *Scorpaena plumieri* (UFRN4553; 4685; 4500); *Selene vomer* (UFRN4570; 4663; 4773; 4502); *Serrasalmus rhombeus* (UFRN4590; 4860); *Sparisoma radians* (UFRN4579; 4630; 4774); *Sphoeroides greeleyi* (UFRN4568; 4861; 4631; 4678; 4537); *Sphoeroides spengleri* (UFRN4555; 4532); *Sphoeroides testudineus* (UFPB12046; UFRN4564; 4862; 4632; 4676; 4493); *Sphyraena barracuda* (UFRN4863; 4634; 4736); *Sphyraena guachancho* (UFRN4864); *Steindachnerina notonota* (UFPB12073); *Stellifer naso* (UFRN4691); *Strongylura marina* (UFPB12053; UFRN4556; 4643; 4677; 4680); *Strongylura timucu* (UFPB12052; UFRN4543; 4876; 4877; 4878; 4615; 4716; 4496; 4497); *Symphurus tessellatus* (UFRN4581; 4690); *Syngnathus pelagicus* (UFRN4588); *Syngnathus* sp. (UFRN4879; 4696); *Synodus bondi* (UFPB12076); *Synodus foetens* (UFRN4775); *Synodus intermedius* (UFRN4576); *Thalassophryne nattereri* (UFRN4746); *Trachinotus carolinus* (UFPB12067); *Trachinotus falcatus* (UFPB12068; UFRN4602; 4629; 4776); *Trinectes paulistanus* (UFPB12049; UFRN5803; 5171; 4648; 4735; 4530).

Appendix 2

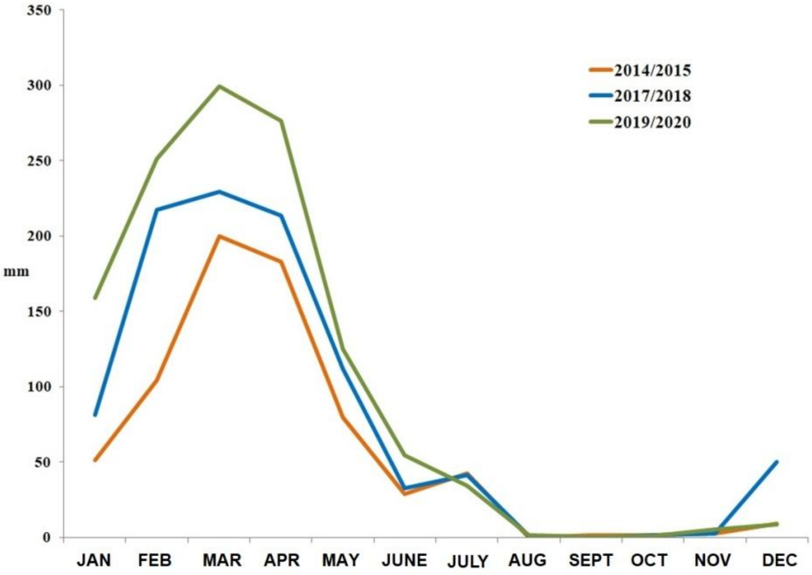

Fig. S2.1 Monthly pluviometric data (mm) for the study area showing hydric deficit in 2014/2015 (yellow) and average or above average precipitation in 2017/2018 (blue) and 2019/2020 (green), respectively. The data were retrieved from the Portal of the Hydrological Service of Ceará (http://www.hidro.ce.gov.br/), based on average monthly rainfall in the four macro-regions (Litoral Norte, Litoral do Pecém, Litoral de Fortaleza, Maciço de Baturité) comprising the hydrographic basins sampled for this study

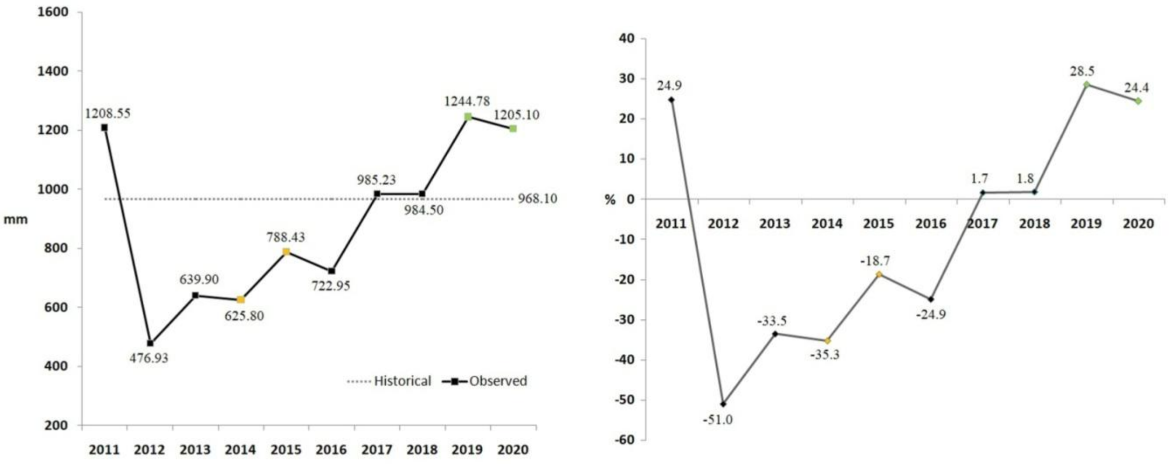

Fig. S2.2 Total annual rainfall (mm) in the study area, showing a deficit in the period 2012-2016, with values below the historical average (a) and the corresponding percentage deviation (b). Data retrieved from the Portal of the Hydrological Service of Ceará (http://www.hidro.ce.gov.br/) based on average monthly rainfall in the four macro-regions (Litoral Norte, Litoral do Pecém, Litoral de Fortaleza, Maciço de Baturité) comprising the hydrographic basins sampled for this study

Appendix 3

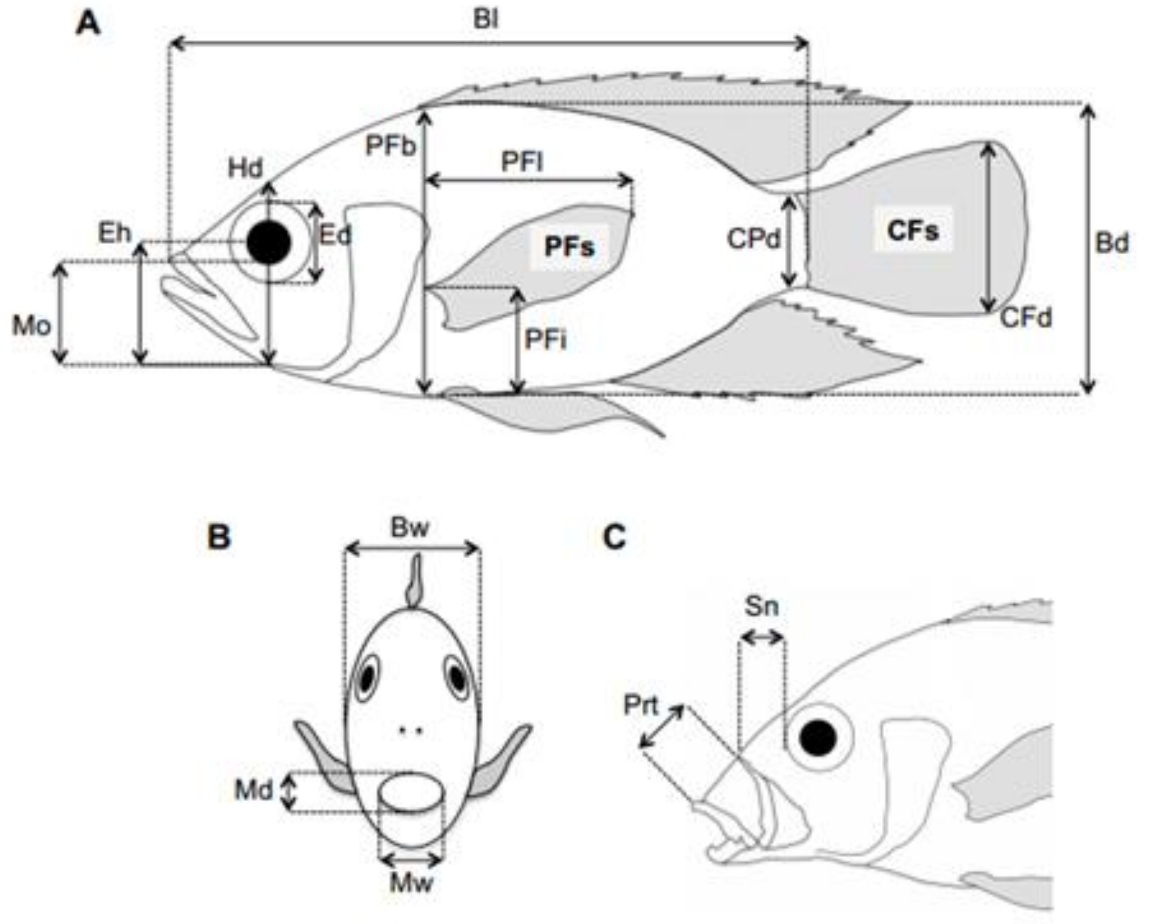

Fig. S3 The functional traits measured from photographs included (A): body standard length (Bl), body depth (Bd), caudal peduncle minimum depth (CPd), caudal fin depth (CFd), caudal fin surface area (CFs), distance between the insertion of the pectoral fin to the bottom of the body (PFi), body depth at the level of the pectoral fin insertion (PFb), pectoral fin length (PFl), pectoral fin surface area (PFs), head depth along the vertical axis of the eye (Hd), eye diameter (Ed), distance between the center of the eye to the bottom of the head (Eh), and distance from the top of the mouth to the bottom of the head along the head depth axis (Mo). The traits measured by caliper (B, C) included: body width (Bw), mouth depth (Md), mouth width (Mw), snout length (Sn), and mouth protrusion length (Prt). Source: Leitão et al. (2016)

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Table S3.1 List of qualitative and quantitative functional traits of the fishes collected for this study

Quantitative functional attributes	**Calculation**	**Abbreviation**	**Ecological meaning**	**Reference**
Body mass	$\ln(Massa + 1)$	LogM	Metabolism, endurance and swimming ability	Villéger et al., 2010
Protrusion length	$\frac{Prt}{Sn}$	Prt	Feeding method	Adapted from Leitão et al. (2016)
Oral gape surface	$\frac{Mw * Md}{Bw * Bd}$	Osf	Size of food items captured	Adapted from Karpouzi & Stergiou (2003)
Oral gape shape	$\frac{Md}{Mw}$	Osh	Method to capture food items	Karpouzi & Stergiou (2003)
Oral gape position	$\frac{Mo}{Hd}$	Ops	Feeding method in the water column	Adapted from Sibbing & Nagelkerke (2001)
Eye size	$\frac{Ed}{Hd}$	Edst	Prey detection	Adapted from Boyle & Horn (2006)
Eye position	$\frac{Eh}{Hd}$	Eps	Vertical position in water column	Gatz (1979)
Body transversal shape	$\frac{Bd}{Bw}$	Bsh	Vertical position in water column and hydrodynamics	Sibbing & Nagelkerke (2001)
Body transversal surface	$\frac{\ln[(\frac{\pi}{4} * Bw * Bd) + 1]}{\ln(Massa + 1)}$	Bsf	Mass distribution along the body for hydrodynamism	Villéger et al., 2010
Pectotal fin position	$\frac{PFi}{PFb}$	PFps	Use of pectoral fin for maneuverability	Dumay et al., (2004)
Aspect ratio of the pectotal fin	$\frac{PFl^2}{PFs}$	PFar	Use of pectoral fin for propulsion	Adapted from Fulton et al., (2001)
Caudal peduncle throttling	$\frac{CFd}{CPd}$	Cpt	Caudal propulsion efficiency through reduction of drag	Webb (1984)
Aspect ratio of the caudal fin	$\frac{CFd^2}{CFs}$	CFar	Caudal fin use for propulsion and/or direction	Webb (1984)
Fins surface ratio	$\frac{2 * PFs}{CFs}$	Frt	Main type of propulsion between caudal and pectoral fins	Villéger et al., 2010
Fins surface to body size ratio	$\frac{(2 * PFs) + CFs}{\frac{\pi}{4} * Bw * Bd}$	Fsf	Acceleration and/or maneuverability efficiency	Villéger et al., 2010
Qualitative functional attributes		**Abbreviation**	**Ecological meaning**	
Diet				
	Detritivore	Detri	Species that feed on detritus and/or microphytobenthos	
	Planktivore	Plank	Species that feed on phytoplankton and/or zooplankton	
	Herbivore	Herb	Species that feed on	

			macroalgae/macrophytes
	Invertivore	Invert	Species that feed mainly on benthic invertebrates
	Macrocarnivore	Macro	Species that mainly consume fish but may prey on benthic invertebrates
	Omnivore	Omniv	Species that consume from plants to plankton and/or benthic invertebrates
Position in the water column			
	Benthic	Bent	Fish that live more associated with the substrate (ex: gobiids)
	Nektobenthic	NektBent	Fish that utilize the pelagic and benthic region (ex: lutjanids)
	Nektonic	Nekt	Fish that live associated with the pelagic region (ex: clupeids)
Activity			
	Active	MO	Fish that constantly move between habitats (e.g. mugilids)
	Sedentary	SE	Less active moving fish (ex: batrachoidids)
Reproductive guild			
	External fertilization	EF	Species that have external fertilization
	External fertilization with parental care	EFPC	Species that have external fertilization and some level of parental care
	Internal fertilization	IF	Species that have internal fertilization
	Internal fertilization with internal development	IFID	Species have internal fertilization and internal development
Estuary use			
	Marine straggler	MS	Species that occur in low numbers and sporadically in estuaries
	Marine migrant	MM	Estuarine-opportunistic or estuarine-dependent species that use the estuary to complete part of the life cycle
	Estuarine	ES	Species capable of completing the entire life cycle in estuaries, but not necessarily doing so. Include estuarine migrants and estuarine residents
	Diadromous	DI	Marine species that need fresh water to complete their life cycle
	Freshwater	FW	Freshwater species
Occurrence			
	Saltwater	0/1	Occurrence at marine salinities or higher
	Brackish water	0/1	Occurrence at intermediate salinities
	Freshwater	0/1	Occurrence in waters with zero salinity

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Table S3.2 Values of qualitative functional traits of the fishes collected for this study. 0/1 = occurrence in freshwater, brackish water and seawater; Nekt = nektonic; NektBent = nektobenthic; Bent = benthic; Detri = detritivore; Herb = herbivore; Plank = planktivore; Invert = invertivore; Macro = macrocarnivore; Omniv = omnivore; EF = external fertilization; EFPC = external fertilization with parental care; IF = internal fertilization; IFID = internal fertilization with internal development; MO = active; SE = sedentary. MS = marine straggler; MM = marine migrant; ES = estuarine species; DI = diadromous species; FW = freshwater fish. Species names in Table S4.2

Species code	Freshwater occurrence	Brackish occurrence	Saltwater occurrence	Position in the water column	Diet	Reproductive guild	Activity	Estuary use
A sax	0	0	1	NektBent	Omniv	EFPC	MO	MS
A bah	0	0	1	NektBent	Herb	EF	MO	MS
A ach	1	1	1	Bent	Invert	EF	SE	MM
A lin	0	1	1	Bent	Invert	EF	SE	MM
A vul	0	1	1	NektBent	Invert	EF	MO	DI
A ana	1	1	1	NektBent	Omniv	IFID	MO	MS
A hep	0	1	1	Nekt	Invert	EF	MO	MM
A spi	1	1	1	Nekt	Invert	EF	MO	MM
A clu	0	1	1	Nekt	Plank	EF	MO	MM
A bre	1	1	1	Nekt	Plank	EF	MO	MS
A str	0	1	1	Bent	Macro	EF	SE	MS
A pro	0	1	1	NektBent	Invert	EF	MO	MS
A rho	0	1	1	NektBent	Omniv	EF	MO	MS
A bim	1	0	0	Nekt	Omniv	EF	MO	FW
A bra	0	1	1	Nekt	Omniv	EF	MO	ES
B sop	1	1	1	Bent	Invert	EFPC	SE	ES
B sur	0	1	1	Bent	Macro	EFPC	SE	MM
B oce	0	0	1	Bent	Invert	EF	SE	MS
B dun	0	0	1	NektBent	Invert	EFPC	MO	MS
C lat	1	1	1	Nekt	Macro	EF	MO	MM
C spx	0	1	1	NektBent	Invert	EFPC	MO	ES
C ede	0	1	1	Nekt	Plank	EF	MO	MM
C par	1	1	1	Nekt	Macro	EF	MO	DI
C und	1	1	1	Nekt	Macro	EF	MO	DI
C fab	0	1	1	Nekt	Invert	EF	MO	MM
C are	0	0	1	Bent	Invert	EF	SE	MM
C spi	1	1	1	Bent	Invert	EF	SE	MM
C bol	1	1	1	Bent	Invert	EF	SE	MM
C sma	1	1	1	Bent	Invert	EF	SE	MM
C sti	0	0	1	Bent	Invert	EF	SE	MM
C aco	1	1	1	Nekt	Macro	EF	MO	MM
D vol	0	1	1	NektBent	Invert	EF	SE	MS
D aur	0	1	1	NektBent	Invert	EF	MO	MM
D rho	0	1	1	NektBent	Invert	EF	MO	MM
E sau	1	1	1	NektBent	Macro	EF	MO	DI
E cro	0	1	1	Bent	Invert	EF	SE	MM
E arg	1	1	1	NektBent	Omniv	EF	MO	MM
E gul	1	1	1	NektBent	Invert	EF	MO	MM
E hav	0	1	1	NektBent	Invert	EF	MO	MM
E lef	0	1	1	NektBent	Invert	EF	MO	MM
E mel	1	1	1	NektBent	Oniv	EF	MO	MM
E bra	0	0	1	NektBent	Invert	EF	MO	MM

E lyr	1	1	1	Bent	Omniv	EFPC	SE	ES
G lut	0	1	1	NektBent	Invert	EF	MO	MM
G oce	1	1	1	Bent	Detri	EF	SE	ES
G sto	0	1	0	Bent	Detri	EF	SE	ES
H par	0	0	1	NektBent	Invert	EF	MO	MM
H cor	1	1	1	NektBent	Invert	EF	MO	MM
*H*_sp	0	1	1	Nekt	Plank	EF	MO	MS
H rei	0	1	1	Bent	Invert	EFPC	SE	ES
H gut	0	0	1	Bent	Invert	IFID	MO	MM
H uni	0	1	1	Nekt	Omniv	EF	MO	MM
L lae	0	1	1	Nekt	Macro	EF	MO	MM
L bre	0	1	1	Nekt	Macro	EF	MO	MS
L piq	0	1	1	Nekt	Plank	EF	MO	ES
L ale	0	0	1	NektBent	Invert	EF	MO	MM
L ana	0	1	1	NektBent	Macro	EF	MO	MM
L apo	0	1	1	NektBent	Macro	EF	MO	MM
L gri	1	1	1	NektBent	Macro	EF	MO	MM
L joc	1	1	1	NektBent	Macro	EF	MO	MM
L gro	1	1	1	Nekt	Macro	EF	MO	MM
M mar	0	1	1	NektBent	Invert	EF	MO	MM
M fur	0	1	1	NektBent	Invert	EF	MO	MM
M cos	1	0	0	Nekt	Omniv	EF	MO	FW
M cur	1	1	1	Nekt	Detri	EF	MO	MM
M cuv	1	1	1	Nekt	Detri	EF	MO	MM
M liz	1	1	1	Nekt	Detri	EF	MO	MM
M rub	0	1	1	Nekt	Detri	EF	MO	MM
*M*_sp	1	1	1	Nekt	Detri	EF	MO	MM
M bon	0	0	1	NektBent	Macro	EF	MO	MM
M oce	0	0	1	Bent	Invert	EF	MO	MS
O ves	0	0	1	Bent	Invert	EF	SE	MS
O pal	1	1	1	Nekt	Macro	EF	MO	MM
O sau	0	1	1	Nekt	Macro	EF	MO	MM
O ogl	0	0	1	Nekt	Plank	EF	MO	MM
O nil	1	1	0	NektBent	Omniv	EFPC	MO	FW
O sca	0	1	1	NektBent	Macro	EF	MO	MS
P bra	0	1	1	Bent	Macro	EF	SE	MM
P ret	1	1	0	Nekt	Omniv	IFID	MO	FW
P vir	0	1	1	NektBent	Invert	EF	MO	MS
P pun	0	1	1	NektBent	Invert	EF	MO	MS
P bre	1	0	0	NektBent	Detri	EF	MO	FW
P nod	1	1	0	NektBent	Oniv	IF	MO	FW
R ama	1	1	0	Nekt	Plank	EF	MO	ES
S her	1	1	1	NektBent	Invert	EFPC	MO	ES
S par	0	1	1	NektBent	Invert	EFPC	MO	ES
S pro	1	1	1	NektBent	Invert	EFPC	MO	ES
S bra	0	0	1	Nekt	Macro	EF	MO	MS
S plu	0	0	1	Bent	Macro	EF	SE	MM
S vom	0	1	1	Nekt	Macro	EF	MO	MM
S rho	1	0	0	Nekt	Macro	EF	MO	FW
S rad	0	0	1	NektBent	Herb	EF	MO	MM
S gre	0	1	1	NektBent	Invert	EF	MO	ES
S spe	0	1	1	NektBent	Invert	EF	MO	MS
S tes	0	1	1	NektBent	Invert	EF	MO	ES
S bar	0	1	1	Nekt	Macro	EF	MO	MM

S gua	0	1	1	Nekt	Macro	EF	MO	MM
S not	1	0	0	NektBent	Detri	EF	MO	FW
S nas	0	1	1	NektBent	Invert	EF	MO	MM
S mar	1	1	1	Nekt	Macro	EF	MO	MM
S tim	1	1	1	Nekt	Macro	EF	MO	MM
S tss	0	1	1	Bent	Invert	EF	SE	MM
S pel	0	0	1	NektBent	Invert	EFPC	MO	MM
*S*_sp	0	0	1	NektBent	Invert	EFPC	MO	MM
S bon	0	0	1	Bent	Macro	EF	MO	MS
S foe	0	1	1	Bent	Macro	EF	MO	MS
T nat	0	1	1	Bent	Macro	EF	SE	MM
T car	0	1	1	Nekt	Macro	EF	MO	MS
T fal	0	1	1	Nekt	Macro	EF	MO	MS
T pau	1	1	1	Bent	Invert	EF	SE	MM

Table S3.3 Mean values of morphofunctional traits of the fishes collected for this study. LogM = body mass; Prt = protrusion length; Osf = oral gape surface; Osh = oral gape shape; Ops = oral gape position; Edst = eye size; Eps = eye position; Bsh = body transversal shape; Bsf = body transversal surface; PFps = pectoral fin position; PFar = aspect ratio of the pectoral fin; Cpt = caudal peduncle throttling; CFar = aspect ratio of the caudal fin; Frt = fin surface ratio; Fsf = fin surface to body size ratio. Species names in Table S4.2

Species	LogM	Prt	Osf	Osh	Ops	Edst	Eps	Bsh	Bsf	PFps	PFar	Cpt	CFar	Frt	Fsf
A sax	3.743	0.588	0.065	1.067	0.481	0.323	0.608	2.498	1.806	0.338	2.795	1.645	1.515	1.242	1.063
A bah	3.640	0	0.039	0.528	0.298	0.236	0.727	2.727	1.793	0.406	1.726	2.276	1.402	1.135	1.376
A ach	2.598	0	0.086	1.717	0.453	0.567	0.869	0.104	2.033	1.000	3.389	1.462	1.229	0.053	1.767
A lin	2.535	0	0.071	1.732	0.481	0.577	0.861	0.119	2.096	1.000	4.963	1.470	1.239	0.049	1.536
A vul	2.980	0	0.236	1.278	0.501	0.509	0.665	1.783	1.844	0.175	4.302	3.433	2.247	0.448	1.801
A ana	3.430	0.831	0.262	0.659	0.408	0.485	0.744	0.843	1.665	0.226	2.988	1.618	0.937	1.084	3.023
A hep	0.977	0	0.449	3.338	0.408	0.521	0.572	2.534	4.110	0.159	3.130	2.109	2.102	0.659	2.862
A spi	0.837	0	0.501	3.239	0.419	0.556	0.618	2.769	4.557	0.130	2.857	2.425	1.951	0.511	3.519
A clu	1.344	0	0.619	3.467	0.512	0.531	0.629	3.482	3.446	0.137	2.663	2.742	2.994	0.512	2.884
A bre	0.270	0	0.530	3.376	0.446	0.497	0.585	2.796	9.619	0.181	2.533	2.274	2.534	0.814	3.786
A str	4.676	0.647	0.248	0.797	0.825	0.135	0.753	1.214	1.577	0.159	2.010	2.090	0.888	1.244	0.806
A pro	2.451	0.503	0.116	1.178	0.272	0.397	0.633	3.078	2.280	0.314	3.817	2.005	1.463	1.204	1.799
A rho	2.576	0.482	0.125	1.221	0.315	0.379	0.659	3.208	2.212	0.332	4.568	2.149	1.786	1.148	1.825
A bim	1.445	0	0.172	1.220	0.633	0.398	0.599	2.942	3.268	0.138	2.980	2.854	2.932	0.597	1.673
A bra	2.437	0.473	0.164	0.996	0.571	0.579	0.584	1.621	2.136	0.720	3.085	2.534	2.172	1.064	2.785
B sop	2.437	0.567	0.386	0.943	0.482	0.293	0.783	1.023	2.274	0.647	2.052	1.499	0.966	1.599	2.470
B sur	3.381	0	0.715	0.540	0.702	0.190	0.832	0.657	1.815	0.736	1.721	1.624	0.775	2.968	1.858
B oce	2.313	0.237	0.072	2.137	0.456	1.031	0.831	0.114	2.527	1.000	4.988	1.826	1.273	0.479	1.514
B dun	0.247	0	0.097	1.501	0.638	0.266	0.430	1.295	7.803	0	0	1.963	0.858	0	1.500
C lat	2.773	0.430	0.244	1.925	0.417	0.383	0.628	3.142	2.109	0.378	5.422	7.182	3.207	1.019	1.757
C spx	2.814	0	0.202	0.805	0.331	0.436	0.638	1.151	2.076	0.174	5.600	3.494	2.907	0.416	1.324
C ede	2.457	0	0.313	3.132	0.344	0.578	0.572	2.497	2.183	0.172	3.649	2.112	2.286	0.455	1.493
C par	3.255	0.154	0.730	2.010	0.444	0.545	0.677	2.099	1.729	0.346	3.154	3.601	2.889	0.450	3.729
C und	3.258	0.152	0.734	2.014	0.442	0.546	0.671	2.095	1.735	0.348	3.158	3.609	2.884	0.455	3.740
C fab	2.424	0.313	0.099	1.168	0.293	0.248	0.602	4.910	3.718	0.324	1.905	1.780	1.479	1.403	1.037
C are	3.176	0	0.141	3.996	0.430	0.738	0.877	0.131	1.806	1.000	3.822	1.469	1.139	0.340	1.847
C spi	2.812	0	0.225	4.640	0.424	0.878	0.868	0.122	1.892	1.000	3.882	1.485	1.114	0.341	2.258
C bol	0.565	0.080	0.570	0.829	0.333	0.242	0.796	1.813	5.158	0.584	2.588	2.114	0.982	1.014	7.757
C sma	0.763	0.094	0.483	0.944	0.317	0.314	0.782	1.327	4.947	0.595	2.603	1.513	0.550	0.832	3.549
C sti	1.138	0.463	0.683	0.837	0.418	0.304	0.777	1.749	3.342	0.582	3.544	1.463	0.636	0.899	5.475
C aco	3.112	0.395	0.343	1.397	0.399	0.466	0.695	1.874	1.883	0.355	3.545	2.267	1.034	0.647	2.046
D vol	5.430	0.758	0.250	1.076	0.222	0.462	0.674	0.719	1.300	0.392	1.570	5.906	1.656	15.256	21.270
D aur	2.964	1.298	0.074	1.123	0.273	0.454	0.500	3.590	2.021	0.325	5.138	3.377	3.299	0.767	1.895
D rho	2.998	1.280	0.081	1.405	0.347	0.488	0.555	3.650	2.011	0.330	4.904	3.457	3.336	0.785	1.826
E sau	2.933	0	0.848	2.215	0.454	0.516	0.680	1.960	1.824	0.150	4.022	3.526	3.106	0.413	3.189
E cro	2.049	0.554	0.065	1.681	0.426	0.682	0.826	0.090	2.307	1.000	4.807	1.444	1.077	0.323	2.256
E arg	1.960	1.217	0.100	1.214	0.399	0.510	0.605	2.464	2.634	0.331	6.389	2.761	2.570	0.786	1.678
E gul	2.225	1.202	0.077	1.307	0.436	0.517	0.587	3.038	2.393	0.331	4.416	3.001	3.064	1.114	2.074
E hav	2.194	1.020	0.083	1.123	0.456	0.544	0.629	2.542	2.419	0.354	4.244	3.106	3.024	0.970	1.932
E lef	2.101	0.982	0.094	1.044	0.503	0.513	0.609	2.252	2.497	0.395	4.409	3.272	3.028	0.886	1.662
E mel	2.652	1.134	0.107	1.101	0.451	0.572	0.586	2.833	2.105	0.350	3.873	3.432	3.374	0.775	1.913
E bra	3.329	1.174	0.104	1.230	0.269	0.485	0.549	3.251	1.900	0.314	4.683	3.325	2.820	0.707	2.129
E lyr	0.920	0.161	0.334	0.861	0.339	0.267	0.736	1.512	4.337	0.590	3.098	1.413	0.871	1.199	2.996
G lut	1.717	0.543	0.107	1.231	0.270	0.496	0.625	2.822	5.360	0.352	2.665	2.068	1.563	1.317	1.679
G oce	2.630	0.473	0.410	1.359	0.418	0.265	0.834	1.477	1.935	0.590	2.023	1.273	0.564	0.961	4.055
G sto	1.603	0.434	0.544	0.969	0.265	0.298	0.786	1.742	2.729	0.656	2.134	1.701	0.636	1.196	5.564
H par	2.568	0.615	0.257	1.670	0.209	0.454	0.643	2.350	2.289	0.398	3.399	2.637	1.979	0.915	1.649
H cor	2.282	0.525	0.194	1.437	0.270	0.485	0.661	2.028	2.336	0.329	3.485	2.247	1.720	0.882	1.717
H_sp	2.868	0	0.184	1.975	0.749	0.488	0.678	2.306	2.004	0.144	4.109	2.833	3.208	0.706	1.426
H rei	1.964	0	0.006	1.366	0.366	0.390	0.627	13.955	3.356	0.953	1.096	0	0	0	0.046
H gut	5.034	0	0.050	0.719	0	0.257	0.672	0.082	1.530	0	0	0	0	0	0
H uni	2.511	0	0.311	1.148	0.683	0.653	0.596	1.653	1.942	0.760	2.986	3.593	2.169	0.900	3.748
L lae	0.912	0	0.101	0.810	0.443	0.433	0.696	1.392	4.547	0.532	1.501	2.966	0.985	1.225	1.379
L bre	0.571	0.538	0.393	1.723	0.527	0.439	0.675	2.284	6.340	0.455	5.806	1.788	0.246	0.237	4.141
L piq	2.458	0	0.107	1.949	0.771	0.567	0.645	2.378	2.201	0.114	3.433	2.692	2.933	0.526	1.686
L ale	2.725	0.266	0.262	1.533	0.381	0.421	0.751	2.520	2.269	0.330	3.194	1.925	1.502	1.144	1.874
L ana	2.881	0.313	0.323	1.634	0.309	0.393	0.735	2.592	2.032	0.314	3.440	2.317	1.782	0.939	2.079
L apo	2.849	0.302	0.275	1.614	0.279	0.418	0.710	2.424	2.048	0.311	3.534	2.032	1.509	1.059	1.895
L gri	3.286	0.326	0.251	1.659	0.287	0.381	0.744	2.307	1.887	0.344	4.028	2.072	1.689	0.973	1.698
L joc	1.327	0.439	0.240	2.012	0.330	0.484	0.686	2.430	3.608	0.332	2.971	1.626	1.233	1.306	1.466
L gro	2.722	0	0.445	3.263	0.450	0.515	0.657	2.698	1.961	0.181	4.018	2.454	2.672	0.469	2.610
M mar	2.808	0.476	0.228	1.127	0.279	0.376	0.708	1.713	2.037	0.290	3.793	2.137	1.334	0.854	2.321
M fur	2.978	0.528	0.196	1.040	0.221	0.368	0.697	2.543	1.967	0.373	5.197	2.923	1.171	0.706	2.001
M cos	1.550	0	0.097	1.670	0.708	0.422	0.554	3.102	3.093	0.128	3.995	2.509	2.572	0.637	1.376

M cur	3.557	0.874	0.202	1.164	0.466	0.502	0.578	1.716	1.756	0.711	3.047	3.278	2.956	0.591	2.348
M cuv	3.226	0.954	0.151	1.178	0.414	0.533	0.603	1.563	1.852	0.769	3.304	2.495	2.122	0.697	1.607
M liz	3.963	0.622	0.151	0.978	0.455	0.480	0.622	1.369	1.617	0.713	3.508	2.299	1.817	0.538	1.812
M rub	3.967	0.936	0.167	1.023	0.441	0.545	0.572	1.733	1.696	0.711	3.615	2.549	2.379	0.614	1.677
*M*_sp	0.706	0.853	0.158	0.803	0.639	0.504	0.604	1.875	5.611	0.704	3.638	2.945	1.841	0.430	2.256
M bon	3.136	0.385	0.444	1.944	0.416	0.383	0.733	2.281	1.854	0.397	2.915	1.875	1.217	1.041	2.548
M oce	3.796	0	0.455	0.988	0.254	0.293	0.657	1.140	1.267	0	0	0	0	0	0
O ves	3.382	0.504	0.109	0.794	0.237	0.137	0.750	0.408	1.956	1.000	1.261	2.667	1.149	1.265	0.887
O pal	2.049	0	0.424	2.158	0.650	0.472	0.611	3.354	2.595	0.432	3.566	5.324	2.634	0.581	2.311
O sau	2.092	0	0.405	2.447	0.676	0.489	0.624	3.558	2.361	0.444	3.770	4.703	2.367	0.496	2.304
O ogl	2.207	0	0.119	2.538	0.757	0.455	0.709	2.656	2.369	0.187	5.469	2.649	2.454	0.496	1.351
O nil	3.929	0.526	0.150	1.197	0.620	0.419	0.719	2.299	1.677	0.293	4.688	1.339	1.027	1.795	1.571
O sca	3.453	0.464	0.183	1.289	0.318	0.468	0.745	2.423	1.800	0.376	1.833	2.545	1.141	0.949	2.467
P bra	3.831	0	0.314	3.285	0.402	0.632	0.891	0.141	1.580	1.000	2.891	2.016	1.537	0.298	2.941
P ret	0.543	0.100	0.795	0.658	0.159	0.858	0.630	1.519	7.484	0.514	3.455	1.524	1.053	0.404	1.638
P vir	2.949	0	0.497	1.507	0.287	0.643	0.749	2.624	1.900	0.129	5.209	2.753	2.669	0.449	2.877
P pun	2.240	0.291	0.754	0.866	0.331	0.455	0.780	1.021	2.315	0.204	1.255	3.358	0.365	3.701	17.395
P bre	2.248	0	0.304	0.821	0.673	0.427	0.530	3.130	2.326	0.155	5.213	3.055	3.143	0.320	1.708
P nod	0.658	0	0.456	0.927	0.283	0.403	0.430	1.386	5.901	0.083	7.223	2.226	1.423	0.170	1.241
R ama	1.202	0	0.143	1.868	0.745	0.489	0.652	3.144	3.479	0.159	3.406	2.292	2.623	0.587	2.780
S her	3.012	0	0.252	0.708	0.392	0.423	0.693	1.058	1.930	0.126	4.140	3.340	2.558	0.629	1.605
S par	2.894	0	0.326	0.641	0.434	0.398	0.694	1.021	2.049	0.165	6.007	3.170	2.272	0.676	1.487
S pro	3.295	0	0.334	0.720	0.288	0.390	0.708	0.884	1.892	0.114	4.111	3.786	2.312	0.632	1.414
S bra	1.399	0	0.700	3.073	0.450	0.488	0.715	2.396	2.915	0.607	0.501	4.344	0.426	0.551	11.038
S plu	3.612	0.473	0.374	1.016	0.473	0.241	0.804	1.589	1.833	0.382	2.577	2.075	1.031	2.074	2.340
S vom	2.730	0	0.082	3.803	0.288	0.152	0.595	7.493	2.216	0.486	4.804	7.865	4.378	1.231	1.936
S rho	4.709	0	0.190	1.175	0.615	0.350	0.721	3.479	1.520	0.177	4.541	5.933	4.618	0.394	1.198
S rad	3.263	0	0.097	1.246	0.571	0.297	0.781	2.285	1.858	0.334	2.538	1.915	1.475	1.100	1.711
S gre	2.475	0	0.103	0.850	0.449	0.216	0.773	0.915	2.215	0.417	1.506	2.437	1.067	0.832	1.411
S spe	2.407	0	0.093	0.919	0.486	0.218	0.709	0.849	2.259	0.434	1.118	2.506	1.125	1.125	1.300
S tes	3.975	0	0.094	0.845	0.419	0.229	0.810	0.869	1.678	0.437	2.139	2.689	1.149	0.581	1.640
S bar	2.979	0	0.617	2.578	0.610	0.491	0.686	1.674	1.805	0.416	3.261	2.650	2.047	0.466	2.493
S gua	2.919	0	0.555	2.482	0.476	0.536	0.607	1.872	1.771	0.379	3.801	3.008	2.509	0.474	2.401
S not	2.293	0	0.921	0.414	0.112	0.862	0.564	1.898	2.277	0.140	4.389	1.712	1.190	0.358	1.232
S nas	2.485	0.635	0.171	1.085	0.262	0.461	0.640	1.871	2.281	0.366	4.535	1.946	1.132	0.712	1.835
S mar	3.861	0	1.120	3.558	0.618	0.626	0.632	1.003	1.400	0.715	3.837	4.174	1.792	1.151	3.855
S tim	3.830	0	1.115	3.549	0.627	0.635	0.621	1.012	1.412	0.724	3.848	4.163	1.781	1.162	3.843
S tss	2.572	0	0.111	2.100	0.545	0.483	0.903	0.197	2.264	1.000	0	1.066	0.658	0	0.154
S pel	0.247	0	0.098	1.500	0.637	0.265	0.429	1.296	7.802	0	0	1.964	0.859	0	1.501
*S*_sp	0.246	0	0.100	1.511	0.629	0.269	0.440	1.310	7.813	0	0	1.955	0.870	0	1.550
S bon	2.456	0	0.877	1.517	0.474	0.361	0.745	0.640	2.022	0.594	3.861	2.219	1.401	0.718	1.468
S foe	3.050	0	0.922	1.349	0.405	0.422	0.705	0.873	1.744	0.434	3.198	3.538	2.330	0.657	2.054
T nat	3.378	0.245	0.316	0.323	1.000	0.199	0.913	0.495	1.875	1.000	1.963	2.698	1.406	2.121	2.165
T car	1.751	0.385	0.175	1.977	0.578	0.426	0.654	3.846	2.929	0.366	3.347	3.692	2.450	0.671	1.500
T fal	3.514	0.667	0.086	1.374	0.278	0.355	0.524	4.232	1.871	0.404	3.037	5.069	3.050	0.667	1.233
T pau	3.704	0	0116	1.149	0.458	0.530	0.855	0.132	1.665	1.000	4.431	1.478	1.252	0.012	1.603

Appendix 4

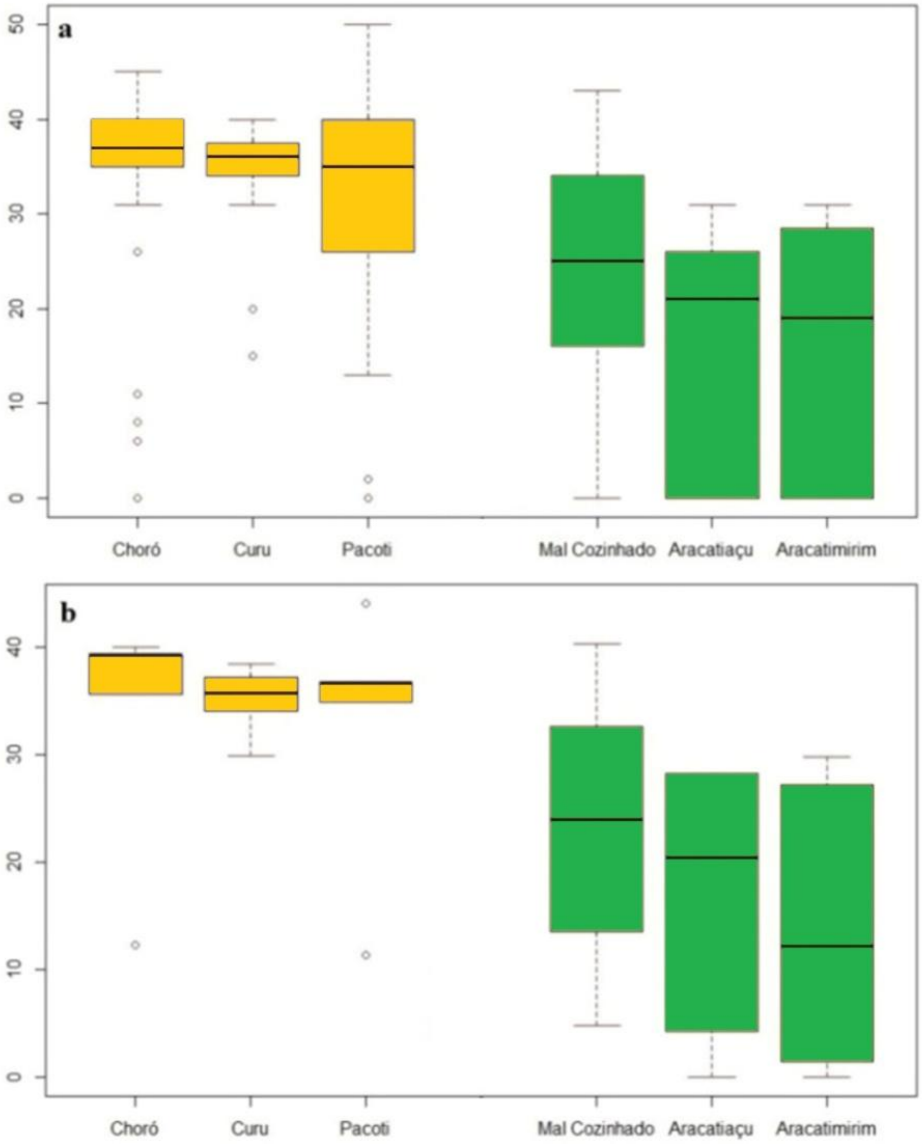

Fig. S4.1 Variation in salinity in the sampled estuaries based on (a) the complete set of raw data and (b) mean salinity values during each campaign

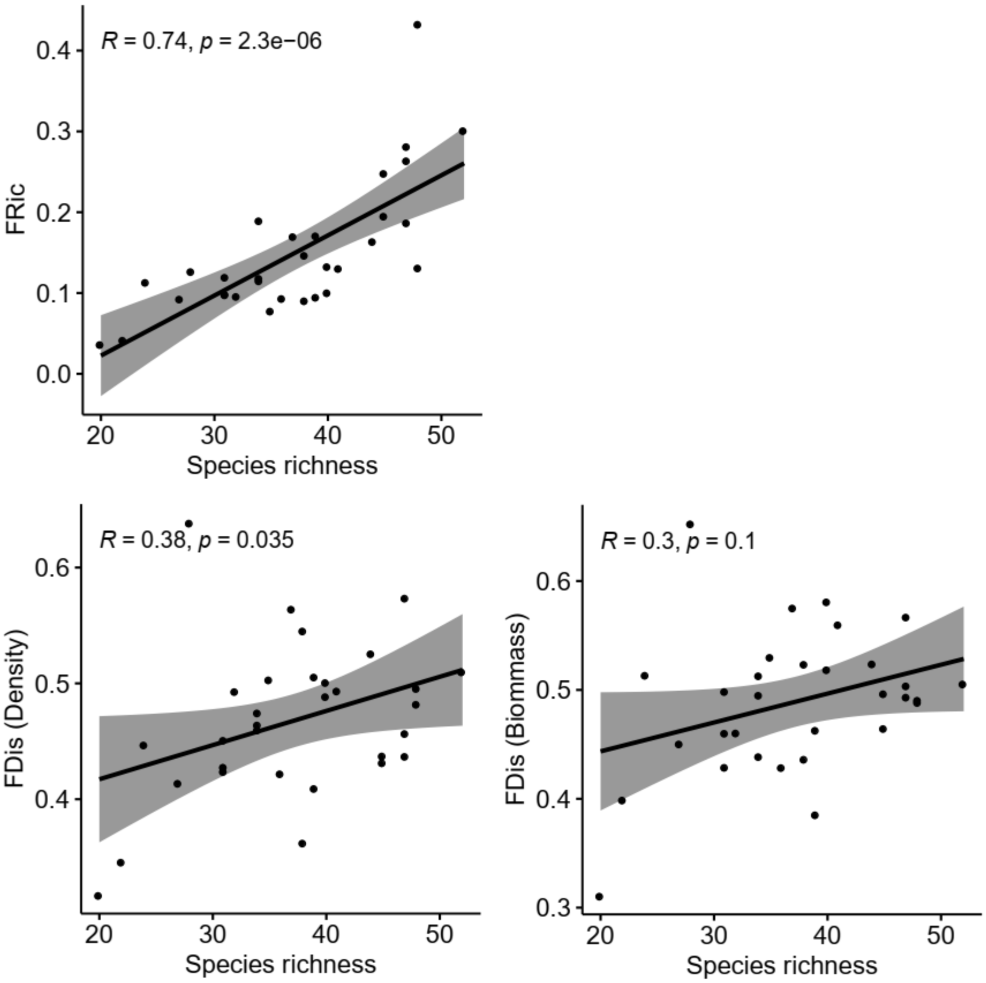

Fig. S4.2 Spearman's correlations between species richness and mean FRic and FDis in the estuaries (mean values during each campaign)

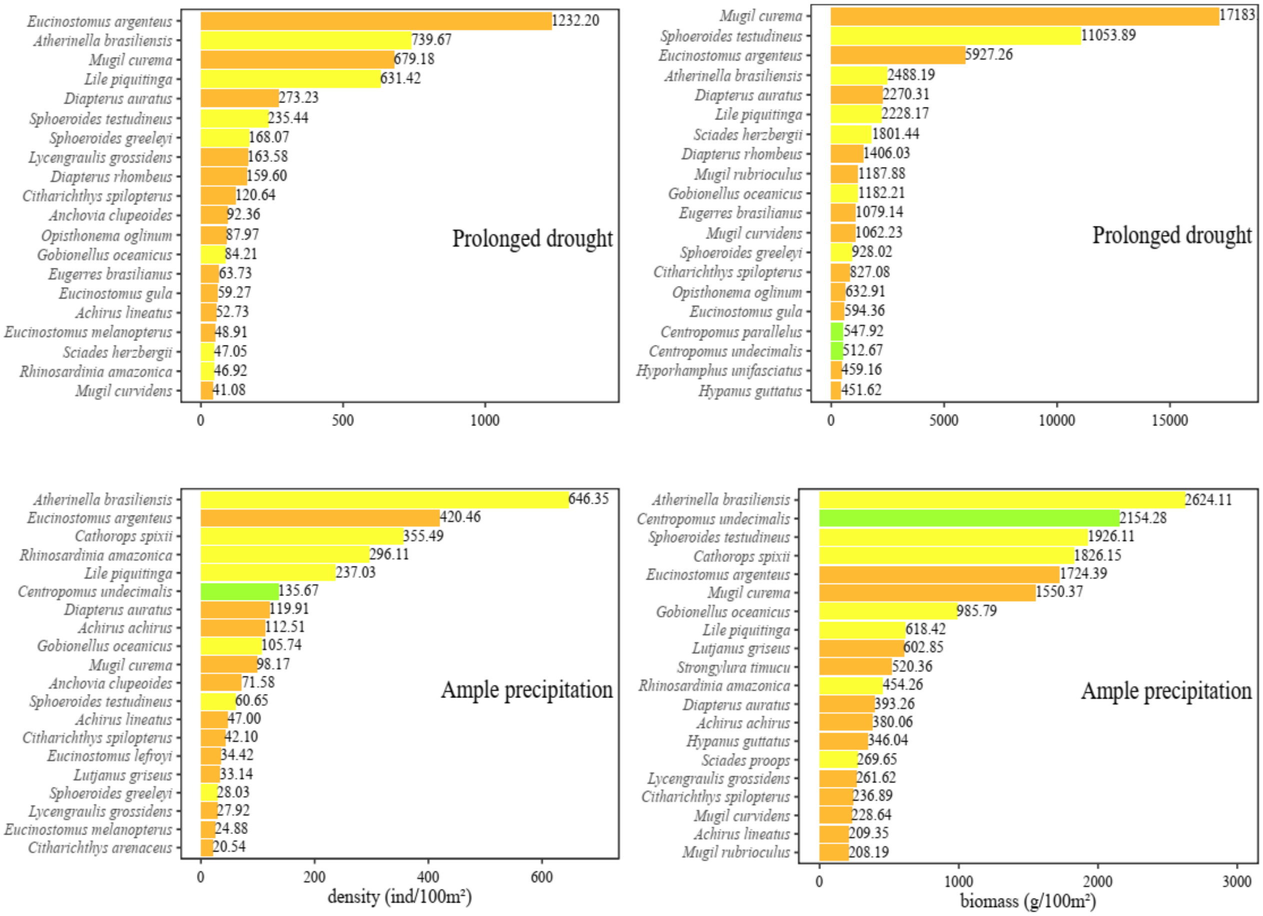

Fig. S4.3 Ranking of species abundance based on total density (ind/100m²) and biomass values (g/100 m²) for estuaries impacted by prolonged drought (Choró, Curu and Pacoti) and estuaries exposed to ample precipitation (Malcozinhado, Aracatimirim and Aracatiaçu). Use guilds: marine migrants (MM, orange), estuarine species (ES, yellow) and diadromous fishes (DI, green)

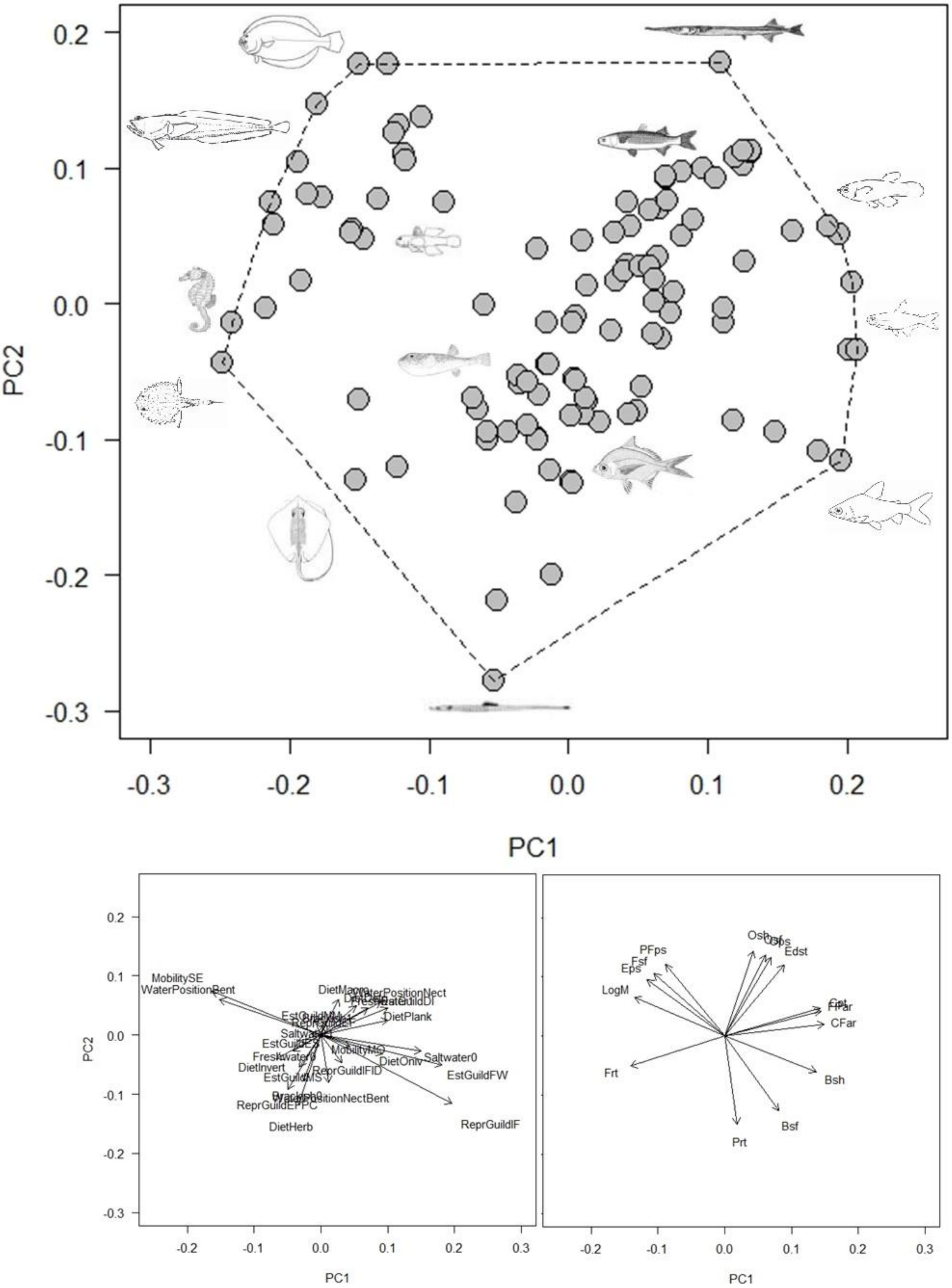

Fig. S4.4 PCoA ordination plot for the first two axes, showing 22 functional traits of 110 species. The plots below show categorical and ecomorphological traits, respectively. Abbreviations in Table S3.1

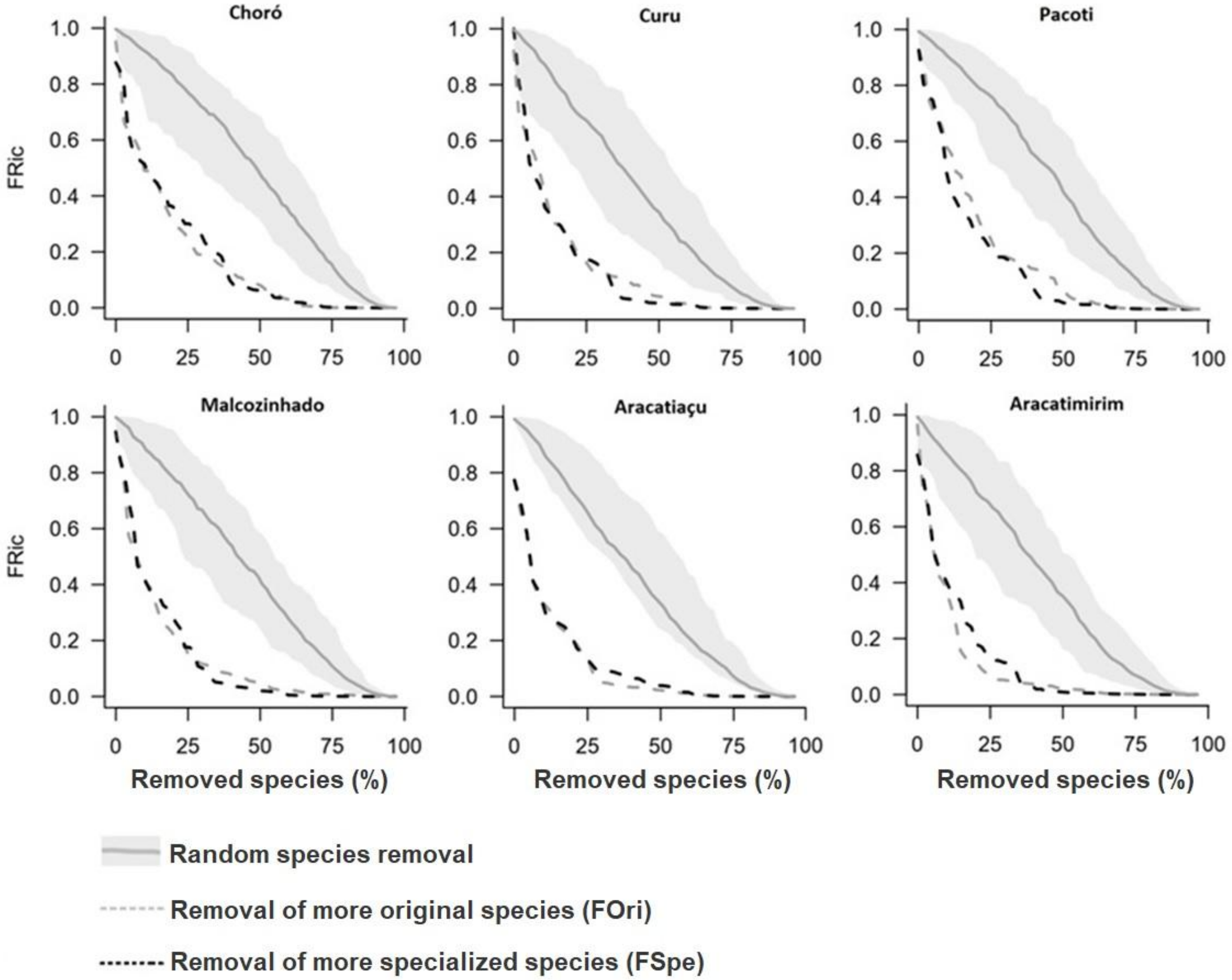

Fig. S4.5 Effect of the removal of the most original (FOri) and specialized (FSpe) species on functional richness (FRic) in each assemblage. Prolonged drought: Choró, Curu and Pacoti. Ample precipitation: Malcozinhado, Aracatiaçu and Aracatimirim. Hypersaline estuaries: Choró, Curu, Pacoti and Malcozinhado. Non-hypersaline estuaries: Aracatiaçu and Aracatimirim

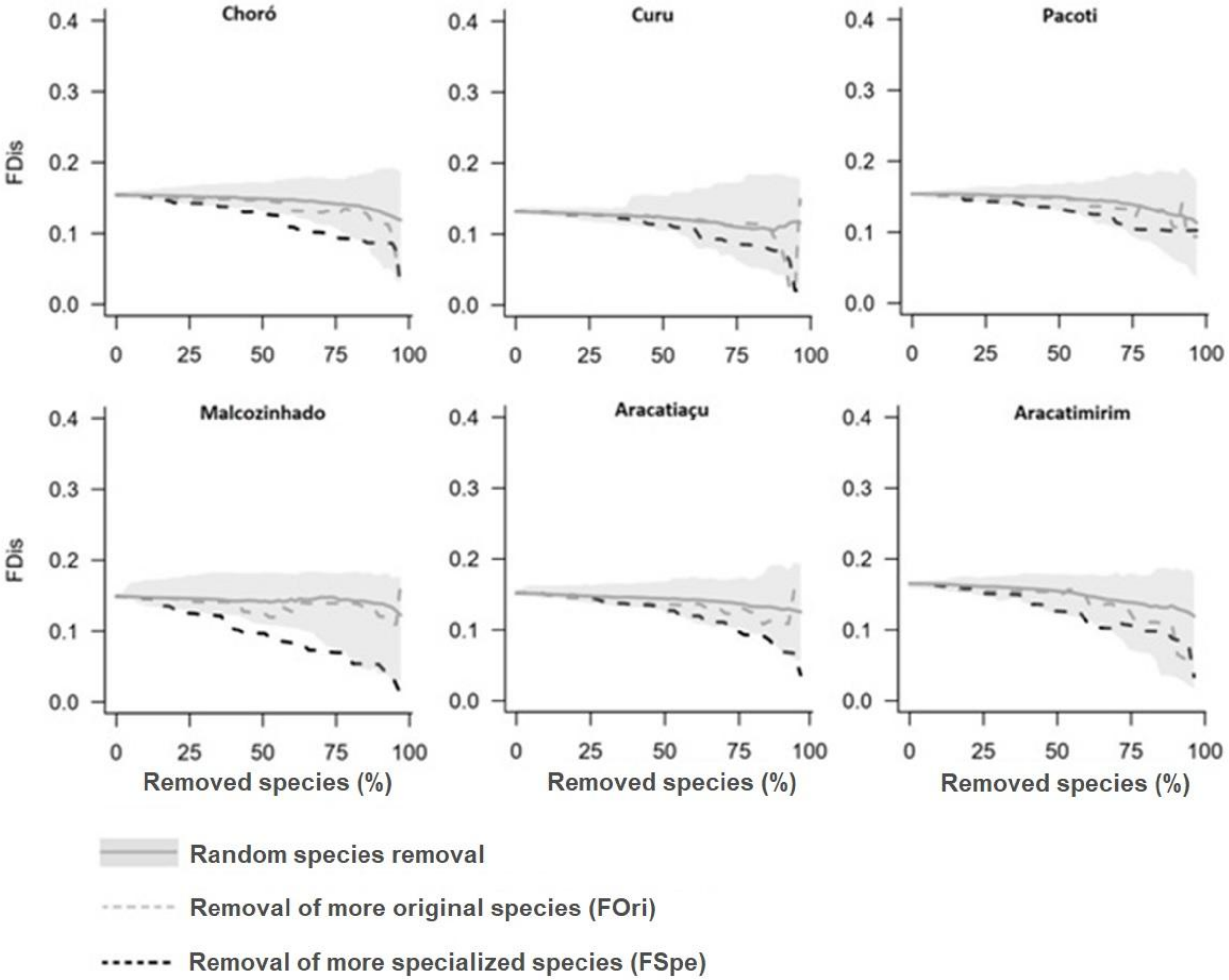

Fig. S4.6 Effect of the removal of the most original (FOri) and specialized (FSpe) species on functional dispersion (FDis) in each assemblage. Prolonged drought: Choró, Curu and Pacoti. Ample precipitation: Malcozinhado, Aracatiaçu and Aracatimirim. Hypersaline estuaries: Choró, Curu, Pacoti and Malcozinhado. Non-hypersaline estuaries: Aracatiaçu and Aracatimirim

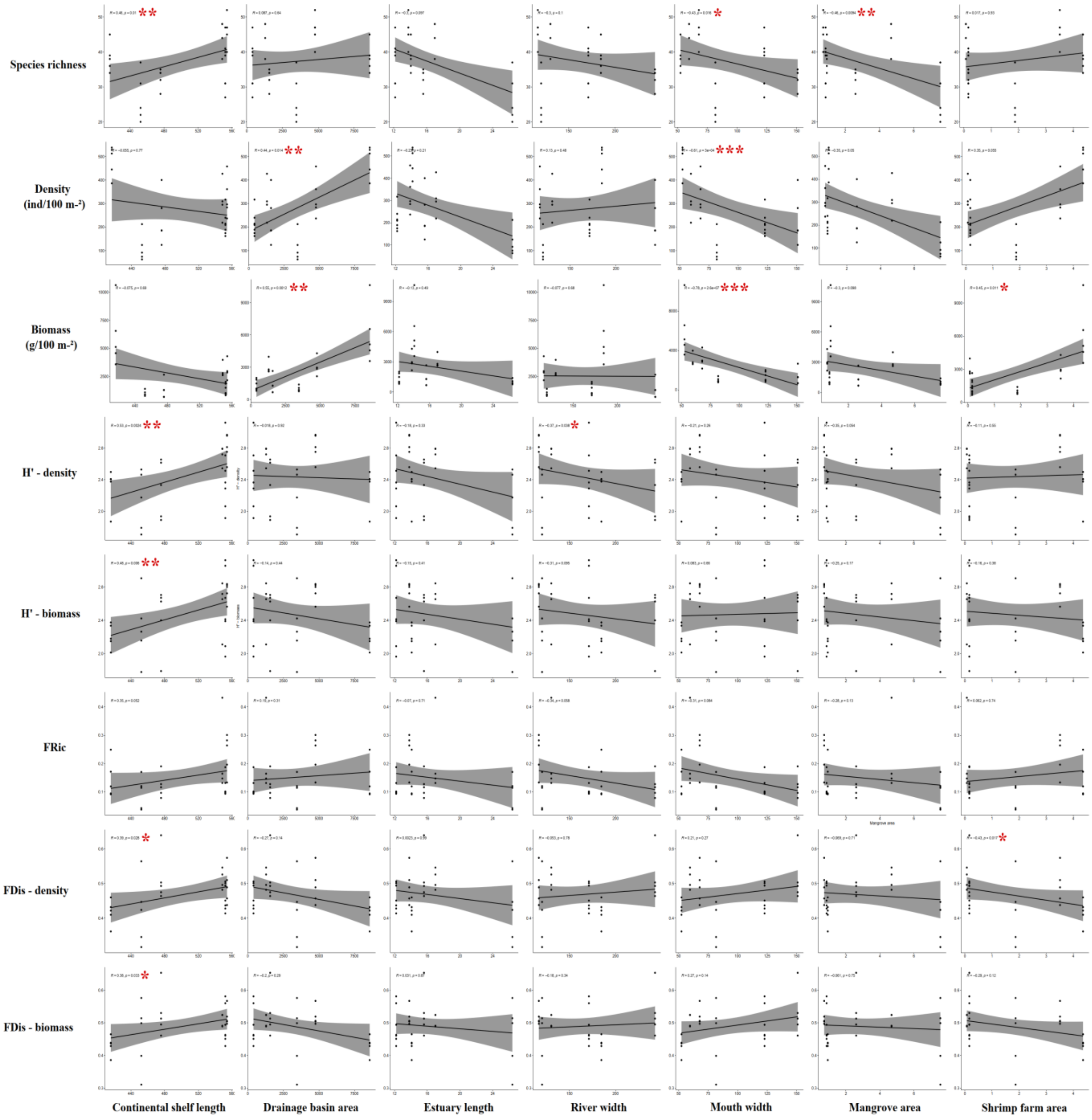

Fig. S4.7 Spearman's correlations between characteristics of estuaries and biodiversity facets (*** < 0.001; ** < 0.01, * < 0.05 p-values).

Table S4.1 Density (individuals per 100 m^2) of the species collected in each estuary. Bold = relative density above 1% in the assemblage. SIMPER p-value in the last column (*** < 0.001; ** < 0.01, * < 0.05, “.” < 0.10) (Prolonged drought vs Ample precipitation)

		Density (individuals/100 m^2)						
		Prolonged drought			Ample precipitation			p-value
Species	Code	Choró	Curu	Pacoti	Malcozinhado	Aracatiaçu	Aracatimirim	
Abudefduf saxatilis	Asax	---	---	---	0.67	---	---	
Acanthurus bahianus	Abah	---	---	---	0.67	---	---	
Achirus achirus	Aach	10.45	12.63	**17.72**	**28.57**	**15.59**	**68.35**	
Achirus lineatus	Alin	14.88	**24.41**	13.44	13.73	3.17	**30.10**	
Albula vulpes	Avul	---	0.33	---	0.33	---	---	
Anableps anableps	Aana	---	10.00	---	---	---	---	***
Anchoa hepsetus	Ahep	13.32	---	---	0.25	---	6.17	
Anchoa spinifer	Aspi	15.25	0.75	---	---	---	---	***
Anchovia clupeoides	Aclu	**68.96**	11.90	11.50	**52.33**	**8.25**	11.00	
Anchoviella brevirostris	Abre	---	---	---	0.67	---	---	
Antennarius striatus	Astr	0.59	---	---	---	0.25	---	
Archosargus probatocephalus	Apro	---	1.95	---	---	---	---	***
Archosargus rhomboidalis	Arho	1.70	9.49	0.25	---	0.63	---	*
Astyanax bimaculatus	Abim	---	1.67	0.17	1.42	0.42	1.34	
Atherinella brasiliensis	Abra	**264.42**	**318.07**	**157.18**	**430.71**	**133.33**	**82.31**	
Bathygobius soporator	Bsop	9.94	4.28	8.84	4.50	1.42	0.75	.
Batrachoides surinamensis	Bsur	0.48	0.17	---	0.50	0.26	5.92	
Bothus ocellatus	Boce	0.91	---	---	---	---	---	***
Bryx dunckeri	Bdun	---	0.25	---	---	---	---	***
Caranx latus	Clat	14.75	11.62	13.49	7.05	6.49	3.59	.
Cathorops spixii	Cspx	8.94	11.33	5.83	3.33	**23.33**	**328.23**	
Cetengraulis edentulus	Cede	8.74	1.19	---	2.42	---	0.88	
Centropomus parallelus	Cpar	---	---	**33.50**	---	---	---	.
Centropomus undecimalis	Cund	2.17	13.77	0.27	**40.98**	**41.98**	**52.71**	***
Chaetodipterus faber	Cfab	4.84	0.50	1.08	0.58	---	0.25	*
Citharichthys arenaceus	Care	1.74	---	3.72	---	5.53	**15.01**	
Citharichthys spilopterus	Cspi	**53.69**	19.44	**47.51**	14.42	**8.59**	**19.09**	*
Ctenogobius boleosoma	Cbol	0.99	0.17	0.50	14.71	1.17	3.50	*
Ctenogobius smaragdus	Csma	---	---	---	1.00	0.67	0.25	
Ctenogobius	Csti	---	0.25	0.33	0.25	---	---	

stigmaticus								
Cynoscion acoupa	Caco	---	---	3.94	---	---	---	***
Dactylopterus volitans	Dvol	---	---	0.63	---	---	---	***
Diapterus auratus	Daur	**38.40**	**72.99**	**161.84**	**60.76**	**12.11**	**47.04**	
Diapterus rhombeus	Drho	**47.44**	**63.98**	**48.18**	2.41	---	3.75	***
Elops saurus	Esau	1.54	---	12.68	3.41	4.10	3.67	
Etropus crossotus	Ecro	---	---	0.38	---	---	1.25	
Eucinostomus argenteus	Earg	**271.39**	**669.35**	**291.46**	**207.06**	**61.51**	**151.89**	*
Eucinostomus gula	Egul	**25.49**	**30.58**	3.20	14.73	1.11	1.82	.
Eucinostomus havana	Ehav	1.60	2.00	8.67	3.61	---	---	.
Eucinostomus lefroyi	Elef	3.75	9.22	3.00	**16.92**	1.00	**16.50**	
Eucinostomus melanopterus	Emel	14.17	**27.01**	7.73	**18.79**	1.00	5.08	
Eugerres brasilianus	Ebra	**18.23**	**36.55**	8.95	4.81	3.77	1.67	**
Evosthodus lyricus	Elyr	---	---	0.67	---	0.33	---	
Genyatremus luteus	Glut	1.80	---	---	0.50	---	1.85	
Gobionellus oceanicus	Goce	**32.88**	**32.87**	**18.46**	**101.49**	0.25	4.00	
Gobionellus stomatus	Gsto	2.08	6.84	6.33	11.92	---	3.25	
Haemulon parra	Hpar	0.45	4.43	---	3.73	---	---	
Haemulopsis corvinaeformis	Hcor	9.60	7.42	4.77	**15.23**	0.77	0.42	
Harengula sp.	H_sp	---	---	---	0.75	---	---	
Hippocampus reidi	Hrei	1.00	2.43	0.17	0.25	0.25	---	
Hypanus guttatus	Hgut	0.92	---	2.21	2.07	---	0.83	
Hyporhamphus unifasciatus	Huni	0.50	13.50	9.34	11.38	1.83	4.67	
Lagocephalus laevigatus	Llae	0.38	---	---	0.25	---	---	
Larimus breviceps	Lbre	---	---	---	---	---	0.50	
Lile piquitinga	Lpiq	**64.13**	**337.54**	**229.75**	**86.49**	**36.71**	**113.83**	
Lutjanus alexandrei	Lale	3.55	2.71	1.50	2.41	0.88	---	
Lutjanus analis	Lana	9.54	4.70	3.65	1.41	0.25	2.41	*
Lutjanus apodus	Lapo	0.75	1.04	2.99	7.49	2.88	4.97	
Lutjtanus griseus	Lgri	4.39	9.93	4.19	13.39	**9.43**	10.32	*
Lutjanus jocu	Ljoc	0.45	3.25	---	---	---	0.25	.
Lycengraulis grossidens	Lgro	**105.10**	**29.13**	**29.35**	8.59	**10.09**	9.24	*
Menticirrhus martinicensis	Mmar	0.50	---	---	1.44	---	0.92	
Micropogonias furnieri	Mfur	1.37	0.67	9.41	---	---	---	***
Moenkhausia costae	Mcos	0.25	---	0.25	---	---	---	***
Mugil curema	Mcur	**145.55**	**406.59**	**127.04**	**63.55**	**30.27**	4.35	***
Mugil curvidens	Mcuv	11.51	**29.24**	0.33	11.39	2.21	0.75	
Mugil liza	Mliz	3.53	---	---	0.48	---	---	.
Mugil rubrioculus	Mrub	10.33	11.67	1.87	2.44	3.06	---	
Mugil sp. (juveniles)	M_sp	**34.75**	---	0.50	6.79	4.58	1.92	
Mycteroperca bonaci	Mbon	0.17	---	---	1.00	---	---	

Myrichthys ocellatus	Moce	1.50	0.63	0.17	---	---	---	***
Ogcocephalus vespertilio	Oves	0.50	---	---	---	0.63	---	
Oligoplites palometa	Opal	1.08	1.50	**38.13**	1.13	0.63	0.25	.
Oligoplites saurus	Osau	2.29	1.29	2.33	0.58	0.25	0.25	**
Opisthonema oglinum	Oogl	**54.34**	---	**33.63**	**16.41**	---	---	
Oreochromis niloticus	Onil	---	---	---	---	**6.83**	0.59	
Orthopristis scapularis	Osca	---	---	0.25	---	---	---	***
Paralichthys brasiliensis	Pbra	0.33	1.91	---	---	0.78	1.53	
Poecilia reticulata	Pret	---	---	0.17	---	---	---	***
Polydactylus virginicus	Pvir	---	---	0.48	---	---	---	***
Prionotus punctatus	Ppun	0.33	---	0.63	---	---	---	***
Prochilodus brevis	Pbre	---	---	---	0.50	---	---	
Pseudauchenipterus nodosus	Pnod	---	---	---	---	---	0.25	
Rhinosardinia amazonica	Rama	40.75	6.17	---	**114.83**	**79.94**	**101.34**	
Sciades herzbergii	Sher	**24.15**	12.76	10.14	0.75	0.26	1.60	***
Sciades parkeri	Spar	**17.51**	1.93	---	0.25	---	---	**
Sciades proops	Spro	---	---	---	8.83	4.83	5.21	
Scomberomorus brasiliensis	Sbra	0.25	---	---	---	---	---	***
Scorpaena plumieri	Splu	3.06	---	0.17	0.67	---	---	.
Selene vomer	Svom	2.33	0.33	3.34	0.77	---	---	*
Serrasalmus rhombeus	Srho	0.50	---	---	---	---	---	***
Sparisoma radians	Srad	9.01	6.16	4.25	4.00	---	---	*
Sphoeroides greeleyi	Sgre	**30.47**	**39.24**	**98.36**	**22.37**	1.17	4.49	*
Sphoeroides spengleri	Sspe	1.33	---	---	---	---	---	***
Sphoeroides testudineus	Stes	**69.23**	**55.50**	**110.71**	**18.14**	**19.97**	**22.54**	*
Sphyraena barracuda	Sbar	---	1.38	4.66	1.39	---	---	
Sphyraena guachancho	Sgua	---	---	---	0.25	---	---	
Steindachnerina notonota	Snot	---	---	---	---	0.25	---	
Stellifer naso	Snas	---	---	7.21	0.25	---	4.36	
Strongylura marina	Smar	4.92	5.50	3.67	4.79	0.25	1.42	
Strongylura timucu	Stim	0.33	3.15	9.34	4.08	**8.16**	2.75	
Symphurus tessellatus	Stss	1.58	---	1.50	---	---	0.25	*
Syngnathus pelagicus	Spel	0.83	0.50	---	---	---	0.25	
Syngnathus sp.	S_sp	---	---	0.17	---	0.17	---	
Synodus bondi	Sbon	---	---	---	---	---	0.71	
Synodus foetens	Sfoe	2.59	---	---	---	---	0.25	.
Thalassophryne	Tnat	---	---	0.67	---	0.50	---	

nattereri								
Trachinotus carolinus	Tcar	---	---	---	0.25	---	---	
Trachinotus falcatus	Tfal	0.37	3.02	0.17	0.42	---	---	
Trinectes paulistanus	Tpau	2.85	0.17	1.29	0.50	3.26	2.33	
TOTAL (ind/100 m²)		1636.73	2410.93	1650.16	1507.16	565.53	1177.56	
Species richness	110	78	63	70	74	54	61	

Table S4.2 Biomass (grams per 100 m^2) of the species collected in each estuary. Bold = relative biomass above 1% in the assemblage. SIMPER p-value in the last column (*** < 0.001; ** < 0.01, * < 0.05, “.” < 0.10) (Prolonged drought vs Ample precipitation)

		Biomass (grams/100 m^2)						
		Prolonged drought			Ample precipitation			
Species	Code	Choró	Curu	Pacoti	Malcozinhado	Aracatiaçu	Aracatimirim	p-value
Abudefduf saxatilis	Asax	---	---	---	25.02	---	---	
Acanthurus bahianus	Abah	---	---	---	24.45	---	---	
Achirus achirus	Aach	**212.53**	8.26	74.16	81.77	**51.05**	**247.24**	
Achirus lineatus	Alin	94.92	61.03	50.68	57.56	5.60	**146.19**	
Albula vulpes	Avul	---	4.02	---	0.17	---	---	
Anableps anableps	Aana	---	49.33	---	---	---	---	***
Anchoa hepsetus	Ahep	18.62	---	---	0.04	---	1.66	
Anchoa spinifer	Aspi	12.87	0.35	---	---	---	---	***
Anchovia clupeoides	Aclu	**272.90**	17.29	81.59	64.99	25.98	13.58	
Anchoviella brevirostris	Abre	---	---	---	0.17	---	---	
Antennarius striatus	Astr	16.55	---	---	---	29.76	---	
Archosargus probatocephalus	Apro	---	21.07	---	---	---	---	***
Archosargus rhomboidalis	Arho	20.03	76.59	1.23	---	9.70	---	*
Astyanax bimaculatus	Abim	---	7.37	0.49	1.73	1.31	5.15	
Atherinella brasiliensis	Abra	**928.23**	**962.38**	**597.58**	**1516.00**	**841.84**	**266.27**	.
Bathygobius soporator	Bsop	92.29	58.53	52.77	71.63	4.74	3.95	
Batrachoides surinamensis	Bsur	4.11	24.52	---	15.79	2.48	**144.20**	
Bothus ocellatus	Boce	10.68	---	---	---	---	---	***
Bryx dunckeri	Bdun	---	0.05	---	---	---	---	***
Caranx latus	Clat	64.42	37.58	38.88	50.95	21.30	18.42	
Cathorops spixii	Cspx	104.08	60.88	91.72	21.85	**137.64**	**1666.66**	
Cetengraulis edentulus	Cede	72.93	11.20	---	5.32	---	4.94	.
Centropomus parallelus	Cpar	---	---	**547.92**	---	---	---	.
Centropomus undecimalis	Cund	64.20	**432.30**	16.16	**719.47**	**633.52**	**801.29**	***
Chaetodipterus faber	Cfab	42.44	24.41	4.92	0.92	---	0.04	**
Citharichthys arenaceus	Care	18.05	---	49.88	---	40.07	**111.63**	
Citharichthys spilopterus	Cspi	**354.59**	163.38	**309.11**	74.96	**67.16**	**94.77**	
Ctenogobius boleosoma	Cbol	0.17	0.12	0.09	1.70	0.28	0.66	*

Ctenogobius smaragdus	Csma	---	---	---	1.50	1.04	0.16	
Ctenogobius stigmaticus	Csti	---	2.84	0.32	0.56	---	---	
Cynoscion acoupa	Caco	---	---	45.65	---	---	---	***
Dactylopterus volitans	Dvol	---	---	86.50	---	---	---	***
Diapterus auratus	Daur	**210.15**	**789.32**	**1270.84**	**178.52**	37.78	**176.96**	
Diapterus rhombeus	Drho	**371.09**	**373.70**	**661.24**	37.47	---	24.03	**
Elops saurus	Esau	39.92	---	134.77	**104.13**	28.94	21.66	
Etropus crossotus	Ecro	---	---	1.20	---	---	8.30	
Eucinostomus argenteus	Earg	**1201.08**	**3479.34**	**1246.84**	**769.26**	**367.60**	**587.53**	
Eucinostomus gula	Egul	**189.89**	**384.24**	20.23	81.06	5.24	17.37	*
Eucinostomus havana	Ehav	12.46	24.98	95.00	29.47	---	---	
Eucinostomus lefroyi	Elef	9.00	74.07	5.45	50.94	2.73	8.24	
Eucinostomus melanopterus	Emel	94.90	236.39	56.26	62.43	1.24	33.56	
Eugerres brasilianus	Ebra	**202.73**	**696.01**	**180.40**	**96.01**	26.28	7.07	**
Evosthodus lyricus	Elyr	---	---	0.57	---	0.62	---	
Genyatremus luteus	Glut	21.26	---	---	0.28	---	34.41	
Gobionellus oceanicus	Goce	**397.03**	**622.87**	**162.31**	**968.80**	1.73	15.27	
Gobionellus stomatus	Gsto	22.63	70.41	39.70	27.15	---	4.65	
Haemulon parra	Hpar	6.03	47.08	---	59.94	---	---	
Haemulopsis corvinaeformis	Hcor	103.37	190.22	69.57	**96.31**	7.28	3.07	.
Harengula sp.	H_sp	---	---	---	8.97	---	---	
Hippocampus reidi	Hrei	6.04	7.56	0.35	0.83	0.83	---	
Hypanus guttatus	Hgut	86.98	---	**364.64**	**265.53**	---	**80.51**	
Hyporhamphus unifasciatus	Huni	3.10	258.69	**197.38**	72.17	14.00	30.09	
Lagocephalus laevigatus	Llae	33.89	---	---	0.36	---	---	
Larimus breviceps	Lbre	---	---	---	---	---	0.28	
Lile piquitinga	Lpiq	**209.22**	**1420.54**	**598.41**	**320.25**	**149.73**	**148.43**	
Lutjanus alexandrei	Lale	19.80	33.69	7.56	30.15	39.08	---	
Lutjanus analis	Lana	118.75	63.71	19.07	80.83	13.85	8.63	
Lutjanus apodus	Lapo	3.77	11.88	94.82	57.70	40.63	**66.38**	
Lutjtanus griseus	Lgri	35.07	118.78	34.38	**215.09**	**230.04**	**157.72**	**
Lutjanus jocu	Ljoc	4.44	2.73	---	---	---	0.72	
Lycengraulis grossidens	Lgro	**158.28**	75.30	59.29	50.52	**121.66**	**89.45**	
Menticirrhus martinicensis	Mmar	14.43	---	---	26.04	---	16.22	
Micropogonias furnieri	Mfur	18.80	2.61	101.28	---	---	---	***

Moenkhausia costae	Mcos	0.56	---	0.58	---	---	---	***
Mugil curema	Mcur	**2702.02**	**12372.46**	**2109.36**	**1134.60**	**360.04**	55.73	***
Mugil curvidens	Mcuv	**210.52**	**849.00**	2.72	**158.58**	**50.48**	19.58	
Mugil liza	Mliz	**205.80**	---	---	4.26	---	---	.
Mugil rubrioculus	Mrub	**253.47**	**803.13**	131.29	**142.82**	**65.37**	---	
Mugil sp. (juveniles)	M_sp	5.08	---	0.07	7.65	0.48	0.24	
Mycteroperca bonaci	Mbon	0.04	---	---	23.11	---	---	
Myrichthys ocellatus	Moce	33.14	24.78	5.36	---	---	---	***
Ogcocephalus vespertilio	Oves	6.03	---	---	---	18.93	---	
Oligoplites palometa	Opal	4.82	23.04	61.41	11.68	4.91	0.85	
Oligoplites saurus	Osau	14.49	5.97	6.00	2.15	2.68	1.60	
Opisthonema oglinum	Oogl	**353.16**	---	**279.75**	**99.21**	---	---	
Oreochromis niloticus	Onil	---	---	---	---	**102.16**	35.05	
Orthopristis scapularis	Osca	---	---	7.65	---	---	---	***
Paralichthys brasiliensis	Pbra	24.60	41.67	---	---	48.18	30.53	
Poecilia reticulata	Pret	---	---	0.10	---	---	---	***
Polydactylus virginicus	Pvir	---	---	8.61	---	---	---	***
Prionotus punctatus	Ppun	2.24	---	6.53	---	---	---	***
Prochilodus brevis	Pbre	---	---	---	5.50	---	---	
Pseudauchenipterus nodosus	Pnod	---	---	---	---	---	0.26	
Rhinosardinia amazonica	Rama	109.28	9.92	---	**157.50**	**137.55**	**159.21**	
Sciades herzbergii	Sher	**873.78**	**827.54**	100.51	15.36	3.49	28.58	***
Sciades parkeri	Spar	**223.98**	18.96	---	1.33	---	---	**
Sciades proops	Spro	---	---	---	**191.31**	24.73	53.61	
Scomberomorus brasiliensis	Sbra	0.76	---	---	---	---	---	***
Scorpaena plumieri	Splu	64.96	---	2.36	12.22	---	---	
Selene vomer	Svom	14.69	0.39	37.44	11.31	---	---	
Serrasalmus rhombeus	Srho	0.30	---	---	---	---	---	***
Sparisoma radians	Srad	**165.91**	54.35	58.60	76.05	---	---	.
Sphoeroides greeleyi	Sgre	**245.41**	232.99	**449.62**	**103.42**	15.65	25.53	*
Sphoeroides spengleri	Sspe	14.28	---	---	---	---	---	***
Sphoeroides testudineus	Stes	**3458.99**	**3778.76**	**3816.14**	**344.62**	**680.20**	**901.29**	**
Sphyraena barracuda	Sbar	---	15.26	88.92	33.27	---	---	

Sphyraena guachancho	Sgua	---	---	---	4.70	---	---	
Steindachnerina notonota	Snot	---	---	---	---	1.87	---	
Stellifer naso	Snas	---	---	47.50	0.98	---	33.28	
Strongylura marina	Smar	61.64	82.56	59.14	64.81	5.04	30.05	
Strongylura timucu	Stim	9.60	155.17	137.11	62.09	**364.39**	**93.89**	
Symphurus tessellatus	Stss	30.49	---	16.92	---	---	0.54	**
Syngnathus pelagicus	Spel	0.03	0.06	---	---	---	0.07	
Syngnathus sp.	S_sp	---	---	0.03	---	0.01	---	
Synodus bondi	Sbon	---	---	---	---	---	8.25	
Synodus foetens	Sfoe	88.08	---	---	---	---	2.58	.
Thalassophryne nattereri	Tnat	---	---	16.51	---	15.20	---	
Trachinotus carolinus	Tcar	---	---	---	1.19	---	---	
Trachinotus falcatus	Tfal	3.53	136.69	3.11	5.66	---	---	
Trinectes paulistanus	Tpau	43.11	12.03	12.03	24.71	**135.60**	31.56	
TOTAL (g/100 m²)		15223.07	30452.30	14936.53	9125.02	4999.66	6579.60	
Species richness	110	78	63	70	74	54	61	

CONSIDERAÇÕES FINAIS

A presente tese traz dados e resultados robustos com informação básica para medidas de conservação e manejo dos estuários do estado do Ceará por meio do conhecimento de quais espécies ocorrem, suas vulnerabilidades no tocando suas raridades de ocorrência e papel nesses ecossistemas, assim como o entendimento inicial de como a dinâmica climática atua sobre esses conjuntos de espécies.

Nota-se que existem discrepâncias em número e abundância de espécies entre os estuários estudados, mostrando que podem haver necessidades de priorização de conservação para os rios mais diversos, assim como a mitigação de impactos ambientais que promovam essa discrepância nos estuários, principalmente no rio Cocó.

O efeito da seca prolongada traz luz a como esses sistemas se comportam perante menor fluxo de rio, também influenciado pelos barramentos. Isso mostra a necessidade de melhor regulação dos recursos hídricos a fim de não impactar o funcionamento original dos estuários. Além disso traz luz de como poderia ser o efeito de mudanças climáticas que agravem a situação de seca através de futuras comparações com o estudo atual.

CONCLUSÕES

Um total de 245 espécies de peixes foi registrado (126 espécies amostradas e 119 espécies compiladas da literatura/*Species*Link). A grande maioria das espécies são marinhas com ampla distribuição pelo oceano Atlântico. As Ordens mais representadas foram Acanthuriformes, Carangiformes e Clupeiformes. Houve menor riqueza de espécies de água doce, compreendende apenas 12% da ictiofauna.

Todos os estuários apresentaram muitas espécies de peixes raras. No geral, a raridade funcional teve correlação positiva com a raridade das espécies. Os estuários apresentaram assembleia de peixes com considerável redundância funcional. Mesmo assim, os estuários se apresentam muito redundantes para somente três entidades funcionais, enquanto na maioria das entidades houve poucas espécies. Logo, as assembleias ainda apresentam muitas exceções na comunidade quanto à redundância funcional, trazendo implicações importantes para o futuro desses ambientes.

Os ecossistemas estuarinos estudados tem seus perfis longitudinais de salinidade associados com secas prolongadas, modificando as estruturas taxonômica e functional das assembleias de peixes. Estuários influenciados pela seca prolongada apresentam maior abundância de espécies marinhas migrantes e marinhas visitantes. As espécies marinhas atraídas pela marinização aumentam a redundância functional dentro da comunidade, explicada pela menor erosão em riqueza funcional quando da exclusão de espécies funcionalmente diferenciadas.

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