



Universidade Federal do Rio Grande
Instituto de Ciências Biológicas
Pós-graduação em Biologia de
Ambientes Aquáticos Continentais



**Variabilidade temporal (1997-2019) de peixes
estuarino-residentes com atributos funcionais
distintos e suas relações com fatores ambientais e
climáticos**

Nuno Mussá Manuel Ussene Escamade

Orientador: Prof. Dr. Alexandre Miranda Garcia
Coorientador (a): Dra. Valeria Marques Lemos

Rio Grande
2025



Universidade Federal do Rio Grande
Instituto de Ciências Biológicas
Pós-graduação em Biologia de Ambientes
Aquáticos Continentais



**Variabilidade temporal (1997-2019) de peixes estuarino-residentes
com atributos funcionais distintos e suas relações com fatores
ambientais e climáticos**

Aluno: Nuno Mussá Manuel Ussene Escamade

Orientador: Prof. Dr. Alexandre Miranda Garcia

Coorientador (a): Dra. Valeria Marques Lemos

Dissertação apresentada ao Programa de
Pós-graduação em Biologia de Ambientes
Aquáticos Continentais como requisito
parcial para a obtenção do título de Mestre
em Biologia de Ambientes Aquáticos
Continentais.

Rio Grande
2025

E74v	Escamade, Nuno Mussá Manuel Ussene Variabilidade temporal (1997-2019) de peixes estuarino-residentes com atributos funcionais distintos e suas relações com fatores ambientais e climáticos / Nuno Mussá Manuel Ussene Escamade. – 2025. 54 f. Dissertação (Mestrado) – Universidade Federal do Rio Grande, Pós-graduação em Biologia de Ambientes Aquáticos Continentais. Orientador: Dr. Alexandre Miranda Garcia. Coorientadora: Dra. Valeria Marques Lemos. 1. Biologia Marinha. 2. Lagoa dos Patos 3. Colunas de água 4. El Niño I. Garcia, Alexandre Miranda II. Lemos, Valeria Marques III. Título. CDU 573(28)
------	---

Catlogação na fonte: Bibliotecário Clérison Ribeiro Ramos CRB10/1889

	MINISTÉRIO DA EDUCAÇÃO - UNIVERSIDADE FEDERAL DO RIO GRANDE (FURG) INSTITUTO DE CIÊNCIAS BIOLÓGICAS - ICB PROGRAMA DE PÓS-GRADUAÇÃO EM BIOLOGIA DE AMBIENTES AQUÁTICOS CONTINENTAIS	
---	--	---

**ATA DE DEFESA DE DISSERTAÇÃO DE MESTRADO EM BIOLOGIA DE
AMBIENTES AQUÁTICOS CONTINENTAIS – Nº 002/2025**

Às 08h30 (oito horas e trinta minutos) do dia 29 (vinte e nove) do mês de janeiro de 2025 (dois mil e vinte e cinco), via Webconferência, no link: <https://conferenciaweb.rnp.br/sala/glauco-cesar-dias-delevedove>, e presencialmente na sala de bioinformática do ICB-FURG, reuniram-se docentes, discentes e comunidade em geral, para a Defesa Pública da Dissertação de Mestrado do acadêmico **Nuno Mussá Manuel Ussene Escamade**. A Dissertação intitulada “**Variabilidade temporal (1997-2019) de peixes estuarino-residentes com atributos funcionais distintos e suas relações com fatores ambientais e climáticos**” foi avaliada pela Banca Examinadora composta pelo Prof. Dr. Alexandre Miranda Garcia (Orientador) e Dra Valeria Marques Lemos (Co-orientadora); Prof. Dr. Leonardo Maltchik Garcia (FURG) e Prof. Dr. André Luiz Machado Pessanha (UEPB). Após a defesa e arguição pública, a Banca Examinadora reuniu-se, para deliberação final, e considerou o acadêmico **APROVADA**. Desta forma, o acadêmico concluiu mais uma das etapas necessárias para a obtenção do grau de **MESTRE EM BIOLOGIA DE AMBIENTES AQUÁTICOS CONTINENTAIS**. Nada mais havendo a tratar, às 11h00h (onze horas) foi lavrada a presente ata, que lida e aprovada, foi assinada pelos membros da Banca Examinadora, pelo Acadêmico e pela Coordenadora do Curso.

Documento assinado digitalmente
 **ALEXANDRE MIRANDA GARCIA**
 Data: 29/01/2025 17:55:56-0300
 Verifique em <https://validar.iti.gov.br>

Prof. Dr. Alexandre Miranda Garcia

Documento assinado digitalmente
 **VALERIA MARQUES LEMOS**
 Data: 30/01/2025 13:48:48-0300
 Verifique em <https://validar.iti.gov.br>

Prof. Dra. Valeria Marques Lemos

Documento assinado digitalmente
 **LEONARDO MALTCHIK GARCIA**
 Data: 30/01/2025 10:45:58-0300
 Verifique em <https://validar.iti.gov.br>

Prof. Dr. Leonardo Maltchik Garcia

Documento assinado digitalmente
 **ANDRE LUIZ MACHADO PESSANHA**
 Data: 30/01/2025 07:47:21-0300
 Verifique em <https://validar.iti.gov.br>

Prof. Dr. André Luiz Machado Pessanha

Nuno Mussá Manuel Ussene Escamade

Nuno Mussá Manuel Ussene Escamade

Documento assinado digitalmente
 **CAMILA DE MARTINEZ GASPAR MARTINS**
 Data: 03/02/2025 09:14:18-0300
 Verifique em <https://validar.iti.gov.br>

Profª. Dra. Camila de Martinez Gaspar Martins
 Coordenadora do Curso

Fragmento da Carta do Cacique Seattle

“... Ensina a teus filhos o que temos ensinado aos nossos: a terra é nossa mãe.

Tudo quanto fere a terra - fere os filhos da terra. Se os homens cospem no chão, cospem sobre eles próprios. De uma coisa sabemos: A terra não pertence ao homem, é o homem que pertence à terra, disso temos certeza. Todas as coisas estão interligadas, como o sangue que une uma família. Tudo está relacionado entre si. Tudo quanto agride a terra, agride os filhos da terra. Não foi o homem quem teceu a trama da vida: ele é meramente um fio da mesma.

Tudo o que ele fizer à trama, a si próprio fará ...”

(Trecho Atribuído ao Pronunciamento do Cacique Indígena Seattle ao presidente norte-americano Franklin Pierce, 1854).

AGRADECIMENTOS

Concluir esta etapa é o resultado de uma trajetória desafiadora, marcada por esforços intensos e momentos de superação. Deixar Moçambique e partir para o Brasil, abrindo mão de tudo o que me era familiar, foi um dos maiores desafios que enfrentei. Ao longo dessa jornada, convivi com dúvidas e escolhas difíceis, mas também vivenciei conquistas que fortaleceram minha determinação. Cada obstáculo superado foi uma oportunidade de aprendizado que moldou não apenas meu conhecimento, mas também meu caráter. Esse caminho, embora árduo, foi profundamente transformador e enriquecedor.

Agradeço, com profundo entusiasmo e reverência, à minha família, que, mesmo à distância, nunca deixou de acreditar em meu potencial. Cada palavra de incentivo e gesto de carinho foi um lembrete constante de que eu não estava sozinho nessa jornada. À minha parceira, que sempre me apoiou emocionalmente e me recordou todos os dias do meu potencial e do que sou capaz de alcançar.

Aos meus orientadores, Professores Alexandre Miranda Garcia e Valéria Marques Lemos, expresso minha sincera gratidão. Obrigado por me aceitarem como aluno em uma situação tão desafiadora. Agradeço por todos os ensinamentos durante essa fase do mestrado e por sempre confiarem em mim. Suas orientações precisas, críticas construtivas e incentivos foram pilares fundamentais para a realização deste trabalho. A palavra "orientador" deveria ser sinônimo de seus nomes, pois sua dedicação e orientação foram essenciais em cada passo dessa jornada. Sou profundamente grato pelas palavras diárias de incentivo e pela educação exemplar que me proporcionaram. "Dale", obrigado por tudo.

Ao Professor Rogério Vianna, agradeço profundamente por ter me recebido e guiado durante a fase inicial do meu mestrado. Sua atenção e dedicação como coordenador do curso transcenderam suas responsabilidades formais, e sou imensamente grato pela sua ajuda e apoio.

Aos meus amigos de Moçambique e Brasil, agradeço por compreenderem minhas diferenças e me oferecerem apoio nos momentos mais desafiadores. Vocês são minha eterna referência de amizade e solidariedade.

Aos meus amigos e colegas do PELD, agradeço pela amizade que construímos durante o estágio e pela troca de conhecimentos durante as coletas. Cada experiência

compartilhada enriqueceu ainda mais essa trajetória. Agradeço também pelas trocas durante as disciplinas e por todo aprendizado que me proporcionaram ao longo do programa.

Ao Programa de Pós-Graduação em Biologia de Ambientes Aquáticos Continentais e à Universidade Federal do Rio Grande, agradeço por toda a estrutura e pelo apoio que tornaram possível a realização deste trabalho. Aos técnicos e demais profissionais envolvidos, o meu muito obrigado por colaborarem de maneira essencial para o sucesso dessa jornada.

À GCUB-mob pelo apoio financeiro na realização deste trabalho e pela bolsa de mestrado.

Por fim, agradeço a todos que, de alguma forma, contribuíram para que esse sonho fosse realizado. A caminhada foi longa, mas ao olhar para trás, vejo que cada passo valeu a pena.

RESUMO

Os ecossistemas estuarinos enfrentam crescente pressão devido às mudanças climáticas, que intensificam distúrbios ambientais associados a processos continentais, atmosféricos e oceânicos. Alterações na hidrodinâmica dos estuários, em escalas espaciais e temporais, desestabilizam comunidades ecológicas. Fenômenos climáticos, como o *El Niño* Oscilação Sul (ENOS), amplificam esses efeitos, gerando impactos negativos em ecossistemas e nas comunidades que deles dependem. As espécies estuarino-residentes, que utilizam esses habitats ao longo de todo o ciclo de vida, são particularmente vulneráveis, enfrentando desafios crescentes para assegurar a manutenção das suas populações. Baseando-se em 22 anos de dados mensais de abundância de espécies residentes do Estuário da Lagoa dos Patos (ELP), este estudo analisa a abundância de três espécies (*Atherinella brasiliensis*, *Jenynsia lineata*, *Ctenogobius shufeldti*) com atributos funcionais distintos (relacionados à estratégia reprodutiva, alimentação e uso da coluna d'água) e suas relações com fatores ambientais regionais e locais. Investigamos as seguintes hipóteses: (i) há uma tendência de declínio à longo prazo na abundância das espécies estuarinas residentes; (ii) as reduções na abundância estão associadas a eventos de *El Niño*; (iii) a abundância de espécies com diferentes traços funcionais responde de forma semelhante aos efeitos dos eventos de *El Niño*. Utilizamos modelos lineares generalizados para analisar as variações na abundância em relação aos fatores ambientais regionais e locais. A análise revelou um declínio na abundância de todas as três espécies estuarino-residentes, relacionado aos fatores locais, regionais e variações climáticas, apesar das diferenças em seus atributos funcionais. Modelos lineares generalizados mostraram que os eventos de *El Niño* impactam as espécies de maneiras distintas, com efeitos mais pronunciados em espécies ovíparas (*A. brasiliensis* e *C. shufeldti*) em comparação com espécies vivíparas (*J. lineata*). Esses resultados fornecem evidências empíricas do declínio na abundância de peixes residentes no ELP ao longo da série temporal de dados analisada, independentemente de seus traços funcionais distintos. Essa tendência de acarreta preocupações sobre a conservação das funções ecológicas e dos serviços ecossistêmicos de espécies de peixes estuarino-residentes em estuários subtropicais sob crescentes pressões antropogênicas e climáticas.

Palavras-chave: Impactos climáticos, *El Niño*, peixes estuarino-residentes, estuário da Lagoa dos Patos, Pesquisas Ecológicas de Longa Duração (PELD)

ABSTRACT

Estuarine ecosystems face increasing pressure due to climate change, which intensifies environmental disturbances associated with continental, atmospheric, and oceanic processes. Changes in estuarine hydrodynamics, on spatial and temporal scales, destabilize ecological communities. Climatic phenomena, such as the *El Niño* Southern Oscillation (ENSO), amplify these effects, generating negative impacts on ecosystems and the communities that depend on them. Estuarine-resident species, which use these habitats throughout their life cycles, are particularly vulnerable, facing growing challenges to maintain their populations. Based on 22 years of monthly abundance data of resident species from the Patos Lagoon Estuary (PLE), this study analyzes the abundance of three species (*Atherinella brasiliensis*, *Jenynsia lineata*, *Ctenogobius shufeldti*) with distinct functional attributes (related to reproductive strategy, feeding, and water column usage) and their relationships with regional and local environmental factors. We investigated the following hypotheses: (i) there is a long-term declining trend in the abundance of estuarine-resident species; (ii) reductions in abundance are associated with *El Niño* events; (iii) the abundance of species with different functional traits responds similarly to the effects of *El Niño* events. Generalized linear models were used to analyze variations in abundance concerning regional and local environmental factors. The analysis revealed a decline in the abundance of all three estuarine-resident species, related to local, regional, and climatic variations, despite differences in their functional attributes. Generalized linear models showed that *El Niño* events impact species in distinct ways, with more pronounced effects on oviparous species (*A. brasiliensis* and *C. shufeldti*) compared to viviparous species (*J. lineata*). These results provide empirical evidence of the decline in resident fish abundance in the PLE over the analyzed data series, regardless of their distinct functional traits. This trend raises concerns about the conservation of ecological functions and ecosystem services provided by estuarine-resident fish species in subtropical estuaries under increasing anthropogenic and climatic pressures.

Key-words: Climatic impacts, estuarine-resident fish, *El Niño*, Patos Lagoon estuary, Brazilian Long-Term Ecological Research (B-LTER)

APRESENTAÇÃO

Essa dissertação está dividida em três segmentos. O primeiro é referente à introdução geral do tema de pesquisa proposto acompanhada pelas referências bibliográficas, formatadas seguindo as normas da ABNT. O segundo segmento é representado pelo capítulo 1 (redigido e organizado na forma de um manuscrito científico) que trata sobre a variabilidade espaço-temporal (1997-2019) de peixes estuarino-residentes com atributos funcionais distintos e suas relações com fatores ambientais e climáticos, o qual está formatado seguindo as normas da revista *Marine Environment Research*. O terceiro segmento contém as considerações finais do trabalho e suas referências bibliográficas, formatadas seguindo as normas da ABNT.

SUMÁRIO

INTRODUÇÃO GERAL	13
REFERÊNCIAS	17
CAPÍTULO 1.....	23
Abstract	25
1.Introduction	26
2. Material and Methods	28
2.1. Study Area	
2.2. Data Collection	
2.3 Data Analysis	
3. Results	31
3.1 Temporal Variability of Environmental Factors	
3.2 Temporal Changes in the Abundance of Estuarine-Resident Fish Species	
4. Discussion	32
4.1 Long-Term Trends in the Abundance of Estuarine-Resident Fish	
4.2. Differential Responses of Estuarine-Resident Fish to Environmental Factors and <i>El Niño</i> Events	
5. References	36
Figuras.....	44
Tabelas.....	51
CONSIDERAÇÕES FINAIS E PERSPECTIVAS	54

LISTA DE FIGURAS

- Figura 1.** Área de estudo: (A) Mapa do Brasil; (B) Localização da Lagoa dos Patos; (C) Estações de amostragem na zona estuarina (círculos vermelhos); e (D) Mapa do estado do Rio Grande do Sul, no sul do Brasil, mostrando a localização das estações de medição do fluxo fluvial ao longo da bacia de drenagem da lagoa (círculos pretos).....pag. 46
- Figura 2.** Atributos funcionais (modo reprodutivo, hábito alimentar e micro-habitat) de três espécies de peixes residentes estuarinos: *Atherinella brasiliensis*, *Jenynsia lineata* e *Ctenogobius shufeldti*. As linhas vermelhas conectam as diferentes características de cada espécie.....pag.47
- Figura 3.** *Boxplots* das variações intra e interanuais de variáveis climáticas (índice ONI), regionais (descarga de água doce) e locais (salinidade, temperatura e transparência). A linha horizontal dentro das caixas indica a mediana, enquanto as caixas representam os valores entre o primeiro e o terceiro quartis.....pag.48
- Figura 4.** *Boxplots* da variação interanual da abundância log10 (CPUE+1) para *Atherinella brasiliensis* (caixas vermelhas), *Jenynsia lineata* (caixas verdes) e *Ctenogobius shufeldti* (caixas laranja). A linha horizontal no centro das caixas indica a mediana; as caixas representam o primeiro e o terceiro quartis; as linhas verticais nas extremidades das caixas indicam os valores mínimos e máximos os pontos representam outliers.....pag. 49
- Figura 5.** Gráficos de Modelos Lineares Generalizados mostrando os efeitos parciais das variáveis explicativas selecionadas sobre a abundância de *Atherinella brasiliensis* no estuário da Lagoa dos Patos. As áreas sombreadas indicam os intervalos de confiança de 95%.....pag.50
- Figura 6.** Gráficos de Modelos Lineares Generalizados mostrando os efeitos parciais das variáveis explicativas selecionadas sobre a abundância de *Jenynsia lineata* no estuário da Lagoa dos Patos. As áreas sombreadas indicam os intervalos de confiança de 95%.....pag. 51
- Figura 7.** Gráficos de Modelos Lineares Generalizados mostrando os efeitos parciais das variáveis explicativas selecionadas sobre a abundância (A e B) e ocorrência (C, D, E e F) de *Ctenogobius shufeldti* no estuário da Lagoa dos Patos. As áreas sombreadas indicam os intervalos de confiança de 95%.....pag.52
- Figura 8.** Distribuição percentual dos efeitos das variáveis ambientais sobre a abundância de *Atherinella brasiliensis* e *Jenynsia lineata* , bem como sobre a ocorrência de *Ctenogobius shufeldti* , de acordo com o modelo selecionado. As variáveis analisadas incluem ano, salinidade, temperatura, transparência e o índice ONI.....pag.53

LISTA DE TABELAS

Tabela 1. Modelos Lineares Generalizados selecionados com valores do Critério de Informação de Akaike (AIC) e o grau de explicação do modelo (Exp) para a abundância de *Atherinella brasiliensis*, *Jenynsia lineata* e *Ctenogobius shufeldti* no estuário da Lagoa dos Patos. Res. Dev., desvio residual; Dev. Expl., desvio explicado em porcentagem; Sig., significância; *, $p < 0,05$; **, $p < 0,01$; ***, $p < 0,001$; inclinação positiva (+) e negativa (–)...pag.53

Tabela 2. Modelos Aditivos Generalizados selecionados com valores do Critério de Informação de Akaike de segunda ordem (AICc) e grau de explicação do modelo (EXP). VAN = modelo válido. As linhas sombreadas em cinza representam os modelos selecionados com o menor AIC e o maior peso de AIC (AICw) para as regiões do estuário e da costa.....pag.54

INTRODUÇÃO GERAL

Impactos da variabilidade ambiental sobre peixes estuarinos

Os estuários estão entre os ecossistemas aquáticos mais produtivos do mundo e são fundamentais para muitas espécies em diferentes estágios de seus ciclos de vida (Costanza et al., 1997; Beck et al., 2001). Esses ambientes de transição entre o continente e o oceano (Delpech et al., 2010; Potter et al., 2015) fornecem abrigo, áreas de alimentação e locais de reprodução, além de oferecerem serviços ecossistêmicos essenciais para várias espécies (Barbier et al., 2011; Day et al., 2012; Warry et al., 2016; Thrush et al., 2025). Um dos grupos taxonômicos que depende desse ecossistema são os peixes estuarino-residentes, que completam todo o seu ciclo biológico dentro do estuário (Kemp & Crump, 1990; Seeliger, 2001).

Diversos esforços vêm sendo desenvolvidos para avaliar o estado ecológico dos estuários (Ley, 2005; Delpech et al., 2010; Nicolas et al., 2010), a diversidade e a composição da comunidade de peixes, conjuntamente com a dinâmica populacional da ictiofauna. Além disso, a ictiofauna estuarina tem sido usada como ferramentas para quantificar as funções ecológicas dos estuários (Whitfield & Elliott, 2002; Delpech et al., 2010; Priya et al., 2023; Janc et al., 2024).

Os ecossistemas estuarinos estão sujeitos a impactos de processos continentais, atmosféricos e oceanográficos, que modificam suas dinâmicas hidrológicas em diferentes escalas espaciais e temporais (Wolfe, 1996; Silva et al., 2018). A variabilidade climática pode induzir mudanças nos padrões de vento e precipitação, além de aumentar a frequência de fenômenos naturais, como a *El Niño* Oscilação Sul (ENOS) (Cai et al., 2014; Freund et al., 2019). No extremo sudoeste do Oceano Atlântico, os sistemas costeiros estão fortemente influenciados pelos impactos climáticos do ENOS, especialmente o excesso de chuva associado à sua fase quente (*El Niño*) e o consequente aumento da descarga continental (Robertson & Mechoso, 1998; Grimm et al., 2000). Esses processos causam impactos significativos nos sistemas ecológicos, na biota estuarina (Garcia et al., 2001; Odebrecht, 2001; Odebrecht et al., 2017; Possamai et al., 2018) o que, consequentemente, gera impactos socioeconômicos em escala global (Glantz, 2000; Anderson et al., 2019).

O aumento contínuo das pressões antropogênicas, combinado com eventos climáticos, pode gerar efeitos sinérgicos que aceleram a degradação ambiental nos estuários, resultando potencialmente na redução da diversidade e da abundância de espécies. Esses impactos são particularmente evidentes em espécies residentes, ou seja, espécies que completam seu ciclo de vida nesses sistemas costeiros (Whitfield & Elliott, 2002; Potts et al., 2015; Whitfield, 2021).

As respostas de longo prazo das espécies residentes às variações locais dos estuários e às mudanças climáticas são complexas, destacando a importância de estudos adicionais para compreender melhor esses efeitos (Whitfield & Elliott, 2002).

Pesquisas recentes têm ressaltado a relevância de considerar os traços funcionais das espécies ao avaliar suas respostas aos impactos ambientais e das mudanças climáticas (Mouillot et al., 2013; Villéger et al., 2017). Traços funcionais são características morfológicas, fisiológicas ou fenológicas mensuradas em nível individual (Violle et al., 2007), com potencial para conectar os papéis desempenhados pelos organismos às funções do ecossistema (Villéger et al., 2017; Esmacili et al., 2021). Por exemplo, os traços funcionais relacionados à reprodução, habitat e alimentação são essenciais para compreender as interações das espécies com o ambiente, sua resposta às mudanças climáticas e seu papel ecológico. Os traços reprodutivos, ajudam a identificar estratégias de persistência populacional e sua resiliência a distúrbios ambientais (Manna et al., 2013). Os traços funcionais relacionados ao uso do habitat fornecem informações sobre a distribuição das espécies e sua adaptação a diferentes condições ambientais, sendo cruciais para o desenvolvimento de estratégias de conservação e manejo (Marsh-Matthews & Matthews, 2000). Enquanto isso, os traços alimentares são essenciais para entender o papel das espécies nas cadeias tróficas, bem como nos fluxos de energia e nutrientes (Hooper et al., 2002). Estudos sobre a influência de fatores ambientais e climáticos, como o *El Niño*, em espécies de peixes residentes em estuários, têm se concentrado predominantemente na análise da abundância (e.g., Garcia et al., 2004; Belarmino et al., 2022), sendo que a influência desses fenômenos em espécies residentes com traços funcionais distintos ainda é pouco compreendida. Aprofundar essa compreensão é crucial, considerando que eventos climáticos extremos, como o *El Niño*, estão se tornando mais frequentes e intensos em decorrência do aquecimento global (Yeh et al., 2009; Cai et al., 2015). Além disso, existe a preocupação que eventos extremos podem exceder a capacidade de adaptação dos organismos, mesmo em sistemas naturalmente bastante variáveis como os estuários (Wainger et al., 2017).

Peixes estuarino-residentes no estuário da Lagoa dos Patos (ELP)

Entre as espécies de peixes presentes em estuários, os peixes estuarino-residentes, que completam todo o seu ciclo de vida nesses ambientes (Mai & Possamai, 2018), constituem um modelo biológico interessante para avaliar os efeitos de pressões naturais sobre a biota estuarina. Esses peixes apresentam diferentes traços funcionais, como reprodução, alimentação e uso do habitat. A análise integrada desses traços proporciona uma visão abrangente da dinâmica ecológica, promovendo abordagens mais eficazes para a conservação e o manejo sustentável

(Blondel, 2003; Manna et al., 2013). Entre as espécies de peixes residentes no estuário da Lagoa dos Patos (ELP) estão: o peixe-rei *Atherinella brasiliensis* (Quoy & Gaimard, 1825) (Figura 1a), o barrigudinho *Jenynsia lineata* (Jenyns, 1842) (Figura 1b) e o gobídeo *Ctenogobius shufeldti* (Jordan & Eigenmann, 1887) (Figura 1c). O peixe-rei *A. brasiliensis* comparado com outros Atherinopsidae, pode ser considerada relativamente pequena (comprimento total máximo de 16 cm) (Bemvenuti, 1987; Barbien et al., 1990; Araújo et al., 1998), ocorrendo desde a Venezuela até as águas costeiras do Sul do Brasil, comumente encontrada na boca de rios e águas salobras (Figueiredo & Menezes, 2003). O peixe-rei *A. brasiliensis* é uma das espécies mais frequentes e abundantes nas zonas rasas (< 2m) do ELP (Chao et al., 1985; Vieira et al., 1997). *Jenynsia lineata* é uma espécie de pequeno porte (comprimento máximo de 7,7 cm (Contente et al., 2012) e amplamente distribuída na bacia do rio Paraná e em habitats costeiros do norte da Argentina, Uruguai e sul do Brasil. *Ctenogobius shufeldti* ocorre do Sul do Brasil até a Carolina do Norte, incluindo o Golfo do México, podendo alcançar até cerca de 4 cm (Bertaco et al., 2016). É uma espécie de gobídeo com preferências por áreas de marismas com baixa salinidade e regiões superiores (i.e., a montante) de estuários, mas ocasionalmente pode ocorrer em baías abertas e enseadas (Lee et al., 1980). Além disso, pode, ocasionalmente, adentrar águas doces (Page e Burr, 2011).

Essas três espécies estuarino-residentes exibem traços funcionais distintos: *A. brasiliensis* é onívora e ovípara, depositando ovos adesivos na vegetação; *C. shufeldti* é zoobentívora, ovípara e exibe cuidado parental; enquanto *J. lineata* é onívora e vivípara (Mai & Possamai, 2022). Essas espécies também diferem no uso da coluna d'água, sendo classificadas como pelágica, bentônica e demersal, respectivamente (Fischer et al., 2004).



Embora existam estudos que elucidem como os eventos de *El Niño* podem afetar de maneira significativa a abundância e a composição das comunidades de peixes ao longo do tempo, ainda há poucos estudos que analisam esses efeitos de forma detalhada sobre as espécies estuarino-residentes do ELP (Garcia et al., 2004; Belarmino et al., 2021; Gowert, 2022). Um estudo anterior sobre a variabilidade na abundância da espécie *A. brasiliensis* (Quoy & Gaimard, 1825)

demonstrou que a diminuição da sua abundância esteve associada às variações na salinidade, causadas por maiores índices de descarga continental durante eventos intensos de *El Niño* (Belarmino et al., 2021). De forma similar, também há estudos para *J. lineata* (Jenyns, 1842) demonstrando uma diminuição de sua abundância relacionada a esses eventos (Garcia et al., 2004). Em contrapartida, não há estudos no ELP para *C. shufeldti*, mas é plausível supor que valores elevados de descarga continental possam favorecer o aumento de sua abundância (Jordan & Eigenmann, 1887), pois trata-se de uma espécie adaptada a habitats rasos e de baixa salinidade em estuários subtropicais do Atlântico Ocidental (Contente et al., 2012).

Além de influenciar a abundância de espécies, algumas condições ambientais, como variações de salinidade, temperatura, turbidez e hidrodinâmica, são reconhecidas como fatores determinantes na morfologia e na ecologia das populações de peixes. Pressões seletivas em gradientes ambientais similares frequentemente resultam em convergência morfológica, especialmente em aspectos relacionados à locomoção (Haas et al., 2010; Theis et al., 2014; Gaston & Lauer, 2015; Lauder, 2015) e à alimentação (Langerhans et al., 2004; Gomes & Monteiro, 2008; Araújo et al., 2014; Zanella et al., 2015). Esse paradigma ecomorfológico destaca a relação entre a forma do corpo e os filtros seletivos impostos por gradientes ambientais (Langerhans et al., 2004). Em estuários, os fortes gradientes de salinidade, combinados com rápidas mudanças em outros fatores ambientais, representam desafios fisiológicos e ecológicos para os organismos residentes (Haedrich, 1983; Vieira & Musick, 1993).

Avançar o conhecimento dos efeitos do *El Niño* sobre populações residentes que habitam estuários subtropicais do Atlântico Sudoeste pode contribuir para a compreensão de impactos das mudanças climáticas nestes ambientes (Whitfield & Elliott, 2002; Booth et al., 2011; James et al., 2013). Como mencionado anteriormente, eventos climáticos extremos como *El Niño* pode tornar-se mais frequentes e intensos no futuro devido as mudanças climáticas (Yeh et al., 2009; Cai et al., 2015). Portanto, é essencial uma melhor compreensão dos efeitos de eventos *El Niño* de na biota e ecossistemas costeiros.

Nesse contexto, este estudo tem como objetivo analisar tendências de longo prazo (1997–2019) na abundância de espécies residentes do estuário (*A. brasiliensis*, *J. lineata*, *C. shufeldti*) com traços funcionais distintos (em termos de estratégia reprodutiva, hábitos alimentares e uso da coluna d'água) e suas relações com fatores ambientais locais, regionais e climáticos. Especificamente, investigamos as seguintes hipóteses: (i) há uma tendência de longo prazo de declínio na abundância de espécies residentes do estuário; (ii) as reduções em sua abundância

estão associadas a eventos de *El Niño*; e (iii) a abundância de espécies com diferentes traços funcionais apresenta respostas similares aos efeitos dos eventos de *El Niño*.

OBJETIVO GERAL

- Analisar a variabilidade temporal da abundância dos peixes estuarino-residentes *Atherinella brasiliensis*, *Jenynsia lineata* e *Ctenogobius shufeldti* com atributos funcionais distintos (e.g., modos reprodutivos, hábitos alimentares, uso do micro-habitat) no estuário da Lagoa dos Patos e suas relações com fatores ambientais e climáticos.

OBJETIVOS ESPECÍFICOS

- Determinar a tendência de longo-prazo na abundância de espécies estuarino-residentes *Atherinella brasiliensis*, *Jenynsia lineata* e *Ctenogobius shufeldti* no ELP
- Relacionar a variabilidade da abundância de espécies estuarino-residentes com fatores ambientais locais, regionais e climáticos;
- Discutir possíveis diferenças nas flutuações na abundância de espécies estuarino-residentes com atributos funcionais distintos em termos de modos reprodutivos, hábitos alimentares e uso do micro-habitat (pelágico vs. demersal/bentônico) às perturbações causadas por eventos *El Niño*.

REFERÊNCIAS

- Anderson, W.B., Seager, R., Baethgen, W., Cane, M., You, L. (2019). Synchronous crop failures and climate-forced production variability. *Sci. Adv.* 5, eaaw1976.
- Araújo FG., Cruz-Filho AGD., Azevêdo MCCD., Santos ACDA. (1998) Estrutura da comunidade de peixes demersais da baía de Sepetiba, RJ. *Rev Bras Biol* 58:417–430.
- Araújo MS., Perez SI., Magazoni MJC., Petry AC. (2014) Body size and allometric shape variation in the molly *Poecilia vivipara* along a gradient of salinity and predation. *BMC Evol Biol* 14
- Booth DJ., Bond N., Macreadie P. (2011) Detecting range shifts among Australian fishes in response to climate change. *Mar Freshwater Res* 62:1027.
- Barbieri LRR., Andreata JV., Santos MA., Silva MHC da., Sebilha ASC, Santos RPdos. (1990) Distribuição e ciclo de vida das espécies de peixes mais abundantes da laguna de Marapendi, Rio de Janeiro, Brasil. *Rev Bras Zool* 7:223–243.
- Barbier, Edward B., Hacker, Sally D., Kennedy, Chris; Koch, Evamaria W., Stier, Adrian C., Silliman, Brian R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, Laramie, v. 81, n. 2, p. 169-193.
- Beck MW., Heck KL., Able KW, Childers DL., Eggleston DB., Gillanders BM., Halpern B., Hays CG., Hoshino K., Minello TJ. (2001) The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates. *BioScience* 51:633.
- Belarmino, E., de Nobrega, M. F., Grimm, A. M., Copertino, M. S., Vieira, J. P., & Garcia, A. M. (2021). Long-term trends in the abundance of an estuarine fish and relationships with *El Niño* climatic impacts and seagrass meadows reduction. *Estuarine, Coastal and Shelf Science*, 260, 107565.
- Bemvenuti, M.A. (1987). Abundância, distribuição e reprodução de peixes-rei (Atherinidae) na região estuarina da Lagoa dos Patos, RS, Brasil. *Atlântica*, 9(1): 5-32
- Booi, Sipesihle., Mishi, Syden., Andersen, Oddgeir. (2022). Ecosystem Services: A Systematic Review of Provisioning and Cultural Ecosystem Services in Estuaries. *Sustainability*, v. 14, n. 12, p. 7252.
- Cai, W., Borlace, S., Lengaigne, M., Rensch, P.V., Collins, M., Vecchi, G., Timmermann, A., Santoso, A., McPhaden, M.J., Wu, L., England, M.H., Wang, G., Guilyard, E., Jin, F.F. (2014).

Increasing frequency of extreme *El Niño* events due to greenhouse warming. *Nat. Clim. Change* 4, 111–116.

Cai W., Borlace S., Lengaigne M., Van Rensch P., Collins M., Vecchi G., Timmermann A., Santoso A., McPhaden MJ., Wu L. (2015). Increasing frequency of extreme *El Niño* events due to greenhouse warming. *Nature Clim Change* 4:111–116.

Chao, L.N., L.E. Pereira and J.P., Vieira. (1985) Estuarine Fish Community of the dos Patos Lagoon, Brazil. A Baseline Study. Cap.20. p.429-450 In: A. Yanez-Arancibia (Ed.)

Contente, R. F., Stefanoni, M. F., & Spach, H. L. (2012). Feeding ecology of the American freshwater goby *Ctenogobius shufeldti* (Gobiidae, Perciformes) in a sub-tropical estuary. *Journal of Fish Biology*, 80(6), 2357-2373.

Costanza, R. (1997). The value of the world's ecosystem services and natural capital. *Nature* 387, 253 - 260.

Day JW, Yáñez-Arancibia A., Kemp WM., Crump BC. (2012) Introduction to Estuarine Ecology. 1–18.

Delpech, C., Courrat, A., Pasquaud, S., Lobry, J., Le Pape, O. (2010). Development of a fish-based index to assess the ecological quality of transitional waters: the case of French estuaries. *Mar. Pollut. Bull.* 60 (6), 908–918.

Esmaili YS., Corte GN., Checon HH., Bilatto CG., Lefcheck JS., Amaral ACZ., Turra A (2021). Revealing the drivers of taxonomic and functional diversity of nearshore fish assemblages: Implications for conservation priorities. *Diversity and Distributions* 00:1-13.

Figueiredo J.L., Menezes, N.A. (2003) Atherinopsidae. In: Menezes N. A., Buckup, P. A.; Figueiredo J. L.; Moura R. L. (eds.) *Catálogo dos peixes marinhos do Brasil*. São Paulo: EDUSP, pp. 65–66

Freund, M.B., Henley, B.J., Karoly, D.J., McGregor, H.V., Abram, N.J., Dommenges, D. (2019). Higher frequency of Central Pacific *El Niño* events in recent decades relative to past centuries. *Nat. Geosci.* 12, 450–455.

Garcia, A. M., Vieira, J. P., & Winemiller, K. O. (2001). Dynamics of the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil) during cold and warm ENSO episodes. *Journal of Fish Biology*, 59(5), 1218-1238.

- Garcia, A. M., Vieira, J. P., Winemiller, K. O., & Raseira, M. B. (2004). Reproductive cycle and spatiotemporal variation in abundance of the one-sided livebearer *Jenynsia multidentata*, in Patos Lagoon, Brazil. *Hydrobiologia*, 515, 39-48.
- Glantz, M.H. (Ed.). (2000). *Currents of Change: El Niño and La Niña Impacts on Climate and Society*, second ed. Cambridge University Press, New York, p. 252pp.
- Grimm, A.M., Barros, V.R., Doyle, M.E. (2000). Climate variability in southern south America associated with *El Niño* and *La Niña* events. *J. Clim.* 13, 35–58.
- Gaston KA., Lauer TE. (2015) Morphometric variation in bluegill *Lepomis macrochirus* and green sunfish *Lepomis cyanellus* in lentic and lotic systems. *J Fish Biol* 86:317–332
- Gomes JL., Monteiro LR. (2008) Morphological divergence patterns among populations of *Poecilia vivipara* (Teleostei Poeciliidae): test of an ecomorphological paradigm. 93:799–812.
- Haas TC, Blum MJ., Heins DC. (2010) Morphological responses of a stream fish to water impoundment. *Biol Lett* 6:803–806.
- Haedrich, R. L. (1983). Estuarine fishes. In *Estuarine and Enclosed Seas (Ecosystems of the World, 26)* (Ketchum, B. H., ed.), pp. 183–203. Amsterdam: Elsevier.
- James N., van Niekerk L., Whitfield A., Potts W., Götz A., Paterson A. (2013) Effects of climate change on South African estuaries and associated fish species. *Clim Res* 57:233– 248.
- Janc, A., Dambrine, C., Lambert, P., Lassalle, G., Lepage, M., Lobry, J., Pierre, M., Kristiansen, T., Butenschön, M., & Cabral, H. N. (2024). Fish distribution shifts due to climate change in the Northeast Atlantic: Using a hierarchical filtering approach on marine-estuarine opportunist species. *Estuarine, Coastal and Shelf Science*, 290, 109013.
- Kemp WM., Crump BC. (1990). Introduction to Estuarine Ecology. In: John W. Day Jr., Alejandro Yáñez-Arancibia, W. Michael Kemp, and Byron C. Crump (eds) *Estuarine Ecology*, New York: John Miley and Sons. pp. 2-7
- Langerhans RB., DeWitt TJ. (2004) Shared and Unique Features of Evolutionary Diversification. *The American Naturalist* 164:335–349.
- Lauder, GV. (2015) Fish Locomotion: Recent Advances and New Directions. *Annu Rev Mar Sci* 7:521–545.
- Ley, J. A. (2005). Linking fish assemblages and attributes of mangrove estuaries in tropical Australia: criteria for regional marine reserves. *Mar. Ecol. Prog. Ser.* 305, 41-57.

- Mouillot D., Grahan NAJ., Villéger S., Mason NWH., Belwood DR. (2013) A functional approach reveals community responses to disturbances. *Trends Ecol. Evol.* 28: 167–177.
- Nicolas D., Lobry J., Lepage M., Sautour B, Le Pape O., Cabral H., Uriarte A, Boët P. (2010) Fish under influence: A macroecological analysis of relations between fish species richness and environmental gradients among European tidal estuaries. *Estuarine, Coastal and Shelf Science* 86:137–147.
- Noletto-Filho, E. M., Pucciarelli, P., & Dumont, L. F. C. (2017). Spatial and temporal variation in juvenile size distribution of the pink shrimp (*Penaeus paulensis*) in the Patos Lagoon Estuary, Brazil. *Marine Biology Research*, 13(1), 62–73.
- Odebrecht, C., Secchi, ER., Abreu, PC., Muelbert., JH & Uiblein, F. (2017). Biota of the Patos Lagoon estuary and adjacent marine coast: longterm changes induced by natural and human-related factors. *Marine Biology Research* 13, 3-8.
- Olsen, Z., & McCulloch, J. (2024). Trends and distribution of hardhead catfish in Texas estuariesshifting relative abundance of a highly ubiquitous generalist predator. *Environmental Biology of Fishes*, 1-27.
- Possamai, B., Vieira, J.P., Grimm, A.M., Garcia, A.M. (2018). Temporal variability (1997-2015) of trophic fish guilds and its relationships with El Niño events in a subtropical estuary. *Estuar. Coast Shelf Sci.* 202, 145–154.
- Potts, W.M., Gotz, A., James, N. (2015). Review of the projected impacts of climate change on coastal fishes in southern Africa. *Rev. Fish Biol. Fish.* 25 (4), 603–630.
- Potter, I. C., Tweedley, J. R., Elliott, M., & Whitfield, A. K. (2015). The ways in which fish use estuaries: a refinement and expansion of the guild approach. *Fish and Fisheries*, 16(2), 230-239.
- Priya, A., Bhavan, S. G., Bella, K., Biji, K., Velayudhan, P. K., Sahadevan, P., Vasudevan, C., Lal, M., Mayekar, T., Ingole, B., Kumar, P., & Kutty, R. (2023). Delineating the fish-based ecosystem services of a small tropical Indian estuary: Identification, evaluation and management. *Estuarine, Coastal and Shelf Science*, 287, 108506.
- Robertson, A.W., Mechoso, C.R. (1998). Interannual and decadal cycles in river flows of southeastern South America. *J. Clim.* 11 (10), 2570–2581.

Seeliger, U. (2001). The Patos Lagoon Estuary, Brazil. In: Seeliger, U., Kjerfve, B. (Eds.), Coastal Marine Ecosystems of Latin America Ecological Studies (Analysis and Synthesis). Springer, Berlin (392 pgs).

Silva, A.C.R.S, Bernardes, M.E.C., Assireu, A.T., Siegle, E., Sousa, P.H.G.O., Brown, D. (2018). Hydrodynamics of a tropical estuary: Buranhém river, Porto Seguro. Brazil 23 e5. ISSN: 2318-0331.

Thrush, Simon F., Townsend, Michael, Hewitt, Judi E., Davies, Kate, Lohrer, Andrew M., Lundquist, Carolyn, Cartner, Katie. (2014). The many uses and values of estuarine ecosystems.

Vieira, J.P., Castello, J.P. (1997). Fish fauna. In: Seeliger, U., Odebrecht, C., Castello, J.P. (Eds.), Subtropical Convergence Environments, the Coast and Sea in the Southwestern Atlantic. Springer, Berlin, pp. 56e61.

Vieira, J. P., & Musick, J. A. (1994). Fish fauna composition in warm-temperate and tropical estuaries of western Atlantic. *Atlântica*, Rio Grande 16, 31–53

Villéger S., Brosse S., Mouchet M., Mouillot D., Vanni MJ. (2017). Functional ecology of fish: current approaches and future challenges. *Aquat. Sci.* 79, 783–801.

Violle, C., Navas, M. L., Vile, D., Kazakou, E., Fortunel, C., Hummel, I., & Garnier, E. (2007). Let the concept of trait be functional. *Oikos*, 116(5), 882-892.

Theis, A., Ronco, F., Indermaur, A., Salzburger, W., & Egger, B. (2014). Adaptive divergence between lake and stream populations of an East African cichlid fish. *Molecular Ecology*, 23, 5304–5322.

Wainger, L. A., Secor, D. H., Gurbisz, C., Kemp, W. M., Glibert, P. M., Houde, E. D., ... & Barber, M. C. (2017). Resilience indicators support valuation of estuarine ecosystem restoration under climate change. *Ecosystem Health and Sustainability*, 3(4), e01268.

Warry, F. Y.; Reich, P.; Cook, P.; Mac Nally, R.; Thomson, J.; Woodland, R. (2016). Nitrogen loads influence trophic organization of estuarine fish assemblages. *Functional Ecology*, v. 30, n. 10, p. 1723–1733.

Whitfield, A. K., & Elliott, M. (2002). Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. *Journal of Fish Biology*, 61, 229–250.

Whitfield, A. K. (2021). Estuaries—how challenging are these constantly changing aquatic environments for associated fish species? *Environmental Biology of Fishes*, 104, 1–12.

Wolfe, D. A. (1996). *Estuarine Variability*. Academic Press, 509 p.

Yeh, S. W., Kug, J. S., Dewitte, B., Kwon, M. H., Kirtman, B., & Jin, F. F. (2009). *El Niño* in a changing climate. *Nature*, 461, 511–514.

Zanella, L. N., Defaveri, J., Zanella, D., Merilä, J., Sanda, R., & Mrakovčić, M. (2015). Does predation drive morphological differentiation among Adriatic populations of the threespined stickleback? *Biological Journal of the Linnean Society*, 115, 219–240.

CAPÍTULO

Manuscrito formatado de acordo com as normas da revista “*Marine Environment Research*”

Nuno Mussá M.U Escamade*¹, Valeria Marques Lemos¹, Alexandre Miranda Garcia¹

**TEMPORAL TRENDS IN ESTUARINE-RESIDENT FISHES: FUNCTIONAL
TRAITS AND RESPONSES TO ENVIRONMENTAL AND CLIMATIC
VARIABILITY**

N.M.M.U. Escamade – V.M. Lemos – A. M. Garcia

Laboratório de Ictiologia, Instituto de Oceanografia, Universidade Federal do Rio Grande
(FURG), Av. Itália s/n - km 8 - Carreiros, Rio Grande, Brasil

Programa de Pós-Graduação em Biologia de Ambientes Aquáticos Continentais (PPGBAC)

E-mail: nunocelio392@gmail.com

ABSTRACT

Extreme climatic events, such as *El Niño*, are becoming increasingly intense and frequent, driving hydrodynamic changes in estuaries and significantly affecting their structure and biodiversity. Using long-term data (22 years) obtained from standardized surveys, we analyzed the abundance of three estuarine-resident species (*Atherinella brasiliensis*, *Jenynsia lineata*, *Ctenogobius shufeldti*) with distinct functional traits (related to reproductive strategy, feeding, and habitat use) and their relationships with local, regional, and climatic environmental factors in a subtropical estuary. We investigated the following hypotheses: (i) there is a long-term declining trend in the abundance of these estuarine-resident species; (ii) reductions in their abundance are associated with *El Niño* events; (iii) the abundance of species with different functional traits responds similarly to the effects of *El Niño* events. The analysis revealed a consistent decline in the abundance of all three estuarine-resident species, driven by local and regional factors and climatic variations, despite differences in their functional traits. Generalized linear models showed that *El Niño* events impact species in distinct ways, with more pronounced effects on oviparous species (*A. brasiliensis* and *C. shufeldti*) compared to viviparous ones (*J. lineata*). These findings provide empirical evidence of decadal changes decline in the abundance of estuarine-resident fishes regardless of their distinct functional traits, raising concerns to the conservation of ecological functions and ecosystem services in subtropical estuaries under increasing anthropogenic and climatic pressures.

KEYWORDS: *El Niño*, climatic impacts, *Atherinella brasiliensis*, *Jenynsia lineata*, *Ctenogobius shufeldti*, Patos Lagoon estuary, B-LTER

1. Introduction

Estuarine ecosystems are widely recognized for their high productive potential and are fundamental to many species at different stages of their life cycles (Costanza et al., 1997; Beck et al., 2001). These transitional environments between land and ocean (Delpech et al., 2010; Potter et al., 2015) provide shelter, feeding grounds, and breeding sites, while also delivering critical ecosystem services (Day et al., 2012; Warry et al., 2016). Estuaries are increasingly vulnerable to anthropogenic impacts such as pollution, dredging, mining, and urbanization, leading to significant alterations as loss habitat and degradation in these coastal systems (Kennish, 1992; Ray, 2006; Andrades et al., 2020).

In addition, these ecosystems are subjected to impacts from continental, atmospheric, and oceanic processes that alter their hydrological dynamics on various spatial and temporal scales (Wolfe, 1996; Silva et al., 2018). Climate variability can induce shifts in wind patterns and rainfall, as well as increase the frequency of natural phenomena such as the *El Niño*-Southern Oscillation (ENSO) (Cai et al., 2014; Freund et al., 2019). The climatic and hydrological changes driven by *El Niño* events have significant effects on ecological systems, with subsequent socioeconomic impacts globally (Glantz, 2000; Anderson et al., 2019). In the southwestern Atlantic Ocean, coastal systems are particularly affected by ENSO's climatic impacts, especially the heavy rainfall associated with its warm phase (*El Niño*) and the resulting increase in continental runoff (Robertson and Mechoso, 1998; Grimm et al., 2000), which exerts considerable impacts on estuarine biota (Garcia et al., 2001; Odebrecht et al., 2017; Possamai et al., 2018).

The ongoing rise in anthropogenic pressures, coupled with climatic events, can lead to combined effects that accelerate environmental degradation in estuaries, potentially resulting in reduced species diversity and abundance, particularly for those estuarine-resident species that reproduce and complete their life cycle within this coastal system (Whitfield and Elliott, 2002; Potts et al., 2015; Whitfield, 2021). Population declines have been observed (Garcia et al., 2004a; Belarmino et al., 2021) and usually attributed both to anthropogenic impacts (e.g., Noleto-Filho et al. 2017) or interspecies resource competition (e.g., Olsen & McCulloch 2024). Hence, the long-term responses of resident species to local estuarine variability and climate change are complex, highlighting the importance of further studies to better understand these effects (Whitfield and Elliott, 2002).

Additionally, recent studies have emphasized the importance of considering species functional traits when assessing their responses to environmental and climatic impacts (Mouillot et al., 2013; Villéger et al., 2017; Caramaschi et al., 2021). Functional traits are defined as morphological, physiological, or phenological characteristics measured at the individual level (Violle et al., 2007), which have the potential to link the roles of organisms to ecosystem functions (Villéger et al., 2017; Esmaeili et al., 2021). The functional traits related to reproduction, habitat, and feeding are essential for understanding species interactions with the environment, their response to climate change, and their ecological role. Reproductive traits, for example, help identify population persistence strategies and their resilience to environmental disturbances (Manna et al., 2013). Functional traits related to habitat use provide information about species distribution and their adaptation to different environmental conditions, being crucial for the development of conservation and management strategies (Marsh-Matthews & Matthews, 2000). Meanwhile, feeding traits are essential for understanding the role of species in trophic chains, as well as in energy and nutrient flows (Hooper et al., 2002). The integrated analysis of these traits offers a comprehensive view of ecological dynamics, promoting more effective approaches for conservation and sustainable management (Blondel, 2003; Manna et al., 2013).

Previous research on the influence of environmental and climatic factors, such as *El Niño*, on estuarine-resident fish has predominantly focused on analyzing species abundance (e.g., Garcia et al., 2004a; Belarmino et al., 2022). However, the influence of these phenomena on estuarine-resident species with distinct functional traits remains poorly understood. The need to advance our understanding in this matter is particularly critical as extreme climatic events, such as *El Niño*, are projected to increase in frequency and intensity due to global warming (Yeh et al., 2009; Cai et al., 2015).

Studies on the responses of estuarine-resident fishes with distinct functional traits to estuarine variability associated with driving forces operating at local, regional and global scales can provide valuable insights to better understand the effects of ongoing climate change (Villéger et al., 2017; Esmaeili et al., 2021; Harrison and Whitfield, 2024). An estuarine system that offers a suitable model for evaluating the effects of environmental and climatic changes on estuarine-resident fish with distinct functional traits is the Patos Lagoon Estuary (PLE), in the Southwestern Atlantic (32°S). This estuary is part of the Brazilian Long-Term Ecological Research Program (B-LTER), which maintains long-term standardized datasets on abiotic and biotic components, continuously collected over several decades

(Lemos et al., 2022), including the ichthyofauna (Vieira et al., 2020). Moreover, prior studies have shown that the hydrodynamics and biota of the PLE are strongly influenced by ENSO (Odebrecht et al., 2017). Among the estuarine-resident fish species inhabiting this system are the Brazilian silverside *Atherinella brasiliensis* (Quoy & Gaimard, 1825), the Onesided livebearer *Jenynsia lineata* (Jenyns, 1842), and the American freshwater goby *Ctenogobius shufeldti* (Jordan & Eigenmann, 1887). *Atherinella brasiliensis* is distributed from Venezuela to southern Brazil and is most common in coastal waters, particularly in river mouths and brackish areas, where it is considered an abundant species. *Jenynsia lineata* is widely distributed across northern Argentina, Uruguay, and southern Brazil and is also abundant in these regions. In contrast, *Ctenogobius shufeldti*, which ranges from southern Brazil to North Carolina, including the Gulf of Mexico, typically inhabits shallow, low-salinity estuarine environments but is not considered an abundant species (Menezes & Figueiredo, 1985; Figueiredo & Menezes, 2003). These estuarine-resident species exhibit distinct functional traits: *A. brasiliensis* is an omnivore and oviparous, laying adhesive eggs on vegetation; *C. shufeldti* is a zoobenthivore feeding on epifauna, also oviparous, and exhibits parental care; whereas *J. lineata* is an omnivore and viviparous (Mai & Possamai, 2022). These species also differ in their use of the water column, being classified as pelagic, benthic, and demersal, respectively (Fischer et al., 2004).

In this context, this study aims to analyze long-term trends (1997–2019) in the abundance of estuarine-resident species (*A. brasiliensis*, *J. lineata*, *C. shufeldti*) with distinct functional traits (in terms of reproductive strategy, feeding habits, and habitat use) and their relationships with local, regional, and climatic environmental factors. Specifically, we investigate the following hypotheses: (i) there is a long-term declining trend in the abundance of estuarine-resident species; (ii) reductions in their abundance are associated with *El Niño* events; and (iii) the abundance of species with different functional traits exhibits similar responses to the effects of *El Niño* events.

2. Material and Methods

2.1. Study Area

Patos Lagoon, located in the southernmost state of Brazil, is recognized as the largest choked coastal lagoon in the world (Kjerfve, 1986). This lagoon receives freshwater from several rivers located in the northern part of the state of Rio Grande do Sul, functioning as the only natural drainage of this watershed, which covers approximately 200,000 km². A single,

narrow inlet, 0.5–3 km wide at its southern end, connects the lagoon to the Atlantic Ocean, forming an estuarine zone that covers about 10% of the total lagoon area (Seeliger, 2001) (Fig. 1). Due to its morphological characteristics and the proximity to an amphidromic point, the tides in the Patos Lagoon region have a low amplitude, averaging 0.47 m (Garcia, 1997). The hydrological conditions in Patos Lagoon vary seasonally and the wind patterns and precipitation within the watershed play a crucial role in the Patos Lagoon Estuary (hereafter PLE). During summer and autumn, low freshwater discharge is generally associated with increased salinity and lower water stratification. In contrast, during winter and spring, precipitation and freshwater discharge result in decreased salinity and reduced oceanic water intrusion into the estuarine area (Marques et al., 2011; Marques et al., 2014).

The hydrodynamics and stratification at PLE are strongly influenced not only by freshwater discharge but also by the ENSO phenomenon (Marques et al., 2011; Marques et al., 2014). During *El Niño* events, positive anomalies in precipitation and continental water flow occur throughout the year, resulting in a significant increase in freshwater flow into the ocean and a reduction in seawater intrusion into PLE, leading to long lasting near-zero salinities in the estuarine zone. On the other hand, during *La Niña* events, reduced precipitation and freshwater discharge tends to increase the estuary's salinity (Garcia et al., 2001; Marques et al., 2011; Marques et al., 2014). Such hydrological changes triggered by ENSO phases have been associated with changes in species composition, abundance and diversity of the fish fauna occurring at PLE aquatic habitats (Belarmino et al., 2024; Garcia et al., 2004b; Possamai et al., 2024; Vollrath et al., 2023).

2.2. Data collection

Monthly fish fauna samplings have been conducted at five stations located in shallow areas (<1.5 m) of PLE as part of the Brazilian Long-Term Ecological Research (LTER) program since 1998 (LTER-PLEA or PELD-ELPA in Portuguese). Fish are collected using a 9-meter beach seine with mesh sizes of 13 mm in the wings and 5 mm in the center. Five monthly hauls are conducted at each of the five sampling sites (Lemos et al., 2021).

Along with fish collection, environmental parameters are measured, including water temperature (°C) with a mercury thermometer, salinity with an optical salinometer, and water transparency with a Secchi disk. In this study, a 22-year time series from the LTER-PLEA database (January 1997 to December 2019) was analyzed, focusing on the abundance of three estuarine-resident species (*Atherinella brasiliensis*, *Ctenogobius shufeldti*, *Jenynsia lineata*).

These fish species are considered estuarine residents because they complete their entire life cycle within the estuary (Garcia et al., 2001; Mai and Possamai, 2022). The estuarine-resident guild was selected not only because these species are good indicators of estuarine changes because they live all their lives within the estuary, but also because they represent species with different functional traits (Fig. 2). Functional traits can be defined as morphological, physiological, or phenological characteristics measured at the individual level (Violle et al., 2007), which could result in different ecological responses (e.g., variations in abundance and occurrence) to the impacts of ENSO events in the PLE.

All fish captured were measured and weighed in the laboratory. Based on this information, the monthly average abundance (1997-2019) was calculated and expressed as catch per unit effort (CPUE). The abundance data of estuarine-resident fish were previously log-transformed ($\log(x + 1)$) for analysis. Additionally, monthly averages of water temperature, salinity, and transparency were calculated based on *in situ* measurements during field samplings. Moreover, data on precipitation (mm) and river flow (m^3/s) data in the PLE drainage basin and values of the Oceanic Niño Index (ONI), which indicate *El Niño* events occurring in the Equatorial Pacific Ocean, were obtained from the National Institute of Meteorology (INMET) and the National Oceanic and Atmospheric Administration's (NOAA), respectively. The ONI is based on sea surface temperature in the Niño 3.4 region ($5^\circ\text{N} - 5^\circ\text{S}$, $120^\circ - 170^\circ\text{W}$). Values above 0.5 indicate the occurrence of *El Niño* events. To determine a monthly value, we calculated the average of the quarterly ONI values that encompassed the month under analysis. To assess the impact of these events, the intensity of *El Niño* events represented by ONI values, was incorporated when modeling the species abundances and their relationships with explanatory variables (see next subsection).

2.3 Data Analyses

Generalized Linear Models (GLMs) were used to model the relationships between the abundance of the three species from 1997 to 2019 and local (water temperature, salinity, transparency), regional (rainfall and river flow along the lagoon's drainage basin) and global (*El Niño* events) factors. For each species, an abundance model was developed using different distributions, such as the Gaussian family for *Atherinella brasiliensis* and the Gamma family for *Jenynsia lineata*. For *Ctenogobius shufeldti*, due to zero inflation in the data, two models were constructed: one for abundance using the Gamma family and another for occurrence using the Binomial family. Before model construction, multicollinearity between explanatory

variables was assessed using the "GGally" package in R (R Core Team, 2022), which built a correlation matrix using Pearson's method (Schloerke et al., 2021). All environmental covariates (water temperature, salinity, water transparency, rainfall, river discharge and ONI) were retained in the GLM models as pairwise Pearson correlations among all variables were ≤ 0.5 . Considering that the relationship between the climatic and hydrological effects caused by *El Niño* events and the fish species abundance at PLE does not occur simultaneously, the ONI and precipitation variables were included in the analysis with time lags of two and one month, respectively (Moraes et al., 2012). To control for the effects of temporal pseudoreplication, the factor 'time' (months/years) was treated as a random effect, while the abiotic variables (water temperature, salinity, water transparency, precipitation, river discharge, and ONI) were treated as fixed effects (Zuur et al., 2009; Crawley, 2012). The Q-Q plot method was used to assess the normality of model residuals, and the most parsimonious model was selected based on ANOVA tests, Akaike's Information Criterion (AIC), and the model's explanatory power. All analyses were performed using R software (R Core Team, 2022), employing the packages "ggplot2", "vegan", "GGally", "lme4", "bbmle", "vcd", "ggpubr", "ggpmisc", "MASS", "car", "glmmML", "multcomp", and "DHARMA", with a significance level of $\alpha = 0.05$.

3. Results

3.1 Temporal Variability of Environmental Factors

El Niño events were associated with increased rainfall and river discharge in the PLE drainage basin, resulting in low salinities and reduced water transparency in the estuarine region, with a lag of approximately 1-2 months. The average monthly precipitation in the drainage basin was 189.8 mm, with peak rainfall reaching 330.1 mm, 349.4 mm, and 318.3 mm in October 1997, November 2009, and October 2015, respectively. River flow followed a similar pattern over the years, with peaks observed during periods of higher ONI index values, such as in 1997, 2009, and 2015. Salinity in the estuary also varied, dropping to nearly zero following the precipitation peaks in those same years. Water temperature exhibited strong seasonality and had little correlation with the ONI index during the study period. Furthermore, both salinity and water transparency showed an inverse correlation with other environmental variables, suggesting a complex response to *El Niño* events and their influence on local and regional abiotic parameters (Fig. 3).

3.2 Temporal Changes in Abundance of Estuarine-Resident Fish Species

The three estuarine-resident species exhibited marked interannual variations in their abundance along the long-term time series (Fig. 4). *Atherinella brasiliensis* showed an average CPUE of 1.0 ± 0.4 , with a conspicuous decline from 1997 to 2004, followed by a stabilization phase in subsequent years. *Ctenogobius shufeldti* exhibited the lowest average CPUE (0.2 ± 0.15) compared with the other species, showing a continuous decline from 1997 to 2019. In contrast, *Jenynsia lineata* had an average CPUE of 0.7 ± 0.35 , with a lesser pronounced decline, suggesting lower temporal variability compared to the other species.

GLM models revealed that all three estuarine-resident species in the PLE experienced a declining trend in abundance over the studied time series (Table 1) (see Supplementary Table 1). *El Niño* events, salinity, water transparency, and temperature were significant factors related with the temporal abundance changes of the three estuarine-resident fish species (Table 1). The GLM model for *A. brasiliensis* indicated that *El Niño*, water transparency, and salinity explained 44% of its variation in abundance in the PLE (Table 1, Fig. 5). The abundance variation of *J. lineata* was influenced by temperature, water transparency, and salinity, with the model explaining 59.5% of the variation (Table 1, Fig. 6). In contrast, water temperature was the only significant variable explaining (46.5%) the temporal variability in the abundance of *C. shufeldti* (Table 1, Fig. 7). However, the GLM model based on the species occurrence (instead of its abundance) indicated a greater number of significant explanatory variables. In addition to temperature, *El Niño* and salinity explained 36% of the occurrence of *C. shufeldti* in the PLE (Table 1, Fig. 7). The percentage distribution of the significant effects of explanatory variables in the GLM models for the abundance of *A. brasiliensis* and *J. lineata*, as well as for the abundance and occurrence of *C. shufeldti*, is presented in Figure 8.

4. Discussion

4.1. Long-term trends in abundance of estuarine-resident fishes

Corroborating our initial hypothesis, our findings revealed that the three estuarine-resident species exhibited a declining abundance trend in the PLE. Overall, estuarine-resident species are adapted to live in an environment characterized by high spatiotemporal variations in physicochemical parameters, such as salinity, temperature and transparency. Some of the benefits to overcome such harsh and unpredictable conditions is the exploitation of abundant food resources and lower predation rates commonly found in shallow estuarine waters, which play a crucial ecological role as nursery grounds for several estuarine organisms. Hence, the

capacity to withstand the physicochemical challenges of completing their entire life cycle within the estuary likely result in ecological advantages that ensure their survival and reproduction in these dynamic and highly productive environments (Whitfeld et al., 2024).

The observed declining abundance trends of the estuarine-resident species in this study may be associated with various anthropogenic impacts and environmental disturbances usually found in estuaries (Wootton, 1991; Belarmino et al., 2021), which may exceed the adaptive capacity of these species (Wainger et al., 2017). For instance, fishing and other human activities have been identified as significant stressors for the ichthyofauna in the PLE (Haimovici & Cardoso, 2017; Possamai et al., 2018). These stressors may also include habitat degradation and fragmentation caused by dam construction (Burns et al., 2006), substrate modification due to bottom trawling (Silveira et al., 2020), and water contamination by heavy metals and other pollutants (Amado et al., 2006; Conдини et al., 2017).

Additionally, climatic phenomena such as *El Niño* events are known to alter hydrological cycles and abiotic conditions both locally and regionally, causing changes in the structure and dynamics of terrestrial and aquatic ecosystems and their biota worldwide (Glantz, 2000; Cai et al., 2020; Belarmino et al., 2021). At PLE, stronger *El Niño* events may trigger positive rainfall anomalies in the lagoon's drainage basins and a subsequent increase in river discharge into the estuary, which can lead to the reduction and/or loss of submerged vegetated habitats (e.g., seagrass meadows) (Copertino, 2010; Lanari & Copertino, 2017). Such climatic-related impact can impair the ecological role of these habitats as spawning sites, food sources, and refuges for these estuarine-resident fishes (Possamai et al., 2018; Belarmino et al., 2021). Moreover, it has been argued that the reduction in the abundance of *J. lineata* in the estuary during periods of heavy rainfall may be attributed to the effect of flooding, which causes dispersion towards the estuarine margins (Garcia et al., 2003). Under these conditions, increased rainfall allows this species greater access to flooded vegetated habitats in low and medium marshes, which could reduce its presence in the areas sampled by beach seine nets operating in open areas (i.e., unobstructed by vegetation) (Garcia et al., 2003).

4.2. Differential responses of estuarine resident fishes to environmental and *El Niño* factors

Our results only partially supported our initial predictions that the reduction in abundance of the three estuarine resident species would be associated with *El Niño* events (hypothesis 2) and they would respond similarly to the effects of these climatic events despite

having distinct functional attributes (hypothesis 3). In fact, GLM modeling of abundance between 1997 and 2019 indicated that *El Niño* events have different effects on the analyzed species. The effects of this phenomenon were negative regarding the abundance of *A. brasiliensis* but was positively associated with an increase in the occurrence of *C. shufeldti*. There was no statistically significant *El Niño* effect either on the abundance of *C. shufeldti* and *J. lineata*.

El Niño events in the southern region of Brazil are associated with high precipitation that can increase continental discharge from 2,400 m³/s to up to 12,000 m³/s at PLE (Vaz et al., 2006; Möller et al., 2009). These extreme discharge events appear to have a more pronounced impact on oviparous species (*A. brasiliensis* and *C. shufeldti*) than on viviparous species (*J. lineata*). For example, the increase in river discharge significantly alters crucial reproductive habitats of *A. brasiliensis*, such as the Wigeon grass *Ruppia maritima* (Lunell, 1753) seagrasses beds, which are used for the deposition and adhesion of its eggs (Copertino, 2010; Belarmino et al., 2021). Although the species uses other substrates, such as marshes and macroalgae, the loss of these seagrasses, essential for egg adhesion, significantly contributed to the decrease in its abundance (Bemvenuti, 1987; Lanari and Copertino, 2017; Belarmino et al., 2021). *El Niño* events can also alter the stability of estuarine sediment, which provides an ideal substrate for the adhesion and fixation of *C. shufeldti* eggs. This reproductive strategy employed by *C. shufeldti* ensures the integrity of the eggs and prevents them from being carried away by currents to unfavorable areas outside the estuarine environment (Contente et al., 2012). In contrast to these oviparous species, *J. lineata* is a viviparous species whose reproduction is less dependent on specific substrates compared to *C. shufeldti* and *A. brasiliensis*. Therefore, this functional attribute related to its reproductive strategy could confer greater resilience to environmental changes caused by these climatic events.

Additionally, the different use of habitat is a functional attribute that may be associated with the varying responses of estuarine-resident species' abundance to the hydrological effects associated with *El Niño* events. Among the three analyzed estuarine-resident species, *A. brasiliensis* is the only with pelagic habit, whereas the other ones are more associated with the substrate, with *J. lineata* and *C. shufeldti* showing demersal and benthic habits, respectively (Mai and Passamai, 2022). In contrast with *J. lineata* and *C. shufeldti*, whose juveniles and adults are usually found inhabiting estuarine shallow waters (< 2m), larger specimens of *A. brasiliensis* may use deeper waters (main lagoon channel). As already speculated by Belarmino and collaborators (2023), individuals inhabiting deeper water could

be more prone to being carried out of the estuary into the adjacent marine waters due to the higher water current intensity found in the main channel. Hence, it seems plausible to hypothesize that demersal and benthic estuarine-resident fishes living in protected shallow waters of the estuary like *J. lineata* and *C. shufeldti* would be less susceptible to the increased river discharge compared to pelagic ones like *A. brasiliensis*.

Our models also indicate that water temperature plays a crucial role in regulating the abundance and occurrence of *J. lineata* and *C. shufeldti*. In estuarine environments, the interaction between physical-chemical factors, such as temperature and turbulence, can directly influence the ecology of species, modifying their morphology, behavior, and physiology (Reyes & Aguirre, 2019). The dynamic nature of estuaries, with pronounced salinity gradients and rapid variations in parameters such as turbidity and temperature, imposes significant ecological and physiological challenges for fish (Ong et al., 2015; Salvador & Muelbert, 2019). These environmental fluctuations affect essential ecological processes, such as growth rate and reproductive success of species (Izzo et al., 2016; Morrongiello et al., 2014). For example, during periods of higher temperatures, estuarine ecosystems provide more favorable conditions for the development of these species, as warmth promotes metabolism and reproduction, enhancing population resilience. Moreover, the interaction between temperature and salinity variations can directly affect community structure and species distribution, modulating ecological and evolutionary responses (Ong et al., 2015; Salvador & Muelbert, 2019). Therefore, our results suggest that temperature is a determining factor for the ecology of these estuarine resident species, reflecting its importance in population dynamics in ecosystems subject to environmental variations.

In conclusion, our findings revealed that over the studied time series (22 years), the three estuarine-resident species of the PLE show a declining trend in their abundance, regardless of differences in functional attributes related to feeding, habitat use, and reproduction. Our results also showed that *El Niño* events distinctly impact each species, with more pronounced effects on oviparous species (*A. brasiliensis* and *C. shufeldti*) compared to the viviparous one (*J. lineata*). These findings raise concerns about the conservation of these estuarine-resident species, particularly in light of predictions regarding the increased frequency of events like *El Niño* due to global warming (Yeh et al., 2009; Cai et al., 2015; Freund et al., 2019; Wang et al., 2020). Future studies are needed to better distinguish between anthropogenic and climatic effects that may reduce the abundance of these species and the ecological impacts of this loss on the functioning of subtropical estuarine ecosystems.

Acknowledgments

N Escamade acknowledges the financial support of the National Council for Scientific and Technological Development (CAPES). AM Garcia thanks research fellowship provided by CNPq (Proc. 313008/2021-3). VM Lemos acknowledges the financial support of the Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul - FAPERGS. We are also thankful to the Brazilian decadal changes Ecological Research Program (PELD - Pesquisas Ecológicas de Longa Duração) site 8 – Patos Lagoon estuary and adjacent marine coast for funding this research.

References

- Amado, L.L., Da Rosa, C.E., Leite, A.M., Moraes, L., Pires, W.V., Pinho, G.L.L., Bianchini, A., 2006. Biomarkers in croakers *Micropogonias furnieri* (Teleostei: Sciaenidae) from polluted and non-polluted areas from the Patos Lagoon estuary (Southern Brazil): evidences of genotoxic and immunological effects. *Mar. Pollut. Bull.* 52 (2), 199–206.
- Anderson, W.B., Seager, R., Baethgen, W., Cane, M., You, L., 2019. Synchronous crop failures and climate-forced production variability. *Sci. Adv.* 5, eaaw1976.
- Andrades, R., Guabiroba, H.C., Hora, M.S., Martins, R.F., Rodrigues, V.L., Vilar, C.C., Joyeux, J.C., 2020. Early evidences of niche shifts in estuarine fishes following one of the world's largest mining dam disasters. *Mar. Pollut. Bull.* 154, 111073.
- Beck, M.W., Heck Jr., K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Minello, T.J., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrate. *Bioscience* 51 (8), 633–641.
- Belarmino, E., de Nobrega, M. F., Grimm, A. M., Copertino, M. S., Vieira, J. P., & Garcia, A. M. (2021). Long-term trends in the abundance of an estuarine fish and relationships with *El Niño* climatic impacts and seagrass meadows reduction. *Estuarine, Coastal and Shelf Science*, 260, 107565.
- Belarmino, E., Cabral, H., & Garcia, A. M. (2024). Long-term trends in the functional structure of estuarine fish assemblages in a subtropical estuary and its relationships with local environmental variability, man-made changes, and climatic drivers. *Marine Environmental Research*, 201, 106698.

Bemvenuti, C.E., 1997. Benthic invertebrates. In: Seeliger, U., Odebrecht, C., Castello, J. P. (Eds.), Subtropical Convergence Environments: the Coast and Sea in the Southwestern Atlantic. Springer-Verlag, Heidelberg, New York, pp. 43–47.

Blondel, J. 2003. Guilds or functional groups: does it matter? *Oikos* 100:223-231.

Burns, M.D., Garcia, A.M., Vieira, J.P., Bemvenuti, M.A., Marques, D.M., Condini, V., 2006. Evidence of habitat fragmentation affecting fish movement between the Patos and Mirim coastal lagoons in southern Brazil. *Neotrop. Ichthyol.* 4 (1), 69–72.

Cai, W., Borlace, S., Lengaigne, M., Rensch, P.V., Collins, M., Vecchi, G., Timmermann, A., Santoso, A., McPhaden, M.J., Wu, L., England, M.H., Wang, G., Guilyard, E., Jin, F.F., 2014. Increasing frequency of extreme *El Niño* events due to greenhouse warming. *Nat. Clim. Change* 4, 111–116.

Cai W, Borlace S, Lengaigne M, van Rensch P, Collins M, Vecchi G, Timmermann A, Santoso A, McPhaden MJ, Wu L (2015). Increasing frequency of extreme *El Niño* events due to greenhouse warming. *Nature Clim Change* 4:111–116.

Cai, W., McPhaden, M.J., Grimm, A.M., Rodrigues, R.R., Taschetto, A.S., Garreaud, R.D., Dewitte, B., Poveda, G., Ham, Y.-G., Santoso, A., Ng, B., Anderson, W., Wang, G., Geng, T., Jo, H.-S., Marengo, J.A., Alves, L.M., Osman, M., Li, S., Wu, L., Karamperidou, C., Takahashi, K., Vera, C., 2020. Climate impacts of the *El Niño*–southern oscillation on South America. *Nat. Rev. Earth Environ.* 1, 215–231.

Caramaschi, É. P., & Brito, M. F. G. (2021). Reprodução de peixes de riacho: estado da arte, métodos e perspectivas. *Oecologia Australis*, 25(2), 323–343.

Condini, M.V., Hoeninghaus, D.J., Roberts, A.P., Soulen, B.K., Garcia, A.M., 2017. Mercury concentrations in dusky grouper *Epinephelus marginatus* in littoral and neritic habitats along the Southern Brazilian coast. *Mar. Pollut. Bull.* 115 (1–2), 266–272.

Contente, R. F., Stefanoni, M. F., & Spach, H. L. (2012). Feeding ecology of the American freshwater goby *Ctenogobius shufeldti* (Gobiidae, Perciformes) in a sub-tropical estuary. *Journal of Fish Biology*, 80(6), 2357-2373.

Copertino, M.S., Seeliger, Ulrich, Org, 2010. Habitats de *Ruppia maritima* e de macroalgas. In: Seeliger, U., Odebrecht, C. (Eds.), O estuário da Lagoa dos Patos: um século de transformações, 1ed, vol. 1. FURG, Rio Grande, pp. 91–98. 2010.

- Crawley, M.J., 2012. Time Series Analysis (Chap 24). In: The R Book. John Wiley & Sons, p. 1051 (pgs).
- Costanza, R. (1997). The value of the world's ecosystem services and natural capital. *Nature* 387, 253 - 260.
- Day JW, Yáñez-Arancibia A, Kemp WM, Crump BC (2012) Introduction to Estuarine Ecology. 1–18.
- Delpech, C., Courrat, A., Pasquaud, S., Lobry, J., Le Pape, O., 2010. Development of a fish-based index to assess the ecological quality of transitional waters: the case of French estuaries. *Mar. Pollut. Bull.* 60 (6), 908–918.
- Esmaili YS, Corte GN, Checon HH, Bilatto CG, Lefcheck JS, Amaral ACZ, Turra A (2021). Revealing the drivers of taxonomic and functional diversity of nearshore fish assemblages: Implications for conservation priorities. *Diversity and Distributions* 00:1-13.
- Figueiredo, J.L., Menezes, Atherinopsidae, N.A., 2003. In: Menezes, N.A., Buckup, P.A., Figueiredo, J.L., Moura, R.L. (Eds.), *Catálogo Dos Peixes Marinhos Do Brasil*. EDUSP, São Paulo, pp. 65–66
- Fischer, L. G., Pereira, L. E. D., & Vieira, J. P. (2004). *Peixes estuarinos e costeiros*. Série Biodiversidade do Atlântico Sudoeste 01. Editora Ecoscientia, Rio Grande, 139pp.
- Freund, M.B., Henley, B.J., Karoly, D.J., McGregor, H.V., Abram, N.J., Dommenges, D., 2019. Higher frequency of Central Pacific *El Niño* events in recent decades relative to past centuries. *Nat. Geosci.* 12, 450–455.
- Garcia, C.A., 1997. Hydrographic characteristics. Subtropical convergence marine ecosystem. The coast and the sea in the warm temperate southwestern Atlantic, Springer Verlag, Heidelberg, 18-20.
- Garcia, A. M., Vieira, J. P., & Winemiller, K. O. (2001). Dynamics of the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil) during cold and warm ENSO episodes. *Journal of Fish Biology*, 59(5), 1218-1238.
- Garcia, A.M., Vieira, J.P., Winemiller, K.O., 2003. Effects of 1997–1998 *El Niño* on the dynamics of the shallow-water fish assemblage of the Patos lagoon estuary (Brazil). *Estuary. Coast Shelf Sci.* 57, 489–500.

- Garcia, A. M., Vieira, J. P., Winemiller, K. O., & Grimm, A. M. (2004). Comparison of 1982–1983 and 1997–1998 *El Niño* effects on the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil). *Estuaries*, 27, 905-914.
- Garcia, A. M., Vieira, J. P., Winemiller, K. O., & Raseira, M. B. (2004a). Reproductive cycle and spatiotemporal variation in abundance of the one-sided livebearer *Jenynsia multidentata*, in Patos Lagoon, Brazil. *Hydrobiologia*, 515, 39-48.
- Garcia, A. M., Vieira, J. P., Winemiller, K. O., & Grimm, A. M. (2004b). Comparison of 1982–1983 and 1997–1998 *El Niño* effects on the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil). *Estuaries*, 27, 905-914.
- Garcia, A. M., Claudino, M. C., Mont'Alverne, R., Pereyra, P. E. R., Copertino, M., & Vieira, J. P. (2016). Temporal variability in assimilation of basal food sources by an omnivorous fish at Patos Lagoon Estuary revealed by stable isotopes (2010–2014). *Marine Biology Research*, 13(1), 98-107.
- Glantz, M.H. (Ed.), 2000. *Currents of Change: El Niño and La Niña Impacts on Climate and Society*, second ed. Cambridge University Press, New York, p. 252pp.
- Grimm, A.M., Barros, V.R., Doyle, M.E., 2000. Climate variability in southern south America associated with *El Niño* and *La Niña* events. *J. Clim.* 13, 35–58.
- Haimovici, M., Cardoso, L.G., 2017. Long-term changes in the fisheries in the Patos Lagoon estuary and adjacent coastal waters in Southern Brazil. *Mar. Biol. Res.* 13, 135–150.
- Harrison, T. D., & Whitfeld, A. K. (2024). A global functional analysis of fish-estuary associations and selected environmental factors. *Reviews in Fish Biology and Fisheries*, 34(4), 805–825.
- Hooper, D. U., M. Solan, A. Symstad, S. Diaz, N. Buchmann, V. Degrang, P. Grime, F. Hulot, F. Mermillod-Blondin, J. Roy, E. Spehn, and L. Van Peer. 2002. Species diversity, functional diversity, and ecosystem functioning. Pages 195-281 in M. Loreau, S. Naeem and P. Inchausti, editors. *Biodiversity and Ecosystem Functioning: Synthesis and Perspectives*. Oxford University Press, USA.
- Izzo, P., Milessi, A.C., Ortega, L., Segura, A.M., 2010. First record of *Aluterus scriptus* (Monacanthidae) in Mar del Plata, Argentina. *Mar. Biodivers. Rec.* 3, 40.

Kennish, M.J., 1992. Ecology of Estuaries: Anthropogenic Effects, vol. 2. CRC Press, Boca Raton, pp. 45–62.

Kjerfve B (2013) Comparative Oceanography of Coastal Lagoons. *Estuary Var*:63–81.

Lanari, M., & Copertino, M. (2016). Drift macroalgae in the Patos Lagoon Estuary (southern Brazil): Effects of climate, hydrology and wind action on the onset and magnitude of blooms. *Marine Biology Research*, 13(1), 36–47.

Lemos, V.M., Cabral, H., Pasquaud, S., Vieira, J.P., 2021. Occurrence and abundance of young mullet *Mugil liza* (Teleostei: Mugilidae) in the surf zone along the southern coast of Brazil. *Sci. Mar.* 85 (4), 245–255.

Lemos, V. M., Lanari, M., Copertino, M., Secchi, E. R., de Abreu, P. C. O., Muelbert, J. H., & Odebrecht, C. (2022). Patos Lagoon estuary and adjacent marine coastal biodiversity long-term data. *Earth System Science Data*, 14(3), 1015-1041.

Mai, A.C., Possamai, B., 2022. Categorizing estuarine fish in the warm temperate Southwestern Atlantic Province: the case of Patos lagoon estuary, Brazil. *Regional Studies in Marine Science* 54.

Manna, L. R., Rezende, C. F., & Mazzoni, R. (2013). Functional diversity of stream fish: How can assemblages be organized? *Oecologia Australis*, 17(3), 402–410.

Marques, W.C., Fernandes, E.H.L., Rocha, L.A.O., 2011. Straining and advection contributions to the mixing process in the Patos Lagoon estuary, Brazil. *J. Geophys. Res.* 116, C03016.

Marques, W.C., Stringari, C.E., Eidt, R.T., 2014. Influence of the freshwater discharge on the hydrodynamics of Patos Lagoon, Brazil. *Adv. Water Resour. Protect.* 2, 11–19.

Marsh-Matthews, E., and W. J. Matthews. 2000. Geographic, terrestrial and aquatic factors: which most influence the structure of stream fish assemblages in the Midwestern United States? *Ecology of Freshwater Fish* 9:9-21.

Moraes, L.E., Paes, E., Garcia, A., Möller Jr., O., Vieira, J., 2012. Delayed response of fish abundance to environmental changes: a novel multivariate time-lag approach. *Mar. Ecol. Prog. Ser.* 456, 159–168.

- Morrongiello, J. R., Walsh, C. T., Gray, C. A., Stocks, J. R., & Crook, D. A. (2014). Environmental change drives long-term recruitment and growth variation in an estuarine fish. *Global Change Biology*, 20(4), 1231–1244.
- Mouillot D, Grahan NAJ, Villéger S, Mason NWH, Belwood DR (2013) A functional approach reveals community responses to disturbances. *Trends Ecol. Evol.* 28: 167–177.
- Noletto-Filho, E. M., Pucciarelli, P., & Dumont, L. F. C. (2017). Spatial and temporal variation in juvenile size distribution of the pink shrimp (*Penaeus paulensis*) in the Patos Lagoon Estuary, Brazil. *Marine Biology Research*, 13(1), 62–73.
- Odebrecht, C; Secchi, ER; Abreu, PC; Muelbert, JH & Uiblein, F. 2017. Biota of the Patos Lagoon estuary and adjacent marine coast: longterm changes induced by natural and human-related factors. *Marine Biology Research* 13, 3-8.
- Olsen, Z., & McCulloch, J. (2024). Trends and distribution of hardhead catfish in Texas estuaries—shifting relative abundance of a highly ubiquitous generalist predator. *Environmental Biology of Fishes*, 1-27.
- Ong, J.J., Rountrey, A.N., Zinke, J., Meeuwig, J.J., Grierson, P.F., O'Donnell, A.J., Newman, S.J., Lough, J.M., Trougan, M., Meekan, M.G., 2016. Evidence for climate-driven synchrony of marine and terrestrial ecosystems in northwest Australia. *Glob. Chang. Biol.* 22, 2776–2786.
- Possamai, B., Vieira, J.P., Grimm, A.M., Garcia, A.M., 2018. Temporal variability (1997-2015) of trophic fish guilds and its relationships with *El Niño* events in a subtropical estuary. *Estuar. Coast Shelf Sci.* 202, 145–154.
- Possamai, B., Vollrath, S. R., Vieira, J. P., & Garcia, A. M. (2024). Synergistic climatic and anthropogenic effects on marine species turnover in estuarine waters. *Science of The Total Environment*, 908, 168324.
- Potter, I.C., Tweedley, J.R., Elliott, M., Whitfield, A.K., 2015. The ways in which fish use estuaries: a refinement and expansion of the guild approach. *Fish Fish.* 16 (2), 230–239.
- Potts, W.M., Gotz, " A., James, N., 2015. Review of the projected impacts of climate change on coastal fishes in southern Africa. *Rev. Fish Biol. Fish.* 25 (4), 603–630.
- R Core Team, 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

Ray, G.C., 2006. The coastal realm's environmental debt. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 16, 1–4.

Reyes, C.W.D., and W.E. Aguirre. 2019. Effects of temperature and water turbulence on vertebral number and body shape in *Astyanax mexicanus* (Teleostei: Characidae). *PLoS ONE* 14: e0219677.

Robertson, A.W., Mechoso, C.R., 1998. Interannual and decadal cycles in river flows of southeastern South America. *J. Clim.* 11 (10), 2570–2581.

Salvador, N.L., Muelbert, J.H., 2019. Environmental variability and body condition of Argentine menhaden larvae, *Brevoortia pectinata* (Jenyns, 1842), in estuarine and coastal waters. *Estuary. Coasts* 42 (6), 1654–1661.

Schloerke, B., Cook, D., Larmarange, J., Briatte, F., Marbach, M., Thoen, E., Elberg, A., Toomet, O., Crowley, J., Hofmann, H., Wickham, H., 2021. GGally: extension to 'ggplot2'. R package version 2.1.2. Available: <https://cran.r-project.org/web/packages/GGally/index.html>.

Seeliger, U., 2001. The Patos Lagoon Estuary, Brazil. In: Seeliger, U., Kjerfve, B. (Eds.), *Coastal Marine Ecosystems of Latin America Ecological Studies (Analysis and Synthesis)*. Springer, Berlin (392 pgs).

Silva, A.C.R.S., Bernardes, M.E.C., Assireu, A.T., Siegle, E., Sousa, P.H.G.O., Brown, D., 2018. Hydrodynamics of a tropical estuary: Buranhém river, Porto Seguro. Brazil 23 e5. ISSN: 2318-0331.

Silveira, Samanta, Ortega, Ileana, Dumont, Luiz Felipe, C., 2020. Artisanal trawling impact over prey availability and diet of estuarine megabenthic organisms in southern Brazil. *Estuary. Coast Shelf Sci.* 237, 106682.

Villéger S, Brosse S, Mouchet M, Mouillot D, Vanni MJ (2017) Functional ecology of fish: current approaches and future challenges. *Aquat. Sci.* 79, 783–801.

Violle, C., Navas, M. L., Vile, D., Kazakou, E., Fortunel, C., Hummel, I., & Garnier, E. (2007). Let the concept of trait be functional. *Oikos*, 116(5), 882-892.

Vieira J P, Garcia A M, Lemos V M (2022). PELD-ELPA Species composition and abundance patterns of fish assemblages at shallow waters of Patos Lagoon estuary. Version 1.11. Sistema de Informação sobre a Biodiversidade Brasileira - SiBBr. Sampling event dataset

- Vollrath, S. R., Tanner, S. E., Reis-Santos, P., Possamai, B., Grimm, A. M., Gillanders, B. M., Vieira, J. P., & Garcia, A. M. (2024). Complex interactions of ENSO and local conditions buffer the poleward shift of migratory fish in a subtropical seascape. *Science of the Total Environment*, 873, 165129.
- Wainger, L.A., Secor, D.H., Gurbisz, C., Kemp, W.M., Glibert, P.M., Houde, E.D., et al., 2017. Resilience indicators support valuation of estuarine ecosystem restoration under climate change. *Ecosys. Health Sustain.* 3 (4), e01268.
- Wang, S., Zhang, Y., Ju, W., Chen, J.M., Ciais, P., Cescatti, A., et al., 2020. Recent global decline of CO₂ fertilization effects on vegetation photosynthesis. *Science* 370 (6522), 1295–1300.
- Warry, F.Y., et al., 2016. Nitrogen loads influence trophic organization of estuarine fish assemblages. *Funct. Ecol.* 30, 1723–1733.
- Whitfield, A.K., 2021. Estuaries—how challenging are these constantly changing aquatic environments for associated fish species? *Environ. Biol. Fish.* 1–12.
- Whitfield, A.K., Potter, I.C., Neira, F.J., Houde, E.D., 2023. Modes of ingress by larvae and juveniles of marine fish into estuaries: from microtidal to macrotidal systems. *Fish.* 24, 488–503.
- Whitfield, A.K., Elliott, M., 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. *J. Fish. Biol.* 61, 229–250.
- Wolfe, Douglas, A., 1996. *Estuarine Variability*. Academic Press, p. 509 (pgs).
- Wootton, R.J., 1991. *Fish Ecology*, first ed. Springer Science & Business Media, p. 212. (pgs)
- Yeh, S.W., Kug, J.S., Dewitte, B., Kwon, M.H., Kirtman, B., Jin, F.F., 2009. *El Niño* in a changing climate. *Nature* 461, 511e514.
- Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. *Mixed Effects Models and Extensions in Ecology with R*, first ed. Springer, New York, p. 574 (pgs).

Figuras

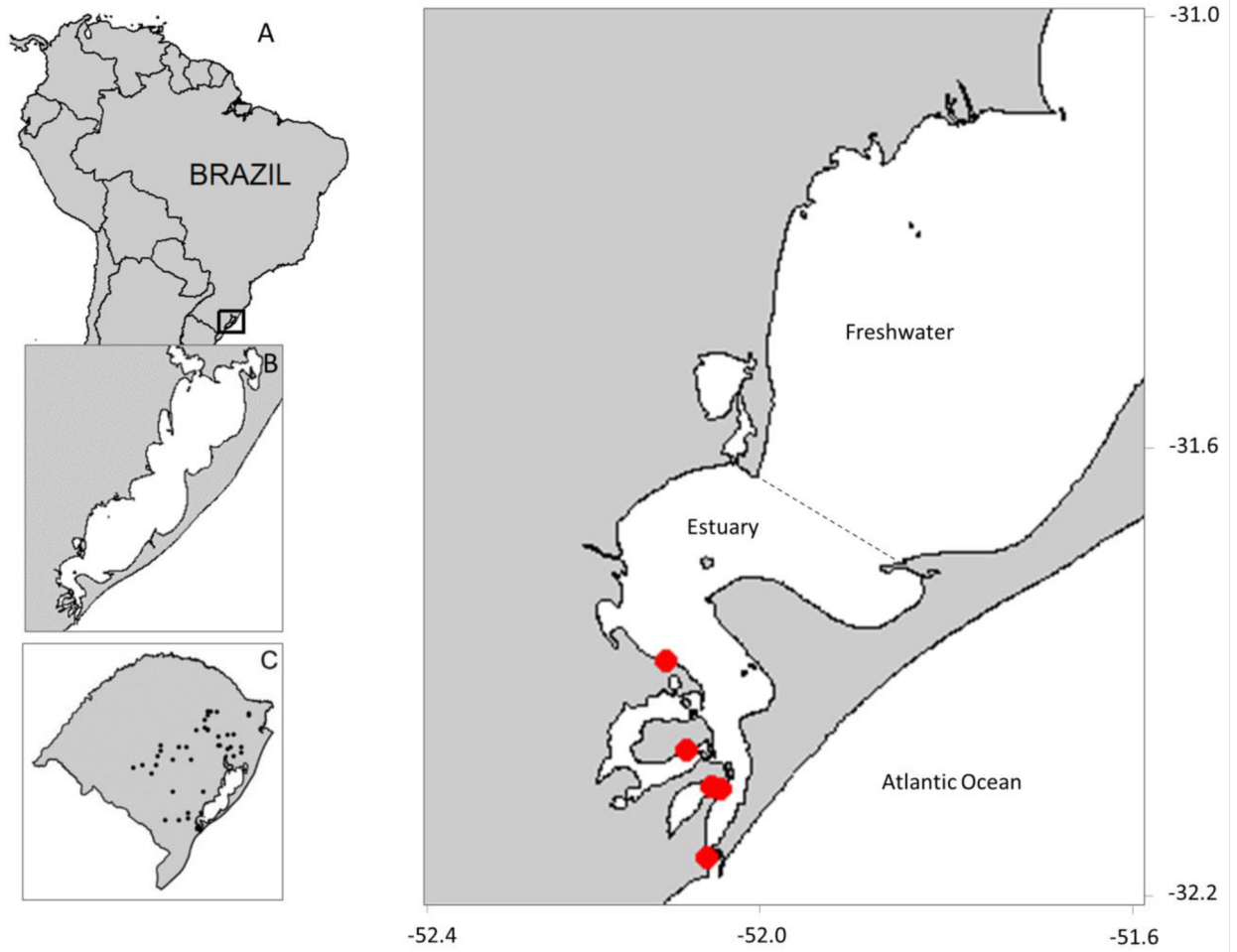


Figure 1. Study area: (A) Map of Brazil; (B) Location of Patos Lagoon; (C) Sampling stations in the estuarine zone (filled red circles, $n = 5$); and (D) Map of the Rio Grande do Sul State in southern Brazil showing the location of the river flow stations along the lagoon's drainage basin (filled black circles).

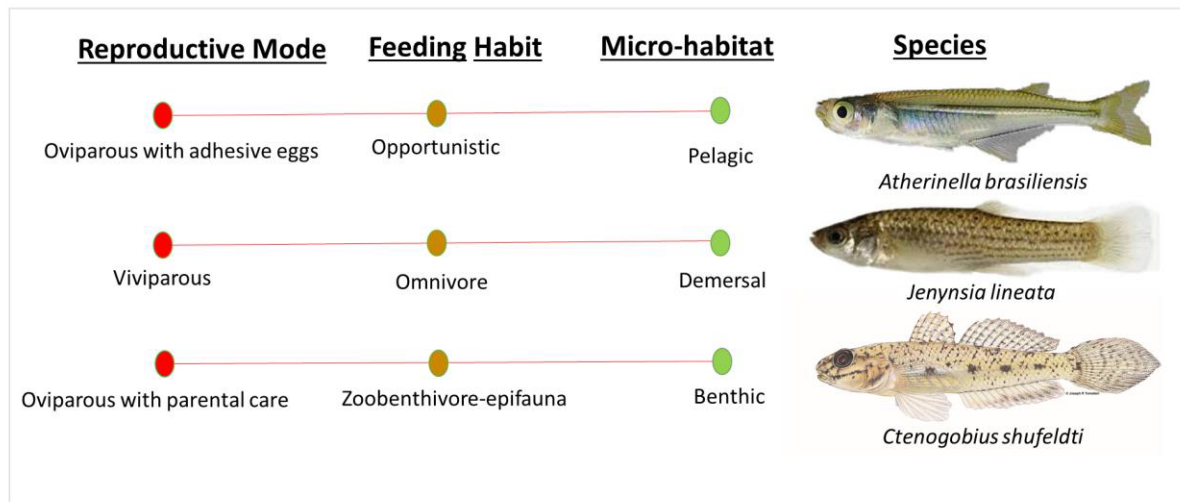


Figure 2. Functional attributes (reproductive mode, feeding habit, and habitat use) of three estuarine-resident fish species *Atherinella brasiliensis*, *Jenynsia lineata*, and *Ctenogobius shufeldti*. The red lines connect the different characteristics of each species.

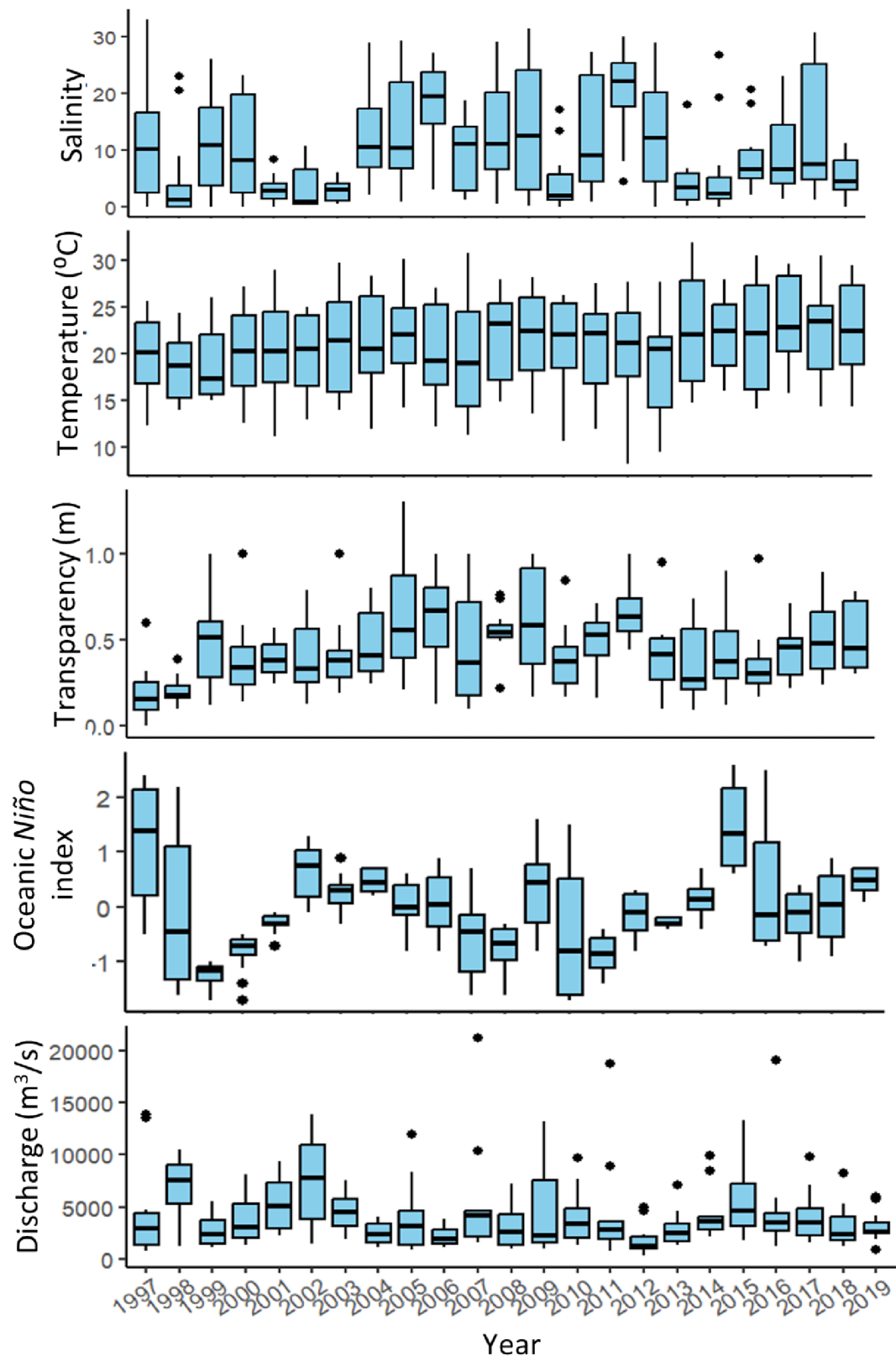


Figure 3. Boxplots of intra- and interannual variations of climatic variables (ONI index) and regional variables (freshwater discharge), and local variables (salinity, temperature, and transparency). The horizontal line inside the boxes indicates the median, while the boxes represent the values between the first and third quartiles.

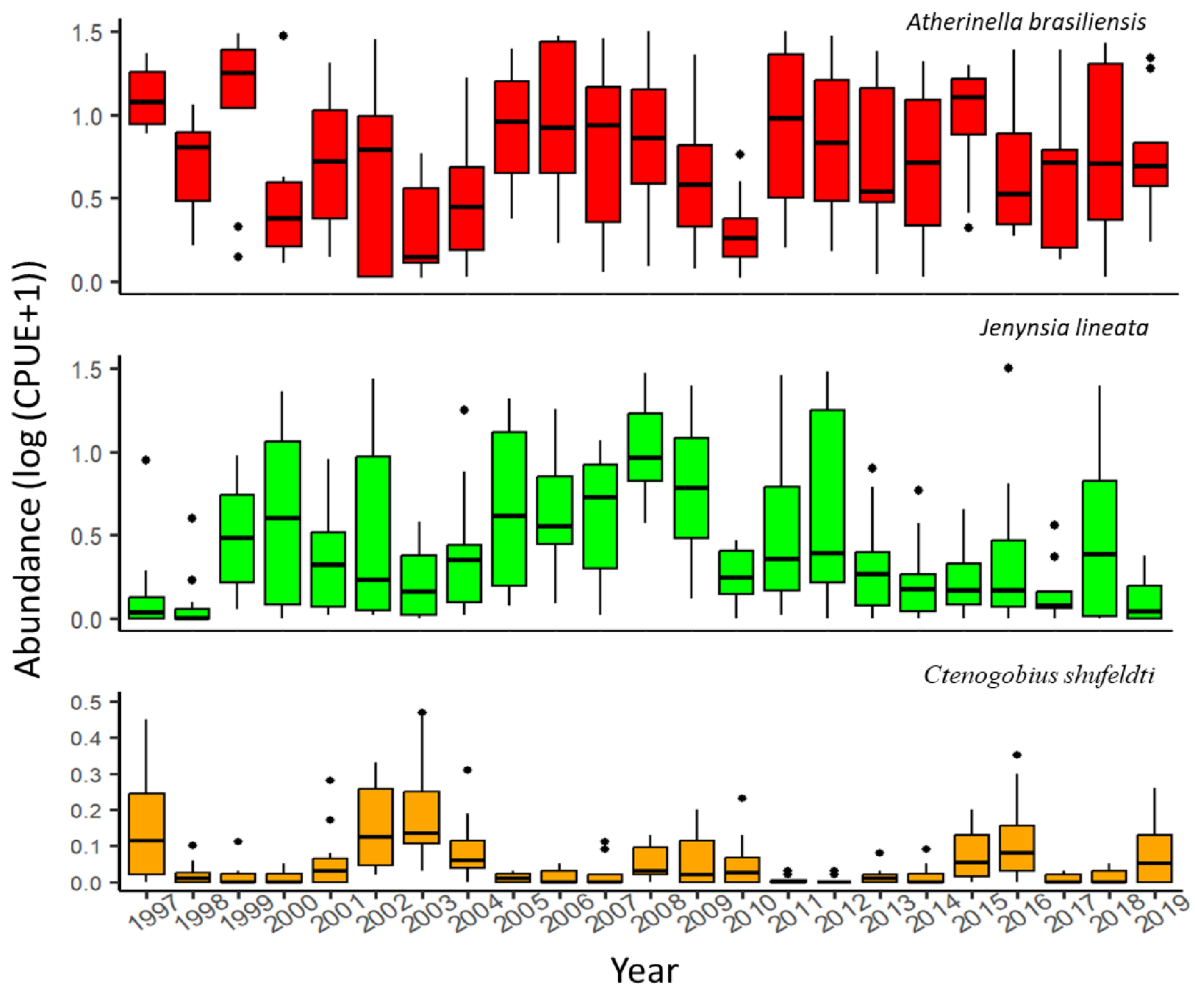


Figure 4. Boxplots of the interannual variation of $\log_{10}(\text{CPUE}+1)$ for *Atherinella brasiliensis* (red boxes), *Jenynsia lineata* (green boxes), and *Ctenogobius shufeldti* (orange boxes). The horizontal line in the middle of the boxes indicates the median, the boxes represent the first and third quartiles, the vertical lines at the ends of the boxes indicate the minimum and maximum values, and the points represent outliers.

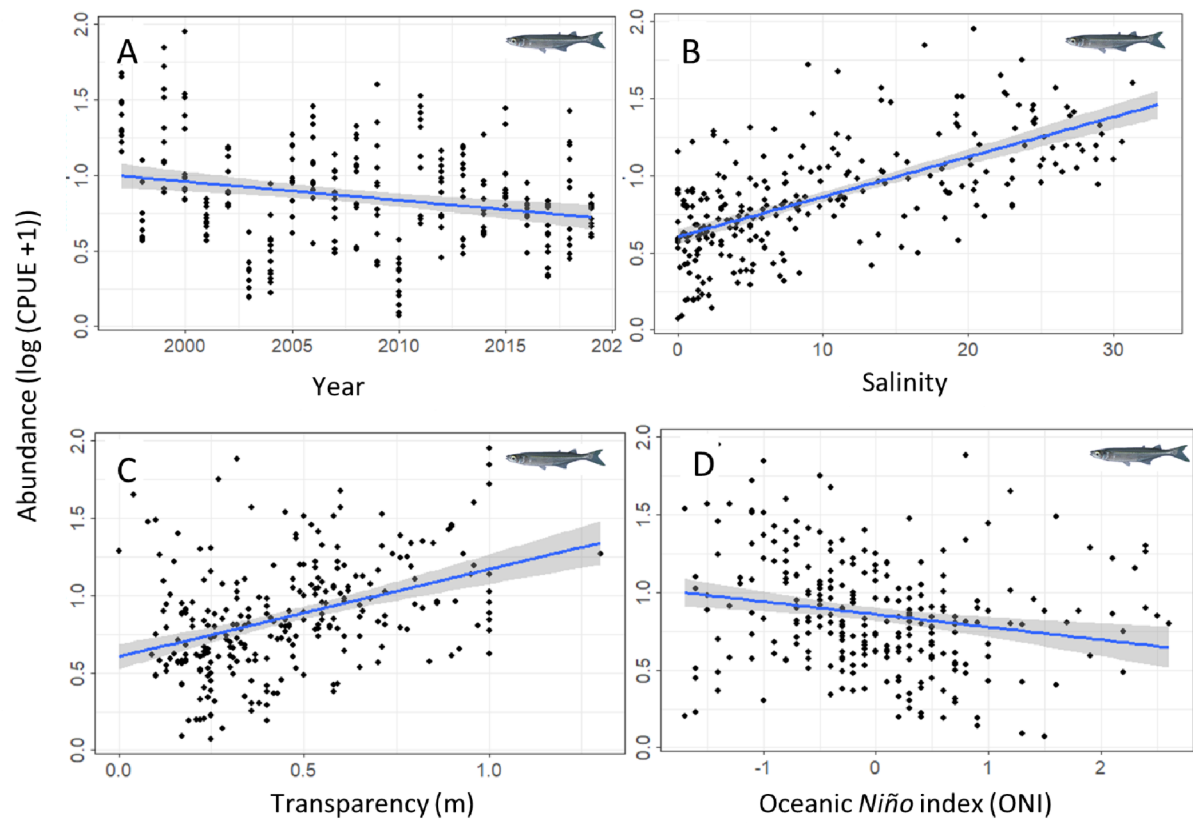


Figure 5. Generalized Linear Model plots showing the partial effects of the selected explanatory variables on the abundance of *Atherinella brasiliensis* in the Patos Lagoon estuary. The shaded areas indicate the 95% confidence intervals.

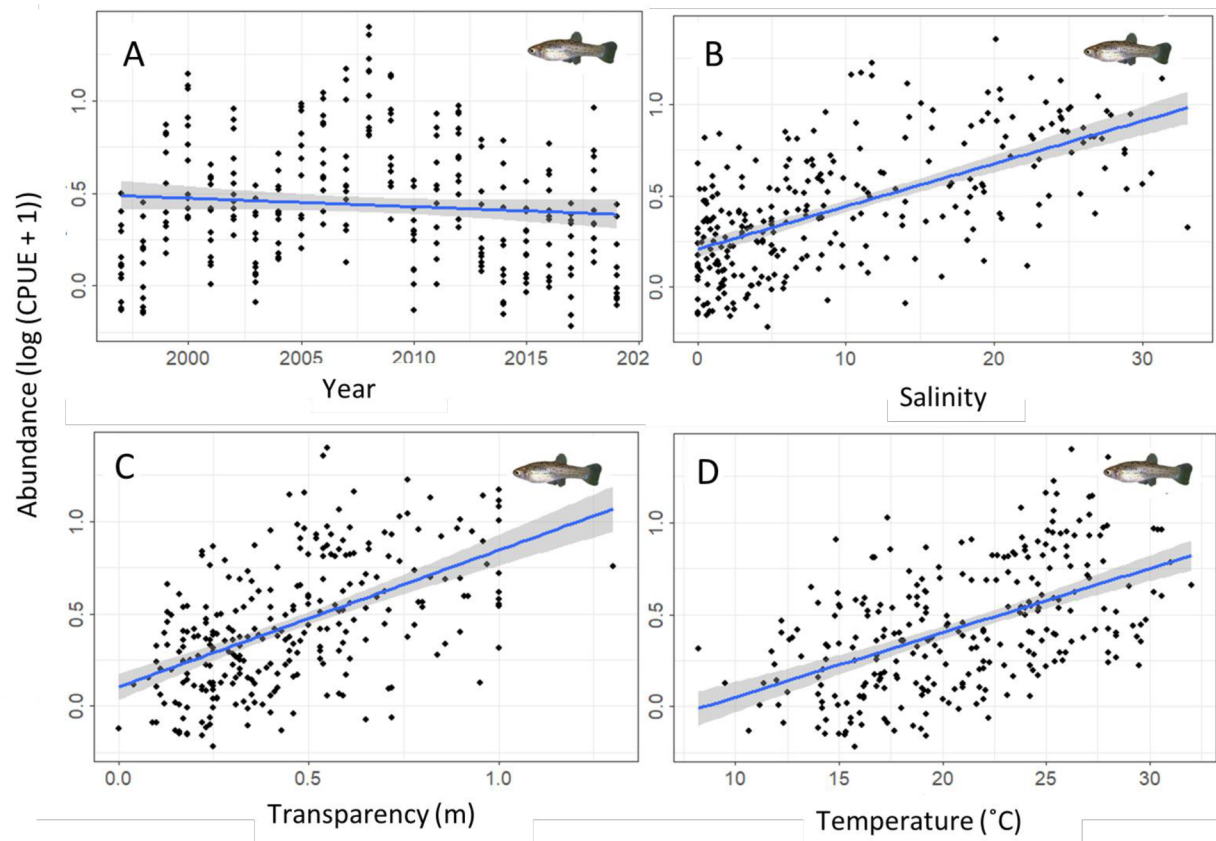


Figure 6. Generalized Linear Model plots showing the partial effects of the selected explanatory variables on the abundance of *Jenynsia lineata* in the Patos Lagoon estuary. The shaded areas indicate the 95% confidence intervals.

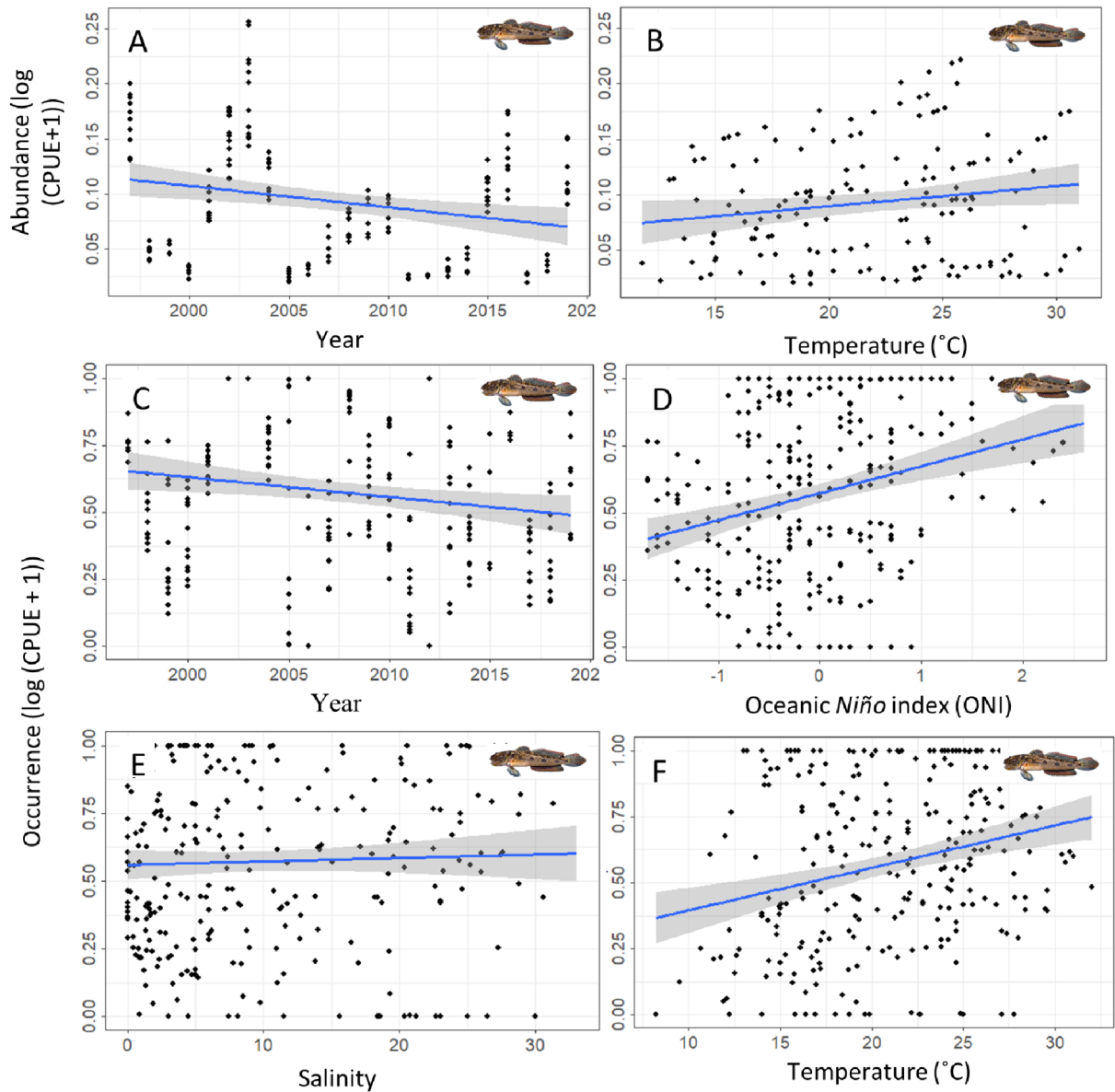


Figure 7. Generalized Linear Model (GLM) plots showing the partial effects of the selected explanatory variables on the abundance (A and B) and occurrence (C, D, E and F) of *Ctenogobius shufeldti* in the Patos Lagoon estuary. The shaded areas indicate the 95% confidence intervals.

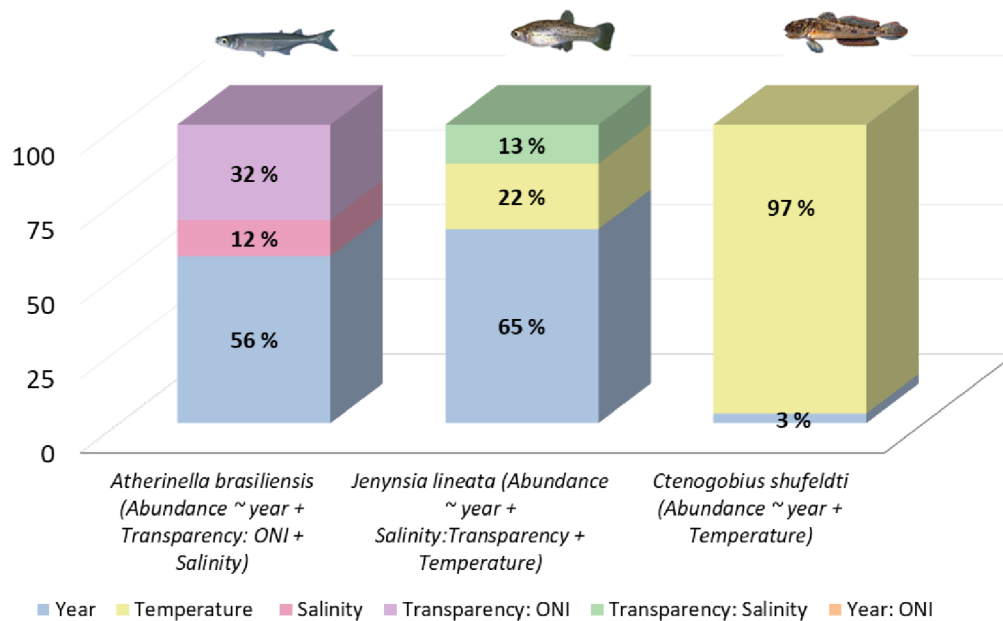


Figure 8. Percentage distribution of the effects of environmental variables on the abundance of *Atherinella brasiliensis* and *Jenynsia lineata*, as well as on the abundance of *Ctenogobius shufeldti*, according to the selected model. The analyzed variables include year, salinity, temperature, transparency, and the ONI index.

Tabelas

Table 1

Selected Generalized Linear Models with values of the Akaike information criterion (AIC) and the model's explanation degree (Exp) for the abundance of *Atherinella brasiliensis*, *Jenynsia lineata*, and *Ctenogobius shufeldti* in the PLE. Res. Dev., residual deviance; Dev. Expl., deviance explained in percentage; Sig., significance; *, $p < 0.05$, **, $p < 0.01$, ***, $p < 0.001$, positive (+) and negative (–) slope.

	Introduced variables	AIC	Res.Dev	Dev.Expl	Sig.	Slope
Abundance (Gaussian model)	<i>Atherinella brasiliensis</i> ~ Year + (Transparency x ONI) + Salinity	326.41				
	Null (abundance ~1)	429.81	77.02			
	~ Year		58.76	24.43	***	-
	+ Transparency x ONI		48.09	14.27	*	-
	+ Salinity		44.14	5.28	***	+
	Total explained			44		
Abundance (Gamma model)	<i>Jenynsia lineata</i> ~ Year + (Salinity x Transparency) +	136.50				

	Temperature					
	Null (abundance ~1)	334.10	53.42			
	~ Year		33.04	38.43	***	-
	+ (Salinity x Transparency)		28.85	7.89	.	+
	+ Temperature		21.87	13.17	***	+
	Total explained			59.50		
<i>Abundance</i> (Gamma model)	<i>Ctenogobius shufeldti</i> ~ Year + Temperature	-494.30				
	Null (abundance ~1)	-432.31	143.01			
	~ Year		141.07	1.45	***	-
	+ Temperature		81.012	45.12	**	+
	Total explained			46.57		

Supplementary Material

Table 2

Selected Generalized Additive Models with second-order Akaike Information Criterion (AIC) values and model explanation degree (EXP). VAN = valid model. The shaded gray lines represent the models selected with the lowest AICc and the highest AICw for the Estuary and Coast region.

n°	Model	AIC	Exp	VAN
<i>Atherinella brasiliensis</i>				
<i>Abundance</i>				
1	~ Year + Salinity + Temperature + Transparency + rainfall + Discharge + ONI	333.2	43.5	
2	~ Year + Salinity + Temperature + Transparency + ONI	329.4	43.5	
3	~ Year + Salinity + Transparency + ONI	330.2	42.8	
4	~ Year + Salinity + Temperature + Transparency	332.1	42.0	Inv.
5	~ Year + Salinity + Transparency	332.2	42.2	
6	~ Year + Salinity * Transparency	333.2	42.3	
7	~ Year * Transparency + Salinity	340.1	49.3	
8	~ Year * ONI + Salinity + Transparency + Temperature	317.1	54.2	Inv.
9	~ Year + Salinity + Transparency * ONI + Temperature	331.1	42.7	
10	~ Year + Salinity * ONI + Transparency + Temperature	330.1	43.7	
11	~ Year + Salinity + Transparency + Temperature * ONI	331.2	43.5	Inv.
12	~ Year * Transparency + Salinity + Temperature + ONI	333.3	51.40	Inv.
13	~ Year * Salinity + Transparency + ONI + Temperature	337.4	50.6	Inv.
14	~ Year * Temperature + Transparency + Salinity + ONI	336.8	50.7	Inv.
15	~ Year + Salinity * Transparency + Temperature + ONI	329.4	43.7	
16	~ Year + Salinity * Temperature + Transparency + ONI	331.2	43.5	
17	~ Year + Salinity + Transparency * Temperature + ONI	330.6	43.6	
18	~ Year + Salinity + Transparency * ONI	326.4	44.0	
29	~ Year + Salinity * ONI + Transparency	330.5	43.2	

*Jenynsia lineata**Abundance*

1	~ Year + Salinity + Temperature + Transparency + Rainfall + Discharge + ONI	141.5	59.3	
2	~ Year + Salinity + Temperature + Transparency	137.5	59.1	
3	~ Year * Salinity+ Temperature + Transparency	135.2	65.4	Inv.
4	~ Year * Temperature + Salinity + Transparency	150.8	63.4	Inv.
5	~ Year * Transparency + Salinity + Temperature	130.4	65.9	Inv.
6	~ Year + Salinity * Temperature + Transparency	139.2	59.1	
7	~ Year + Salinity + Temperature * Transparency	138.8	59.1	
8	~ Year + Salinity * Transparency + Temperature	136.0	59.5	

*Ctenogobius shufeldti**Abundance*

1	~ Year + Salinity + Temperature + Transparency + Rainfall + Discharge + ONI	-486.1	46.6	
2	~ Year + Temperature	-494.3	46.0	
3	~ Year * Temperature	-488.9	57.4	

Occurrence

1	~ Year + Salinity + Temperature+ Transparency + Rainfall + Discharge + ONI	343.1	24.3	
2	~ Year + Salinity + Temperature + ONI	338.8	23.8	
3	~ Year + Salinity + Temperature	337.3	23.7	
4	~ Year * Salinity + Temperature	360.8	29.1	
6	~ Year * Temperature + Salinity	342.3	34.1	
5	~ Year + Salinity * Temperature	339.0	23.8	
7	~ Year * ONI + Salinity + Temperature	336.7	36.1	
8	~ Year + Salinity * ONI + Temperature	337.9	24.6	
9	~ Year + Salinity + Temperature * ONI	339.7	24.5	

CONSIDERAÇÕES FINAIS E PERSPECTIVAS

Os resultados obtidos sobre a análise temporal da variabilidade na abundância das três espécies estuarino-residentes do estuário da Lagoa dos Patos corroboram parcialmente nossas hipóteses. Observamos uma tendência geral de declínio na abundância das três espécies analisadas, independentemente das diferenças dos atributos funcionais relacionados à alimentação, uso do micro-hábitat (pelágico vs. demersal/bentônico) e reprodução.

Os eventos de *El Niño* mostraram impactos distintos em cada espécie, com efeitos mais acentuados nas espécies ovíparas (*Atherinella brasiliensis* e *Ctenogobius shufeldti*) em comparação com a vivípara (*Jenynsia lineata*).

Esses resultados reforçam a necessidade de implementação de estratégias de conservação dessas espécies estuarino-residentes, especialmente diante das previsões de aumento na frequência de eventos de *El Niño* devido às mudanças climáticas globais. Considerando a vulnerabilidade das espécies estuarino-residentes, é essencial que estudos futuros sejam realizados para gerar uma melhor compreensão e diferenciação entre os efeitos climáticos e ambientais, tratados aqui, dos efeitos de fatores antropogênicos (e.g., poluição, perda e fragmentação de habitats com a expansão urbana, atividades portuárias) na redução de suas abundâncias. Além disso, é fundamental investigar os impactos ecológicos potenciais relacionados a diminuição da abundância dessas espécies no funcionamento desse importante ecossistema estuarino subtropical.