Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Functional composition of fish assemblage structure in a modified subtropical estuarine system

Julia Maria Maccari

maccarijulia@gmail.com

Instituto Meros do Brasil

Caio Henrique Gonçalves Cutrim

Universidade Federal do Estado do Rio de Janeiro

Pedro Carlos Pinheiro

Universidade da Região de Joinville

Matheus Oliveira Freitas

Instituto Meros do Brasil

Vinícius Abilhoa

Museu de História Natural Capão da Imbuia, MAPCF/SMMA, Prefeitura de Curitiba

Johnatas Adelir-Alves

Instituto Meros do Brasil

Research Article

Keywords: Babitonga Bay, ichthyofauna, ecological research, conservation

Posted Date: November 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11310658/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Estuaries are essential for marine biodiversity, and promoting the sustainable use of these ecosystems has become increasingly necessary due to their ecological and socioeconomic importance. This study presents a survey of estuarine fishes in the Linguado Channel, Santa Catarina, southern Brazil. A total of 28 species belonging to 24 families and 12 orders were recorded, including three species listed as threatened according to IUCN criteria and one non-native species, the mud sleeper *Butis koilomatodon*. The ichthyofauna was dominated by marine stragglers and zoobenthivores. Fish assemblages differed between the two sampled habitat contexts and seasons, with variation primarily driven by species turnover rather than nestedness. However, trophic and estuarine-use structures remained relatively stable across habitats and seasons, suggesting that taxonomic changes were not accompanied by equivalent shifts in ecological functions. These findings indicate that the ecological relevance of the Linguado Channel extends beyond its taxonomic richness, as the assemblage includes species with distinct trophic roles, estuarine-use strategies, and conservation statuses despite the environmental heterogeneity and long history of anthropogenic modification. The Linguado Channel supports fish biodiversity and provides habitats with ecological and societal importance, yet remains poorly understood by the scientific community and decision-makers. Further studies are therefore needed to provide baseline information and support effective management and conservation actions.

Introduction

The conservation of biodiversity is fundamental for maintaining ecosystem structure and functioning, as well as for preserving ecological processes and the ecosystem services they support (Hooper et al. 2005; Tilman et al. 2014). Conservation efforts have largely centred on safeguarding individual species (Stuart-Smith et al. 2013), however, species-focused approaches and assessments based primarily on species richness may provide an incomplete representation of biodiversity (Fletcher Jr. et al. 2025), particularly in a rapidly changing world where entire ecosystems and biological communities are being reshaped (Belitz et al. 2025). Therefore, understanding the different facets of biodiversity and their ecological drivers is essential for developing more comprehensive approaches to biodiversity assessment and conservation (Zhang et al. 2021).

Fish are the most diverse group of vertebrates and perform numerous key ecological roles, contributing to the structure and functioning of aquatic ecosystems (Mao et al. 2026; Yoshida et al. 2026). Their occurrence across freshwater, estuarine, and marine environments reflects a wide range of ecological strategies and habitat requirements (Nelson et al. 2016). In coastal and estuarine systems, many fish species use shallow waters either temporarily or permanently (Vilar et al. 2011a), and understanding their relationship with the environment is essential for the success of conservation strategies for this ecosystem.

The Brazilian coastal zone extends for approximately 8,700 km and encompasses a wide diversity of ecosystems along its entire extent (Nicolodi et al. 2009), including estuarine systems. These systems are of great socio-economic and ecological importance, widely recognized as breeding, feeding, and nursery areas for numerous organisms, including threatened fish species (Bordin et al. 2024). They are highly vulnerable to anthropogenic pressures (Barletta et al. 2023), and despite their ecological value and socio-economic relevance, such as artisanal fisheries, these ecosystems have been steadily declining (Lotze et al. 2006; Martínez et al. 2007). The consequences of these impacts on estuarine ecosystems are worrying, given that estuaries are essential

habitats for maintaining the diversity of species functions, as they act as sources for larger ecosystems through the recruitment and replacement of species (Belarmino et al. 2024).

In southern Brazil, three major estuarine complexes stand out: the Paranaguá Estuarine Complex, the Babitonga Bay Estuarine Complex, and the Patos Lagoon Estuarine-Lagoon System (Lana et al. 2001; Cremer 2006; Dias et al. 2011). In these subtropical estuaries, the ichthyofauna is relative known (de Andrade Tubino et al. 2008; Vilar et al. 2011c) and is characterized mainly by small-sized species with cryptic habits (Freitas and Velastin, 2010), including species of commercial and subsistence importance (Gerhardinger et al. 2020; Bordin et al. 2024).

Babitonga Bay plays an important role for the composition of regional ichthyofauna, evidenced by the high abundance of juvenile individuals recorded (Souza-Conceição et al. 2013a, b; Bordin et al. 2024). In this sense, Babitonga Bay and adjacent marine areas stand out as a region rich in ichthyological composition. Despite its high complexity, studies conducted so far on the fish biodiversity of this estuarine complex have focused mainly on its main channel, leaving the ichthyofauna of adjacent areas largely unexplored (Gerhardinger et al. 2020).

The Linguado Channel corresponds to the southern mouth of Babitonga Bay, which was completely artificially blocked in 1935 to allow the passage of a railway. Following its blocking, the channel is no longer connected to or influenced by the Babitonga Bay estuarine complex, presenting estuarine lagoon characteristics with restricted communication with the sea (Suguio 1992). Despite its distinct environmental conditions and long history of anthropogenic alteration (Gerhardinger et al. 2006c), baseline information on the faunal assemblages inhabiting the channel remains limited (Côrrea et al. 2006; Vilar et al. 2011b), hindering a comprehensive assessment of its biodiversity and ecological functioning. Characterizing the taxonomic composition and dynamics of the ichthyofauna, together with the ecological roles represented within the community, can therefore provide important insights into how this unique and altered environment supports biodiversity and ecosystem functioning (Vilar et al. 2011a). Such information is particularly relevant for establishing baseline knowledge in a poorly studied system and for supporting future monitoring, conservation, and management actions.

Therefore, this study aimed to conduct a visual census survey of the fish community in the Linguado Channel. Here, we provide an ichthyofaunal inventory and characterize its species according to estuarine habitat use. By integrating taxonomic and functional (trophic and ecological) perspectives, this study establishes a baseline for the channel's ichthyofauna and contributes to a broader effort to evaluate variation of this fish assemblage between two contrasting habitat contexts and seasons.

Material and methods

Study area

The study was conducted in a portion of Linguado Channel, on the north coast of Santa Catarina State, southern Brazil (26°27'04"S, 48°35'05"W). This estuarine ecosystem covers approximately 1,250 ha, extends for about 20 km, and separates the municipalities of São Francisco do Sul (SFS) and Balneário Barra do Sul (BBS). There are remnants of dune forest and mangroves along the channel, but they are heavily altered by human occupation (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) 2018; Kilca et al. 2019). Tourism and artisanal fishing are the main economic activities in the estuary (Gerhardinger et al. 2021).

Data were collected in two opposing margins of the Linguado Channel (Fig. 1), separated by approximately 80 m. These two sampling areas were designated as 'Anthropic' and 'Mangrove', representing contrasting local habitat contexts. The Anthropic area is characterized by the replacement of native vegetation by human infrastructure (e.g. houses, decks, fish markets). Due to its direct exposure to domestic and recreational activities, the submerged portion contains artificial structures such as fishing nets, ropes, and debris, in addition to algae and associated fauna, including annelids, arthropods, and mollusks (Maccari et al. 2024).

In contrast, the Mangrove area is more preserved and includes mangrove forests composed of *Avicennia schaueriana*, *Laguncularia racemosa* and *Rhizophora mangle* (Kilca et al. 2019). In the submerged portion, natural structures such as branches, leaves, and roots are present, along with algae (e.g. Chlorophyta and Rhodophyta) and benthic organisms (e.g. tube-dwelling worms, ascidians, bryozoans) (Maccari et al. 2024).

Fish assemblages sampling

Fish assemblages were surveyed biweekly between December 2021 and May 2022, encompassing two seasons, characterized by a warm-rainy period (December-March) and a cold-dry period (April-May), totaling 12 sampling campaigns. Surveys were conducted in two contrasting habitat contexts within the Linguado Channel: a Mangrove area and an Anthropogenic area. In each sampling area, three fixed strip transects were established and repeatedly sampled throughout the study period, providing three spatially replicated transects within each sampled habitat context.

Fish communities were assessed using underwater visual censuses conducted during the ebb tide approaching low tide. During each survey, divers swam approximately 1 m above the substrate along a 20 m transect and recorded on PVC slates the identity and abundance of all fishes observed within 1 m on each side of the transect line, resulting in a sampled area of 40 m² per transect. The same six transects (three per habitat) were surveyed during each campaign, totaling 72 transect surveys and a cumulative sampled area of 2,880 m². The two sampling areas were selected to represent contrasting local environmental conditions associated with vegetation cover, substrate characteristics, and degree of anthropogenic influence, and were therefore classified as Mangrove or Anthropic areas.

The fishes were identified to the lowest taxonomic category based on original descriptions, taxonomic reviews, or dichotomous keys following Marceniuk et al. (2021) and Carvalho-Filho (2024), and the systematic classification and nomenclature of valid names following Eschmayer's Catalog of Fishes (Fricke et al. 2026) was adopted.

The estuarine use and trophic guilds for species was categorized according to Pastro (2017), Chaves et al. (2018), Ferreira et al. (2019), Afonso et al. (2023), Mai and Possamai (2022), Rodrigues et al. (2022), Floeter et al. (2023) and Lima et al. (2026). The conservation status was used following to the criteria of the International Union for Conservation of Nature and Natural Resources (IUCN 2026) and the Official List of Threatened Species of Brazilian Flora and Fauna, published by the Chico Mendes Institute for Biodiversity Conservation, through the Biodiversity Extinction Risk Assessment System (ICMBio - SALVE 2026).

Statistical analyses

To evaluate patterns in fish assemblage composition, species abundance data were first log-transformed using log(x + 1) to reduce the influence of highly abundant species while retaining information from less abundant taxa. Prior to analysis, abundances from repeated surveys were pooled by transect within each season, resulting in 12 analytical sampling units (3 transects × 2 sampling areas × 2 seasons), thereby avoiding temporal pseudoreplication while retaining the spatial structure of the sampling design. A Bray–Curtis dissimilarity matrix was then calculated from the transformed abundance data. Patterns of variation in assemblage composition among habitats (Mangrove and Anthropic) and seasons (Rainy and Dry) were explored using Principal Coordinates Analysis (PCoA) based on the Bray–Curtis dissimilarity matrix. Species scores were calculated as weighted averages to aid interpretation of species distributions within the ordination space. The proportion of variation explained by each ordination axis was estimated from the positive eigenvalues of the PCoA solution. Differences in assemblage composition were tested using a two-way Permutational Multivariate Analysis of Variance (PERMANOVA) based on Bray–Curtis dissimilarities, with sampling area, season, and their interaction included as explanatory factors. Statistical significance was assessed using 999 unrestricted permutations. To verify whether significant PERMANOVA results reflected differences in multivariate group centroids rather than unequal within-group variability, homogeneity of multivariate dispersions was evaluated using PERMDISP with 999 permutations.

Beta diversity was assessed for taxonomic (species), trophic guild, and estuarine-use matrices, using the same aggregated sampling units, to quantify variation in community composition on a consistent basis. To ensure comparability among taxonomic and functional datasets, species abundance data were converted to presence–absence prior to beta-diversity analyses. Total beta diversity was estimated using Sørensen dissimilarity (βSOR) and partitioned into turnover (βSIM) and nestedness-resultant (βSNE) components following Baselga (2010). The same procedure was applied to trophic guild and estuarine-use matrices, coded as binary presence–absence data based on the occurrence of species belonging to each category within each sampling unit. In addition, differences in trophic guild and estuarine-use composition between the sampled areas and seasons were tested using two-way PERMANOVA based on Sørensen dissimilarities, with area, season, and their interaction included as explanatory factors and significance assessed using 999 permutations. Pairwise beta-diversity values were calculated for each matrix, and mean contributions of turnover and nestedness were obtained to evaluate their relative importance across taxonomic and functional dimensions of the assemblage.

Sampling completeness was evaluated with a species accumulation curve (random method, 999 permutations) and the Chao2 richness estimator. Frequency of occurrence (FO%) was calculated for each species as the percentage of individual transects in which it was recorded, out of the total number of transects sampled across the study (n = 72), independent of the point and season-level aggregation used for the multivariate analyses described above.

Species contributions to differences in assemblage composition between the sampled areas and seasons were evaluated using Similarity Percentage (SIMPER) analysis based on Bray–Curtis dissimilarities, with significance assessed through 999 permutations. Indicator Species Analysis (IndVal) was used to identify species associated with the sampled areas, seasons, and their combinations, using 999 permutations. For both analyses, p-values were adjusted for multiple comparisons using the Benjamini–Hochberg false discovery rate (FDR).

All analyses were performed in the R environment (version 4.5.1; R Core Team 2025), using the packages vegan (Oksanen et al. 2022), indicspecies (Cáceres and Legendre 2009), and betapart (Baselga et al. 2025).

Results

Fish assemblage composition

A total of 2,592 individuals representing 12 orders, 24 families, and 28 species were recorded during the study (Table 1; Fig. 2). The species accumulation curve indicated that observed richness corresponded to 77.6% of the estimated richness (Chao2 = 36.1 species; Fig. 3), suggesting that additional rare species likely remained undetected despite the sampling effort. Species richness and abundance were higher in the Anthropic area (24 species; 1,664 individuals) than in the Mangrove area (19 species; 928 individuals). Nine species were exclusive to the Anthropic area, four were exclusive to the Mangrove area, and 15 species occurred in both sampled areas.

The assemblage was dominated by marine and estuarine fishes, with 27 species recorded, whereas only one freshwater species, *Geophagus iporangensis*, was observed. One non-native species, *Butis koilomatodon*, was recorded exclusively in the Mangrove area. The most species-rich order was Acanthuriformes (five species), followed by Perciformes and Tetraodontiformes (four species each). Gobiidae, Epinephelidae, Gerreidae, and Tetraodontidae were the most representative families, each comprising two species, whereas the remaining families were represented by a single species.

Regarding conservation status, *Mycteroperca bonaci* was classified as Endangered (EN), whereas *Hippocampus reidi* and *Epinephelus marginatus* were classified as Vulnerable (VU) according to the Brazilian Red List (ICMBio-SALVE 2026). Three additional species (*Centropomus parallelus*, *Mugil curema*, and *Pomacanthus paru*) were classified as Data Deficient (DD). According to the IUCN Red List (2026), *E. marginatus* was classified as Vulnerable, whereas *H. reidi* and *M. bonaci* were classified as Near Threatened (NT). All remaining species were classified as Least Concern.

Table 1

List of fish species recorded in Linguado Channel, including PCoA acronyms, frequency occurrence (FO%), *p-adj FDR values* obtained from SIMPER analyses and Red List status for each fish species over the study period. Estuarine use: MS = Marine straggler, ER = Estuarine resident, AS = Anadromous, MM = Marine migrant and FM = Freshwater migrant. Trophic guilds: ZP = Zooplanktivorous, ZB = Zoobenthic, PV = Piscivorous, OV = Omnivorous, DV = Detritivorous and GC = Generalist carnivore. Red List categories: VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient, NE = Not Evaluated. NON = Non-native species, the Brazilian red list status not considered.

PCoA Codes	SIMPER (*p*)						Conservation Status	
	Taxon	**FO%**	**Seasons**	**Areas**	**Estuarine use**	**Trophic guild**	**IUCN**	**ICMBio**
	CLUPEIFORMES							
	Pristigasteridae							
Chible	*Chirocentrodon bleekerianus* (Poey, 1867)	7.04	0.885	0.998	MS	ZP	LC	LC
	Dorosomatidae							
Har	*Harengula* sp. Valenciennes, 1847	15.49	0.625	0.119	MS	ZP	LC	LC
	SILURIFORMES							
	Ariidae							
Gengen	*Genidens genidens* (Cuvier, 1829)	5.63	0.625	0.502	ER	ZB	LC	LC
	AULOPIFORMES							
	Synodontidae							
Synfoe	*Synodus foetens* (Linnaeus, 1766)	2.82	0.625	0.998	MS	PV	LC	LC
	GOBIIFORMES							
	Butidae							
Butkoi	*Butis koilomatodon* (Bleeker, 1849) NON	1.41	0.625	0.998	ER	GC	LC	-
	Gobiidae							
Batsop	*Bathygobius soporator* (Valenciennes, 1837)	92.96	0.848	0.006	MS	ZB	LC	LC
Gob	*Gobiosoma* sp. Girard, 1858	1.41	0.848	0.006	MS	ZB	LC	LC
	SYNGNATHIFORMES							
	Syngnathidae							

PCoA Codes	SIMPER (*p*)						Conservation Status	
	Taxon	**FO%**	**Seasons**	**Areas**	**Estuarine use**	**Trophic guild**	**IUCN**	**ICMBio**
	CLUPEIFORMES							
Hiprei	*Hippocampus reidi* Ginsburg, 1933	28.17	0.625	0.998	MS	ZB	NT	VU
	CARANGIFORMES							
	Centropomidae							
Cenpar	*Centropomus parallelus* Poey, 1860	45.07	0.848	0.998	AS	GC	LC	DD
	Cyclopsettidae							
Etrcro	*Etropus crossotus* Jordan & Gilbert, 1882	5.63	0.848	0.777	MM	ZB	LC	LC
	CICHLIFORMES							
	Cichlidae							
Geopip	*Geophagus iporangensis* Haseman, 1911	4.23	0.625	0.651	FM	OV	LC	LC
	MUGILIFORMES							
	Mugilidae							
Mugcur	*Mugil curema* Valenciennes, 1836	1.41	0.848	0.998	EM	DV	LC	DD
	BLENNIIFORMES							
	Pomacentridae							
Abusax	*Abudefduf saxatilis* (Linnaeus, 1758)	18.31	0.848	0.164	MS	OV	LC	LC
	Bleniidae							
Hypfis	*Hypleurochilus fissicornis* (Quoy & Gaimard, 1824)	30.99	0.098	0.777	MS	ZB	LC	LC
	Labrisomidae							
Maldel	*Malacoctenus delalandii* (Valenciennes, 1836)	8.45	0.625	0.050	MS	ZB	LC	LC
	PERCIFORMES							
	Serranidae							
Diprad	Diplectrum radiale (Quoy & Gaimard, 1824)	21.13	0.028	0.998	MS	ZP	LC	LC

PCoA Codes		SIMPER (*p*)					Conservation Status	
	Taxon	**FO%**	**Seasons**	**Areas**	**Estuarine use**	**Trophic guild**	**IUCN**	**ICMBio**
	CLUPEIFORMES							
	Epinephelidae							
Epimar	*Epinephelus marginatus* (Lowe, 1834)	1.41	0.625	0.006	MS	PV	VU	VU
Mycbon	*Mycteroperca bonaci* (Poey, 1860)	1.41	0.625	0.006	MS	PV	NT	EN
	Grammistidae							
Rypsap	*Rypticus saponaceus* (Bloch & Schneider, 1801)	2.82	0.848	0.006	MS	GC	LC	LC
	ACANTHURIFORMES							
	Gerreidae							
Diarho	*Diapterus rhombeus* (Cuvier, 1829)	22.54	0.205	0.939	MS	ZB	LC	LC
Euc	*Eucinostomus* sp. Baird & Girard, 1855	69.01	0.625	0.777	MM	ZB	LC	LC
	Ephippidae							
Chafab	*Chaetodipterus faber* (Broussonet, 1782)	1.41	0.625	0.006	MM	OV	LC	LC
	Haemulidae							
Ortrub	*Orthopristis rubra* (Cuvier, 1830)	7.04	0.625	0.006	MS	ZB	LC	LC
	Pomacanthidae							
Pompar	*Pomacanthus paru* (Bloch, 1787)	4.23	0.625	0.006	MS	OV	LC	DD
	TETRAODONTIFORMES							
	Diodontidae							
Chispi	*Chilomycterus spinosus* (Linnaeus, 1758)	2.82	0.581	0.998	MM	ZB	LC	LC
	Tetraodontidae							
Sphgre	*Sphoeroides greeleyi* Gilbert, 1900	1.41	0.625	0.006	ER	ZB	LC	LC
Sphtes	*Sphoeroides testudineus* (Linnaeus, 1758)	59.15	0.625	0.048	ER	ZB	LC	LC

PCoA Codes	SIMPER (*p*)						Conservation Status	
	Taxon	**FO%**	**Seasons**	**Areas**	**Estuarine use**	**Trophic guild**	**IUCN**	**ICMBio**
	CLUPEIFORMES							
	Monacanthidae							
Stehis	*Stephanolepis hispida* (Linnaeus, 1766)	12.68	0.848	0.777	MS	ZB	LC	LC

The PCoA revealed partial overlap among samples from both habitats and seasons, although spatial and seasonal structuring was evident along the first two axes, which explained 31.7% and 23.0% of the variation, respectively (Fig. 4). Mangrove samples occupied a broader portion of the ordination space and included two samples associated with the restricted-occurrence species *B. koilomatodon* and *G. iporangensis*, positioned towards the negative extreme of PCoA1. PERMANOVA detected significant effects of both areas ($F = 2.46$, $R^2 = 18.4\%$, $p = 0.029$) and seasons ($F = 2.36$, $R^2 = 17.6\%$, $p = 0.048$), indicating that fish assemblage composition differed between the two sampled areas and between seasons. No significant area × season interaction was detected ($F = 0.57$, $R^2 = 4.3\%$, $p = 0.747$), suggesting that seasonal changes were broadly consistent across habitats. Although significant, both factors explained a relatively modest proportion of the total variation, with most variation remaining within groups (Residual $R^2 = 59.8\%$). PERMDISP indicated homogeneous multivariate dispersion for both area ($F = 2.49$, $p = 0.144$) and season ($F = 0.15$, $p = 0.687$), supporting the interpretation that PERMANOVA results reflected differences in assemblage composition rather than differences in within-group variability.

SIMPER analyses showed that differences between the two sampled areas were primarily associated with *Bathygobius soporator* (27.3% of cumulative dissimilarity, $p = 0.006$), followed by *Harengula* sp. (16.7%), *Eucinostomus* sp. (16.3%), and *Chirocentrodon bleekerianus* (11.1%). Among these species, only *B. soporator* was significantly associated with habitat differences. *Sphoeroides testudineus* also contributed significantly despite a smaller share of the overall dissimilarity (8.0%, $p = 0.048$). Several species with restricted occurrence, including *Gobiosoma* sp., *Epinephelus marginatus, Mycteroperca bonaci*, *Rypticus saponaceus*, *Chaetodipterus faber*, *Orthopristis rubra*, *Pomacanthus paru*, and *Sphoeroides greeleyi*, were significantly associated with the sampled areas despite their low contribution to total dissimilarity (all $p = 0.006$). seasonal differences were numerically dominated by *Eucinostomus* sp. (19.6%), *B. soporator* (18.5%), and *Harengula* sp. (16.5%), although none of these contributions were statistically significant. Only *Diplectrum radiale* showed a significant association with season (3.0% of cumulative dissimilarity, $p = 0.028$) (Table 1).

Indicator species analysis did not identify any species significantly associated with habitat, season, or their interaction after correction for multiple comparisons. Although *Hypleurochilus fissicornis* (IndVal = 0.989, $p = 0.023$), *Diapterus rhombeus* (IndVal = 0.953, $p = 0.028$), and *Diplectrum radiale* (IndVal = 0.957, $p = 0.014$) exhibited the lowest uncorrected p-values, none remained significant after adjustment (all adjusted $p > 0.05$).

Taxonomic beta diversity

Species beta diversity was high ($\beta SOR = 0.710$) and was predominantly explained by species turnover ($\beta SIM = 0.622$), whereas nestedness accounted for a comparatively small fraction of total dissimilarity ($\beta SNE = 0.088$).

The same pattern was observed at the pairwise level, with mean turnover (βSIM = 0.274) substantially exceeding mean nestedness (βSNE = 0.084), resulting in a mean Sørensen dissimilarity of 0.359. These results indicate that differences among assemblages were primarily driven by species replacement rather than by ordered species loss.

Functional structure

Marine stragglers represented the largest estuarine-use category (17 species, 60.71%), followed by marine migrants (4 species, 14.29%), estuarine residents (4 species, 14.29%), estuarine migrants (1 species, 3.57%), anadromous species (1 species, 3.57%), and freshwater migrants (1 species, 3.57%). Zoobenthivores were the dominant trophic guild (14 species, 50%), followed by omnivores (4 species, 14.29%), piscivores (3 species, 10.71%), zooplanktivores (3 species, 10.71%), generalist carnivores (3 species, 10.71%), and detritivores (1 species, 3.57%) (Fig. 5).

Despite the spatial and seasonal variation observed in species composition, neither trophic guild composition nor estuarine-use composition varied significantly between the sampled areas or seasons. For trophic guilds, PERMANOVA detected no significant effects of area ($F = 0.25$, $R^2 = 2.5\%$, $p = 0.689$), season ($F = 1.42$, $R^2 = 14.4\%$, $p = 0.346$), or their interaction ($F = 0.17$, $R^2 = 1.7\%$, $p = 0.839$). Functional beta diversity was moderate (βSOR = 0.408) and was predominantly explained by turnover (βSIM = 0.300), although nestedness also contributed substantially (βSNE = 0.108).

Similarly, estuarine-use composition did not vary significantly between the sampled areas ($F = 1.48$, $R^2 = 15.1\%$, $p = 0.171$), seasons ($F = 0.18$, $R^2 = 1.8\%$, $p = 0.807$), or their interaction ($F = 0.18$, $R^2 = 1.8\%$, $p = 0.792$). Beta diversity based on estuarine-use categories was lower (βSOR = 0.292) and was predominantly explained by nestedness (βSNE = 0.231) rather than turnover (βSIM = 0.061). This result indicates that differences among samples reflected the loss of ecological categories in a subset of samples rather than their replacement by different categories.

Discussion

This is the most up-to-date study on the fish fauna of the Linguado Channel using an underwater visual census, a method that, although well established (Pei et al. 2025), remains relatively underused for sampling estuarine fish assemblages (Serafy et al. 2003). This method substantially expanded the known ichthyofauna of the area: of the 28 species recorded in this study, only 10 had previously been documented in the area by Corrêa et al. (2006), whose survey relied exclusively on gill nets. Among the species recorded for the first time, ecologically and economically important species such as *Hippocampus reidi* and *Epinephelus marginatus* stand out, along with *Harengula* sp. and *Diapterus rhombeus*. These findings highlight the value of methods complementary to those traditionally used in estuaries (O'Brien et al. 2021), such as underwater visual census, for improving knowledge of fish assemblage composition and for detecting species that may be under-sampled by conventional methods. In addition, our results demonstrate that fish assemblage composition differed significantly between the two sampled areas contexts and seasons, indicating that local spatial heterogeneity and seasonal environmental variation are the principal drivers of assemblages structure. Studies conducted in other regions, such as Passos et al. (2016) and da Silva Lima et al. (2022), have also demonstrated the influence of these factors, although they are not always the main determinants of fish assemblage structure (Roshni et al. 2022). In Babitonga Bay, an

overall increase in fish abundance and diversity during warmer periods has been observed, which has been attributed to the reproductive and recruitment patterns of several species inhabiting the region (Côrrea et al. 2006; Gerhardinger et al. 2020; Bordin et al. 2024). Estuaries comprise a variety of habitat types and support a range of fish species that can be grouped into different feeding guilds (Whitfield et al. 2024). These habitat characteristics can act as filters for species occurrence (Harrison and Whitfield 2024). The sampled Anthropic area, owing to its structural composition, was considerably more complex than the sampled Mangrove area and supported greater species richness, with nine species occurring exclusively in this area. Artificial structures can supplement or enhance natural habitats and may attract species because of their structural complexity (La Mesa et al. 2008; Pereira et al. 2017; Miranda et al. 2020). Fish may select complex structures in search of refuge, which can be provided by artificial habitats (Roocker et al. 2018), including by the epinephelids *Mycteroperca. bonaci* and *E. marginatus*. *M. bonaci* and *E. marginatus*, which has a cryptobenthic habit, has also been observed in other studies in association with these structures, showing a preference for crevices, making shelter availability a determining factor for habitat suitability (La Mesa et al. 2002). Although artificial habitats may be attractive to fish, they do not necessarily provide the same quality of refuge, diversity of microhabitats, and availability of food resources as mangroves (Aschenbrenner et al. 2016; Goetze et al. 2021). In the anthropized environment, the substrate is consolidated, resembling a rocky reef, this characteristic attracts a range of marine organisms that colonize the substrate (Pereira et al. 2017), supporting a fish fauna similar to that found on natural reefs in the region (Alves and Pinheiro 2011). Therefore, despite their potential to supplement natural habitats and provide important structures for economically important species, artificial habitats should be considered complementary rather than substitutes for natural habitats in conservation and management strategies (Mercader et al. 2017). In relation to trophic guilds, half of the numerical abundance of the sampled fishes consisted of zoobenthivores. Some species such as *Bathygobius soporator*, *Eucinostomus* sp. and *Chirocentrodon bleekerianus* contributed with the most abundance in Anthropic and Mangrove area, which may be related to the presence of these organisms in both sampling areas. This pattern further suggests that the availability of benthic food resources may contribute to structuring the fish assemblage in the Linguado Channel. This result is in line with the literature for these environments (Whitfield et al. 2024) with benthic food being important agents in the maintenance of estuaries and its adjacent areas (Dias et al. 2023). Estuarine use was predominantly represented by marine stragglers, suggesting that the Linguado Channel may function primarily as a transit area for these species, potentially associated with tidal movements (Scurfield et al. 2025). The proximity of the study area to the sea may also explain the occurrence of these species, as marine stragglers are generally restricted to the lower reaches of estuaries, close to the mouth, where marine influence is greater, due to their stenohaline nature (Potter et al. 2015).

The high taxonomic β-diversity observed in the Linguado Channel was driven primarily by species turnover (βSIM = 0.62), indicating that differences among the sampled assemblages across habitat contexts and seasons resulted mainly from species replacement rather than species loss. Estuarine ecosystems are characterized by pronounced environmental heterogeneity, which promotes the coexistence of species with distinct habitat requirements and environmental tolerances (de Andrade-Tubino et al. 2008; Potter et al. 2015; Whitfield et al. 2024). The species identified by the SIMPER analysis suggest that this turnover was largely associated with the replacement of estuarine resident taxa by marine-associated species. Estuarine residents such as *B. soporator*, *Gobiosoma sp., Malacoctenus delalandii* and *Sphoeroides testudineus* were important contributors to differentiation between the sampled areas, reflecting their strong association with shallow sheltered environments. In contrast, species such as *Chaetodipterus faber*, *Orthopristis ruber*, *Rypticus saponaceus*, *Pomacanthus paru*, *E. marginatus* and *M. bonaci* are more commonly associated with reef habitats and

structurally complex substrates, suggesting that portions of the estuary provide suitable habitat for marine species that use the system opportunistically (Potter et al. 2015; Henderson et al. 2021).

Seasonal differences in assemblage composition were also evident and likely reflect the dynamic nature of tropical estuaries. Variations in freshwater input, salinity and temperature can influence fish movements, recruitment and habitat use throughout the year (Potter et al. 2015; Franco et al. 2022). Species contributing to seasonal turnover, including *Diplectrum radiale*, *D. rhombeus*, *Hypleurochilus fissicornis* and *Harengula* sp., may therefore reflect seasonal shifts in habitat use and local abundance. Similar patterns have been documented in other Brazilian estuaries, where species composition changes seasonally despite relatively stable richness values (de Andrade-Tubino et al. 2008; Camara et al. 2023). Although species composition varied significantly between the sampled areas and seasons, trophic guilds and estuarine-use categories remained relatively constant. This indicates that the observed turnover primarily involved species occupying similar ecological roles. For example, several taxa contributing to habitat differentiation belonged to comparable feeding guilds despite differing in habitat affinity. Consequently, environmental variation influenced which species were present in the estuary without substantially altering the ecological structure of the assemblage. Similar patterns have been reported for estuarine fish communities in which taxonomic variation exceeds functional variation across environmental gradients (Elliott et al. 2007; Potter et al. 2015; Camara et al. 2023).

The PCoA ordination highlighted the uncommon species that contributed disproportionately to assemblage differentiation. *Geophagus iporangensis* and *Butis koilomatodon* occupied peripheral positions in the ordination space and were recorded in a limited number of samples, indicating that they represented unique components of the local fish assemblage. The occurrence of *G. iporangensis* was associated with samples collected near the mouth of a river, suggesting an influence of freshwater connectivity on local assemblage composition. Although rarely recorded in estuarine surveys, species of this genus have been documented in oligohaline and mesohaline estuarine environments (Petry et al. 2016; Cutrim et al. 2025). Such occurrences may be facilitated by the physiological tolerance of cichlids to salinity fluctuations, consistent with the previous record of non-native cichlid species, including tilapias, in the similar area surveyed in the present study (Franco et al. 2024). In contrast, *B. koilomatodon*, a non-native species in Brazil, is recognized for its broad environmental tolerance and successful establishment in estuarine habitats, and its occurrence contributes to the growing number of records documenting its expansion along the Brazilian coast (Bonfim et al. 2017). Although both species were infrequent, their influence on the ordination highlights the contribution of uncommon taxa to local β-diversity and assemblage differentiation (da Silva Lima et al. 2022).

Among the species previously recorded in the Babitonga estuary, it is important to highlight the first record of the non-native invasive fish *B. koilomatodon* (mud sleeper) for Babitonga Bay. Another non-native species, *Omobranchus sewalli* (Valenciennes, 1836), had previously been reported from the area (Gerhardinger et al. 2006a; Cabezas et al. 2022). Adults of *O. sewalli* were recorded associated with mariculture structures in the bay, and years later, Costa et al. (2011) recorded larvae and individuals at different developmental stages throughout the estuary, from 2004 onwards, demonstrating that the species is capable of maintaining a self-sustaining population in the system. In contrast, *B. koilomatodon* has previously been recorded in northern, northeastern, and southeastern Brazil (Guimarães et al. 2017; Rodrigues et al. 2022; Santana et al. 2025), making its occurrence in the Linguado Channel also the first record for southern Brazil. The introduction of *O. sewalli* into Babitonga Bay has been associated with port activities, probably through ship biofouling (Gerhardinger et al. 2006a; Freitas and Velastin 2010). For *B. koilomatodon*, possible pathways include shipping, aquaculture

activities, or natural range expansion along the Brazilian coast (Santana et al. 2025). Previous studies have suggested that the species may compete for food and microhabitats with native fishes (Blennidae and Gobidae species) and prey on native fishes and crustaceans, however, such interactions were not evaluated in the present study (Macieira et al. 2012). Therefore, the potential ecological consequences of its occurrence in the Linguado Channel warrant further investigation (Mooney et al. 2005).

Without overlooking the limitations associated with the method used here, the Linguado Channel showed relatively low species richness, and our results indicate that it still provides habitat for species of conservation importance, including *M. bonaci*, classified as Endangered (EN), and *H. reidi* and *E. marginatus*, both classified as Vulnerable (VU) (ICMBio-SALVE 2026). *M. bonaci* and *H. reidi* had also been previously reported for the system (Vilar et al. 2011b). For *M. bonaci*, Bender et al. (2013) found that more experienced fishers perceived a reduction in stock size and reported population declines in northeastern Brazil. Notably, at the time of their study, *M. bonaci* was classified as VU according to the IUCN Regional Consensus Assessment for Epinephelidae and Lutjanidae species (Bender et al. 2013), whereas the current ICMBio-SALVE assessment classifies it as EN (ICMBio - SALVE 2026), indicating a deterioration in its conservation status. The black grouper is also a priority fishing target due to its high commercial value (Freitas et al. 2018; de Abreu Rodrigues Ponte et al. 2022). For *H. reidi*, Maccari et al. (2024) reported a consistent but low-density population in the Linguado Channel, showing flexibility in habitat use, including mangrove fragments and impacted areas, where artificial structures were used as holdfasts, as previously reported for the species in other Brazilian estuarine systems (Aylesworth et al. 2015; Carmo et al. 2022; Valentim et al. 2023).The absence of a direct relationship with the analyzed abiotic factors may further indicate tolerance to local environmental variation, consistent with patterns observed for the species in other estuarine systems (Carmo et al. 2022; Valentim et al. 2023) and the fish assemblage in the present study. Based on interviews with local fishers, Martins (2008) identified *E. marginatus* as one of the most threatened species in the system, with the closure of the Linguado Channel and consequent siltation suggested as important factors contributing to declines in fishery resource abundance (Gerhardinger 2004; Gerhardinger et al. 2006b). The occurrence of these threatened species in the present survey reinforces the importance of the Linguado Channel for the conservation of threatened fish species, highlighting the need to maintain suitable habitats and strengthen monitoring efforts in this highly modified system.

Although our sampling design allowed us to detect spatial and seasonal differences in the fish assemblage, some limitations should be considered when interpreting these patterns. The sampling design also requires caution regarding the spatial scale of inference. The study comprised three transects within each of two closely located sampling areas, rather than three independent locations representing each habitat type. Although repeated surveys were aggregated within transects and seasons to avoid temporal pseudoreplication, the comparison between Mangrove and Anthropic areas therefore represents a contrast between the two sampled habitat contexts rather than a replicated test of habitat type. In addition, the absence of species reported in other studies of Babitonga Bay (Gerhardinger et al. 2020) should not be interpreted as evidence of their absence from the Linguado Channel, as their non-detection may be related to the sampling method employed in the present study (underwater visual censuses). Therefore, longer-term monitoring with greater temporal replication and complementary sampling methods would help refine estimates of species richness and better characterize spatial and seasonal variation in the assemblage. Future studies including multiple independent sampling locations within each habitat type would also allow stronger inference regarding habitat-level effects.

Taken together, the presence of species with distinct trophic roles, estuarine-use strategies, and conservation statuses suggests that the Linguado Channel continues to contribute to the maintenance of fish diversity within the broader Babitonga ecosystem despite its long history of anthropogenic modification. Future conservation and management strategies should therefore consider not only species richness, but also the ecological functions and conservation value represented within the assemblage.

Declarations

Author Contribution

J.M.M., C.H.G.C., J.A-A. wrote the main manuscript text, J.M.M. and C.H.G.C. did the analyses and prepared the table and figures. All authors reviewed the manuscript.

Acknowledgement

We thank the Meros do Brasil project (sponsored by Petrobras) and UNIVILLE for the field and logistic support.

References

1. Afonso MG, Alves JA, Spach HL, Schwingel PR (2023) Análise interanual da assembleia de peixes estuarinos após impacto de construção de obra rodoviária no litoral sul do Brasil. Arq Ciênc Mar 55(2):82–95. https://doi.org/10.32360/acmar.v55i2.60505
2. Alves JA, Pinheiro PC (2011) Peixes recifais das ilhas costeiras do Balneário Barra do Sul, Santa Catarina, Brasil. Rev CEPSUL Biodivers Conserv Mar 2:10–21.
3. Aschenbrenner A, Hackradt CW, Ferreira BP (2016) Spatial variation in density and size structure indicate habitat selection throughout life stages of two Southwestern Atlantic snappers. Mar Environ Res 113:49–55. https://doi.org/10.1016/j.marenvres.2015.10.013
4. Aylesworth LA, Xavier JH, Oliveira TPR et al (2015) Regional-scale patterns of habitat preference for the seahorse Hippocampus reidi in the tropical estuarine environment. Aquat Ecol 49(4):499–512. https://doi.org/10.1007/s10452-015-9542-3
5. Barletta M, Melo RC, Whitfield AK (2023) Past and present conservation of South American estuaries. Estuar Coast Shelf Sci 295:108542. https://doi.org/10.1016/j.ecss.2023.108542
6. Baselga A (2010) Partitioning the turnover and nestedness components of beta diversity. Glob Ecol Biogeogr 19(1):134–143. https://doi.org/10.1111/j.1466-8238.2009.00490.x
7. Baselga A, Orme D, Villeger S, De Bortoli J, Leprieur F, Logez M, Martinez-Santalla S, Martin-Devasa R, Gomez-Rodriguez C, Crujeiras R (2025) betapart: Partitioning Beta Diversity into Turnover and Nestedness Components. R package version 1.6.1.
8. Belarmino E, Cabral H, Garcia AM (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. Mar Environ Res 201:106698. https://doi.org/10.1016/j.marenvres.2024.106698

9. Belitz MW, Campbell CJ, Drum RG et al (2025) A case for assemblage-level conservation to address the biodiversity crisis. Nat Rev Biodivers 1:134–143. https://doi.org/10.1038/s44358-024-00014-9
10. Bender MG, Floeter SR, Hanazaki N (2013) Do traditional fishers recognise reef fish species declines? Shifting environmental baselines in Eastern Brazil. Fish Manag Ecol 20:58–67. https://doi.org/10.1111/fme.12006
11. Bonfim M, Barbosa Martins AP, Coelho de Carvalho GKF, Magalhães Piorski N, Silva Nunes JL (2017) Non-native mud sleeper Butis koilomatodon (Bleeker, 1849) (Perciformes: Eleotridae) in Eastern Amazon Coastal region: an additional occurrence for the Brazilian coast and urgency for ecological assessment. BioInvasions Rec 6(2):111–117. https://doi.org/10.3391/bir.2017.6.2.04
12. Bordin D, Souza-Conceição JM, Spach HL et al (2024) Ocorrência de peixes em áreas entremarés na Baía Babitonga, região Sul do Brasil. Rev CEPSUL Biodivers Conserv Mar 13:e2024002. https://doi.org/10.37002/revistacepsul.vol13.2473e2024002
13. Cabezas MP, Lasso-Alcala OM, Quintero-T E, Xavier R, Giarrizzo T, Nunes JL et al (2022) Clarifying the taxonomy of some cryptic blennies (Blenniidae) in their native and introduced range. Sci Rep 12(1):9514. https://doi.org/10.1038/s41598-022-12580-z
14. Cáceres M, Legendre P (2009) Associations between species and groups of sites: indices and statistical inference. Ecology 90:3566–3574. https://doi.org/10.1890/08-1823.1.
15. Camara EM, de Andrade-Tubino MF, Franco TP, Neves LM, Dos Santos LN, Dos Santos AFGN, Araújo FG (2023) Temporal dimensions of taxonomic and functional fish beta diversity: scaling environmental drivers in tropical transitional ecosystems. Hydrobiologia 850(8):1911–1940. https://doi.org/10.1007/s10750-023-05202-w
16. Carmo TF, Santos LN, Bertoncini AA et al (2022) Population structure of the seahorse Hippocampus reidi in two Brazilian estuaries. Ocean Coast Res 70:e22009. https://doi.org/10.1590/2675-2824070.21016tfdc
17. Carvalho-Filho A (2024) Peixes, costa brasileira. 4th edn. Literare Books International, São Paulo.
18. Chaves MCNR, Franco ACS, Seixas LB, da Cruz LR, dos Santos LN (2018) Testing the ecocline concept for fish assemblages along the marine-estuarine gradient in a highly-eutrophic estuary (Guanabara Bay, Brazil). Estuar Coast Shelf Sci 211:118–126. https://doi.org/10.1016/j.ecss.2018.02.004
19. Corrêa MFM, Pinheiro PC, Almeida HK, Kersten M, Lienstadt J, Vollrath F (2006) Diagnóstico ambiental da ictiofauna. In: Cremer MJ, Morales PRD, Oliveira TMN (eds) Diagnóstico ambiental da Baía da Babitonga. Editora Univille, Joinville, pp 159–185.
20. Costa MDP, Souza-Conceição JM, Schwingel PR, Spach HL (2011) Assessment of larval distribution of invasive Omobranchus punctatus (Valenciennes, 1836) (Pisces: Blenniidae) in a subtropical estuary (Southern Brazil). Aquat Invasions 6(1):33–38. https://doi.org/10.3391/ai.2011.6.S1.008
21. Cremer MJ (2006) O estuário da Baía da Babitonga. In: Cremer MJ, Morales PRD, Oliveira TMN (eds) Diagnóstico ambiental da Baía da Babitonga. Editora Univille, Joinville.
22. Cutrim CHG, Neves RAF, Santos LN (2025) Recursos pesqueiros da Lagoa Rodrigo de Freitas: guia prático ilustrado. Editora CRV, Curitiba. https://doi.org/10.24824/978652517181.4
23. da Silva Lima CS, Maciel EB, Clark FJK, Pessanha ALM (2022) Does environmental heterogeneity explain β diversity of estuarine fish assemblages? Example from a tropical estuary under the influence of a semiarid climate, Brazil. PLoS ONE 17(9):e0273765. https://doi.org/10.1371/journal.pone.0273765

24. de Abreu Rodrigues Ponte I, de Vasconcelos Filho JE, Feitosa CV et al (2022) Demography of the black grouper, Mycteroperca bonaci (Poey, 1860) (Teleostei: Epinephelidae) from the North Brazil Shelf. J Fish Biol 101(1):190–203. https://doi.org/10.1111/jfb.15085
25. de Andrade Tubino MF, Ribeiro ALR, Vianna M (2008) Organização espaço-temporal das ictiocenoses demersais nos ecossistemas estuarinos brasileiros: uma síntese. Oecol Bras 12(4):5. https://doi.org/10.4257/oeco.2008.1204.05
26. Dias E, Morais P, Antunes C, Hoffman JC (2023) The benthic food web connects the estuarine habitat mosaic to adjacent ecosystems. Food Webs 35:e00282. https://doi.org/10.1016/j.fooweb.2023.e00282.
27. Dias RA, Gianuca D, Gianuca AT, Gomes Junior A, Chiaffitelli R, Ferreira WLS (2011) Estuário da Lagoa dos Patos. In: Conservação de aves migratórias neárticas no Brasil. Conservação Internacional, Belém, pp 335–341.
28. Elliott M, Whitfield AK, Potter IC, Blaber SJM, Cyrus DP, Nordlie FG, Harrison TD (2007) The guild approach to categorizing estuarine fish assemblages: a global review. Fish Fish 8(3):241–268. https://doi.org/10.1111/j.1467-2679.2007.00253.x
29. Ferreira V, Le Loc'h F, Ménard F, Frédou T, Frédou F (2019) Composition of the fish fauna in a tropical estuary: the ecological guild approach. Sci Mar 83(2):133–142. https://doi.org/10.3989/scimar.04855.25A
30. Fletcher RJ Jr, Green RE, Bladon EK (2025) Beyond species richness for biological conservation. Conserv Lett 18:e13124. https://doi.org/10.1111/conl.13124
31. Floeter SR, Pinheiro HT, Rocha LA (2023) Biogeografia e evolução dos peixes recifais brasileiros. In: Floeter SR, Krajewski JP, Fiuza TMJ, Rocha LA, Carvalho-Filho A (eds) Peixes recifais brasileiros / Brazilian reef fishes. CRV, Curitiba, pp 21–26.
32. Franco ACS, Azevedo-Santos VM, Nogueira MAMDP, Giarrizzo T, Hauser-Davis RA, Guimarães EC et al (2024) Tilapia venturing into high-salinity environments: a cause for concern? Aquat Ecol 58(1):47–55. https://doi.org/10.1007/s10452-023-10069-z
33. Franco ACS, Araújo FG, dos Santos AFGN, de Andrade-Tubino MF, dos Santos LN (2022) From meso to hyperhaline: the importance of Neotropical coastal lagoons in supporting the functional fish diversity at regional scale. Hydrobiologia 849:4101–4118. https://doi.org/10.1007/s10750-021-04683-x
34. Freitas MO, Velastin R (2010) Ictiofauna associada a um cultivo de mexilhão Perna perna (Linnaeus, 1758) norte catarinense, Sul do Brasil. Acta Sci Biol Sci 32:31–37. https://doi.org/10.4025/actascibiolsci.v32i1.2515
35. Freitas MO, Previero M, Minte-Vera CV et al (2018) Reproductive biology and management of two commercially important groupers in the SW Atlantic. Environ Biol Fish 101:79–94. https://doi.org/10.1007/s10641-017-0682-2
36. Fricke R, Eschmeyer WN, van der Laan R (eds) (2026) Eschmeyer's Catalog of Fishes: genera, species, references.
37. Gerhardinger LC, Freitas MO, Andrade AB, Rangel CA (2006a) Omobranchus punctatus (Teleostei: Blenniidae), an exotic blenny in the Southwestern Atlantic. Biol Invasions 8:941–946. https://doi.org/10.1007/s10530-005-5104-2
38. Gerhardinger LC, Marenzi RC, Hostim-Silva M, Medeiros RP (2006b) Conhecimento ecológico local de pescadores da Baía da Babitonga, Santa Catarina, Brasil: peixes da família Serranidae e alterações no ambiente marinho. Acta Sci Biol Sci 28:253–261. https://doi.org/10.4025/actascibiolsci.v28i3.226

39. Gerhardinger LC, Marenzi RC, Bertoncini AA, Medeiros RP, Hostim-Silva M (2006c) Local ecological knowledge on the goliath grouper Epinephelus itajara (Teleostei: Serranidae) in southern Brazil. Neotrop Ichthyol 4(4):441–450. https://doi.org/10.1590/S1679-62252006000400008
40. Gerhardinger LC (2004) Conhecimento ecológico do Mero Epinephelus itajara como ferramenta para a conservação marinha em São Francisco do Sul, SC. Undergraduate thesis, Universidade do Vale do Itajaí, Itajaí.
41. Gerhardinger L, Herbst D, Cunha S, Costa M (2020) Diagnóstico da ictiofauna do ecossistema Babitonga. Rev CEPSUL Biodivers Conserv Mar 9:e2020001. https://doi.org/10.37002/revistacepsul.vol9.693eb2020001
42. Gerhardinger C, Herbst DF, Carvalho FG, Freitas RR, Vila-Nova D, Cunha S et al (2021) Diagnóstico socioambiental do ecossistema Babitonga. Rev CEPSUL Biodivers Conserv Mar 10:e2021002. https://doi.org/10.37002/revistacepsul.vol10.830e2021002
43. Goetze JS, Wilson S, Radford B, Fisher R, Langlois TJ, Monk J et al (2021) Increased connectivity and depth improve the effectiveness of marine reserves. Glob Change Biol 27(15):3432–3447. https://doi.org/10.1111/gcb.15635
44. Guimarães EC, de Brito PS, Ottoni FP (2017) First record of Butis koilomatodon (Bleeker, 1849) (Gobiiformes: Eleotridae) for the Maranhão state, northeastern Brazil: a case of bioinvasion. Cybium 41(3):299–300. https://doi.org/10.26028/cybium/2017-413-009
45. Harrison TD, Whitfield AK (2024) A global functional analysis of fish-estuary associations and selected environmental factors. Rev Fish Biol Fish 34:805–825. https://doi.org/10.1007/s11160-024-09839-1
46. Henderson CJ, Gilby BL, Stone E, Borland HP, Olds AD (2021) Seascape heterogeneity modifies estuarine fish assemblages in mangrove forests. ICES J Mar Sci 78(3):1108–1116. https://doi.org/10.1093/icesjms/fsab022
47. Hooper DU, Chapin FS III, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setala H, Symstad AJ, Vandemeer J, Wardle DA (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol Monogr 75(1):3–35. https://doi.org/10.1890/04-0922
48. Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) (2018) Atlas dos manguezais do Brasil. ICMBio, Brasília.
49. Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) (2026) Sistema de avaliação do risco de extinção da biodiversidade – SALVE.
50. International Union for Conservation of Nature (IUCN) (2026) The IUCN Red List of Threatened Species. Version 2025-2.
51. Kilca RV, Melo Júnior JCF, Esemann-Quadros K, Larcher L, Pfuetzenreuter A (2019) Os manguezais e marismas da Baía Babitonga: uma síntese. Rev CEPSUL Biodivers Conserv Mar 8:e2019002. https://doi.org/10.37002/revistacepsul.vol8.682eb2019002
52. La Mesa G, Longobardi A, Sacco F, Marino G (2008) First release of hatchery juveniles of the dusky grouper Epinephelus marginatus (Lowe, 1834) (Serranidae: Teleostei) at artificial reefs in the Mediterranean: results from a pilot study. Sci Mar 72(4):743–756. https://doi.org/10.3989/scimar.2008.72n4743
53. La Mesa G, Louisy P, Vacchi M (2002) Assessment of microhabitat preferences in juvenile dusky grouper (Epinephelus marginatus) by visual sampling. Mar Biol 140:175–185. https://doi.org/10.1007/s002270100682

54. Lana PC, Marone E, Lopes RM, Machado EC (2001) The Subtropical Estuarine Complex of Paranaguá Bay, Brazil. In: Seeliger U, Kjerfve B (eds) Coastal Marine Ecosystems of Latin America. Ecological Studies, vol 144. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-04482-7_11
55. Lima R, Araújo FG, dos Santos LN (2026) The response of fish functional guilds to environmental and spatial processes in a Neotropical coastal lagoon. Hydrobiologia 853:687–700. https://doi.org/10.1007/s10750-025-05957-4
56. Lotze HK, Lenihan HS, Bourque BJ et al (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312(5781):1806–1809. https://doi.org/10.1126/science.1128035
57. Maccari JM, Adelir-Alves J, Freret-Meurer NV et al (2024) The habitat use of longsnout seahorse Hippocampus reidi in a subtropical Brazilian estuary. Neotrop Ichthyol 22(4):e240041. https://doi.org/10.1590/1982-0224-2024-0041
58. Macieira RM, Giarrizzo T, Gasparini JL, Sazima I (2012) Geographic expansion of the invasive mud sleeper Butis koilomatodon (Perciformes: Eleotridae) in the western Atlantic Ocean. J Fish Biol 81:308–313. https://doi.org/10.1111/j.1095-8649.2012.03285.x
59. Mai ACG, Possamai B (2022) Categorizing estuarine fish assemblages in the warm temperate southwestern Atlantic province: the case of Patos Lagoon Estuary, Brazil. Reg Stud Mar Sci 54:102482. https://doi.org/10.1016/j.rsma.2022.102482
60. Mao Z, Cao Y, Quirino BA et al (2026) Contrasting responses of fish taxonomic and functional diversity to eutrophication in Danish shallow lakes. Innov Geosci 4:100237. https://doi.org/10.59717/j.xinn-geo.2026.100237
61. Marceniuk AP, Caires RA, Carvalho-Filho A, Rotundo MM, Santos WCRD, Klautau AGCDM (2021) Peixes teleósteos da costa norte do Brasil. Museu Paraense Emílio Goeldi, Belém.
62. Martínez ML, Intralawan A, Vázquez G et al (2007) The coasts of our world: ecological, economic and social importance. Ecol Econ 63(2–3):254–272. https://doi.org/10.1016/j.ecolecon.2006.10.022
63. Martins GA (2008) O conhecimento ecológico dos pescadores na Baía da Babitonga, Santa Catarina, Brasil, sobre o estado de conservação dos peixes marinhos. Undergraduate thesis, Universidade da Região de Joinville, São Francisco do Sul.
64. Mercader M, Mercière A, Gilles S, Cheminée A, Crec'hriou R, Pastor J, Rider M, Dubas R, Lecaillon G, Boissery P, Lenfant P (2017) Small artificial habitats to enhance the nursery function for juvenile fish in a large commercial port of the Mediterranean. Ecol Eng 105:78–86. https://doi.org/10.1016/j.ecoleng.2017.03.022.
65. Miranda RJ, Malhado ACM, Fabré NN, Batista VS, Santos R, Campos-Silva JV et al (2020) Integrating long term ecological research (LTER) and marine protected area management: challenges and solutions. Oecol Aust 24(2):279–300. https://doi.org/10.4257/oeco.2020.2402.05
66. Mooney HA, Mack RN, McNeeley JA et al (2005) Invasive alien species: a new synthesis. Island Press, Washington.
67. Nelson JS, Grande TC, Wilson MVH (2016) Fishes of the World, 5th edn. John Wiley & Sons, Hoboken. https://doi.org/10.1002/9781119174844
68. Nicolodi JL, Zamboni A, Barroso GF (2009) Gestão integrada de bacias hidrográficas e zonas costeiras no Brasil: implicações para a Região Hidrográfica Amazônica. Rev Gest Cost Integr 9(2):9–32. https://doi.org/10.5894/rgci115

69. O'Brien DA, Masonjones HD, Bethel E, O'Shea OR (2021) Nocturnal surveys reveal novel insights into the community dynamics of an anchialine ecosystem from The Bahamas. Estuar Coast Shelf Sci 262:107588. https://doi.org/10.1016/j.ecss.2021.107588
70. Oksanen J, Simpson GL, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Solymos P, Stevens MHH, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, De Caceres M, Durand S, Evangelista HBA, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill MO, Lahti L, McGlinn D, Ouellette MH, Ribeiro Cunha E, Smith T, Stier A, Ter Braak CJF, Weedon J (2022) vegan: Community Ecology Package. R package version 2.6-4.
71. Passos CVB, Fabré NN, Malhado ACM, Batista VS, Ladle RJ (2016) Estuarization increases functional diversity of demersal fish assemblages in tropical coastal ecosystems. J Fish Biol 89:847–862. https://doi.org/10.1111/jfb.13029
72. Pastro G, Dias GM, Pereira-Filho GH, Gibran FZ (2017) The consequences of small-scale variations in habitat conditions driven by a floating marina on reef fish assemblages of SE Brazil. Ocean Coast Manag 141:98–106. https://doi.org/10.1016/j.ocecoaman.2017.03.012
73. Pei YD, Heard J, Xu W, Leung SK, Yung CC, Wyatt AS et al (2025) Characterisation of coastal reef fish assemblages across an estuarine-urbanisation gradient using underwater visual census and environmental DNA metabarcoding. Ecol Indic 170:112938. https://doi.org/10.1016/j.ecolind.2024.112938
74. Pereira PHC, dos Santos MVB, Lippi DL, Silva PHDP, Barros B (2017) Difference in the trophic structure of fish communities between artificial and natural habitats in a tropical estuary. Mar Freshw Res 68(3):473–483. https://doi.org/10.1071/MF15326
75. Petry AC, Araújo PB, Fulgencio LL, Hartz SM, Becker FG (2016) Fish composition and species richness in eastern South American coastal lagoons: additional support for the freshwater ecoregions of the world. J Fish Biol 89:280–314. https://doi.org/10.1111/jfb.13011
76. Potter IC, Tweedley JR, Elliott M, Whitfield AK (2015) The ways in which fish use estuaries: a refinement and expansion of the guild approach. Fish Fish 16(2):230–239. https://doi.org/10.1111/faf.12050
77. R Core Team (2025) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
78. Rodrigues VLA, Guabiroba HC, Vilar CC, Andrades R, Villela A, Hostim-Silva M, Joyeux J-C (2022) Fish biodiversity of a tropical estuary under severe anthropic pressure (Doce River, Brazil). Neotrop Ichthyol 20(3):e220022. https://doi.org/10.1590/1982-0224-2022-0022
79. Rooker JR, Dance MA, Wells RJD, Quigg A, Hill RL, Appeldoorn RS et al (2018) Seascape connectivity and the influence of predation risk on the movement of fishes inhabiting a back-reef ecosystem. Ecosphere 9(4):e02200. https://doi.org/10.1002/ecs2.2200
80. Santana TC, Sác JP, Abreu JMSB et al (2025) The marine and estuarine bony fishes (Teleostei) of the Golfão Maranhense on the eastern Amazon coast, northern Brazil. Braz J Biol 85:e286625. https://doi.org/10.1590/1519-6984.286625
81. Scurfield DJ, Gross PL, Gan JCL, Moore JW (2025) Surfing the tidal wave: use of transiently aquatic habitat by juvenile Pacific salmon and other fishes in estuaries. Ecology 106(5):e70100. https://doi.org/10.1002/ecy.70100
82. Serafy JE, Faunce CH, Lorenz JJ (2003) Mangrove shoreline fishes of Biscayne Bay, Florida. Bull Mar Sci 72(1):161–180.

83. Souza-Conceição JM, Spach HL, Bordin D, Costa MDP, Bot Neto RL (2013a) Comparação de três redes para identificar a estrutura de assembléias de peixes em praias estuarinas de São Francisco do Sul, Santa Catarina. Rev Bras Zoociênc 15(1–3):203–217.
84. Souza-Conceição JM, Spach HL, Bordin D, Frisanco D, Costa MDP (2013b) O papel de praias estuarinas como habitats para peixes em um ambiente subtropical Brasileiro. Neotrop Biol Conserv 8(3):121–131. https://doi.org/10.4013/nbc.2013.83.02
85. Stuart-Smith RD, Bates AE, Lefcheck JS et al (2013) Integrating abundance and functional traits reveals new global hotspots of fish diversity. Nature 501:539–542. https://doi.org/10.1038/nature12529
86. Suguio K (1992) Dicionário de geologia marinha com termos correspondentes em inglês, francês e espanhol. T.A. Queiroz Editor, São Paulo.
87. Tilman D, Isbell F, Cowles JM (2014) Biodiversity and ecosystem functioning. Annu Rev Ecol Evol Syst 45:471–493. https://doi.org/10.1146/annurev-ecolsys-120213-091917
88. Valentim GA, Pinto LM, Gurgel-Lourenço RC, Rodrigues-Filho CAS, Sánchez-Botero JI (2023) Population structure of the seahorse Hippocampus reidi (Syngnathiformes: Syngnathidae) in a Brazilian semi-arid estuary. Neotrop Ichthyol 21(4):e230004. https://doi.org/10.1590/1982-0224-2023-0004
89. Vilar CC, Spach HL, Joyeux JC (2011a) Spatial and temporal changes in the fish assemblage of a subtropical estuary in Brazil: environmental effects. J Mar Biol Assoc UK 91(3):635–648. https://doi.org/10.1017/S0025315410001943
90. Vilar CC, Spach HL, Santos L (2011b) Fish fauna of Baía da Babitonga (southern Brazil), with remarks on species abundance, ontogenic stage and conservation status. Zootaxa 2734:40–52. https://doi.org/10.11646/zootaxa.2734.1.3.
91. Vilar CC, Spach HL, Souza-Conceição JM (2011c) Fish assemblage in shallow areas of Baía da Babitonga, southern Brazil: structure, spatial and temporal patterns. Pan-Am J Aquat Sci 6(4):303–319.
92. Whitfield AK, Blaber SJM, Elliott M, Harrison TD (2024) Trophic ecology of fishes in estuaries. Rev Fish Biol Fish 34(4):1371–1405. https://doi.org/10.1007/s11160-024-09878-8
93. Yoshida T, Kawato M, Tsuchida S et al (2026) Environmental DNA from pumped deep-sea water enables monitoring of deep-sea fish diversity. Sci Rep 16:26870. https://doi.org/10.1038/s41598-026-56998-1
94. Zhang C, Zhu R, Sui X et al (2021) Understanding patterns of taxonomic diversity, functional diversity, and ecological drivers of fish fauna in the Mekong River. Glob Ecol Conserv 28:e01711. https://doi.org/10.1016/j.gecco.2021.e01711

Figures

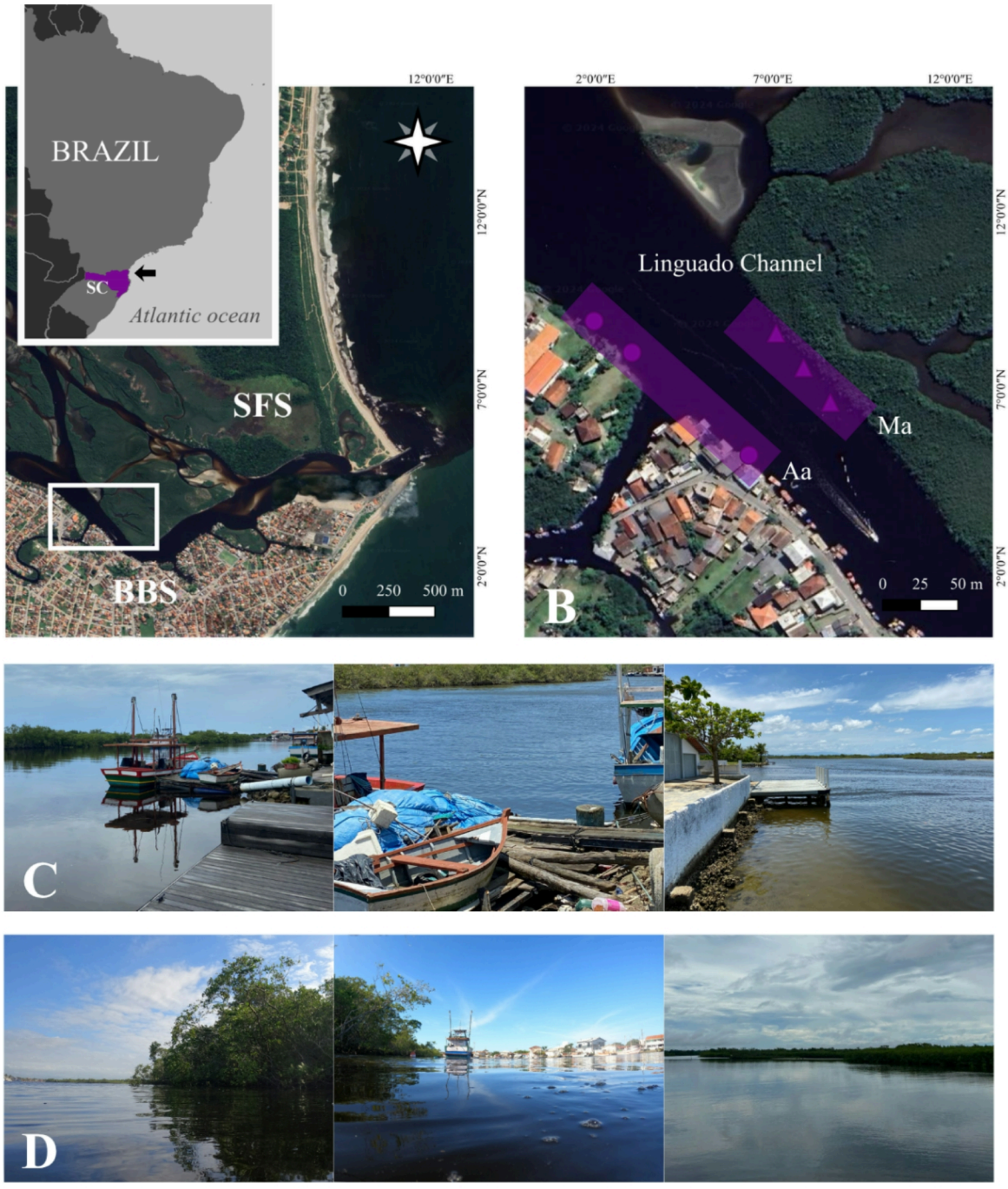


Figure 1

Location of the study area between December 2021 and May 2022 in the Linguado Channel. (A) Linguado Channel, Babitonga Bay, on the northern coast of Santa Catarina State (SC), southern Brazil (SFS = São Francisco do Sul; BBS = Balneário Barra do Sul). (B) Sampling sites in Anthropic area (Aa, circles) and Mangrove area (Ma, triangles) and (C) Characterization of the Anthropic and (D) Mangrove areas.

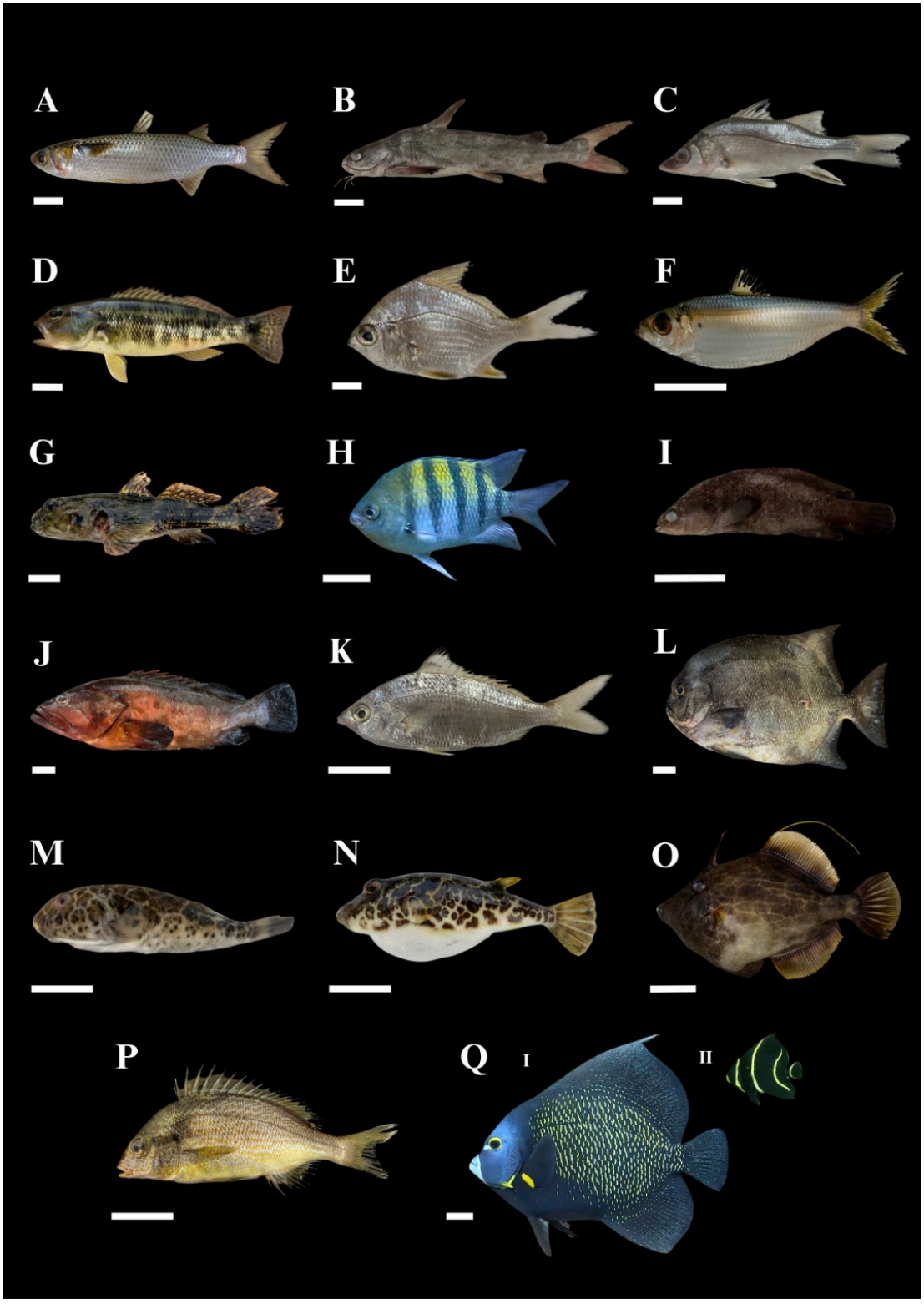


Figure 2

Some fish species observed in Linguado Channel. A. *Mugil curema*. B. *Genidens genidens.* C. *Centropomus parallelus.*D. *Diplectrum radiale.* E. *Diapterus rhombeus.* F. *Harengula*sp. G. *Bathygobius soporator*. H. *Abudefduf saxatilis*. I. *Rypticus saponaceus.* J. *Epinephelus marginatus*. K. *Eucinostomus* sp. L. *Chaetodipterus faber*. M. *Sphoeroides testudineus*. N. *Sphoeroides greeleyi*. O. *Stephanolepis hispida*. P. *Orthopristis rubra*. Q. *Pomacanthus paru* (I-Adult; II-Juvenile). Scale bars: 10 mm.

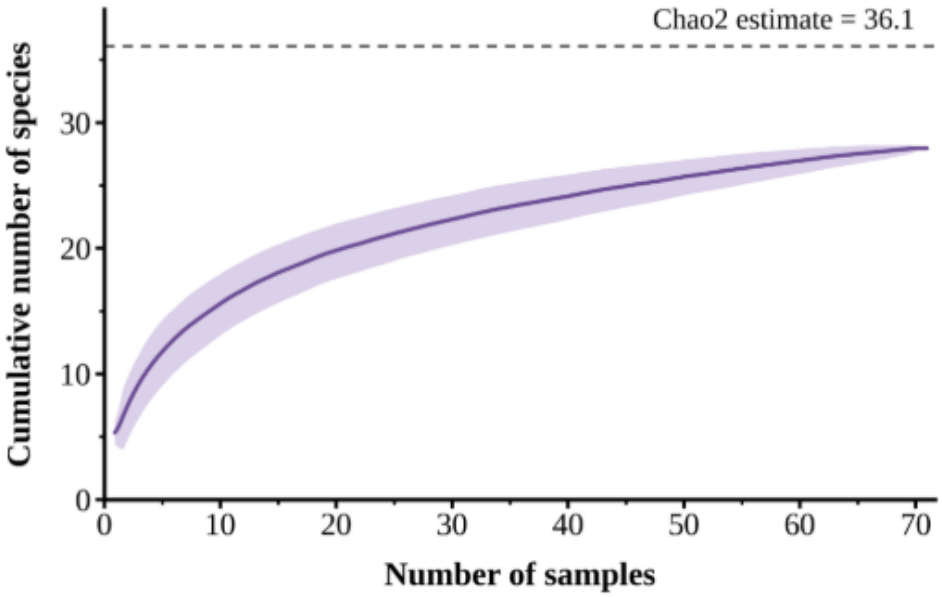


Figure 3

Species accumulation curve for the fish assemblage recorded in the Linguado Channel. The solid line shows the mean cumulative species richness obtained from 999 random permutations of the 72 underwater visual census transects, with the shaded area representing ±1 standard deviation. The dashed horizontal line indicates the richness estimated by the Chao2 estimator, allowing comparison between observed and expected species richness and assessment of sampling completeness.

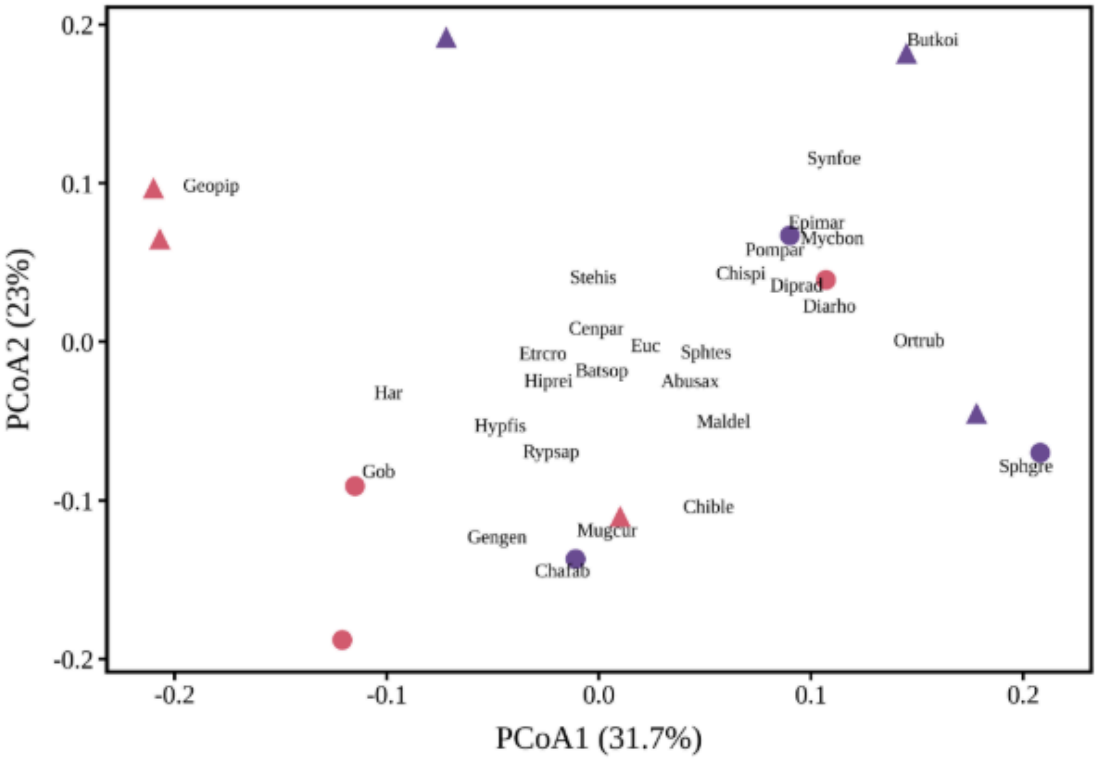


Figure 4

Principal Coordinates Analysis (PCoA) of fish assemblages based on species composition. Symbols represent sampling areas (circles = Anthropic; triangles = Mangrove), while colors indicate seasons (Pink = warm-rainy period; Purple = cold-dry period). Black labels indicate species scores.

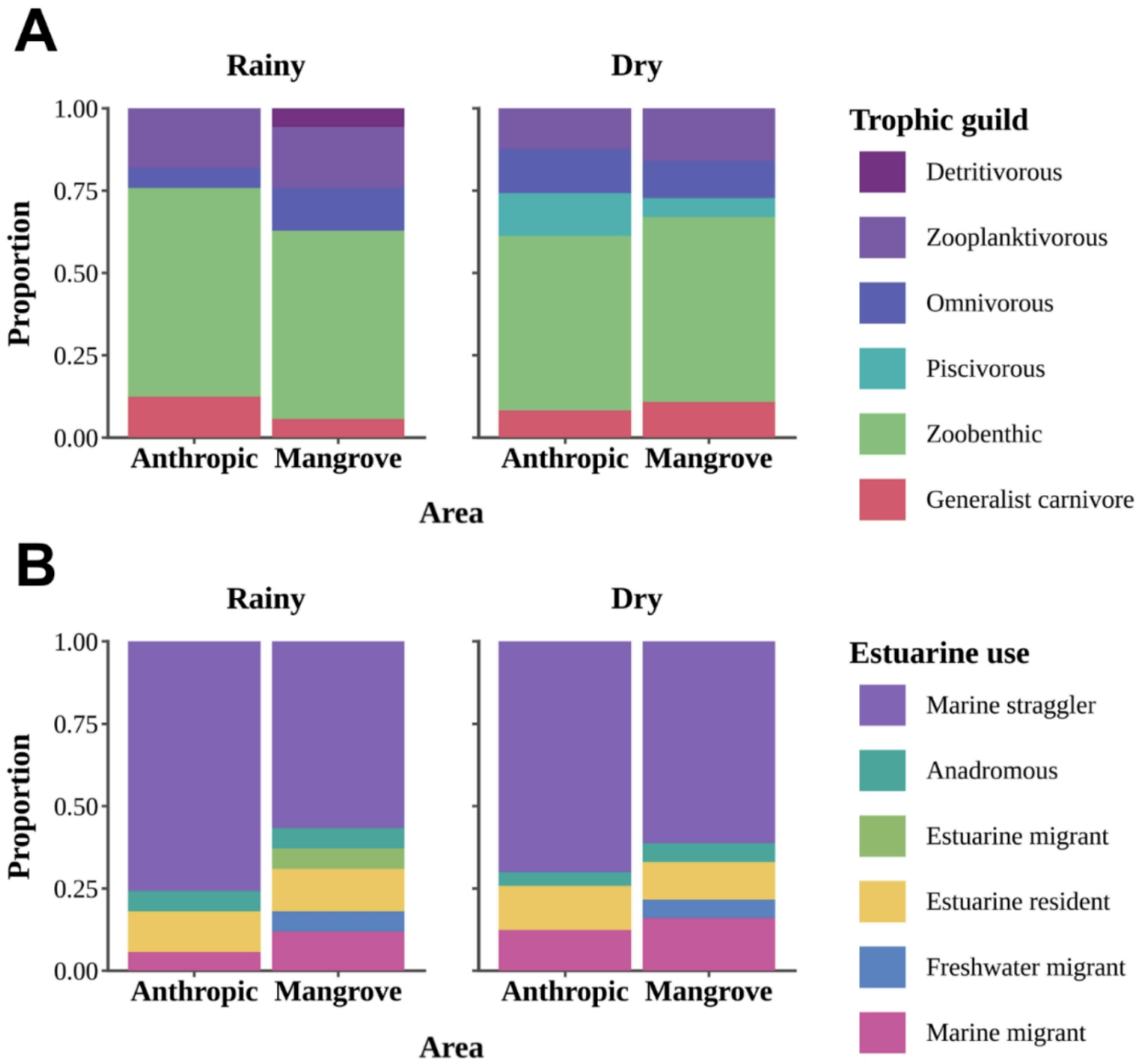


Figure 5

Proportions of species in trophic guilds (A), and estuarine-use (B) categories across sampling areas (Anthropic and Mangrove) and seasons (warm-rainy and cold-dry).