Marine Environmental Research 209 (2025) 107251

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Trophic dynamics of shallow water consumers in coastal systems with distinct connectivity degrees and anthropogenic pressures

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ARTICLE INFO

Keywords:
Isotopic niche
Basal resources
Maricá lagoon complex
Sepetiba bay
Stable isotopes
Trophic position

ABSTRACT

Coastal systems are dynamic ecosystems with strong environmental and anthropogenic gradients, offering daily challenges to their biological communities. Our goal was to compare the trophic structure of two hydromorphological distinct coastal systems (bay vs. lagoon) with different connectivity gradients and anthropogenic impacts along the coast of Rio de Janeiro state, Brazil. We expected that trophic position and resource utilization would be different by similar species due to the distinct marine connectivity and anthropogenic influences between the two environments. The results agreed with our hypotheses of a broader isotopic niche in the bay probably due to energy exchange with the marine system, as well as differential producers sustaining these two coastal systems. Conversely, the more eutrophicated lagoon system showed a greater reliance on phytoplankton production, with a lower diversity of basal resources sustaining the food chain. Contrary to our expectations, the trophic position did not vary between the two systems, and the isotopic niche overlap was higher in the bay than the lagoon. By using two geographic-close systems with similar community composition, we showed how geomorphology and sea connectivity can influence trophic interactions and shape energy flow in coastal ecosystems.

1. Introduction

Transitional coastal ecosystems, such as bays and coastal lagoons, are highly productive estuarine areas that offer a wide range of ecological and social benefits. Their ability to sustain significant biological diversity is largely due to high productivity and environmental variability, providing abundant food resources, refuge sites, and spawning grounds for many species (Islam et al., 2006; Macário et al., 2021; Gomes-Gonçalves et al. 2022). However, this variability poses challenges for organisms, as they must adapt to the dynamic physical habitat and fluctuating resource availability. These systems benefit from multiple sources of primary productivity, including basal trophic resources, which include phytoplankton, aquatic macrophytes, detritus, periphyton, particulate and dissolved organic matter, and vascular plants from land and sea. (Galvan et al., 2012; Tiselius et al., 2017). These resources are vital to coastal food webs, supporting diverse consumers and primary producers and connecting habitats through energy and material flows (Moore et al., 2020; Camara et al., 2020, 2023).

Bays are coastal systems typically characterized by larger area and depth, as well as more stable environmental conditions, including lower variability in salinity and temperature compared to coastal lagoons (Kjerfve, 1994; Kennish and Paerl, 2010). They encompass diverse habitats such as tidal flats, mangroves, and tidal channels, which enhance both habitat diversity and biological productivity. Terrestrial runoff delivers nutrients and organic matter, while strong connectivity with the ocean introduces marine-derived nutrients and organisms, such as phytoplankton, both of which shape the structure of the food chain (Abreu et al., 2010; Possamai et al., 2020, 2021; Zhang et al., 2022). Greater water exchange with the sea further supports a broader availability of basal food resources, ultimately contributing to a more complex trophic structure.

Compared to bays, coastal lagoons are typically shallower, making them highly susceptible to changes in precipitation and evaporation. These variations lead to fluctuation in salinity and temperature, which are also influenced by tidal exchange and freshwater inputs (Kjerfve et al., 1990; Kjerfve, 1994; Kennish and Paerl, 2010). Due to their

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https://doi.org/10.1016/j.marenvres.2025.107251
Received 5 September 2024; Received in revised form 6 May 2025; Accepted 25 May 2025
Available online 27 May 2025

shallow bathymetry and limited connection with the sea, often there is natural reduction in hydrological renewal (Sfriso et al., 2020), and different lagoons present different physicochemical conditions, with water ranging from fresh to hypersaline (Kjerfve, 1994). Terrestrial inputs, such as river runoff and nutrient-rich sediments, are fundamental in shaping these ecosystems. Nutrient-rich water from nearby rivers carries organic matter and minerals, affecting the composition and productivity of primary producers. Typically, the resources found in lagoon systems include a greater abundance of autochthonous phytoplankton (Yamamuro, 2000), as well as macroalgae and submerged plants, and beach vegetation, which provide habitat and food for various fish species. Narrower basal resource availability in coastal lagoons compared to bays may lead to lower consumer diversity and greater overlap in isotopic niches (Quillien et al., 2016), likely shortening the food chain due to reduced food web complexity (i.e., fewer trophic connections than in bays).

Understanding how species utilize resources within an ecosystem can be achieved through the analysis of stable isotope ratios, such as $\delta^{13}C$ and $\delta^{15}N$, which define their isotopic niches. These isotopic niche descriptors serve as effective tools for providing insights on trophic niche variability and for comparing fish populations across different ecological systems (Andolina et al., 2022; Cárcamo et al., 2024). When species are assumed to access the same resources within an ecosystem, their position in isotope niche space, along with the degree of overlap, can help predict potential resource partitioning (Possamai et al., 2025). High isotopic niche overlap among species inhabiting similar geographic areas may indicate direct competition (Newsom et al., 2007; Hammerschlag-Peyer et al., 2011). Consequently, identifying both resource use and isotopic niche overlap is essential for understanding the trophic web structure, particularly in transitional systems.

Despite their enormous ecological value, these coastal ecosystems are severely impacted by human activities stemming from rapid population growth. This expansion is marked by irregular urban development, industrial and agricultural practices, fishing, commercial shipping, and tourism. These activities diminish natural habitats and introduce excess nutrients, exotic species, and pollutants, significantly impacting biodiversity (Lotze et al., 2006; Sfriso et al., 2020; Gomes--Gonçalves et al. 2023), and leading to the loss of ecosystem services (Polis and Winemiller, 1996; Post et al., 2000; Sanchéz-Quinto et al., 2020; Possamai et al., 2021). As climate change and human activities intensify, ecosystem and food webs are often reorganized (Zhao et al., 2022). These disturbances can alter species interactions and resource availability, meaning that systems subject to different types and levels of human impact are likely to exhibit distinct trophic structures (Hutchinson, 1959; Schoener, 1989; Possamai et al., 2021). The Southwestern Atlantic coast features several semi-enclosed coastal systems, such as bays and lagoon. Among them, Sepetiba Bay and Maricá Lagoon System are transitional coastal environments of significant ecological and economic importance, characterized by high species richness and abundance (Araújo et al., 2016; Camara et al., 2020). These systems differ notably in their degree of marine connectivity, environmental conditions, geomorphological characteristics, and type and intensity of anthropogenic impacts (Camara et al., 2023). Furthermore, both systems are affected by diffuse pollution, the large industrial complex surrounding the bay, especially metallurgical and chemical activities, along with port operations (Clarke et al., 2004; Cunha et al., 2006; Leal-Neto et al., 2006) appears to be the main source of contamination. In contrast, the significant population growth around the lagoon suggests that domestic sewage and organic waste discharges are likely the primary sources of pollution there (Guerra et al., 2011; Toledo et al., 2021).

The study aims to investigate how differences in sea connectivity, anthropogenic impacts, and the availability of basal resources influence the trophic structure and isotopic niches of fish communities in Sepetiba Bay and Maricá Lagoon. We expected that differences between the two ecosystems will be reflected in the structure of their trophic webs. We hypothesize that, due to its shallower depth, limited water renewal, and restricted sea connectivity, the trophic structure in Maricá Lagoon will primarily rely on autochthonous phytoplankton and a narrower range of basal sources. This is likely to result in a lower producer diversity supporting consumers, and a higher overlap in consumers' isotopic niches. In contrast, the Sepetiba Bay is expected to exhibit a more diverse range of basal resources and a more complex trophic structure, driven by its greater dynamism and wider connection to the sea. This should lead to higher diversity among producers and consumers, as well as broader and more distinct isotopic niches. We also expect that differences in the anthropogenic pollutants between the two systems will be reflected in differences in their trophic web, and in species trophic positions.

2. Materials and methods

2.1. *Study area*

The research was conducted in two semi-enclosed coastal systems located in the state of Rio de Janeiro, Brazil: Sepetiba Bay (22°54′–23°40′S; 43°34′–44°10′W) and the Maricá Lagoon System (22°55′–22°58′S; 42°42′–42°53′W). Sepetiba Bay (Fig. 1) is a semi-enclosed coastal area covering approximately 450 km^2, situated in the southern part of the state of Rio de Janeiro state, Brazil. The bay is connected to the sea through a broad area at the western end and a narrow channel to the east, with an extensive sandbank forming the southern limit and the continental margin to the north (Fig. 1B). Some coastal islands are located near the sea connection, thus enhancing habitat diversity in the bay (Cunha et al., 2006). The water mass turnover time was estimated to be approximately 6 days, with maximum current velocity at peak tides ranging from 50 to 75 cm s^{-1} (Molisani et al., 2004). The mean depth is 8.6 m, with a maximum depth of 30 m. The mean water temperature ranges from 21.5 °C in the winter to 26.5 °C in the summer. Average salinity ranges from 29 to 33. Small rivers and streams drain into the bay, contributing to decrease salinity and increasing turbidity in the inner bay areas. This system has faced significant impacts due to industrial and port activities, particularly in the chemical and metallurgical industries (Clarke et al., 2004; Molisani et al., 2004; Cunha et al., 2006), leading to water pollution through waste and effluents, along with rapid urbanization (Pellegatti et al., 2001; Leal Neto et al., 2006). Since the 1970s, Sepetiba Bay has faced significant impacts as agriculture and fishing have given way to industrial and port activities, particularly chemical and metallurgical industries (Clarke et al., 2004; Molisani et al., 2004; Cunha et al., 2006). These activities have led to water pollution through waste and effluents (Pellegatti et al., 2001), along with rapid urbanization, increasing the population from ~60,000 in 1980 to 2 million by 2000 (Leal Neto et al., 2006). Habitat loss, pollution (Azevedo et al., 2007) and submarine terminal were followed by the installation of four thermoelectric power plants, which raise water temperature by cooling at 8.6 m^3/s (INEA, 2022).

Maricá Lagoon (Fig. 1) is a lagoon complex that covers an area of 35.3 km^2 and is in the Coastal Lowlands region. The complex consists of four interconnected lagoon cells (Fig. 1C), linked to the sea through a 1.3 km long channel at the westernmost cell. This lagoon receives a considerable input of freshwater in the main tributaries, presenting predominantly mesohaline conditions, with salinity ranging from 8 to 38 (mean value of 18) and annual average temperature ranges from 24 to 27°C (Franco et al., 2019). Due to the narrow (15–30 m wide) and shallow (1–2 m) channel, water renewal time for 50 % of the Maricá Lagoon varies between 27 days (farthest from the channel) and 7 days (nearest to the channel) (Kjerfve et al., 1990; Knoppers et al., 1991), which leads to a significant accumulation of nutrients in the lagoon. This coastal system shows clear signs of eutrophication, evidenced by elevated total phosphorus levels, which are 2–6 times above the limit of 0.12 mg L^{-1} (Amora-Nogueira et al., 2023). The low water renewal rate combined with a high potential for organic matter retention likely

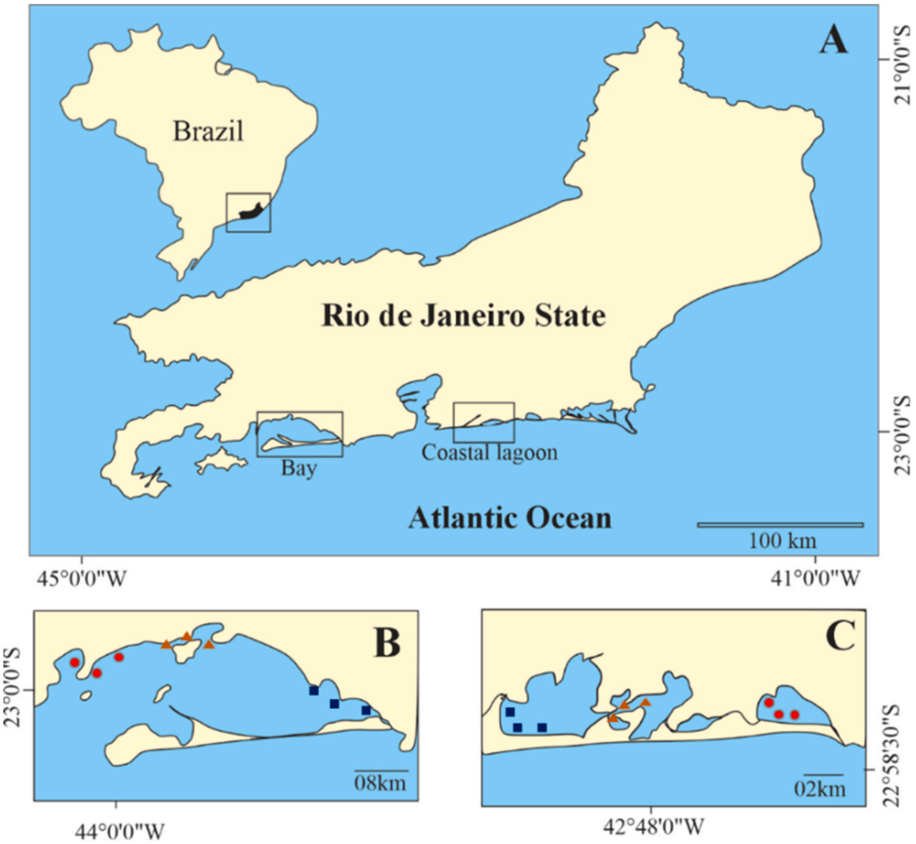

Fig. 1. (A) Study area showing the studied coastal systems in the state of Rio de Janeiro, Southeastern Brazil. Sampling locations are represented for the (B) Sepetiba Bay and (c) Maricá Lagoon System. The collection points were identified using the following symbols: red circle, Outer Zone; orange triangle, Middle Zone; blue square, Inner Zone.

promote nutrient availability, enhancing local productivity and reflecting in high chlorophyll-a concentrations (Batista, 2018). Unlike Sepetiba Bay, which faces industrial impact, the Maricá Lagoon suffers from high organic pollution due to rapid population growth (Kjerfve et al., 1996). Over the past decade, population density increased 55 % reaching 197,300 people in the lagoon surroundings (IBGE, 2020). Unplanned urban expansion has led to untreated waste and silting, (Guerra et al., 2011). Additionally, land use changes like sand and clay extraction have increased sediment and nutrient inputs, further contributing to silting and eutrophication (Laut et al., 2019; Toledo et al., 2021). Unplanned urban expansion has led to untreated waste and silting, (Guerra et al., 2011). Additionally, land use changes like sand and clay extraction have increased sediment and nutrient inputs, further contributing to silting and eutrophication (Laut et al., 2019; Toledo et al., 2021).

2.2. Field collections

Representative components of the food chain, including basal sources and fish, were sampled from the austral winter of 2017 to the austral summer of 2018 in the Maricá Lagoon and Sepetiba Bay. For each system, sampling was performed at three sites per zone (i.e. Inner, Middle, and Outer) and each sample included three replicates per site, where representative species of primary producers, invertebrates and fish were collected (Fig. 1).

Primary sources were collected in triplicate for each species of main groups: macroalgae, terrestrial and aquatic C3 and C4 plants (Table 1) for species list and δ^{13}C and δ^{15}N values), Suspended Particulate Organic Matter (POM – proxy for phytoplankton), and Sedimentary Organic Matter (SOM – proxy for periphyton and detrital material) (Vollrath et al., 2021). POM samples were obtained by filtering approximately 0.25–1 L of water collected at each site through fiberglass filters (0.75 μm). SOM samples were obtained by removing surface sediment (~2 cm) using a PVC plastic pipe. The fish were captured using a beach seine net (12 × 2.5 m, 5-mm mesh size), dragged perpendicular to the coastline at 1.5 m depth. Two individuals conducted the hauls, one at each end of the rope, covering an area of around 300 m^2. Benthic invertebrates were sampled using a PVC "corer" (50 cm long, 10 cm diameter). All collected material was placed in plastic bags and preserved on ice until transferred to the laboratory, where it was stored in a freezer until processing.

2.3. Sample processing

In laboratory, each sample was rinsed with distilled water, placed in sterile Petri dishes and dried in oven at 60 °C for 48h. Dried samples were ground to a fine powder with a mortar and pestle and stored in clean 2 ml plastic tubes. Subsamples were weighed, pressed into ultra-pure tin capsules (Elemental Microanalysis), and sent to the Centro de Isótopos Estáveis Prof. Dr. Carlos Ducatti (Universidade Estadual de São Paulo, UNESP Botucatu - SP), for analysis of carbon and nitrogen isotope values. No acidification for the removal of inorganic carbon in the samples was performed because neither Sepetiba Bay nor Maricá Lagoon has a significant presence of corals or carbonated sediments (following Claudino et al., 2013; Garcia et al., 2016).

The analysis of the isotopic ratio ^{13}C/^{12}C and ^{15}N/^{14}N was conducted using the Delta Advantage Isotope Ratio MS Flash 2000 Elemental Analyzer coupled to a Mass Spectrometer (IRMS). The values are expressed in delta (parts per thousand deviations from a standard material): $\delta^{13}C$ or $\delta^{15}N = [(R_{sample}/R_{standard}) - 1] * 1000$; where $R = {}^{13}C/{}^{12}C$ or $^{15}N/^{14}N$. The standard material for carbon was Pee Dee Belemnite (PDB) limestone, and the nitrogen standard was atmospheric nitrogen

Table 1
Average ± sd δ^{13}C and δ^{15}N of different community components of two systems (Sepetiba Bay – Bay, and Maricá Lagoon System - Lagoon), Brazil. Data from 2018. NI = non-identified.

	Bay					Lagoon				
	n	δ^{13}C	±sd	δ^{15}N	±sd	n	δ^{13}C	±sd	δ^{15}N	±sd
POM	11	−20.08	1.25	8.32	2.05	9	−22.07	0.53	6.61	2.37
Periphyton	16	−21.18	7.37	4.96	1.47	10	−19.06	1.49	5.63	2.09
Macroalgae										
Algae NI						1	−17.39	0.00	3.98	0.00
Sargassaceae	5	−17.71	1.47	9.19	0.79					
Ulvaceae	7	−16.87	3.00	6.73	1.93					
Grass/C4 plants	3	−16.02	1.21	6.99	0.39	9	−15.37	1.03	7.57	3.27
Alternanthera littoralis						3	−15.28	0.68	7.37	0.59
Sporobolus virginicus						2	−16.92	0.55	7.64	0.84
Stenotaphrum secundatum	3	−16.02	1.21	6.99	0.39	4	−14.65	0.35	7.68	5.28
Terrestrial plant/C3 plants										
Clusia sp.	3	−30.68	0.65	6.36	1.76	4	−29.29	1.44	7.29	0.96
Dalbergia ecastophyllum						1	−30.41	0.00	−0.08	0.00
Hydrocotyle bonariensis						1	−29.82	0.00	7.55	0.00
Laguncularia racemosa	1	−25.54	0.00	7.08	0.00					
Mangifera indica	1	−29.68	0.00	5.39	0.00	1	−30.82	0.00	6.26	0.00
Rhizophora mangle	5	−28.13	1.67	6.41	1.17					
Schinus terebinthifolius	1	−30.07	0.00	8.29	0.00	6	−28.76	0.87	5.49	4.17
Terminalia catappa	9	−29.62	0.99	6.14	2.20	5	−30.60	2.78	8.20	4.68
Plant NI1	3	−29.56	2.05	4.11	0.84					
Plant NI2	1	−27.44	0.00	8.91	0.00					
Ascidiacea	4	−18.81	0.69	10.12	0.20					
Gastropoda										
Collisella sp.	2	−15.62	0.33	9.98	0.41					
Gastropoda NI	6	−16.88	2.54	9.60	2.53					
Bivalvia										
Anomalocardia brasiliana						3	−21.94	0.51	9.07	0.83
Bivalvia NI	5	−19.67	2.77	8.79	1.29					
Small Crustacea										
Zooplankton NI						2	−20.59	0.15	9.58	0.30
Amphipoda NI						2	−17.73	0.59	10.48	0.23
Isopoda NI	2	−18.53	1.23	11.44	1.73	1	−17.96	0.00	13.55	0.00
Barnacle										
Balanomorpha NI						5	−16.34	2.67	11.50	0.78
Polychaeta										
Nereididae						3	−20.78	1.18	9.81	0.89
Polychaeta NI	3	−17.98	1.04	10.64	1.19					
Shrimp										
Farfantepenaeus brasiliensis						3	−15.14	3.49	7.71	2.63
Penaeidae	6	−14.48	3.25	9.70	1.61					
Blue crab	11	−16.29	1.48	11.40	1.41	3	−15.43	0.27	7.42	0.20
Callinectes danae						2	−15.58	0.15	7.31	0.09
Callinectes sapidus						1	−15.14	0.00	7.63	0.00
Callinectes sp.	11	−16.29	1.48	11.40	1.41					
Herbivore										
Mugil curema	2	−19.74	0.11	3.73	1.96	1	−9.67	0.00	7.25	0.00
Mugil liza						3	−12.24	2.67	5.81	1.07
Zooplanktivore										
Anchoa januaria	7	−15.82	1.44	14.97	1.14	15	−18.66	1.09	14.40	1.71
Anchoa tricolor	5	−15.73	1.02	14.35	1.89					
Brevoortia aurea	1	−15.73	0.00	8.25	0.00	2	−18.53	0.57	13.76	1.35
Cetengraulis edentulus	8	−15.29	0.27	11.46	1.23					
Stellifer rastrifer	2	−15.61	0.06	13.18	2.42					
Omnivore										
Chaetodipterus faber	1	−16.79	0.00	15.55	0.00					
Jenynsia multidentata						13	−16.88	1.23	12.69	1.57
Myrophis punctatus	1	−17.50	0.00	12.89	0.00					
Oreochromis niloticus						1	−14.80	0.00	12.14	0.00
Poecilia vivipara						3	−20.07	0.75	13.08	0.24
Epibenthic feeders										
Ctenosciaena gracilicirrhus	1	−18.37	0.00	11.98	0.00					
Eucinostomus argenteus	14	−16.09	2.38	13.98	1.27	4	−14.14	1.29	8.86	0.38
Larimus breviceps	3	−17.22	0.56	15.10	0.40					
Menthicirrus littoralis	2	−18.42	1.06	13.73	1.76					
Micropogonias furnieri						1	−16.29	0.00	13.66	0.00
Odontoscion dentex	1	−15.22	0.00	13.31	0.00					
Ophioscion punctatissimus	1	−16.86	0.00	16.16	0.00					
Trachinotus carolinus	5	−17.29	0.58	13.53	0.64					
Infaunal feeders										
Etropus crossotus	3	−15.61	0.11	14.04	0.57					
Genidens barbus	2	−17.97	0.40	14.45	0.35					
Genidens genidens	5	−19.02	0.83	10.97	2.04					

(*continued on next page*)

Table 1 (*continued*)

	Bay					Lagoon				
	n	δ^{13}C	±sd	δ^{15}N	±sd	n	δ^{13}C	±sd	δ^{15}N	±sd
Microgobius meeki						5	−18.54	0.61	13.82	1.21
Sphoeroides testudineus	22	−16.57	1.32	13.23	1.02					
Opportunist	50	−16.35	1.31	13.61	0.88	51	−17.78	1.62	13.66	1.77
Atherinella brasiliensis	43	−16.45	1.32	13.65	0.85	49	−17.94	1.45	13.83	1.59
Diapterus rhombeus	7	−15.75	1.14	13.41	1.11	2	−13.95	0.11	9.52	0.62
Piscivore	8	−16.13	1.55	14.79	2.31	1	−18.09	0.00	15.21	0.00
Caranx latus	2	−17.81	0.78	11.62	1.55					
Elops saurus						1	−18.09	0.00	15.21	0.00
Oligoplites saurus	4	−15.84	1.61	15.56	1.56					
Strongylura timucu	2	−15.02	0.06	16.40	0.27					

calibrated using certified reference materials. Laboratorial standards for instrument precision resulted in standard deviation of 0.10 ‰ for δ^{13}C, and 0.15 ‰ for δ^{15}N.

2.4. *Data analysis*

Producers and consumers species were classified into groups considering taxonomic and/or trophic similarities in order to allow comparison between the two systems, as well as other ecosystems worldwide. Producers included 'macroalgae', 'terrestrial plant', 'grass', 'POM', and 'SOM'. Benthic invertebrates were classified as 'gastropod', 'bivalve', 'isopoda', 'amphipoda', 'polichaeta', 'shrimp', and 'blue crab'. Fish were grouped into the trophic groups 'herbivore', 'omnivore', 'zooplanktivore', benthivores (divided in 'epibenthic feeders, and 'infaunal feeders'), 'piscivore', and 'opportunist'. Epibenthic feeders included species that feed on zoobenthos not closely associated to the bottom (hyperfauna/epifauna, e.g. Mysidae), while infaunal feeders included species feeding on zoobenthos strongly associated to the bottom (infauna/epifauna, e.g., Polychaeta). Opportunists are species that feed on multiple categories in similar proportions and cannot be classified under a single feeding habit (Mai and Possamai, 2022).

In order to evaluate differences in stable isotopes values between the bay system and the lagoon, orthogonal PERMANOVAs were performed using fixed effects (System and Group) with 999 permutations. The distance matrix was built using Euclidian Distance calculations, and the analysis was performed using the vegan R package. Isotopic niche breath was evaluated for each fish trophic group in each system. We calculated the Bayesian Standard Ellipse Area (SEAb in ‰^{2}) and the Corrected Standard Ellipse Area (SEAc in ‰^{2}) using the 'SIBER' package (Jackson et al., 2011). Ellipses were calculated in a bivariate space of δ^{13}C and δ^{15}N, using 40 % of the isotopic data to avoid bias of differential sample sizes (Jackson et al., 2011). Bayesian bivariate normal distributions were fitted with 20,000 iterations (1000 *burn-in*) to calculate each SEAb. Isotopic niche overlaps among trophic groups in each system were calculated based on the overlapped corrected Standard Ellipse Area (SEAc) to evaluate whether the bay community has higher isotopic niche overlap compared to the lagoon community. Because in pairwise comparisons the two ellipses may have different SEAc (e.g., trophic group *i* has a 2-fold isotopic niche of group *j*), the overlaps can differ (e.g., the overlap of *i* in *j* may be higher than the overlap of *j* in *i*). To have a clearer pattern and be able to compare overlaps among trophic groups, we converted the overlaps in percentage ($\text{Overlap}_{ji} = \text{Overlapped area}/\text{SEA}_i * 100$) and calculated the overlaps in both directions (e.g., overlap of *i* in *j*, and *j* in *i*), with 100 % indicating a complete overlap among trophic groups.

Trophic position calculations and mixing models of fish consumers were conducted to evaluate the hypothesis of differential use of basal resources between bay and lagoon. Herbivores were used as baselines for each system, considering they represent an integration of the primary production mix (Vander Zanden and Rasmussen, 1999, 2001; Post, 2002; Mancinelli et al., 2013). Two baselines were used for each system to improve trophic position estimation. The first baseline was planktonic, comprising filter feeders (Ascidiacea + Bivalvia in the Bay; Bivalvia + Zooplankton in the Lagoon). The second baseline was benthic, consisting of grazers (Gastropoda in the Bay and *Mugil* sp. in the Lagoon). The trophic enrichment factors (TEF) used in these estimates were 0.4 ± 1.3 for δ^{13}C, and 3.4 ± 1.0 for δ^{15}N (Post, 2002). Trophic positions of each species were calculated with a Bayesian approach using the Markov chain Monte Carlo (MCMC) method with 10,000 interactions and 10,000 adaptive samples in JAGS 4.3.1., through tRophicPosition R package (Quezada-Romegialli et al., 2018). This is a Bayesian method that allows the incorporation of multiple baselines and stable isotopes (e.g., δ^{13}C and δ^{15}N) to better incorporate individual variability and propagating sampling error in the modelling and posterior estimates (Quezada-Romegialli et al., 2018). To test differences in trophic positions between bay and lagoon, a paired Student's *t*-test was employed, using $\alpha = 0.05$. Pairs consisted of the same species values. Normality and homoscedasticity prerequisites were analysed before performing the test (Levene and Shapiro-Wilk test >0.10).

Information about trophic position was used to better incorporate trophic enrichment factors into the mixing models. Mixing models were built considering one fixed factor (System) for each group of fish consumer. Models were adjusted using the Markov chain Monte Carlo (MCMC) method, with 100,000 simulations for each model, and burn-in of 50,000 for the choice of the best model using JAGS 4.3.1. The median (50 %) of the 95 % Bayesian credibility interval was used to summarize the contribution results. Models were performed using the MixSIAR R package (Stock and Semmens, 2016), with TEFs 0.4 ± 1.3 for δ^{13}C, and 3.4 ± 1.0 for δ^{15}N (Post, 2002). All models presented Gelman diagnostic <1.05 and passed in the Geweke diagnostics (maximum of 5 % of variables outside ±1.96 in each chain). Biplots (δ^{13}C and δ^{15}N) can be seen in the Supplementary Material (Fig. S1). All analyses were performed in R 4.3.2 (R Core Team, 2023).

3. Results

3.1. *Isotopic values (δ^{13}C e δ^{15}N) of taxonomic groups*

The isotopic values of producers did not vary between bay ($\delta^{13}\text{C} = -22.6 \pm 5.6$; $\delta^{15}\text{N} = 6.7 \pm 2.4$, $n = 75$) and lagoon ($\delta^{13}\text{C} = -22.9 \pm 5.9$; $\delta^{15}\text{N} = 6.4 \pm 3.1$, $n = 47$) for both δ^{13}C and δ^{15}N (Fig. 2, Tables 1 and 2). The only variation found among producers was related to the taxonomic group (Table 2). For invertebrates, both δ^{13}C and δ^{15}N of the same taxonomic groups varied depending on the systems, indicated by the interactive term (Tables 1 and 2). For fish, overall δ^{13}C (-16.9 ± 1.8; $n = 248$) and δ^{15}N (13.3 ± 2.1; $n = 248$) differed between trophic groups, but not among systems. The same trophic groups showed differences in δ^{13}C depending on the system, but no differences were found in the δ^{15}N values of these consumers (Fig. 2, Tables 1 and 2).

3.2. *Basal carbon sources*

Concerning the basal resources sustaining the food chain, in the bay system, macroalgae (35.4 %) and grass (40.3 %) were the main

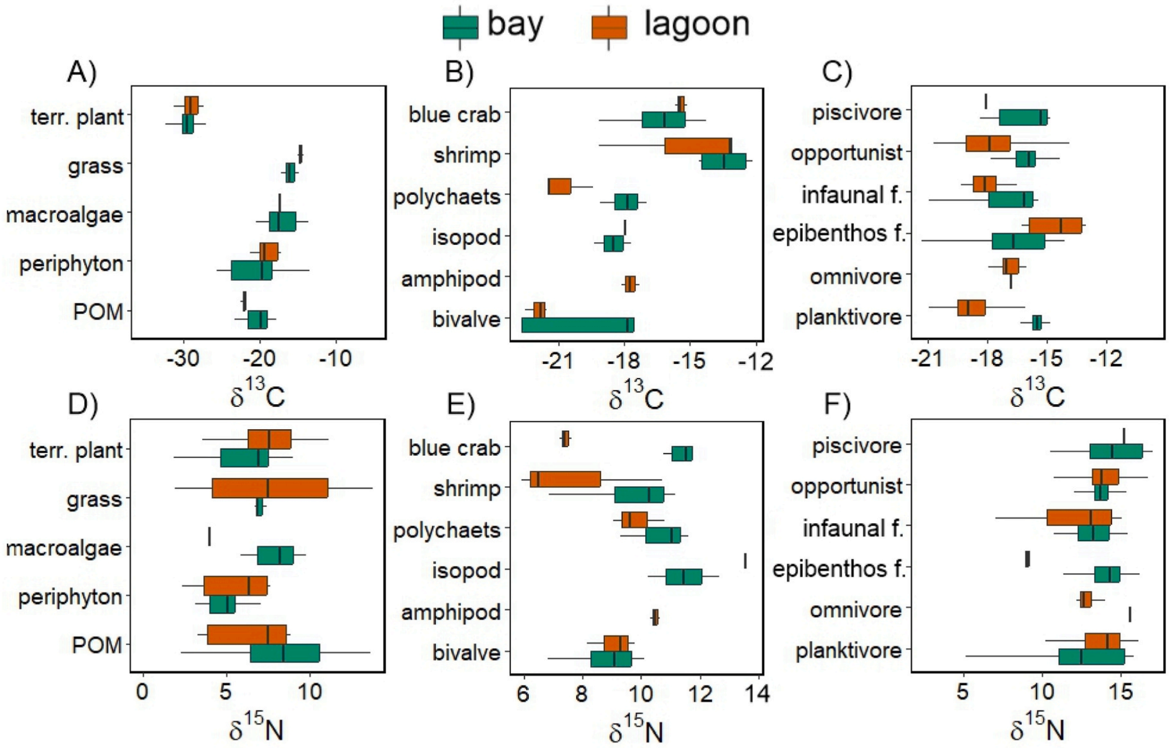

Fig. 2. Variation in stable isotopic values of each category of organisms between Sepetiba Bay and Maricá Lagoon, Brazil, during the winter of 2018. Variation in $\delta^{13}C$ of A) primary producers ('terr.plant' for terrestrial plants, 'POM' for suspended particulate organic matter, proxy for phytoplankton), B) invertebrates, and C) fish trophic groups (infaunal f. = infaunal feeders, epibenthos f. = epibenthic feeders). Variation in $\delta^{15}N$ of D) primary producers, E) invertebrates, and F) fish trophic groups. Trophic groups are explained in Methods section. Lower and upper hinges correspond to the 25th and 75th percentiles, whiskers correspond to 1.5 x the interquartile ranges.

producers contributing to the base of the shallow water food chain. In the lagoon, POM (proxy for phytoplankton; 30.5 %) was one of the main sources, along with grass (51.2 %) (Fig. 3, Table S1). When analysing each trophic group separately, zooplanktivores showed a higher utilization of POM in the lagoon (45.2 %) compared to the bay (19.1 %) (Fig. 3 and S1A). In the bay, opportunists assimilated macroalgae, POM and dune grass in similar proportions. In contrast, these species were primarily sustained by carbon derived from grass and POM (61.1 % and 30.8 %, respectively; Fig. 3 and S1C) in the lagoon. Epifaunal feeders exhibit a similar pattern between bay and lagoon, with main resources derived from grass and macroalgae. However, infaunal feeders showed an increase in the assimilation of carbon derived from POM in the lagoon (61.0 %) compared to the bay (23.9 %) (Fig. 3 and S1B, D, Table S1).

3.3. Tropic position

Trophic position (TP) of fish consumers was estimated in 2.37 ± 0.16 for the bay and 2.50 ± 0.34 for the lagoon. No differences in TP between bay and lagoon TP were found (t = 0.27, df = 4, p-value = 0.796), and no clear pattern was observed among trophic groups. Zooplanktivores was the group that presented higher average trophic position in both systems (2.6 ± 0.23), mostly driven by *Brevoortia aurea* (Table 3). The maximum trophic positions were 2.80 for *B. aurea* and 2.5 for the piscivore *Strongylura timucu* in the bay, and 2.95 for the benthivore *Micropogonias furnieri* in the lagoon, indicating that the shallow water food-chains in both systems have 3 trophic levels.

3.4. Isotopic niche

In the bay system, zooplanktivores (n = 15 individuals) presented the broader niche, followed by piscivores (n = 8) and both groups of benthivores (epibenthic n = 19, infaunal n = 32) fishes (Table 4, Fig. 4A). In the lagoon, epibenthic feeders (n = 5 had the larger niche breadth, followed by opportunists (n = 51) and zooplanktivores (n = 17) (Table 4, Fig. 4B).

Evaluating isotopic niche overlap, infaunal feeders (n = 5) and opportunists (n = 51) exhibited the highest overlap in the bay, with 89 % of the opportunists' niche was shared with infaunal feeders. Opportunists also showed high isotopic niche overlaps with nearly all other guilds (Table 5; Fig. 4A). Herbivores did not share an isotopic niche with any other guild, showing a very small overlap with zooplanktivores (Table 5; Fig. 4A). In the lagoon, isotopic niche was less shared among trophic guilds compared to the bay. The highest niche overlap occurred between opportunists and zooplanktivores, with opportunists occupying 86 % of zooplanktivores isotopic niche. Opportunists showed the most overlaps with other trophic guilds (Table 5; Fig. 4B).

4. Discussion

Here, we evaluated the trophic structure of shallow water communities in two coastal systems with contrasting geomorphologies and degrees of connectivity with the sea. We found that, while the bay and lagoon hosted similar communities, their trophic structures differed, likely reflecting variation in anthropogenic pressures and marine connectivity. These results support our hypotheses of distinct isotopic niches and different primary producers sustaining each system. Isotopic variation was more pronounced in invertebrate and fish trophic groups than at the base of the food web, indicating that although similar producers (e.g. macroalgae, POM, dune grass) are present, their utilization by the community differ between systems.

The MixSIAR model revealed that fish in both the lagoon and the bay assimilated a mixture of basal production sources, with a greater contribution of phytoplankton (using POM as a proxy) in the lagoon than in the bay. These results support our hypothesis that the systems

Table 2
Results of PERMANOVA analysis for comparisons of isotopic values ($\delta^{13}C$ and $\delta^{15}N$) of each category (Producers, Invertebrates, and Fishes) of organisms between individual (taxonomic or trophic group) and ecosystem (bay, lagoon). Samples collected in Sepetiba Bay and Maricá Lagoon, Brazil, during the winter of 2018.

	Df	Sum(X^2)	R^2	F	p-value
Producers $\delta^{13}C$					
System	1	9.3	0.002	0.796	0.379
Taxonomic group	4	2840.5	0.644	60.684	0.001
System*Group	4	55.7	0.013	1.190	0.326
Residual	*110*	*1287.2*	*0.307*		
Producers $\delta^{15}N$					
System	1	2.3	0.002	0.347	0.534
Taxonomic group	4	91.0	0.106	3.444	0.013
System*Group	4	34.2	0.040	1.293	0.256
Residual	*110*	*726.8*	*0.850*		
Invertebrates $\delta^{13}C$					
System	1	62.9	0.074	20.884	0.001
Taxonomic group	5	22.1	0.025	1.464	0.210
System*Group	5	55.9	0.065	3.707	0.010
Residual	*235*	*708.6*	*0.834*		
Invertebrates $\delta^{15}N$					
System	1	8.7	0.007	2.046	0.175
Taxonomic group	5	60.8	0.053	2.858	0.017
System*Group	5	82.1	0.071	3.857	0.019
Residual	*235*	*1000.9*	*0.868*		
Fish/consumers $\delta^{13}C$					
System	1	14.3	0.011	1.157	0.270
Trophic group	13	321.5	0.353	2.763	0.004
System*Group	4	17.8	0.143	3.658	0.019
Residual	*50*	*210.4*	*0.491*		
Fish/consumers $\delta^{15}N$					
System	1	14.3	0.025	3.396	0.069
Trophic group	13	321.5	0.570	5.876	0.001
System*Group	4	17.8	0.031	1.057	0.381
Residual	*50*	*210.4*	*0.373*		

would be sustained by contrasting sets of primary producers, resulting in more distinct isotopic niches among consumers. In general, consumers in the bay were primarily supported by macroalgae, dune grass, and, to a lesser extent, phytoplankton, whereas in the lagoon, phytoplankton and grass were the main producers sustaining the food web. Saltmarsh vegetation is the primary basal source sustaining shallow-water consumers in subtropical and temperate estuaries (Bergamino and Richoux, 2015; Possamai et al., 2020; Lesser et al., 2021), with its contribution likely occurring in form of detritus after plant senescence and degradation (Bergamino and Richoux, 2015; Lanari et al., 2021). The significant contribution of dune grass, primarily composed of the C4 species *Sporobolus virginicus* likely follows the same detrital pathway, playing and important role in supporting shallow-water food webs in both systems. Moreover, although not present in the coves where our samples were collected, Sepetiba Bay is bordered by dense patches of *Spartina alterniflora*, which form saltmarshes zones between mangroves and water (Lacerda et al., 1997). Given that isotopic values of marsh and grass plants tend to be less variable than those of phytoplankton and benthic producers (Lanari et al., 2021), the high contribution of C4 grass to the food web observed in Sepetiba Bay is likely derived from saltmarshes vegetation as well.

Phytoplankton was a key resource for zooplanktivores and infaunal feeders in the Maricá Lagoon System, while macroalgae were important primary producers for benthivores and opportunistic species in Sepetiba Bay. Previous studies highlight the role of macroalgae in food webs across freshwater, estuarines, and shallow coastal ecosystems (Lepoint et al., 2000; Zhao et al., 2022). Zhao et al. (2022) showed that in the of the Miaodao Archipelago, macroalgae serve as a major carbon source for consumers through two pathways: direct grazing and ingestion of decomposing detritus. The isotopic similarity between live and decomposing macroalgae complicates distinguishing their contributions (Gabara, 2020). Both forms likely support epibenthic feeders, either via

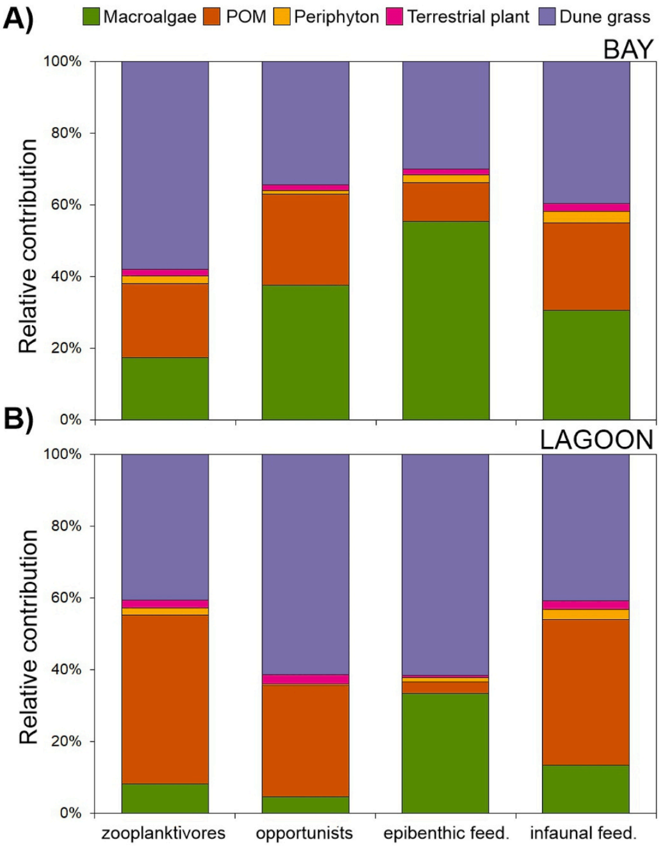

Fig. 3. Relative contribution of primary producers to each trophic group of fish consumers in A) Sepetiba Bay and B) Maricá Lagoon, Brazil, winter of 2018. 'Terrestrial plant' included mangrove and other C3 trees; 'dune grass' includes C4 grasses bordering the lagoon/bay. Trophic groups are explained in the Methods section (feed. = feeders).

Table 3
Fish species tropic position (TP) estimates in Sepetiba Bay and Maricá Lagoon, Brazil, during the winter of 2018. TG refers to trophic group. Trophic groups are explained in the Methods section.

TG	Species	Common name	Bay TP	Lagoon TP
Opportunist	*Atherinella brasiliensis*	Brazilian silversides	2.21	2.50
Opportunist	*Diapterus rhombeus*	Caitipa mojarra	2.34	2.24
Piscivore	*Caranx latus*	Horse-eye jack	2.21	
Piscivore	*Oligoplites saurus*	Leatherjacket	2.41	
Piscivore	*Strongylura timucu*	Timucu	2.56	
Epibenthic feeders	*Eucinostomus argenteus*	Silver mojarra	2.35	2.21
Epibenthic feeders	*Larimus breviceps*	Shorthead drum	2.37	
Epibenthic feeders	*Menticirrhus littoralis*	Gulf kingcroaker	2.33	
Epibenthic feeders	*Micropogonias furnieri*	Whitemouth croaker		2.95
Infaunal feeders	*Etropus crossotus*	Fringed flounder	2.31	
Infaunal feeders	*Genidens barbus*	White sea catfish	2.34	
Infaunal feeders	*Genidens genidens*	Guri sea catfish	2.11	
Infaunal feeders	*Microgobius meeki*	Meek's goby		2.54
Infaunal feeders	*Sphoeroides testudineus*	Checkered puffer	2.24	
Zooplanktivore	*Anchoa januaria*	Rio anchovy	2.46	2.60
Zooplanktivore	*Anchoa tricolor*	Piquitinga anchovy	2.47	
Zooplanktivore	*Brevoortia aurea*	Brazilian menhaden	2.80	2.90
Zooplanktivore	*Stellifer rastrifer*	Rake stardrum	2.34	

Table 4
Corrected Standard Ellipse Area (SEAc in ‰^{2}), and Bayesian Standard Ellipse Area (SEAb in ‰^{2}) expressed in median of each trophic group in Sepetiba Bay and Maricá Lagoon, Brazil. SEAb (2.5 %) and (97.5 %) represent the lower and maximum estimates. Areas were calculated considering 40 % of isotopic data. Trophic groups are explained in the Methods section.

Trophic group	Bay				Lagoon			
	SEAc	SEAb	2.50 %	97.50 %	SEAc	SEAb	2.50 %	97.50 %
epibenthic feeders	6.08	6.07	3.42	12.48	9.81	8.88	2.67	83.86
infaunal feeders	5.54	5.54	3.21	11.54	2.84	2.36	0.68	24.03
herbivore	1.18	1.17	0.36	5.33	11.73	1.03	2.02	155.72
opportunist	3.08	3.06	1.88	5.38	5.18	5.34	3.32	8.89
omnivore					6.21	6.79	3.12	15.85
piscivore	4.59	6.64	2.29	29.54				
zooplanktivore	8.08	7.75	3.22	30.57	2.02	2.57	1.22	6.70

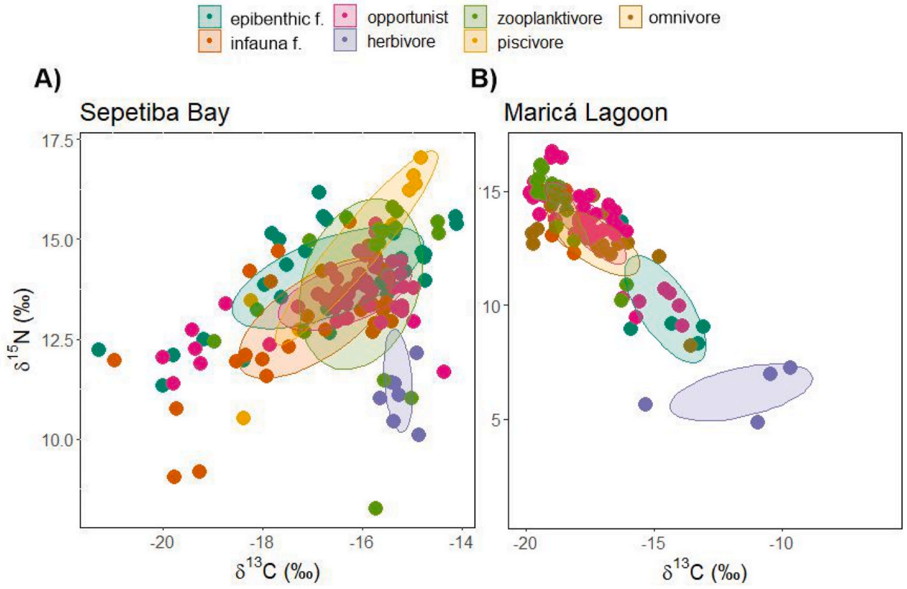

Fig. 4. Isotopic ellipses (δ^{13}C, δ^{15}N) of fish trophic groups at A) Sepetiba Bay, and B) Maricá Lagoon, Brazil, collected during the winter of 2018. All ellipses are based on 40 % isotopic niche area. Points in the graphs represent samples size (n). Trophic groups are explained in the Methods section. Epibenthic f. = epibenthic feeders; Infauna f. = infaunal feeders.

Table 5
Isotopic niche overlap among trophic groups. The overlapped area (based on SEAc), and the percentage of the overlapped area of paired isotopic ellipses (δ^{13}C, δ^{15}N) is expressed in each system (bay and lagoon). "Overlap 1 in 2" is the % of overlapped area of the first ellipse (i.e., group 1) on the second ellipse; "Overlap 2 on 1" is the opposite pattern (% of overlapped area of the second ellipse on the first ellipse). All overlaps are based on 40 % isotopic niche area. Trophic groups are explained in the Methods section.

Group 1	—	Group 2	Sepetiba Bay			Maricá Lagoon		
			Overlap (‰^{2})	Overlap 1 in 2	Overlap 2 in 1	Overlap (‰^{2})	Overlap 1 in 2	Overlap 2 in 1
epibenthic feeders	vs.	infaunal feeders	2.82	49.8 %	45.4 %	0.00	0.0 %	0.0 %
epibenthic feeders	vs.	herbivore	0.00	0.0 %	0.0 %	0.00	0.0 %	0.0 %
epibenthic feeders	vs.	opportunist	2.46	78.1 %	39.6 %	0.01	0.2 %	0.1 %
epibenthic feeders	vs.	omnivore				0.57	8.5 %	5.7 %
epibenthic feeders	vs.	piscivore	2.65	56.5 %	42.7 %			
epibenthic feeders	vs.	zooplanktivore	4.13	50.0 %	66.5 %	0.00	0.0 %	0.0 %
infaunal feeders	vs.	herbivore	0.00	0.0 %	0.0 %	0.00	0.0 %	0.0 %
infaunal feeders	vs.	opportunist	2.80	89.0 %	49.5 %	1.91	36.0 %	65.8 %
infaunal feeders	vs.	omnivore				1.77	26.3 %	61.1 %
infaunal feeders	vs.	piscivore	1.91	40.7 %	33.7 %			
infaunal feeders	vs.	zooplanktivore	3.38	40.9 %	59.7 %	1.46	65.8 %	50.3 %
herbivore	vs.	opportunist	0.00	0.0 %	0.0 %	0.00	0.0 %	0.0 %
herbivore	vs.	omnivore				0.00	0.0 %	0.0 %
herbivore	vs.	piscivore	0.00	0.0 %	0.0 %			
herbivore	vs.	zooplanktivore	0.12	1.4 %	9.5 %	0.00	0.0 %	0.0 %
opportunist	vs.	omnivore				3.20	47.4 %	60.4 %
opportunist	vs.	piscivore	1.49	31.8 %	47.3 %			
opportunist	vs.	zooplanktivore	2.85	34.5 %	90.4 %	1.79	86.8 %	33.9 %
piscivore	vs.	zooplanktivore	3.13	37.9 %	66.6 %			
zooplanktivore	vs.	omnivore				0.86	12.8 %	41.8 %

predation on grazer snails (live macroalgae/green pathway) or detritivore shrimps (detritus/brown pathway). Overall, our finding reinforces the critical role of macroalgae in sustaining higher trophic level in coastal food webs.

Consumers in Sepetiba Bay exhibited broader isotopic niche than those in Maricá Lagoon, reflecting greater diversity of available resources in the bay and supporting our initial hypothesis. Sepetiba Bay's open connection to the Atlantic Ocean enables, daily materials and energy exchange, while Maricá Lagoon primary receives allochthonous resources from surrounding land (Laut et al., 2019; Hartz et al., 2019; Franco et al., 2019; Camara et al., 2021). Water turnover in the bay is much faster than in the lagoon, which has a longer water residence time (Knoppers et al., 1991). This likely contributes to the differences observed in isotopic niche sizes.

Although we hypothesized greater isotopic niche overlap among trophic groups in the lagoon compared to the bay, we observed the opposite pattern. The broader isotopic niche in the bay suggests a wider variety of resources, with high overlap indicating shared use. Similar pattern have been reported for fish species in Amazonian floodplains, and in South Brazilian coastal system, where high prey abundance led to overlapped niches (Vollrath et al., 2021; Andrade et al., 2024). In contrast, lower prey availability promoted resource partitioning, likely to reduce competition (Vollrath et al., 2021; Andrade et al., 2024). Given Sepetiba Bay's high resources availability (Guedes and Araújo, 2008; Carvalho et al., 2021), consumers likely share resources without strong competition. However, isotopic niches, while useful proxies, do not directly correspond to trophic niches (Hette-Tronquart, 2019; van Rensburg et al., 2023). Our isotopic analysis reflects overlap in carbon sources rather than specific diets. Direct methods, such as stomach content analysis, can complement these findings and provide a more detailed understanding of trophic dynamics.

Opportunist species showed high isotopic niche overlap with nearly all trophic guilds, as expected given their use both pelagic and benthic resources (Mai and Possamai, 2022). The pronounced overlap among guilds, particularly infaunal feeders and zooplanktivores in Maricá Lagoon system, suggests strong benthic-pelagic coupling (Possamai et al., 2025). Fish from different trophic groups likely exploit both benthic and pelagic materials, facilitated by shallow depths and species' trophic plasticity (Timmerman et al., 2021). Shallow habitats promote sediment resuspension and organic matter mixing through hydrodynamics processes (Vizzini and Mazzola, 2003) and bioturbation by benthic invertebrates (Josefson and Rasmussen, 2000). Fish also contribute to sediment resuspension during foraging. The Maricá Lagoon System is dominated by benthivorous fish (Andrade-Tubino et al., 2020), such as the gerreid *Eucinostomus argenteus*, whose protrusible mouth facilitates sediment disturbance and increases prey availability for other trophic groups (Ramos et al., 2014).

We observed significant spatial variation in phytoplankton δ^{15}N especially in the Maricá Lagoon system, likely reflecting different levels of anthropogenic influence. Greater δ^{15}N variability often indicates stronger human impact (Ke et al., 2020). Spatial variations in POM δ^{15}N is also common in structured ecosystems like bays and lagoons, where freshwater and marine inputs fluctuate (Garcia et al., 2016; Possamai et al., 2020; Lanari et al., 2021). In Maricá, this variability aligns with contrasting ecosystem conditions, from well-preserved areas within the Environmental Protection Area to regions affected by coastal development.

Contrary to our expectations, the trophic position did not differ between the two systems. Although food chain length is often linked to system productivity (Elton, 1927; Hutchinson, 1959; Schoener, 1989), this pattern was not observed in our study, considering Maricá Lagoon is more eutrophicated than Sepetiba Bay (Guerra et al., 2011; Toledo et al., 2021). Other factors likely influence trophic structure, including ecosystem size (Vander Zanden et al., 1999; Post et al., 2000), geomorphology (Hoeinghaus et al., 2008), biodiversity (Paine, 1966), disturbance (Pimm and Lawton, 1977; Possamai et al., 2021), and prey-predator size relationships (Hairston and Hairston 1993; Jennings and Warr, 2003). Communities may also exhibit resilience to disturbances (Possamai et al., 2021), which could explain the observed patterns. Nonetheless, ongoing anthropogenic pressures and increasing climatic-related extreme events underscore the need for continuous monitoring of these ecosystems.

Both ecosystems are heavily impacted by human activities, with industrial pollution dominant around Sepetiba Bay (Cunha et al., 2006; Leal-Neto et al., 2006) and organic pollution more concentrated around Maricá Lagoon (Guerra et al., 2011; Toledo et al., 2021). In Maricá, unregulated population growth and untreated sewage discharge have created a spatial gradient of degradation. Weaks currents have contributed to channel silting, leading to persistent pollution accumulation (Guerra et al., 2011; Amora-Nogueira et al., 2023). Increased wastewater input has elevated nitrogen and phosphorus levels (Guerra et al., 2011; Laut et al., 2019; Toledo et al., 2021), intensifying eutrophication and promoting microalgae as a major carbon source for zooplanktivores and benthivores. In contrast, in Sepetiba Bay consumers rely on carbon from multiple sources, reflected in higher isotopic niche overlap observed. The mixing of carbon inputs, combined with regular seawater inflow, likely homogenizes isotopic signatures, expanding niche width but increasing overlap. Although, we did not collect marine and freshwater POM to quantify allochthonous contribution, the influence of marine inputs likely contributed to the broader isotopic niche in the bay. Future research should incorporate allochthonous sources to better understand energy flows and trophic interactions across these two geomorphologically distinct systems.

Estuarine food webs are shaped by organic matter from multiples habitats, influenced by estuarine size and configuration (Young et al., 2022). Thus, studies on isotopic niches must account for spatial gradients. Factors such as pollution, depth, and water renewal also alter basal sources and trophic dynamics. In this study, we compared the trophic structure of Sepetiba Bay and the Maricá Lagoon System, considering ocean connectivity, but did not explore spatial variation or human impacts in detail. Future research incorporating these factors, along with a broader range of species and adjacent systems, would deepen our understanding of interspecific relationships and anthropogenic effects, supporting more effective environmental management and a holistic view of biotic-abiotic interactions in transitional ecosystems.

CRediT authorship contribution statement

Rafaela de Sousa Gomes-Gonçalves: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Bianca Possamai:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Victória de Jesus Souza:** Methodology, Investigation. **Francisco Gerson Araújo:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Funding

This project was financially supported by CNPq—Brazilian National Agency for Scientific and Technological Development (Proc. 305712/2020-9) and by FAPERJ - Rio de Janeiro State Agency for Research Development (Proc. E−26/200.897/2021).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to several students at the Laboratório de Ecologia de Peixes (UFRRJ) for field sampling and laboratory procedures. This project was financially supported by CNPq—Brazilian National Agency for Scientific and Technological Development (Proc. 305712/2020-9) and by FAPERJ - Rio de Janeiro State Agency for Research Development (Proc. E-26/200.897/2021).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marenvres.2025.107251.

Data availability

Data will be made available on request.

References

Abreu, P.C., Bergesch, M., Proença, L.A., Garcia, C.A.E., Odebrecht, C., 2010. Short- and long-term chlorophyll a variability in the shallow microtidal Patos Lagoon Estuary, Southern Brazil. Estuaries Coasts 33, 554–569. https://doi.org/10.1007/s12237-009-9181-9.

Amora-Nogueira, L., Smoak, J., Abuchacra, R., Carvalho, C., Ribeiro, F., Campos, K., Oliveira, A., Carvalho, M., Machado, L., Faustino, A., Carvalho da Silva, A.L., Enrich-Prast, A., Oliveira, V., Sanders, C., Sanders, L., Marotta, H., 2023. Linking centennial scale anthropogenic changes and sedimentary records as lessons for urban coastal management. Sci. Total Environ. 902, 165620. https://doi.org/10.1016/j.scitotenv.2023.165620.

Andolina, C., Franzoi, P., Cavraro, F., Jackson, A.L., Mazzola, A., Vizzini, S., 2022. Trophic adaptability shapes isotopic niche of the resident fish *Aphanius fasciatus* across lagoon habitats. Estuar. Coast Shelf Sci. 264, 107685. https://doi.org/10.1016/j.ecss.2021.107685.

Andrade, F.S., Possamai, B., Freitas, C.E., Batista, J.S., Hoeinghaus, D.J., Clements, L., Siqueira-Souza, F.K., 2024. Niche partitioning and seasonality may mediate coexistence of piranha species in Amazonian floodplain lakes. Hydrobiologia (The Hague) 23, 1–6. https://doi.org/10.1007/s10750-024-05536-z.

Andrade-Tubino, M.F., Azevedo, M.C.C., Franco, T.P., Araújo, F.G., 2020. How are fish assemblages and feeding guilds organized in different tropical coastal systems? Comparisons among oceanic beaches, bays and coastal lagoons. Hydrobiologia (The Hague) 847, 403–419. https://doi.org/10.1007/s10750-019-04101-3.

Araújo, F.G., Azevedo, M.C.C., Guedes, A.P.P., 2016. Inter-decadal changes in fish communities of a tropical bay in southeastern Brazil. Reg Stud Mar Sci 3, 107–118. https://doi.org/10.1016/j.rsma.2015.06.001.

Azevedo, M.C.C., Araújo, F.G., Cruz Filho, A.G., Pessanha, A.L.M., Silva, M.A., Guedes, A.P.P., 2007. Demersal fishes in a tropical bay in southeastern Brazil: partitioning the spatial, temporal and environmental components of ecological variation. Estuar. Coast Shelf Sci. 75, 468–480. https://doi.org/10.1016/j.ecss.2007.05.027.

Batista, A.S., 2018. Diagnóstico geoambiental da Lagoa de Maricá (RJ) como subsídio as formas de uso e ocupação do litoral. Master dissertation. Universidade do Estado do Rio de Janeiro. https://www.bdtd.uerj.br:8443/handle/1/19967.

Bergamino, L., Richoux, N.B., 2015. Spatial and temporal changes in estuarine food web structure: differential contributions of marsh grass detritus. Estuaries Coasts 38, 367–382. https://doi.org/10.1007/s12237-014-9814-5.

Camara, E.M., Andrade-Tubino, M.F., Franco, T.P., Araújo, F.G., 2020. Multilevel decomposition of spatial and environmental effects on nearshore fish assemblages in tropical semi-enclosed ecosystems. Estuar. Coast Shelf Sci. 237, 106691. https://doi.org/10.1016/j.ecss.2020.106691.

Camara, E.M., de Andrade-Tubino, M.F., Franco, T.P., Neves, L.M., Santos, L.N., dos Santos, A.F.G.N., Araújo, F.G., 2023. Temporal dimensions of taxonomic and functional fish beta diversity: scaling environmental drivers in tropical transitional ecosystems. Hydrobiologia (The Hague) 850, 1911–1940. https://doi.org/10.1007/s10750-023-05202-w.

Camara, E.M., Andrade-Tubino, M.F., Franco, T.P., Santos, L.N., Santos, A.F.G.N., Araújo, F.G., 2021. Scale sensitivity of environmental effects on the temporal beta diversity of fishes in tropical coastal lagoons. Mar. Ecol. Prog. Ser. 658, 195–217. https://doi.org/10.3354/meps13571.

Cárcamo, C., Schultz, E.T., Leiva, F., Saavedra, A., Klarian, S.A., 2024. A deep dive into the trophic ecology of *Engraulis ringens*: assessing diet through stomach content and stable isotope analysis. Fishes 9 (12), 475. https://doi.org/10.3390/fishes9120475.

Carvalho, C., Monteiro, L., Keunecke, K., Lavrado, H., Beneditto, A., 2021. Trophic assessment and isotopic niches of the sympatric penaeids species Penaeus brasiliensis and P. paulensis in SW Atlantic estuarine systems. Mar. Biol. Res. 17, 1–11. https://doi.org/10.1080/17451000.2021.2011320.

Clarke, C., Hilliard, R., Junqueira, A.O.R., Neto, A.C.L., Polglaze, J., Raaymakers, S., 2004. Ballast Water Risk Assessment, Port of Sepetiba, Federal Republic of Brazil, Final Report. IMO, London. GloBallast Monogr No. 14.

Claudino, M.C., Abreu, P.C., Garcia, A.M., 2013. Stable isotopes reveal temporal and between-habitat changes in trophic pathways in a southwestern Atlantic estuary. Mar. Ecol. Prog. Ser. 489, 29–42. https://doi.org/10.3354/meps10400.

Cunha, C.L.N., Rosman, P.C.C., Ferreira, A.P., Monteiro, T.C.N., 2006. Hydrodynamics and water quality models applied to Sepetiba Bay. Cont. Shelf Res. 26, 1940–1953. https://doi.org/10.1016/j.csr.2006.06.010.

Elton, C., 1927. Animal Ecology. Sidwick and Jackson. Ltd, London.

Franco, T.P., Neves, L.M., Araújo, F.G., 2019. Better with more or less salt? The association of fish assemblages in coastal lagoons with different salinity ranges. Hydrobiologia (The Hague) 828, 83–100. https://doi.org/10.1007/s10750-018-3804-8.

Gabara, S.S., 2020. Trophic structure and potential carbon and nitrogen flow of a rhodolith bed at Santa Catalina Island inferred from stable isotopes. Mar. Biol. 167, 30. https://doi.org/10.1007/s00227-019-3635-9.

Galvan, K., Bargu, S., White, J., Li, C., Sullivan, M., Weeks, E., 2012. The effects of two consecutive hurricanes on basal food resources in a shallow coastal lagoon in Louisiana. J. Coast Res. 28 (2), 407–420. https://doi.org/10.2307/41509941.

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). Mar. Biol. Res. 13 (1), 98–107. https://doi.org/10.1080/17451000.2016.1206939.

Gomes-Gonçalves, R.S., Araújo, F.G., 2022. Relationships between environmental heterogeneity and fish beta diversity in a tropical bay. Mar. Biol. Res. https://doi.org/10.1080/17451000.2022.2063902.

Gomes-Gonçalves, R.S., Araújo, F.G., 2023. Interdecadal changes in ichthyofauna in a tropical bay with high anthropogenic influences: functional stability despite turnover predominance. J. Fish. Biol. 1–12. https://doi.org/10.1111/jfb.15596.

Guedes, A.P.P., Araújo, F.G., 2008. Trophic resource partitioning among five flatfish species (Actinopterygii, Pleuronectiformes) in a tropical bay in south-eastern Brazil. J. Fish. Biol. 72, 1035–1054. https://doi.org/10.1111/j.1095-8649.2007.01788.x.

Guerra, L.V., Savergnini, F., Silva, F.S., Bernardes, M.C., Crapez, M.A.C., 2011. Biochemical and microbiological tools for the evaluation of environmental quality of a coastal lagoon system in Southern Brazil. Braz. J. Biol. 71, 461–468. https://doi.org/10.1590/S1519-69842011000300016.

Hairston NG Jr., Hairston NG (1993) Cause-effect relationships in energy flow, trophic structure, and interspecific interactions. Am. Nat. 142:379–411.

Hammerschlag-Peyer, C.M., Yeager, L.A., Araújo, M.S., Layman, C.A., 2011. A hypothesis-testing framework for studies investigating ontogenetic niche shifts using stable isotope ratios. PLoS One 6 (11), e27104. https://doi.org/10.1371/journal.pone.0027104.

Hartz, S.M., Rocha, E.A., Brum, F.T., Luza, A.L., Becker, F.G., 2019. Influences of the area, shape and connectivity of coastal lakes on the taxonomic and functional diversity of fish communities in Southern Brazil. Zool. 36, 1–12. https://doi.org/10.3897/zoologia.36.e23539.

Hette-Tronquart, N., 2019. Isotopic niche is not equal to trophic niche. Ecol. Lett. 22 (11), 1987–1989. https://doi.org/10.1111/ele.13218.

Hoeinghaus, D.J., Winemiller, K.O., Agostinho, A.A., 2008. Hydrogeomorphology and river impoundment affect food-chain length of diverse Neotropical food webs. Oikos 117, 984–995. https://doi.org/10.1111/j.0030-1299.2008.16459.x.

Hutchinson, G.E., 1959. Homage to Santa Rosalia, or why are there so many kinds of animals? Am. Nat. 93, 145–159.

INEA, 2022. State Institute of the Environment. Government of the State of Rio de Janeiro, p. 40. Technical Report 6/2022/INEA/COOEAM. Process No. SEI-070002/005430/2022. https://sei.fazenda.rj.gov.br/sei/controlador.php?acao=documento_imprimir_webandacao_origem=arvore_visualizarandid_documento=36472705andi.

Islam, S., Hibino, M., Tanaka, M., 2006. Distribution and diets of larval and juvenile fishes: influence of salinity gradient and turbidity maximum in a temperate estuary in upper Ariake Bay, Japan. Estuar. Coast Shelf Sci. 68, 62–74. https://doi.org/10.1016/j.ecss.2006.01.010.

Jackson, A., Inger, R., Parnell, A., Bearhop, S., 2011. Comparing isotopic niche width among and within communities: SIBER – stable Isotope Bayesian Ellipses in R. J. Anim. Ecol. 80, 595–602. https://doi.org/10.1111/j.1365-2656.2011.01806.x.

Jennings, S., Warr, K.J., 2003. Smaller predator-prey body size ratios in longer food chains. Proc. R. Soc. A 270, 1413–1417. https://doi.org/10.1098/rspb.2003.2392.

Josefson, A.B., Rasmussen, B., 2000. Nutrient retention by benthic macrofaunal biomass of Danish estuaries: importance of nutrient load and residence time. Estuar. Coast Shelf Sci. 50, 205–216. https://doi.org/10.1006/ecss.1999.0562.

Ke, Z., Chen, D., Liu, J., Tan, Y., 2020. The effects of anthropogenic nutrient inputs on stable carbon and nitrogen isotopes in suspended particulate organic matter in Jiaozhou Bay, China. Cont. Shelf Res. 208, 104244. https://doi.org/10.1016/j.csr.2020.104244.

Kennish, M.J., Paerl, W.H., 2010. Coastal lagoons: critical habitats of environmental change. In: Kennish, M.J., Paerl, W.H. (Eds.), Coastal Lagoons Critical Habitats of Environmental Change. Mar Sci Ser. CRC Press, USA, pp. 1–16.

Kjerfve, B., 1994. Coastal lagoon processes. Elsevier Oceanogr. Ser. 60.

Kjerfve, B., Knoppers, B., Moreira, P.F., 1990. Hydrological regimes in Lagoa de Guarapina, a shallow Brazilian coastal lagoon. Acta Limnol. Bras. 3, 291–317.

Kjerfve, B., Schettini, C.A.F., Knoppers, B., Lessa, G., Ferreira, H.O., 1996. Hydrology and salt balance in a large, hypersaline coastal lagoon: Lagoa de Araruama, Brazil. Estuar. Coast Shelf Sci. 42, 701–725.

Knoppers, B., Kjerfve, B., Carmouze, J.P., 1991. Trophic state and water turnover time in six choked coastal lagoons in Brazil. Biogeochemistry 14, 149–166.

Lacerda, L.D., Freixo, J.L., Coelho, S.M., 1997. The effect of Spartina alterniflora Loisel on trace metals accumulation in inter-tidal sediments. Mangroves Salt Marshes 1, 201–209.

Lanari, M., Possamai, B., da Silva Copertino, M., et al., 2021. Seasonal and El Niño Southern Oscillation-driven variations in isotopic and elemental patterns among estuarine primary producers: implications for ecological studies. Hydrobiologia (The Hague) 848, 593–611. https://doi.org/10.1007/s10750-020-04462-0.

Laut, L.M., Belart, P., Lorini, M.L., Clemente, I., Ferreira, L., Juliace, A., Fontana, L., Martins, M.V., 2019. Organic compounds as proxies of the sedimentary environmental quality of the Maricá-Guarapina Lagoon System (Se, Brazil). J Sedim Environ 4, 159–173. https://doi.org/10.12957/jse.2019.43371.

Leal Neto, A.C., Legey, L.F.L., González-Araya, M.C., Jablonski, S., 2006. A system dynamics model for the environmental management of the Sepetiba Bay watershed, Brazil. Environ. Manag. 38, 879–888. https://doi.org/10.1007/s00267-005-0211-5.

Lepoint, G., Nyssen, F., Gobert, S., Dauby, P., Bouquegneau, J.M., 2000. Relative impact of a seagrass bed and its adjacent epilithic algal community in consumer diets. Mar. Biol. 136, 513–518. https://doi.org/10.1007/s002270050711.

Lesser, J.S., Floyd, O., Fedors, K., Deegan, L.A., Johnson, D.S., Nelson, J.A., 2021. Cross-habitat access modifies the 'trophic relay' in New England saltmarsh ecosystems. Food Webs 29.

Lotze, H.K., Lenhan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Jackson, J.B., 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312, 1806–1809. https://doi.org/10.1126/science.1128035.

Macário, B.S., Olímpio, M.S., Sales, N.S., Pessanha, A.L.M., 2021. The effect of habitat structure and the interactions between four juvenile fishes and zooplankton-prey in a tropical estuary. Estuar. Coast Shelf Sci. 261, 107528. https://doi.org/10.1016/j.ecss.2021.107528.

Mai, A.C.G., 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.

Mancinelli, G., Vizzini, S., Mazzola, A., Maci, S., Basset, A., 2013. Cross-validation of δ15N and FishBase estimates of fish trophic position in a Mediterranean lagoon: the importance of the isotopic baseline. Estuar. Coast Shelf Sci. 135, 77–85. https://doi.org/10.1016/j.ecss.2013.04.004.

Molisani, M.M., Marins, R.V., Machado, W., Paraquetti, H.H.M., Bidone, E.D., Lacerda, L.D., 2004. Environmental changes in Sepetiba bay, SE Brazil. Reg. Environ. Change 4, 17–27. https://doi.org/10.1007/s10113-003-0060-9.

Moore, A., Fauset, E., Asher, F., 2020. Consumer impacts on ecosystem functions in coastal wetlands: the data gap. Ecosphere 11 (2), e03042. https://doi.org/10.1002/ecs2.3042.

Newsom, S., del Rio, C.M., Bearhop, S., Phillips, 2007. A niche for isotopic ecology. Front. Ecol. Environ. 5, 429–436. https://doi.org/10.1890/060150.1.

Paine, R.T., 1966. Food web complexity and species diversity. Am. Nat. 100 (910), 66–75.

Pellegatti, F., Figueiredo, A.M.G., Wasserman, J.C., 2001. Neutron activation analysis applied to determination of heavy metals and other trace elements in sediments from Sepetiba Bay (RJ). Braz. J. Geostand. Geoanal. 25 (2–3), 307–315. https://doi.org/10.1111/j.1751-908X.2001.tb00607.x.

Pimm, S.L., Lawton, J.H., 1977. Number of trophic levels in ecological communities. Nature 268, 329–331.

Polis, G.A., Winemiller, K.O. (Eds.), 1996. Food Webs: Integration of Patterns and Dynamics. Chapman and Hall, New York.

Possamai, B., Chapina, R.J., Yule, D.L., Stockwell, J.D., 2025. Partial diel vertical migration and niche partitioning in *Mysis* revealed by stable isotopes. J. Great Lake. Res., 102549 https://doi.org/10.1016/j.jglr.2025.102549.

Possamai, B., Hoeinghaus, D.J., Garcia, A.M., 2021. Environmental factors drive interannual variation in estuarine food-chain length. Estuar. Coast Shelf Sci. 252, 107241. https://doi.org/10.1016/j.ecss.2021.107241.

Possamai, B., Hoeinghaus, D.J., Odebrecht, C., Abreu, P.C., Moraes, L.E., Santos, A.C.A., Garcia, A.M., 2020. Freshwater inflow variability affects the relative importance of allochthonous sources for estuarine fishes. Estuaries Coasts 43, 880–893. https://doi.org/10.1007/s12237-019-00693-0.

Post, D.M., 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. Ecology 83, 703–718. https://doi.org/10.2307/3071875.

Post, D.M., Pace, M.L., Hairston Jr., N.G., 2000. Ecosystem size determines food-chain length in lakes. Nature 405, 1047–1049.

Quezada-Romegialli, C., Jackson, A., Hayden, B., Kahilainen, K., Lopes, C., Harrod, C., 2018. tRophicPosition, an R package for the Bayesian estimation of trophic position from consumer stable isotope ratios. Methods Ecol. Evol. 9. https://doi.org/10.1111/2041-210X.13009.

Quillien, N., Nordström, M.C., Schaal, G., Bonsdorff, E., Grall, J., 2016. Opportunistic basal resource simplifies food web structure and functioning of a highly dynamic marine environment. J. Exp. Mar. Biol. Ecol. 477, 92–102. https://doi.org/10.1016/j.jembe.2016.01.010.

Ramos, J., Barletta, M., Dantas, D., Lima, A., Costa, M., 2014. Trophic niche and habitat shifts of sympatric Gerreidae. J. Fish. Biol. 85. https://doi.org/10.1111/jfb.12499.

Schoener, T.W., 1989. Food webs from the small to the large. Ecology 70, 1559–1589.

Sfriso, A., Mistri, M., Munari, C., Buosi, A., Sfriso, A., 2020. Management and exploitation of macroalgal biomass as a tool for the recovery of transitional water systems. Front Ecol Evol 8. https://doi.org/10.3389/fevo.2020.00020.

Stock, B., Semmens, B.X., 2016. Unifying error structures in commonly used biotracer mixing models. Ecology 97. https://doi.org/10.1002/ecy.1517.

Timmerman, C.A., Giraldo, C., Cresson, P., Ernande, B., Travers-Trolet, M., Rouquette, M., Denamiel, M., Lefebvre, S., 2021. Plasticity of trophic interactions in fish assemblages results in temporal stability of benthic-pelagic couplings. Mar. Environ. Res. 170, 105412. https://doi.org/10.1016/j.marenvres.2021.105412.

Tiselius, P., Belgrano, A., Andersson, L., Lindahl, O., 2017. Primary productivity in a coastal ecosystem: a trophic perspective on a long-term time series. J. Plankton Res. 38 (4), fbv094. https://doi.org/10.1093/plankt/fbv094.

Toledo, L., Wall, F., Obraczka, M., Salomão, A., 2021. Panorama do Sistema Lagunar de Maricá – RJ: indicadores de saneamento vs. qualidade de água. Rev Int Cienc 11, 6–24. https://doi.org/10.12957/ric.2021.51768.

van Rensburg, H., Richoux, N.B., Simon, C.A., 2023. The trophic position and isotopic niche of a cryptogenic tube-building polychaete in a protected clear-water estuarine bay. Estuar. Coast Shelf Sci. 295, 108549. https://doi.org/10.1016/j.ecss.2023.108549.

Vander Zanden, M.J., Rasmussen, J.B., 1999. Primary consumer δ13C and δ15N and the trophic position of aquatic consumers. Ecology 80, 1395–1404.

Vander Zanden, M.J., Rasmussen, J.B., 2001. Variation in δ15N and δ13C trophic fractionation: implications for aquatic food web studies. Limnol. Oceanogr. 46, 2061–2066. https://doi.org/10.4319/lo.2001.46.8.2061.

Vander Zanden, M.J., Shuter, B.J., Lester, N., Rasmussen, J.B., 1999. Patterns of food chain length in lakes: a stable isotope study. Am. Nat. 154, 406–416. https://doi.org/10.1086/303250.

Vizzini, S., Mazzola, A., 2003. Seasonal variations in the stable carbon and nitrogen isotope ratios (13C/12C and 15N/14N) of primary producers and consumers in a western Mediterranean coastal lagoon. Mar. Biol. 142, 1009–1018. https://doi.org/10.1007/s00227-003-1027-6.

Vollrath, S.R., Possamai, B., Schneck, F., Hoeinghaus, D.J., Albertoni, E.F., Garcia, A.M., 2021. Trophic niches and diet shifts of juvenile mullet species coexisting in marine and estuarine habitats. J. Mar. Biol. Assoc. U. K. 101, 431–441.

Yamamuro, M., 2000. Chemical tracers of sediment organic matter origins in two coastal lagoons. J. Mar. Syst. 26, 127–134. https://doi.org/10.1016/S0924-7963(00)00049-X.

Young, M., Feyrer, F., Fong, D., Johnson, R., Kraus, T., Larwood, V., Stumpner, E., Young, M., 2022. Ocean connectivity drives trophic support for consumers in an intermittently closed coastal lagoon. Estuar. Coast Shelf Sci. 264, 107665. https://doi.org/10.1016/j.ecss.2021.107665.

Zhang, P., Luo, W., Fu, M., Zhang, J., Chen, M., Xie, J., 2022. Effects of tidal variations on total nitrogen concentration, speciation, and exchange flux in the Shuidong Bay coastal water, South China Sea. Front. Mar. Sci. 10, 961560. https://doi.org/10.3389/fmars.2022.961560.

Zhao, Y., Yang, T., Shan, X., Jin, X., Teng, G., Wei, C., 2022. Stable isotope analysis of food web structure and the contribution of carbon sources in the sea adjacent to the Miaodao Archipelago (China). Fishes 7, 32. https://doi.org/10.3390/fishes7010032.