Marine Biodiversity (2026) 56:29
https://doi.org/10.1007/s12526-026-01644-2

SENCKENBERG
NATURE RESEARCH

ORIGINAL PAPER

Rocky-shore polychaetes in southeastern Brazil: diversity, zonation, and human influence

Alexia de Lima Domingues da Cruz[1,2] · Breno Monzato Gisbert[1] · Patrick Targino Braga Pessoa[1] · Cinthya Simone Gomes Santos[1,2]

Received: 8 October 2025 / Revised: 24 February 2026 / Accepted: 27 February 2026

Abstract
Brazilian rocky shores occur across a wide range from wave-exposed headlands to sheltered embayments, and zonation patterns can shift even within small or enclosed areas as wave exposure, geomorphology, and local hydrodynamics modify intertidal stress gradients. We investigated how this fine-scale variability shapes polychaete assemblages on hard substrates at two rocky shore localities in eastern Rio de Janeiro, Brazil: Itaipu (22°58′S, 43°02′W), an urban site with intense recreational use, and Sacristia (22°57′S, 42°40′W), an isolated protected site. Sampling was conducted in midlittoral and upper infralittoral zones at two stations per site, between April and June 2024, totaling 24 samples. We recorded 1,293 individuals belonging to 15 families, with Syllidae, Sabellidae, and Nereididae as the most abundant. Rarefaction curves did not reach an asymptote, suggesting that total richness is higher than recorded. PERMANOVA showed that polychaete assemblage structure varied across spatial scales: assemblages differed between sites, vertical zonation was detected at Sacristia but not at Itaipu, and stations differed within Itaipu, with higher richness and diversity at the less accessible station. SIMPER indicated that these dissimilarities were largely driven by shifts in the dominant families. Canonical Correspondence Analysis indicated associations between families and environmental gradients, particularly salinity, dissolved oxygen, temperature, and algal biomass. These findings show that even neighboring rocky shores can display sharply contrasting community organization, highlighting the value of polychaetes for monitoring environmental change in coastal ecosystems.

Keywords Biodiversity · Benthic community · Zonation · Coastal ecosystems · Anthropogenic impact

Introduction

Rocky shores are among the most studied marine ecosystems worldwide, with research dating back more than two centuries (Wahlenberg 1812; Baker 1909; Stephenson et al. 1937; Stephenson and Stephenson 1949). Much of the current knowledge on vertical zonation of coastal organisms stems from classic works by Stephenson et al. (1937) and Stephenson and Stephenson (1949), as well as Lewis (1955, 1961, 1964), and Southward (1958). A central feature of these environments is the heterogeneous distribution of organisms along the tidal gradient, typically divided into supralittoral, midlittoral, and infralittoral zones (Knox 2001). Despite variation in local conditions, zonation patterns are often consistent, with similar taxonomic groups occupying equivalent levels across biogeographic regions (Chappuis et al. 2014). However, within the same biogeographic region, rocky shores may differ markedly in wave exposure and local geomorphology, leading to small-scale variation in hydrodynamic conditions and habitat structure. Such fine-scale heterogeneity can result in differences in community composition, even among nearby or partially sheltered rocky shores (Benedetti-Cecchi and Trussell 2014).

The structural complexity of rocky shores, including crevices, tide pools, and shaded or exposed surfaces, provides diverse microhabitats that support high species richness (Underwood 2000). These ecosystems also deliver crucial

Communicated by P. C. Paiva.

✉ Alexia de Lima Domingues da Cruz
alexiadomingues@id.uff.br

[1] Laboratório de Sistemática e Ecologia de Polychaeta, Universidade Federal Fluminense, Niterói, Rio de Janeiro, Brazil

[2] Programa de Pós-Graduação Em Biologia Marinha E Ambientes Costeiros, Universidade Federal Fluminense, Niterói, Rio de Janeiro, Brazil

Published online: 19 March 2026

ecological functions and ecosystem services, acting as natural barriers against erosion and storms, enhancing nutrient cycling, and sustaining fisheries and other resources (Little and Kitching 1996; Satyam and Thiruchitrambalam 2018). Moreover, rocky shores act as natural laboratories for studying environmental change. Long-term time series in these habitats are essential for detecting trends associated with climate change and for guiding adaptation strategies (Hawkins et al. 2008), as demonstrated by monitoring studies in southeastern Brazil (Puga et al. 2019; Simões et al. 2024).

Annelid polychaetes are among the dominant components of rocky-shore assemblages and represent one of the most diverse groups of benthic invertebrates. With approximately 12,000 described species and about 80 families (Rouse et al. 2022; Jumars et al. 2015; Read and Fauchald 2026), they exhibit remarkable morphological, functional, and ecological diversity. This diversity is reflected in the contrast between Errantia and Sedentaria, two major clades that differ markedly in mobility, feeding strategies, and habitat use (Rouse et al. 2022). Polychaete life strategies include free-living, tube-dwelling, and burrowing forms, and feeding modes encompass predation, suspension feeding, herbivory, and detritivory. Ecologically, polychaetes play fundamental roles in benthic systems, including bioturbation, nutrient recycling, and sediment stabilization in soft-bottom habitats, as well as tube construction and aggregation on hard-bottom substrates, which increase habitat complexity and provide secondary habitats for other taxa (Amaral 1979; Zühlke 2001; Díaz-Castañeda and Reish 2009; Rouse et al. 2022). In addition, they are important prey for fish and invertebrates of economic relevance, reinforcing their role in trophic networks (Serrano et al. 2003; Liedke et al. 2016). Owing to their abundance and diversity, polychaetes are widely recognized as key components of benthic communities, contributing significantly to their structure and functioning (Fauchald and Jumars 1979; Hutchings 1998; Jumars et al. 2015; Rouse et al. 2022). They also play an important role as bioindicators of environmental quality. Shifts in the composition of their assemblages, such as the loss of sensitive taxa and the increase of opportunistic species under degraded conditions, have long been used to assess human impacts in coastal environments (Giangrande et al. 2005; Dean 2008; Maximov and Berezina 2023).

In Brazil, rocky shores extend along much of the coastline, but these habitats are among the most impacted by human activities, particularly in metropolitan areas (Cordeiro et al. 2024). Pressures such as urban development, sewage and nutrient input, coastal engineering, tourism, and artisanal fisheries exert strong influences on rocky-shore communities. Consequently, conservation and monitoring of these ecosystems are considered essential (Coutinho et al. 2016; Cordeiro et al. 2024). Despite their importance, knowledge of the fauna associated with Brazilian rocky shores remains fragmented. Most studies addressing polychaete assemblages in Brazil have focused on soft-bottom habitats such as sandy beaches, estuaries, or muddy bottoms, whereas assemblages on hard-bottom substrates, such as rocky shores, remain comparatively less explored (Amaral and Jablonski 2005; Amaral et al. 2022).

Historical works reported polychaetes along the Rio de Janeiro coast (Rullier and Amoureux 1979; Nonato 1981; Bolívar 1990; Almeida and Ruta 2000; Amaral and Rossi-Wongtschowski 2004), yet detailed assessments of polychaete assemblages in rocky shores remain rare. This gap is critical considering that global estimates suggest more than 10,000 annelid species remain undescribed, nearly half of them polychaetes (Pamungkas et al. 2019; Capa and Hutchings 2021). Such figures highlight the magnitude of our knowledge deficit and the need for regional studies that document local assemblages and assess ecological patterns.

Rocky shores along the coast of Rio de Janeiro occur across a broad gradient of wave exposure and shelter, shaped by local geomorphology and hydrodynamic conditions. Within this context, urban beaches such as Itaipu experience high levels of recreational activity, receive inflows from nearby lagoons, and are subject to coastal development. In contrast, areas such as Sacristia are less accessible and legally protected, representing comparatively sheltered environments with less human impact. Despite their geographic proximity, these contrasting physical and anthropogenic settings can result in differences in zonation patterns and community structure, even at small spatial scales.

This study represents the first assessment of polychaete assemblages on rocky shores of eastern Rio de Janeiro. We aimed to describe and compare the diversity and structure of these assemblages across sampling sites and tidal zones, and to evaluate associations with environmental variables.

Methodology

Study area

This study was conducted at two coastal localities in Rio de Janeiro State, southeastern Brazil: Itaipu Beach, in the municipality of Niterói, and Sacristia Beach, in the municipality of Maricá (Fig. 1).

Itaipu Beach (22°58′S, 43°02′W) forms a semi-circular embayment partly sheltered by the Pai, Mãe, and Menina islands (Fig. 1C; Fig. 2A). Its coastal waters result from the mixing of oceanic inputs, Guanabara Bay, and the Itaipu–Piratininga lagoon system, with a permanent connection to Itaipu Lagoon through an artificial channel (Tubino 2007; Eccard et al. 2017). The beach has a reflective profile with depths of 3–28 m and sediments dominated by medium sand, with finer deposits near the lagoon channel (Salvador

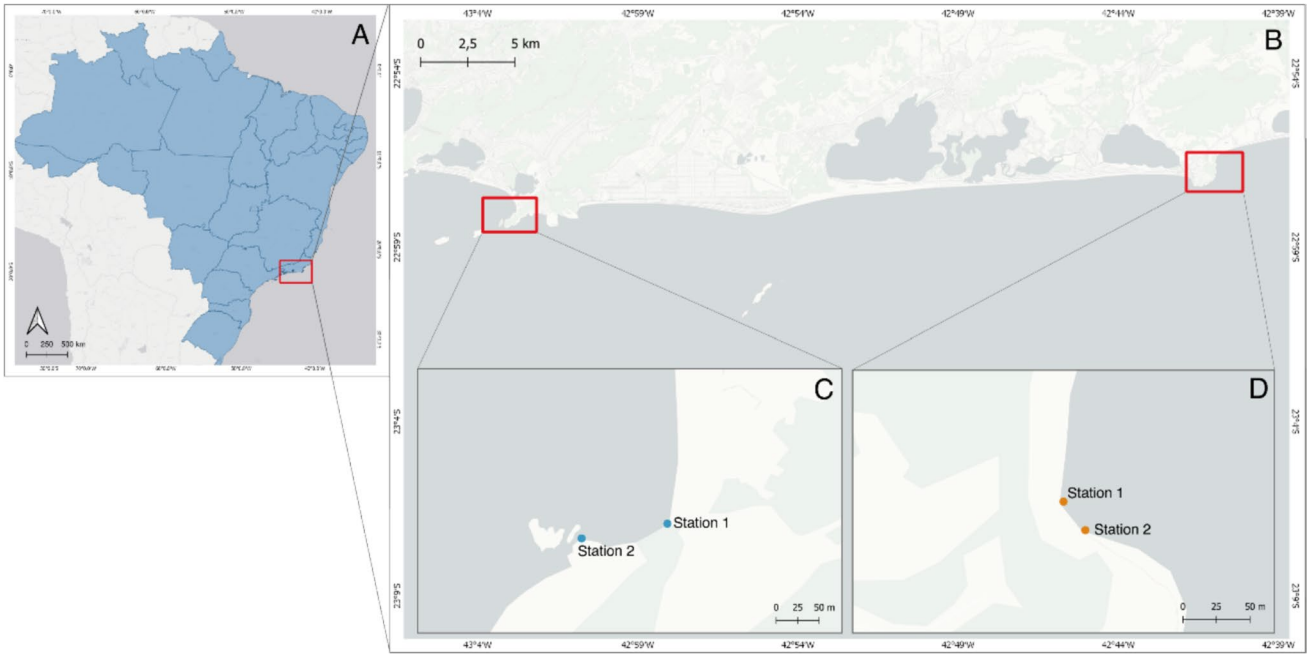

Fig. 1 Location of the study sites on the coast of Rio de Janeiro State, southeastern Brazil. (**A**) Map of Brazil with the state of Rio de Janeiro highlighted. (**B**) Eastern coast of Rio de Janeiro State showing Niterói and Maricá municipalities, with Itaipu (left) and Sacristia (right) sites indicated. (**C**) Sampling stations (1 and 2) at Itaipu. (**D**) Sampling stations (1 and 2) at Sacristia

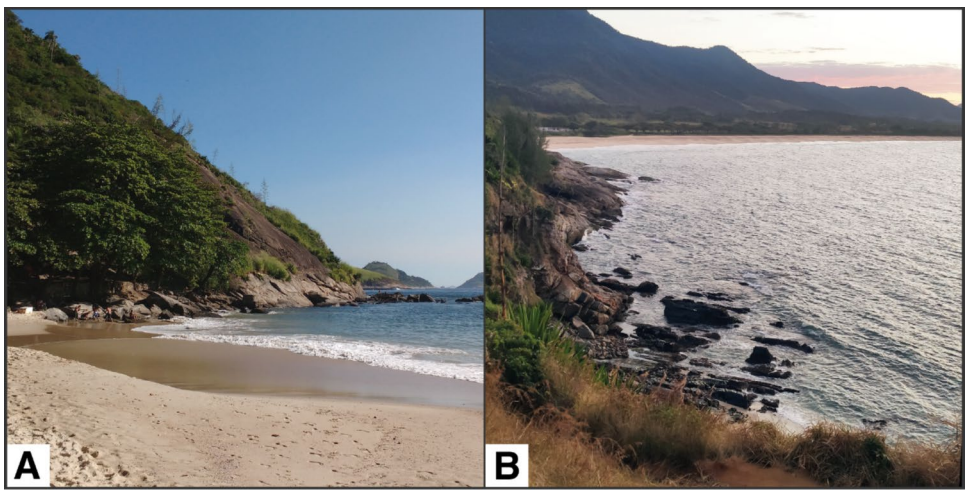

Fig. 2 Study sites on the coast of Rio de Janeiro State, southeastern Brazil. (**A**) Itaipu, municipality of Niterói. (**B**) Sacristia, municipality of Maricá

and Silva 2002; Monteiro-Neto et al. 2008). The tide is mixed semidiurnal (< 1.5 m), and wave action is the dominant driver of coastal dynamics: waves from the south and southeast are refracted by the islands, whereas storm waves from the southwest can reach 3 m and cause marked erosion (Santos et al. 2004). Since the 1970 s, the surrounding area has undergone intense urbanization and tourism development (Silva et al. 2009, 2021). Today, Itaipu is among the most visited beaches in Niterói, supporting bathing, tourism, and artisanal fisheries. A traditional fishing community has occupied the site since at least 1921, when the Colônia de Pesca Z-7 was formally recognized; artisanal fishing was later declared Intangible Cultural Heritage of Niterói (Costa 2011). The coastal area and adjacent waters are part of the Itaipu Marine Extractive Reserve (RESEX), created in 2013 to protect fisheries and biodiversity, contiguous with Serra da Tiririca State Park (Prefeitura de Niterói 2013).

Sacristia Beach (22°57′S, 42°40′W) is a narrow embayment, ~ 45 m wide shoreline bordered by the rocky outcrops of Ponta Negra (Fig. 1D; Fig. 2B). It is composed mainly of sandy sediments interspersed with rocky substrate (Lins-de-Barros et al. 2018). Regional hydrodynamics are shaped

by northeast trade winds and storm waves from the south and southeast, which can drive severe coastal erosion (Silva et al. 2012). Geologically, the site belongs to the Cabo Frio Tectonic Domain, comprising Proterozoic orthogneiss and amphibolite outcrops that record the amalgamation of Gondwana (Mansur 2010; Schmitt 2016). Sacristia remains largely isolated, with no urban infrastructure or concessions, limited accessibility, and only occasional visitors. It is recognised as a geosite of scientific and educational value within the "Geoparque Costões e Lagunas do Rio de Janeiro" and has been legally protected as part of the Maricá Wildlife Refuge since 2011 (Geoparque Costões e Lagunas 2025). This conservation status, together with its geological and scenic features, underscores Sacristia as a low-impact site in sharp contrast with the urbanized and heavily used shorelines of Niterói.

Data collection

Field sampling was conducted between April and June 2024. At each site, two stations were established, each including the midlittoral and upper infralittoral zones. The midlittoral was defined as the zone regularly exposed and submerged by tides, whereas the upper infralittoral corresponded to the permanently submerged zone immediately below the lowest tide level (Little and Kitching 1996).

At each station, a 5 m horizontal transect was laid on the rocky substrate. Along each transect, six 10 × 10 cm quadrats were randomly positioned, with three placed in the midlittoral and three in the upper infralittoral; their positions were randomized to ensure sampling randomness, totaling six quadrats per station. The substrate within each quadrat was scraped, yielding a total of 24 quantitative samples. All material was fixed and preserved in 95% ethanol. In the laboratory, polychaetes were sorted under a stereomicroscope and identified using specialized literature and taxonomic keys, with consultation of specialists when necessary.

Environmental variables (temperature, salinity, pH, and dissolved oxygen) were measured in situ with a multiparameter probe (Akso AK88). Algal biomass was determined as dry weight after oven-drying samples at 60 °C until constant weight was reached (approximately 24 h).

Data analysis

Some specimens were identified only to family or genus level when juvenile or incomplete and lacking diagnostic characters, following a conservative identification approach. The structure of polychaete assemblages was analyzed by univariate and multivariate analyses performed in R v4.4.3 using the *vegan* package (Oksanen et al. 2022). Prior to multivariate procedures, abundance data were log(x + 1) transformed and Bray–Curtis dissimilarities were calculated.

Sampling sufficiency was evaluated using sample-based species-accumulation curves based on random permutations (1,000 runs), computed separately for localities and zones. To further interpret the non-asymptotic behavior of accumulation curves, beta diversity was partitioned into turnover and nestedness components at the same spatial scales considered in the rarefaction analyses (between sites; between zones within each site; and between stations within each site). Beta diversity was computed from presence–absence data using Sørensen dissimilarity (βSOR) and decomposed into turnover (βSIM) and nestedness-resultant components (βSNE).

Diversity metrics included total abundance (N), species richness (S), Shannon–Wiener diversity (H′, based on the natural logarithm, base *e*), Simpson diversity (1 – D), and Pielou's evenness (J′ = H′/ln S). These metrics were calculated at the sample level and used for descriptive characterization across sites, stations, and tidal levels.

Non-metric multidimensional scaling (NMDS) was used to visualize similarity patterns among sites (Itaipu and Sacristia), stations (within each site) and shore zones (mesolittoral and upper infralittoral). Homogeneity of multivariate dispersions was tested with PERMDISP. To complement the NMDS ordinations, similarity among groups was also assessed using agglomerative hierarchical cluster analysis (UPGMA; average linkage) based on Bray–Curtis dissimilarities of log(x + 1)-transformed abundance data. Group centroids were calculated by averaging abundances across replicate quadrats within each Site × Station × Zone combination.

Differences in the structure of polychaete assemblages were evaluated using PERMANOVA (9,999 permutations), each addressing a specific ecological question: (i) differences between sites (Itaipu vs Sacristia); (ii) differences between shore zones within each site (mesolittoral vs infralittoral, tested separately for Itaipu and Sacristia); and (iii) differences between sampling stations within each site (Station 1 vs Station 2 in Itaipu; Station 1 vs Station2 in Sacristia). Functional composition was explored using a clade-level functional perspective by classifying all taxa into three categories: Errantia, Sedentaria, or *incertae sedis*. For each Site × Station × Zone combination, abundances were pooled across replicate quadrats and converted to relative abundance (%) for each category. SIMPER was performed to identify the taxa contributing most to between-group dissimilarities in significant contrasts, as well as to summarize contributions within each group.

Associations between community composition and environmental variables were analyzed using canonical correspondence analysis (CCA), including temperature, salinity, pH, dissolved oxygen, and algal biomass. Significance of the overall model and of individual variables was assessed by permutation tests (9,999 permutations).

Sampling sufficiency was evaluated using sample-based species-accumulation curves based on random permutations (1,000 runs), computed separately for sites and zones. All analyses adopted a significance level of $\alpha = 0.05$. Figures were produced with *ggplot2* v3.5.1 (Wickham 2016) and finalized in Adobe Illustrator ©.

Results

Sampling effort and compositional heterogeneity

Species-accumulation curves (Fig. 3) increased steeply at low sampling effort and did not reach an asymptote within the sampling window (12 *quadrats*). At the site scale, Itaipu accumulated more species than Sacristia, with 41 and 31 species, respectively, at maximum effort. Within sites, the upper infralittoral curve exceeded the midlittoral in Itaipu, whereas an opposite pattern was observed in Sacristia, where the midlittoral surpassed the upper infralittoral across the shared effort (up to 6 *quadrats*).

To better understand whether the non-asymptotic rarefaction curves were associated with spatial compositional heterogeneity, beta diversity was partitioned into turnover and nestedness components at the same spatial scales considered in the rarefaction analyses (Table S1). Beta diversity was high between sites (βSOR = 0.7169) and remained high within sites (βSOR = 0.6266), with turnover accounting for most dissimilarity (prop_turnover = 0.78 and 0.70, respectively). At finer spatial scales, beta diversity also remained high. In Itaipu, dissimilarity between stations (βSOR = 0.6723) slightly exceeded within-station heterogeneity (βSOR = 0.5939), and turnover accounted for a larger fraction of dissimilarity than nestedness (prop_turnover = 0.54; prop_nestedness = 0.46). Between-zone dissimilarity in Itaipu was also high (βSOR = 0.6514) and driven mostly by turnover (prop_turnover = 0.70; prop_nestedness = 0.30), while within-zone heterogeneity showed a similar pattern (prop_turnover = 0.56; prop_nestedness = 0.44). In Sacristia, station- and zone-level contrasts were similarly high (stations: βSOR between = 0.6175; within = 0.6154; zones: βSOR between = 0.6402; within = 0.5882), with turnover accounting for most of the dissimilarity (prop_turnover ≈ 0.72–0.79).

Diversity metrics

A total of 1,293 polychaete specimens were identified, including 15 families (Table S2). The highest abundance was recorded for Syllidae (n = 560), followed by Sabellidae (n = 233) and Nereididae (n = 147). Considering relative abundances, Syllidae reached its maximum at Sacristia (Station 2, midlittoral), where it accounted for 87.3% of individuals. At Itaipu (Station 2), Nereididae was more abundant in the midlittoral (48.33%), whereas Sabellidae predominated in the upper infralittoral (42.75%) (Table S3). The lowest abundances were observed for Sabellariidae (n = 2), Lumbrineridae (n = 1), and Dorvilleidae (n = 1).

Abundance and richness were higher at Station 2 (Fig. 4A–B) in both sites. In Itaipu, abundance increased from the midlittoral to the upper infralittoral at both stations, whereas at Sacristia it was higher in the midlittoral. Richness

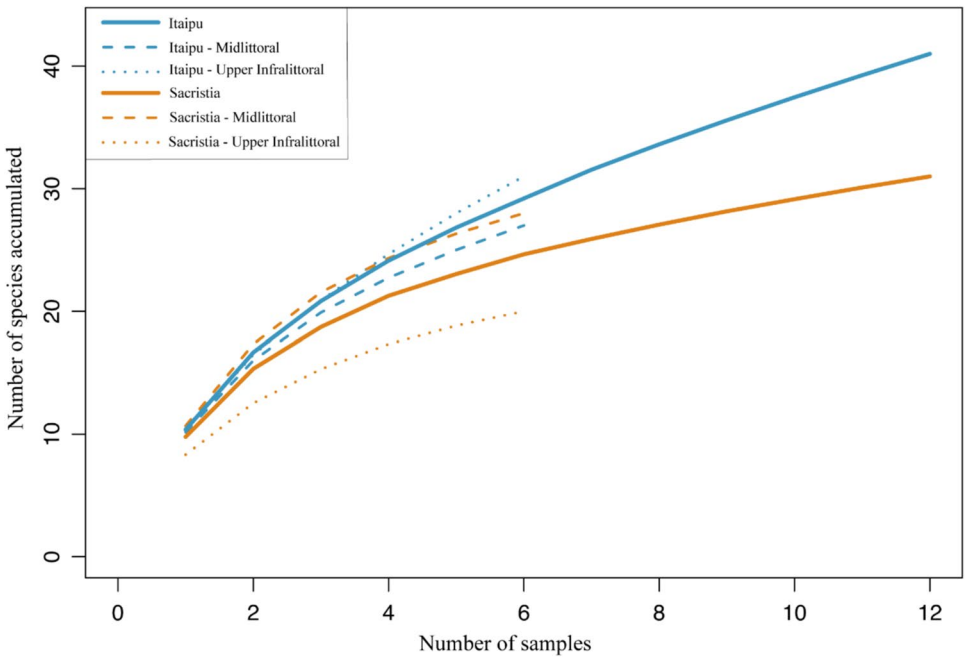

Fig. 3 Species–accumulation curves (sample-based rarefaction; 1,000 random permutations) by site and zone. Lines show the mean expected cumulative richness as quadrats are added

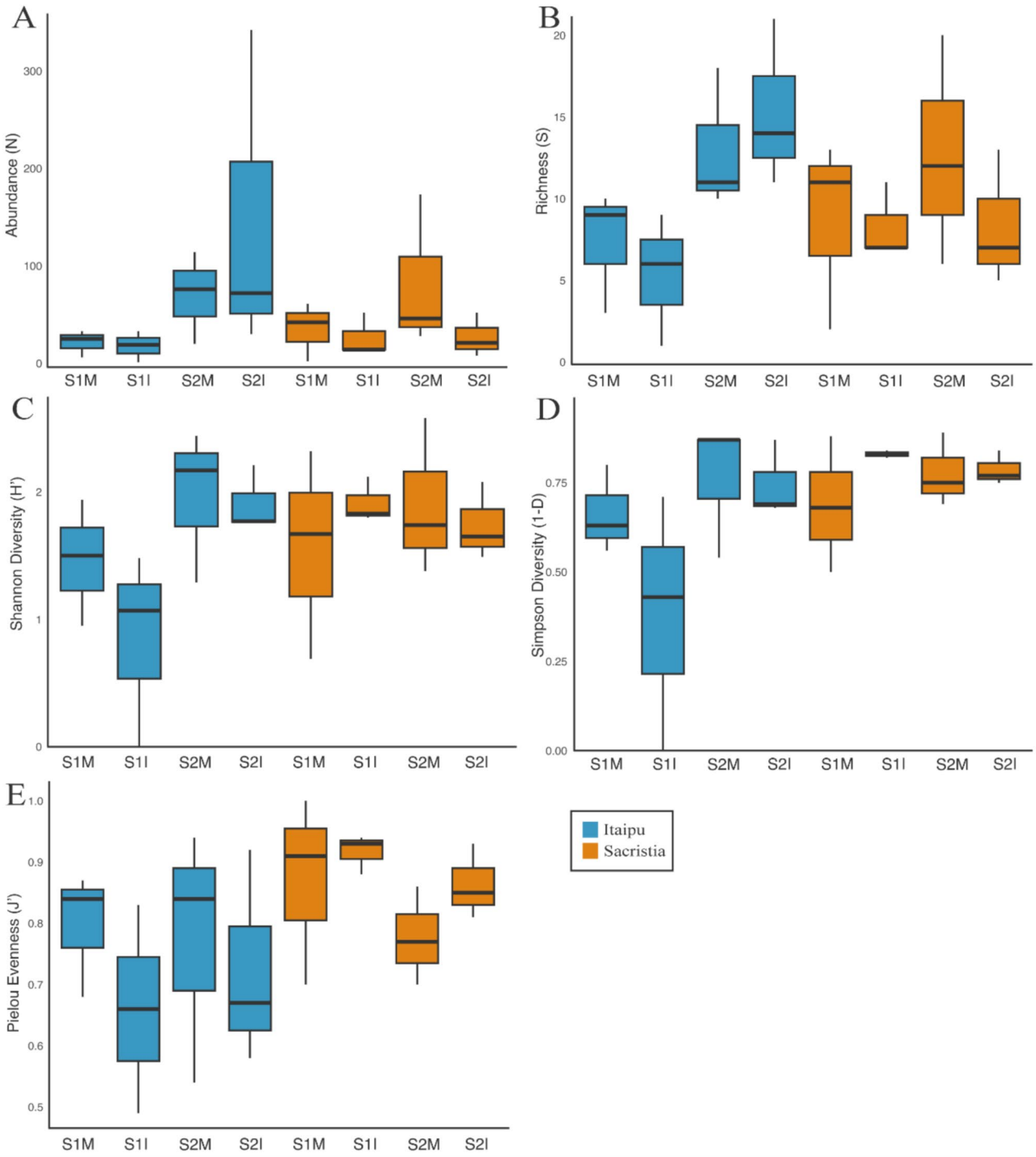

Fig. 4 Boxplots of abundance (N), species richness (S), and diversity indices—Shannon (H′), Simpson (1–D), and Pielou evenness (J′)—across stations and shore zones at the study sites of Itaipu (blue) and Sacristia (orange). Each boxplot summarizes three replicate samples per shore zone (midlittoral or upper infralittoral) within each station. Abbreviations: S1M = Station 1 Midlittoral; S1I = Station 1 Upper Infralittoral; S2M = Station 2 Midlittoral; S2I = Station 2 Upper Infralittoral

mirrored these site-specific contrasts, except at Itaipu Station 2, where the midlittoral showed smaller richness values than the upper infralittoral.

Shannon (H′) and Simpson (1–D) displayed similar patterns at Itaipu (Fig. 4C–D), with higher values in the midlittoral at both stations. At Sacristia, Shannon (H′) values were

equal to or lower in the upper infralittoral than in the midlittoral at both stations, whereas Simpson (1–D) values in the upper infralittoral were equal to or slightly higher than those in the midlittoral.

Considering sites and stations, Pielou evenness (J′) generally followed the same trend: higher in the midlittoral than in the upper infralittoral (Fig. 4E). The exception was Sacristia Station 2, where J′ was higher in the upper infralittoral than in the midlittoral, suggesting a more homogeneous distribution of abundances among species.

Across diversity metrics, patterns at Itaipu were influenced by high among-replicate variability in the upper infralittoral, particularly at Station 2. Given the limited replication per zone, this variability may have generated overlap between midlittoral and infralittoral values, reducing the power to detect zone-level differences. These factors help explain the lack of statistically significant contrasts between zones despite the station-level trends.

Patterns of community structure

A non-metric multidimensional scaling (NMDS) (Bray–Curtis dissimilarity on log[x + 1]–transformed abundances; stress = 0.163) suggested some differentiation between sites, with Sacristia and Itaipu occupying different regions of the ordination space (Fig. 5). Within Sacristia, the midlittoral and upper infralittoral tended to form separate clusters in the plot, whereas the two zones overlapped at Itaipu. At Itaipu, Station 1 and Station 2 were displaced from each other in the ordination, while at Sacristia the stations overlapped.

A hierarchical clustering analysis (UPGMA, Bray–Curtis on log[x + 1]–transformed abundances) showed a pattern broadly consistent with the NMDS ordination (Fig. 6). Samples from the same site tended to group together, with Sacristia forming more cohesive clusters than Itaipu. The dendrogram also supported the zonation pattern observed at Sacristia, where midlittoral and upper infralittoral samples

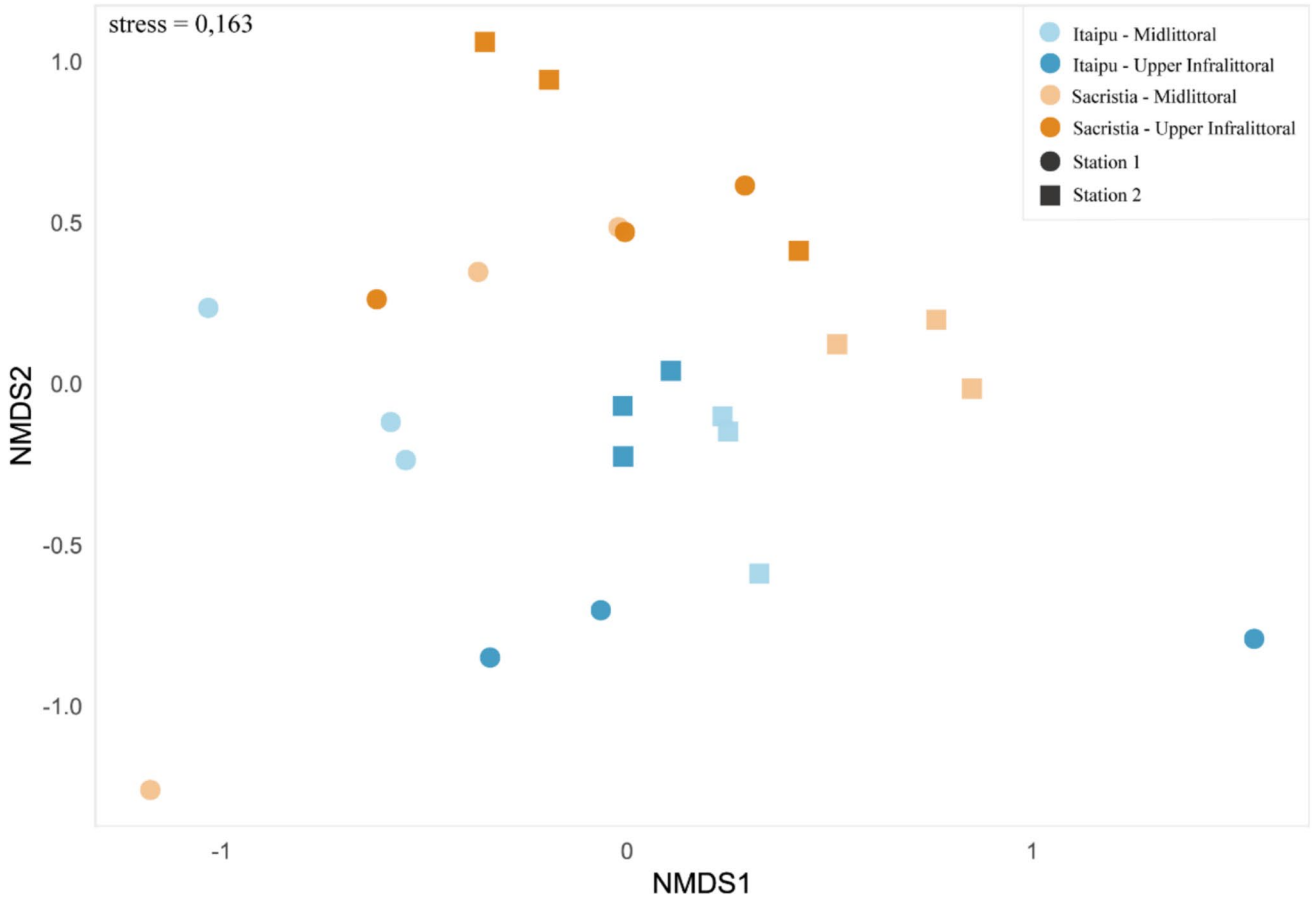

Fig. 5 Non-metric multidimensional scaling (NMDS) ordination of polychaete assemblages based on Bray–Curtis dissimilarities of log[x + 1] abundances (2D stress = 0.163)

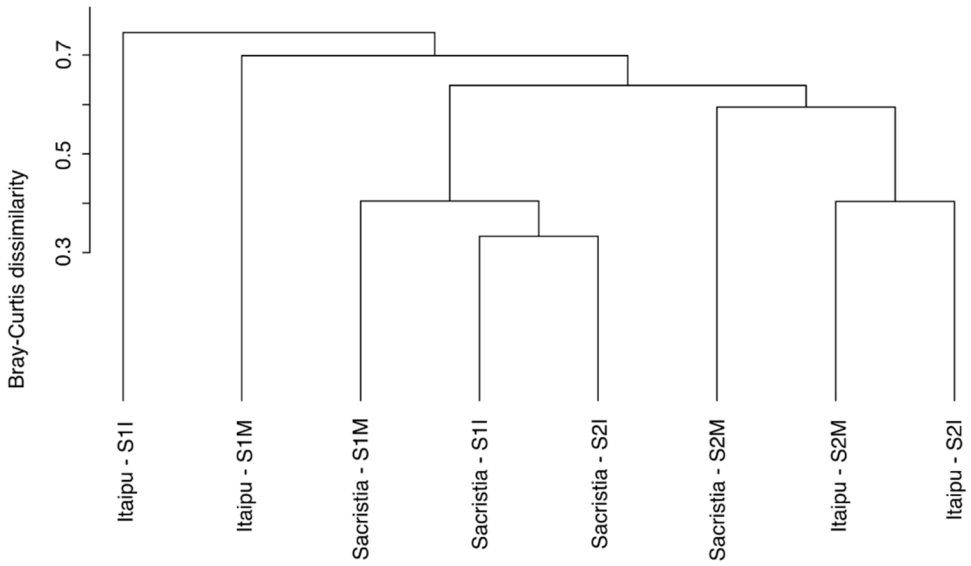

Fig. 6 Hierarchical cluster analysis (UPGMA; average linkage) of polychaete assemblages based on Bray–Curtis dissimilarities of log[x + 1] abundances, summarizing Site × Station × Shore zone group centroids. Abbreviations: S1M = Station 1 Midlittoral; S1I = Station 1 Infralittoral; S2M = Station 2 Midlittoral; S2I = Station 2 Infralittoral

tended to form distinct branches, whereas samples from the two zones at Itaipu were more interspersed. At the station level, Itaipu showed a separation between Station 1 and Station 2, while Sacristia again exhibited greater similarity between stations. Overall, the clustering analysis aligns with the NMDS results by reinforcing the contrast between the more structured assemblages at Sacristia and the higher within-site variability observed at Itaipu.

The PERMANOVA (Bray–Curtis on log[x + 1]–transformed abundances per family; 9,999 permutations) (Table 1) corroborated the ordination: communities differed between sites (pseudo-F = 3.252, $p < 0.001$). Within sites, zonation was non-significant at Itaipu (pseudo-F = 1.568, $p = 0.091$) but significant at Sacristia (pseudo-F = 2.243, $p = 0.0289$). Station differed within Itaipu (pseudo-F = 2.814, $p = 0.0022$) but not within Sacristia (pseudo-F = 1.168, $p = 0.312$). SIMPER (Bray–Curtis on log[x + 1]–transformed abundances per family) indicated high between-group dissimilarities: 79.26% (sites), 76.59% (stations in Itaipu), 75.36% (zones in Sacristia), 72.94% (zones in Itaipu), and 72.70% (stations in Sacristia), with the main contributing taxa detailed in Tables S3, S4 and S5. PERMDISP showed no dispersion differences for sites or zones (all $p > 0.19$).

When polychaete taxa were grouped into functional groups (Errantia vs Sedentaria), contrasting patterns were observed among sites, stations, and tidal levels (Fig. 7). At Itaipu, Sedentaria dominated the assemblages at Station 1 in both the midlittoral and infralittoral, as well as in the infralittoral at Station 2, whereas Errantia were relatively more abundant in the midlittoral at Station 2. In contrast, at Sacristia, Errantia dominated the assemblages at all stations, accounting for at least half of the total abundance in each case. Taxa classified as *incertae sedis* were restricted to a single station per site, where they constituted a small proportion of the community.

Table 1 PERMANOVA results for polychaete assemblage structure at different spatial scales, based on Bray–Curtis dissimilarities of log[x + 1] transformed abundances per family. The table shows Pseudo-F, unique permutations, p(perm), and average dissimilarities from SIMPER. Significant results ($p < 0.05$) are in bold

Factors	Pseudo-F	Unique perms	p(perm)	SIMPER (Bray %)
Itaipu x Sacristia	3.252	9999	**< 0.001**	79.26
Zone — Itaipu	1.568	9999	0.0910	72.94
Zone — Sacristia	2.243	9999	**0.0289**	75.36
Stations — Itaipu	2.814	9999	**0.0022**	76.59
Stations — Sacristia	1.168	9999	0.3118	72.70

Environmental variables

The first two axes in the CCA explained 78.8% of the community-environment relationship (CCA1 = 46.1%; CCA2 = 32.7%) (Fig. 8). The first axis (CCA1) was defined by the nearly collinear vectors of salinity and algal biomass. Eunicidae (Errantia) and Cirratulidae (Sedentaria) were associated with higher values of these variables, suggesting that increased algal biomass and salinity are associated with shifts in both mobile and sedentary lineages. The second axis (CCA2) reflected the opposition between dissolved oxygen and temperature, with vectors oriented in opposite directions. Along this gradient, Lumbrineridae (Errantia) and the Sedentaria families Orbiniidae and Serpulidae were associated with higher dissolved oxygen, whereas Capitellidae and Terebellidae (Sedentaria), together with Dorvilleidae (Errantia), were related to higher temperature values.

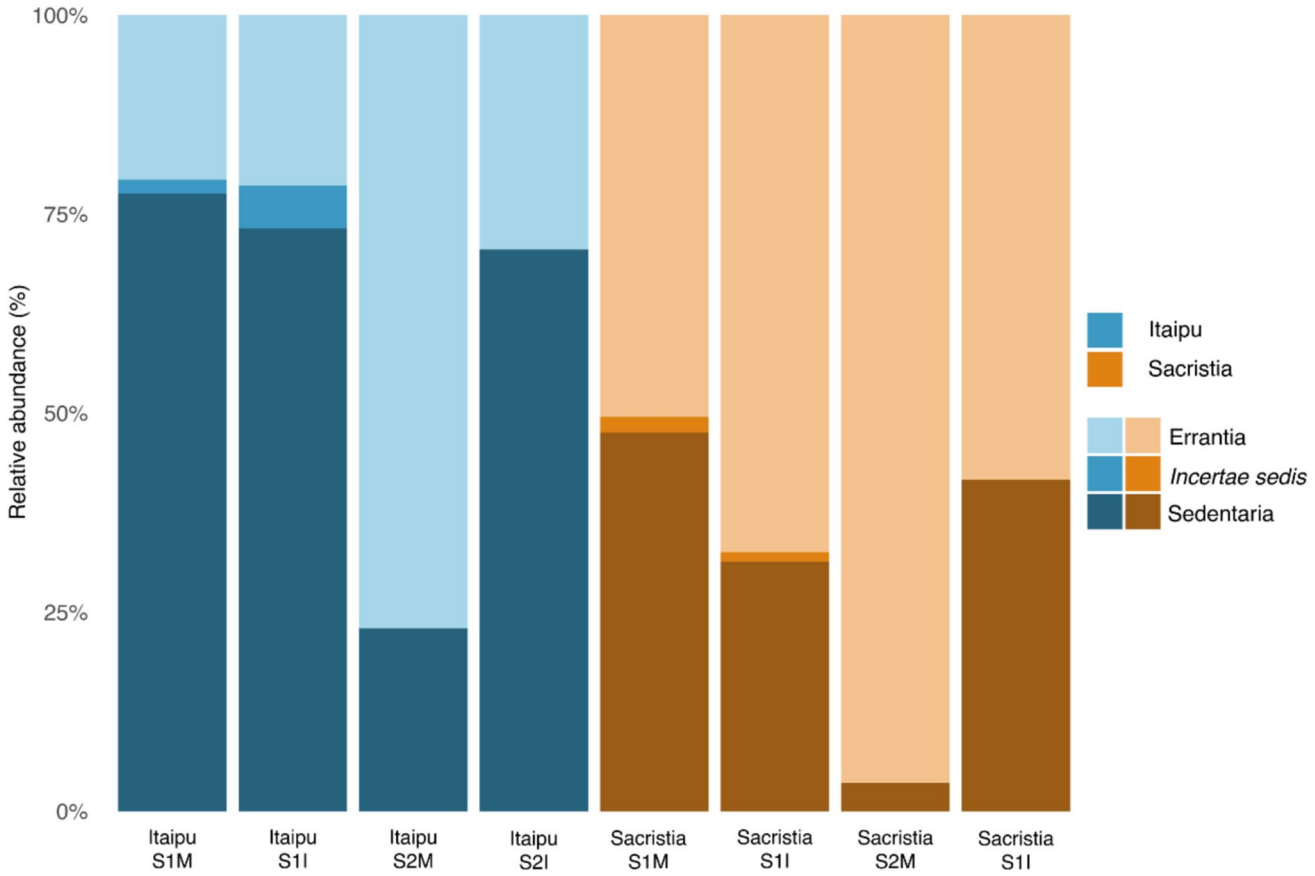

Fig. 7 Relative abundance (%) of functional clades across Site × Station × Shore zone combinations. Abbreviations: S1M = Station 1 Midlittoral; S1I = Station 1 Infralittoral; S2M = Station 2 Midlittoral; S2I = Station 2 Infralittoral

The pH vector was very short, indicating a low contribution of this variable to the ordination. Environmental variables measured at each site and station are presented in Table S7.

Discussion

This study investigated whether rocky-shore polychaete assemblages differ between two sites with contrasting geomorphological and hydrodynamic characteristics and human use, and whether assemblage structure varies across tidal levels and among nearby stations. Assemblages differed between Itaipu and Sacristia, vertical zonation (midlittoral vs upper infralittoral) was detected at Sacristia but not at Itaipu, and station-level differences were detected at Itaipu but not at Sacristia. In addition, the assemblages were dominated by Syllidae, Sabellidae, and Nereididae, and the CCA indicated consistent associations between families and environmental gradients, particularly salinity, algal biomass, dissolved oxygen, and temperature.

Although several studies have described polychaete assemblages along the coast of Rio de Janeiro, most have focused on soft-bottom substrates, such as those by Attolini (1997), Almeida and Ruta (2000), Santi and Tavares (2009), and Oliveira (2013). In contrast, investigations on hard-bottom substrates remain scarce. Coutinho et al. (2016), in a synthesis of 327 studies on rocky shores in Brazil, emphasized that most research efforts have been concentrated in Rio de Janeiro and São Paulo, with additional emphasis in Bahia due to Abrolhos. However, this synthesis provides a broad overview of benthic assemblages and research themes, without addressing Polychaeta specifically; and, when mentioned, usually at higher taxonomic levels. One of the few exceptions in the state is Álvarez (2019), who carried out a faunal survey of polychaetes on rocky shores in Sepetiba Bay, focusing on species inventories, new records, and distribution. Unlike that taxonomic approach, the present study focuses on community-level diversity and structure within polyhaete assemblages across multiple spatial scales (sites, stations, and tidal levels), providing a baseline for rocky shores in eastern Rio de Janeiro State.

Polychaete assemblages differed between Itaipu and Sacristia, as evidenced by the NMDS and PERMANOVA results. This pattern is consistent with studies showing that

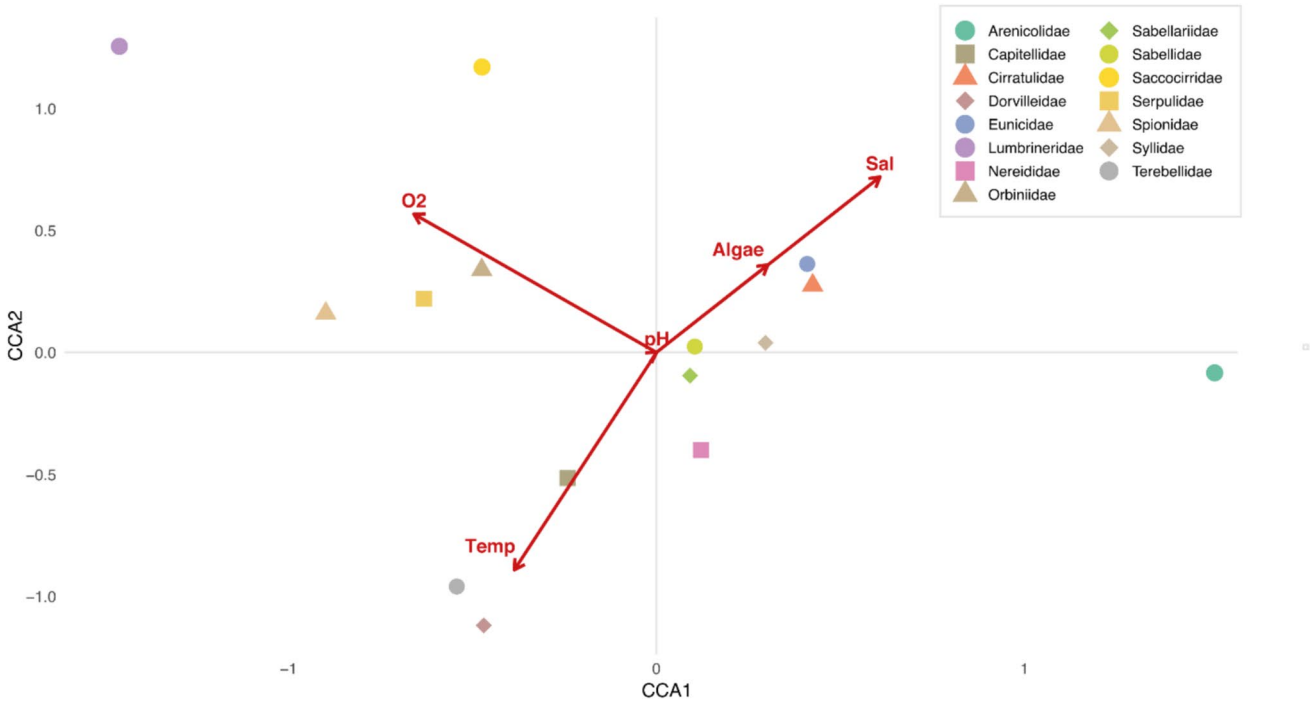

Fig. 8 Canonical correspondence analysis (CCA) of polychaete families in relation to environmental variables. The first two axes explained 78.8% of the total variation (CCA1 = 46.1%; CCA2 = 32.7%). Vectors represent environmental variables: Temp = temperature, O_2 = dissolved oxygen, Sal = salinity, pH = hydrogen potential, Algae = algal biomass

anthropogenic pressures such as urbanization, tourism, and coastal pollution promote shifts in the structure of rocky-shore communities (Coutinho et al. 2016). Deepananda and Macusi (2012) demonstrated that areas subject to greater recreational use exhibited lower diversity, with unstable communities dominated by opportunistic species, whereas communities within protected areas maintained more balanced compositions. At Itaipu, although there are no signs of severe degradation, intense recreational use during summer and inputs from the adjacent lagoon may contribute to greater variation in polychaete assemblages composition. In contrast, Sacristia is an isolated and scarcely accessible beach, with no infrastructure or significant recreational use, functioning as a reference site of a natural environment with lower human impact.

Differences between rocky-shore zones also varied between the two sites. At Sacristia, the midlittoral and upper infralittoral showed distinct compositions, whereas at Itaipu there was no clear separation between zones. Vertical zonation has long been recognized as a remarkable pattern in rocky shores, associated with tidal variation gradients and characterized by a progressive increase in diversity from the supralittoral to the infralittoral (Lewis 1964; Stephenson and Stephenson 1972; Chappuis et al. 2014). The absence of a clear zonation pattern at Itaipu suggests a less pronounced differentiation between zones in polychaete assemblages, which may be influenced by local human use, although this relationship was not directly tested here. In addition, site-specific physical conditions (e.g., shoreline configuration and exposure) may modulate the strength of zonation by altering microhabitat availability and the sharpness of stress gradients across tidal levels. Similar effects have been reported on rocky shores in southeastern Brazil, where trampling and tourism activities altered intertidal community structure (Ferreira and Rosso 2009), and more broadly in other impacted coastal contexts, where species replacement led to increased similarity among communities (Claudet and Fraschetti 2010; Méndez et al. 2017).

At Sacristia, no significant differences were observed between sampling stations, indicating greater similarity between them. In contrast, the sampling stations at Itaipu differed significantly. This contrast may be related to different levels of human use and disturbance: Station 1 is located in an easily accessible area, subject to intense bathing activity, whereas Station 2 corresponds to a less accessible site with fewer visitors. This difference was reflected in higher values of abundance, richness, and diversity at Station 2 compared to Station 1. These results suggest that, even at the scale of a few meters, the intensity of human use can influence the structure of polychaete assemblages, corroborating observations from other rocky shores where tourism and trampling altered organism cover and local diversity (Silva and Ghilardi-Lopes 2012; Veiga et al. 2023).

The families Syllidae, Sabellidae, and Nereididae were the most abundant in the present study. This pattern is consistent with previous observations on rocky shores, where these families have also been reported as dominant, both in tropical regions (Nogueira et al. 2006; Álvarez 2019) and in temperate regions (Giangrande et al. 2004; Serrano et al. 2006). The high abundance of these families may be associated with ecological strategies that favor success in dynamic coastal environments, such as high dispersal and colonization capacity and trophic plasticity, as well as traits that can reduce physical stress (e.g. tube building in some groups). Their dominance therefore reflects both intrinsic characteristics of the taxa and their adaptability to variable environmental conditions typical of rocky shores. These families also contributed substantially to the dissimilarities observed among groups, as indicated by the SIMPER results.

CCA revealed consistent associations between polychaete families and environmental variables: Eunicidae and Cirratulidae were related to salinity and algal biomass, Orbiniidae, Serpulidae, and Lumbrineridae occurred in sampling stations with higher dissolved oxygen, while Capitellidae and Dorvilleidae were associated with higher temperatures. These gradients may reflect, at least in part, differences in local geomorphological and hydrodynamic conditions between sites. For example, Itaipu's embayed setting and lagoon–ocean mixing may increase variability in nearshore conditions, whereas the more exposed setting at Sacristia may favor stronger water exchange and oxygenation. From a functional overview based on major groups, Errantia and Sedentaria track the same environmental gradients but with distinct family-level alignments. In addition, the short pH vector suggests a comparatively low contribution of this variable to the ordination.

These patterns reinforce that different families respond predictably to environmental gradients, supporting their potential value as bioindicators (Dean 2008). In soft-bottom substrates, several taxa within Capitellidae are widely recognized as classic indicators of organic enrichment and impacted environments (Tsutsumi et al. 1990; Fernández-Rodríguez et al. 2019; Méndez 2022). For rocky shores, the use of polychaetes as indicators is less standardized, but recent studies have reported certain families associated with environmental conditions, such as Capitellidae (*Capitella capitata* (Fabricius, 1780)) in polluted sites and Sabellariidae (*Sabellaria alveolata* (Linnaeus, 1767)) in less disturbed habitats (El-Azzouzi et al. 2025). Additionally, Syllidae have been described as sensitive to disturbance, typically decreasing or disappearing under negative environmental impacts (Giangrande et al. 2005), a pattern that aligns with their higher abundances observed at Sacristia in the present study. Thus, the observed assemblages structure reflects not only local environmental conditions but also different degrees of ecological tolerance among families, highlighting the usefulness of polychaetes in environmental monitoring programs.

Despite the clear patterns observed in the present study, rarefaction curves did not reach an asymptote at any site or zone, indicating that the sampling effort was insufficient to capture the full diversity of polychaetes on the rocky shores. This suggests that the actual richness of the assemblages is greater than recorded, in agreement with studies showing that undersampling is a recurring issue in benthic communities and emphasizing the need to expand sampling effort to detect rare species (Montes et al. 2021; Ma et al. 2022). Our beta-diversity partitioning indicates that compositional heterogeneity across sampling units is driven primarily by species replacement (turnover) rather than by nestedness, which is expected to increase complementarity among samples and delay the approach to an asymptote in rarefaction and accumulation curves (Baselga 2010, 2012; Colwell and Coddington 1994; Gotelli and Colwell 2001; Chao et al. 2014). Continuous monitoring with greater sampling intensity is therefore essential for a more comprehensive assessment of local diversity.

In addition to the sampling limitations, part of the material analyzed was identified only to family or genus level, which may have led to an underestimation of recorded richness. Several studies have shown that family-level data may be sufficient to detect major ecological gradients and community responses (Carreira-Flores et al. 2024; Hadiyanto 2017), supporting its use in monitoring programs when resources are limited. However, other investigations highlight that relying solely on coarser taxonomic levels can mask subtle but ecologically meaningful differences, particularly in diverse families such as Syllidae, where species may respond in opposite ways to disturbance (Musco et al. 2009, 2011). This limitation is recurrent in studies on polychaetes, as many species are small, cryptic, and morphologically challenging to identify, in addition to significant knowledge gaps that persist in the taxonomy of the group in Brazil (Amaral et al. 2013; Nascimento et al. 2024). Therefore, while our results provide valuable insights into spatial patterns of polychaete assemblages on rocky shores, actual diversity is likely greater than observed, reinforcing the need for continued taxonomic work and species-level descriptions to strengthen ecological and conservation assessments.

Conclusion

This study provides a detailed assessment of polychaete assemblages on rocky shores of eastern Rio de Janeiro, revealing spatial patterns across sites, stations and tidal zones. Differences in polychaete assemblages between Itaipu and Sacristia were consistent with contrasting levels of human use and accessibility, while also occurring under distinct geomorphological and hydrodynamic contexts, while vertical

zonation between the midlittoral and upper infralittoral was detected only at Sacristia. Dominance of families such as Syllidae, Sabellidae, and Nereididae, together with a functional overview based on major clades (Errantia vs Sedentaria) and consistent associations between taxa and environmental gradients, highlights the ecological strategies and bioindicator potential of polychaetes in these habitats. Nonetheless, rarefaction curves and taxonomic limitations, together with turnover-driven beta diversity, indicate that actual diversity is likely higher than recorded, emphasizing the need for increased sampling effort and further taxonomic research. By comparing midlittoral and infralittoral zones in sites subject to different human pressures, this work adds a more detailed perspective to the study of rocky-shore polychaete communities in Rio de Janeiro, contributing a baseline for future monitoring and reinforcing the importance of polychaetes as indicators of environmental quality.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12526-026-01644-2.

Acknowledgements We thank Peter Prado Santana for assistance during fieldwork, Gaby Oliveira da Nóbrega and Luiza Oliveira da Silva for help with field sampling and sorting, and Matheus Vianna de Sousa for support with taxonomic identifications.

Funding The Article Processing Charge (APC) for the publication of this research was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) (ROR identifier: 00x0ma614). This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

Data Availability All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical approval All applicable, national, and/or institutional guidelines for animal sampling and analysis were followed by the authors.

Author contributions ALDC: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. BMG: Investigation, Taxonomic identification, Sample processing. PTBP: Investigation, Taxonomic identification, Sample processing. CSGS: Supervision, Resources, Project administration, Writing – review & editing. All authors read and approved the final manuscript.

References

Almeida TCM, Ruta C (2000) Effects of a subtidal macroalgae bed on soft-bottom polychaete assemblages in Arraial do Cabo, southeastern Brazil. Bull Mar Sci 67:199–207

Álvarez RIC (2019) Poliquetas associados aos costões rochosos da Baía de Sepetiba, RJ. Dissertation, Universidade Federal Rural do Rio de Janeiro

Amaral ACZ (1979) Ecologia e contribuição dos anelídeos poliquetos para a biomassa bêntica da zona das marés, no litoral norte do Estado de São Paulo. Bol Inst Oceanogr 28:1–52. https://doi.org/10.1590/S0373-55241979000100001

Amaral ACZ, Jablonski S (2005) Conservation of marine and coastal biodiversity in Brazil. Conserv Biol 19:625–631. https://doi.org/10.1111/j.1523-1739.2005.00692.x

Amaral ACZ, Nallin SAH, Steiner TM, Forroni TO, Gomes-Filho D, Araújo GR, Freitas R, Costa CAO, Ruta C, Gomes KRE, Bonaldo RO (2013) Catálogo das espécies de Annelida Polychaeta do Brasil. Unicamp, Campinas. Available at: https://www.ib.unicamp.br/museu_zoologia/system/files/2022-01/Cat%C3%A1logo_Polychaeta_Brasil_Amaral_et_al_2013_1a.pdf

Amaral ACZ, Nallin SAH, Steiner TM, Forroni TO, Gomes-Filho D, Araújo GR, Freitas R, Costa CAO, Ruta C, Gomes KRE, Bonaldo RO (2022) Catálogo das espécies de Annelida Polychaeta do Brasil. Available at: http://www.ib.unicamp.br/museu_zoologia/files/lab_museu_zoologia/Catalogo_Polychaeta_Amaral_et_al_2022.pdf. Accessed 11 Sep 2025

Amaral ACZ, Rossi-Wongtschowski CLDB (2004) Biodiversidade bentônica da região Sudeste-Sul do Brasil – plataforma externa e talude superior. Série Revizee – Score Sul, São Paulo

Attolini FS (1997) Composição e distribuição dos anelídeos poliquetas (Annelida, Polychaeta) na plataforma continental da região da Bacia de Campos, RJ, Brasil. Dissertation, Instituto Oceanográfico, Universidade de São Paulo

Baker SM (1909) On the causes of the zoning of brown seaweeds on the shore. New Phytol 8:196–202. https://doi.org/10.1111/j.1469-8137.1909.tb05252.x

Baselga A (2010) Partitioning the turnover and nestedness components of beta diversity. Glob Ecol Biogeogr 19:134–143. https://doi.org/10.1111/j.1466-8238.2009.00490.x

Baselga A (2012) The relationship between species replacement, dissimilarity derived from nestedness, and nestedness. Glob Ecol Biogeogr 21:1223–1232. https://doi.org/10.1111/j.1466-8238.2011.00756.x

Benedetti-Cecchi L, Trussell GC (2014) Rocky intertidal communities. In: Bertness MD, Bruno JF, Silliman BR, Stachowicz JJ (eds) Marine Community Ecology and Conservation. Sinauer Associates, Sunderland, pp 203–225

Bolívar GA (1990) Orbiniidae, Paraonidae, Heterospionidae, Cirratulidae, Capitellidae, Maldanidae, Scalibregmidae e Flabelligeridae (Annelida: Polychaeta) da costa sudeste do Brasil (22°57′S–27°20′S). Dissertation, Universidade Federal do Paraná

Capa M, Hutchings P (2021) Annelid diversity: historical overview and future perspectives. Diversity 13:129. https://doi.org/10.3390/d13030129

Carreira-Flores D, Rubal M, Cabecinha E, Díaz-Agras G, Gomes PT (2024) Unveiling the role of taxonomic sufficiency for enhanced ecosystem monitoring. Mar Environ Res 200:106631. https://doi.org/10.1016/j.marenvres.2024.106631

Chao A, Gotelli NJ, Hsieh TC, Sander EL, Ma KH, Colwell RK, Ellison AM (2014) Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. Ecol Monogr 84:45–67. https://doi.org/10.1890/13-0133.1

Chappuis E, Terradas M, Cefalì ME, Mariani S, Ballesteros E (2014) Vertical zonation is the main distribution pattern of littoral assemblages on rocky shores at a regional scale. Estuar Coast Shelf Sci 147:113–122. https://doi.org/10.1016/j.ecss.2014.05.035

Claudet J, Fraschetti S (2010) Human-driven impacts on marine habitats: a regional meta-analysis in the Mediterranean Sea. Biol Conserv 143:2195–2206. https://doi.org/10.1016/j.biocon.2010.06.004

Colwell RK, Coddington JA (1994) Estimating terrestrial biodiversity through extrapolation. Philos Trans R Soc Lond B Biol Sci 345:101–118. https://doi.org/10.1098/rstb.1994.0091

Costa PCP (2011) Interações socioecológicas na pesca à luz da etnoecologia abrangente: a praia de Itaipu, Niterói/Rio de Janeiro. Dissertation, Universidade Estadual de Campinas https://doi.org/10.47749/T/UNICAMP.2011.790476

Cordeiro CAMM, Floeter SR, Ferreira CEL (2024) Biogeographic patterns of Brazilian rocky reef fauna. In: Coutinho R, Christofoletti RA (eds) Brazilian rocky shores. Brazilian marine biodiversity. Springer, Cham, pp 15–28. https://doi.org/10.1007/978-3-031-67206-4_2

Coutinho R, Yaginuma L, Siviero F, Santos J, López M, Christofoletti R, Berchez F, Ghilardi-Lopes N, Ferreira C, Gonçalves J, Masi B, Correia M, Sovierzoski H, Skinner L, Zalmon I (2016) Studies on benthic communities of rocky shores on the Brazilian coast and climate change monitoring: status of knowledge and challenges. Braz J Oceanogr 64:27–36. https://doi.org/10.1590/S1679-875920161015064sp2

Dean HK (2008) The use of polychaetes (Annelida) as indicator species of marine pollution: a review. Rev Biol Trop 56:11–38

Deepananda KHMA, Macusi ED (2012) Human disturbance on tropical rocky shore assemblages and the role of marine protected areas in reducing its impact. Philipp Agric Sci 95:87–98

Díaz-Castañeda V, Reish DJ (2009) Polychaetes in environmental studies. In: Shain DH (ed) Annelids in modern biology. Wiley, Hoboken, pp 203–227

Dos Santos CL, Silva MAM, Salvador MVS (2004) Dinâmica sazonal e os efeitos das ressacas nas praias de Niterói/RJ. Rev Bras Geociênc 34:355–360

Eccard LR, Silva ALC, Silvestre CP (2017) Variações morfológicas nas praias oceânicas de Niterói (RJ, Brasil) em resposta à incidência de ondas de tempestades. Rev Bras Geogr Fís 10:41–55. https://doi.org/10.5935/1984-2295.20170011

El-Azzouzi Z, Dahbi A, Kouali H, Achtak H, Sabour B, Chaouti A (2025) Polychaete functional traits and environmental filtering on intertidal rocky shores in northwestern Morocco: community structure and ecological quality assessment. Sci Total Environ 998:180299. https://doi.org/10.1016/j.scitotenv.2025.180299

Fauchald K, Jumars PA (1979) The diet of worms: a study of polychaete feeding guilds. Oceanogr Mar Biol Annu Rev 17:193–284

Fernández-Rodríguez V, Santos CSG, Pires APF (2019) Meta-analysis of the effects of organic matter on polychaetes of the east coast of South America. Mar Environ Res 149:148–156. https://doi.org/10.1016/j.marenvres.2019.06.001

Ferreira MN, Rosso S (2009) Effects of human trampling on a rocky shore fauna on the São Paulo coast, southeastern Brazil. Braz J Biol 69:993–999. https://doi.org/10.1590/S1519-69842009000500003

Geoparque Costões e Lagunas (2025) Maricá. https://www.geoparquecostoeselagunas.com/marica/. Accessed 8 Sep 2025

Giangrande A, Delos AL, Musco L, Licciano M, Pierri C (2004) Polychaete assemblages of rocky shore along the South Adriatic coast (Mediterranean Sea). Cah Biol Mar 45:85–95

Giangrande A, Licciano M, Musco L (2005) Polychaetes as environmental indicators revisited. Mar Pollut Bull 50:1153–1162. https://doi.org/10.1016/j.marpolbul.2005.08.003

Gotelli NJ, Colwell RK (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol Lett 4:379–391. https://doi.org/10.1046/j.1461-0248.2001.00230.x

Hadiyanto (2017) Taxonomic level needed to detect significant changes in polychaete communities over different macrophyte assemblages on rocky intertidal shores. Mar Res Indones, 42:93–108. https://doi.org/10.14203/mri.v42i2.189

Hawkins SJ, Moore PJ, Burrows MT, Poloczanska E, Mieszkowska N, Herbert RJH, Jenkins SR, Thompson RC, Genner MJ, Southward AJ (2008) Complex interactions in a rapidly changing world: responses of rocky shore communities to recent climate change. Clim Res 37:123–133. https://doi.org/10.3354/cr00768

Jumars PA, Dorgan KM, Lindsay SM (2015) Diet of worms emended: an update of polychaete feeding guilds. Annu Rev Mar Sci 7:497–520. https://doi.org/10.1146/annurev-marine-010814-020007

Knox GA (2001) The ecology of seashores. CRC Press, Boca Raton

Lewis JR (1955) The mode of occurrence of the universal intertidal zones in Great Britain. J Ecol 43:270–286. https://doi.org/10.2307/2257134

Lewis JR (1961) The littoral zone on rocky shores: a biological or physical entity? Oikos 12:280–301. https://doi.org/10.2307/3564701

Lewis JR (1964) The ecology of rocky shores. English Universities Press, London

Liedke AMR, Barneche DR, Ferreira CEL, Segal B, Nunes LT, Burigo AP, Carvalho JA, Buck S, Bonaldo RM, Floeter SR (2016) Abundance, diet, foraging and nutritional condition of the banded butterflyfish (*Chaetodon striatus*) along the western Atlantic. Mar Biol 163:1–13. https://doi.org/10.1007/s00227-015-2788-4

Lins-de-Barros FM, Klumb-Oliveira L, Lima RF (2018) Historical evaluation of marine storm occurrence and associated damage between 1979 and 2013 in the coast of the state of Rio de Janeiro (Brazil). J Integr Coast Zone Manag 18:85–102. https://doi.org/10.5894/rgci-n146

Little C, Kitching JA (1996) The biology of rocky shores. Oxford University Press, Oxford

Ma KCK, McKindsey CW, Johnson LE (2022) Detecting rare species with passive sampling tools: optimizing the duration and frequency of sampling for benthic taxa. Front Mar Sci 9:809327. https://doi.org/10.3389/fmars.2022.809327

Mansur KL (2010) Diretrizes para geoconservação do patrimônio geológico do Estado do Rio de Janeiro: o caso do Domínio Tectônico Cabo Frio. Dissertation, Universidade Federal do Rio de Janeiro

Maximov AA, Berezina NA (2023) Benthic opportunistic polychaete/amphipod ratio: an indicator of pollution or modification of the environment by macroinvertebrates? J Mar Sci Eng 11:190. https://doi.org/10.3390/jmse11010190

Méndez MM, Livore JP, Calcagno JA, Bigatti G (2017) Effects of recreational activities on Patagonian rocky shores. Mar Environ Res 130:213–220. https://doi.org/10.1016/j.marenvres.2017.07.023

Méndez N (2022) Effects of sediment organic matter on mortality, growth and development of the polychaetes *Capitella teleta* and *Capitella* sp. (Annelida: Capitellidae) in laboratory conditions. Sci Mar 86:e034. https://doi.org/10.3989/scimar.05208.034

Monteiro-Neto C, Tubino RA, Moraes LES, Neto JPM, Esteves GV, Fortes WL (2008) Associações de peixes na região costeira de Itaipu, Niterói, RJ. Iheringia Ser Zool 98:50–59. https://doi.org/10.1590/S0073-47212008000100007

Montes E, Miloslavich P, Cruz-Motta JJ, Altieri AH, Báez DP, Bigatti G, Cocito S, Gobin J, Herrera C, Klein E, Knowlton A, Lovelock CE, Mach ME, Milchakova NA, Palomo G, Piriz ML, Riosmena-Rodríguez R, Sardi AE, Solis-Weiss V, Viejo RM, Wong MC, Benedetti-Cecchi L (2021) Optimizing large-scale biodiversity

sampling effort: toward an unbalanced survey design. Oceanography 34:80–91. https://doi.org/10.5670/oceanog.2021.216
Musco L, Terlizzi A, Licciano M, Giangrande A (2009) Taxonomic structure and the effectiveness of surrogates in environmental monitoring: a lesson from polychaetes. Mar Ecol Prog Ser 383:199–210. https://doi.org/10.3354/meps07989
Musco L, Mikac B, Tataranni M, Giangrande A, Terlizzi A (2011) The use of coarser taxonomy in the detection of long-term changes in polychaete assemblages. Mar Environ Res 71:131–138. https://doi.org/10.1016/j.marenvres.2010.12.004
Nascimento RL, Mendes S, Vital MVC, Paiva PC (2024) Polychaete research in Brazil: a bibliometric analysis. Ocean Coast Res 72:e24018. https://doi.org/10.1590/2675-2824072.23105
Nogueira JMM, Rossi MCS, López E (2006) Intertidal species of *Branchiomma* Kölliker and *Pseudobranchiomma* Jones (Polychaeta: Sabellidae: Sabellinae) from the State of São Paulo, southeastern Brazil. Zootaxa 1189:1–37. https://doi.org/10.11646/zootaxa.1189.1.1
Nonato EF (1981) Contribuição ao conhecimento dos anelídeos poliquetos bentônicos da plataforma continental brasileira, entre Cabo Frio e Arroio Chuí. Dissertation, Universidade de São Paulo, São Paulo
Oksanen J, Simpson G, Blanchet F et al. (2022) vegan: Community Ecology Package. R package version 2.6–10. https://CRAN.R-project.org/package=vegan
Oliveira FSC (2013) Distribuição espacial da fauna de poliquetas de praias arenosas ao longo de um gradiente de poluição orgânica na Baía de Guanabara, RJ. Dissertation, Universidade Federal da Bahia, Salvador
Pamungkas J, Glasby CJ, Read GB, Wilson SP, Costello MJ (2019) Progress and perspectives in the discovery of polychaete worms (Annelida) of the world. Helgol Mar Res 73:4. https://doi.org/10.1186/s10152-019-0524-z
Prefeitura de Niterói (2013) Reserva Extrativista (RESEX) Marinha de Itaipu. Prefeitura de Niterói, Secretaria de Meio Ambiente, Recursos Hídricos e Sustentabilidade. https://meioambiente.niteroi.rj.gov.br/resex-itaipu. Accessed 02 Sep 2025
Puga CA, Torres A, Paiva PC, Yoneshigue-Valentin Y, Junqueira AOR (2019) Multi-year changes of a benthic community in the mid-intertidal rocky shore of a tropical bay (Guanabara Bay, RJ-Brazil). Estuar Coast Shelf Sci 226:106265. https://doi.org/10.1016/j.ecss.2019.106265
Read, G.; Fauchald, K. (Ed.) (2026). World Polychaeta Database. Accessed at https://www.marinespecies.org/polychaeta. Accessed 9 Feb 2026.
Rouse GW, Pleijel F, Tilic E (2022) Annelida. Oxford University Press, New York
Rullier F, Amoreux L (1979) Annélides Polychaètes. Ann Inst Oceanogr 55:145–206
Salvador MVS, Silva MAM (2002) Morphology and sedimentology of Itaipu embayament, Niterói/RJ. An Acad Bras Cienc 74:127–134. https://doi.org/10.1590/S0001-37652002000100009
Santi L, Tavares M (2009) Polychaete assemblage of an impacted estuary, Guanabara Bay, Rio de Janeiro, Brazil. Braz J Oceanogr 57:287–303. https://doi.org/10.1590/S1679-87592009000400004
Satyam K, Thiruchitrambalam G (2018) Habitat ecology and diversity of rocky shore fauna. In: Sivaperuman C, Velmurugan A, Singh AK, Jaisankar I (eds) Biodiversity and climate change adaptation in tropical islands. Academic Press, Cambridge, pp 187–215. https://doi.org/10.1016/B978-0-12-813064-3.00007-7
Schmitt RS, Trouw R, Van Schmus WR, Armstrong R, Stanton NSG (2016) The tectonic significance of the Cabo Frio Tectonic Domain in the SE Brazilian margin: a Paleoproterozoic through Cretaceous saga of a reworked continental margin. Braz J Geol 46(Suppl 1):37–66. https://doi.org/10.1590/2317-4889201620150025
Serrano A, Velasco F, Olaso I (2003) Polychaete annelids in the diet of demersal fish from the southern shelf of the Bay of Biscay. J Mar Biol Assoc UK 83:619–623
Serrano A, San Martín G, López E (2006) Ecology of syllidae (Annelida: Polychaeta) from shallow rocky environments in the Cantabrian Sea (South Bay of Biscay). Sci Mar 70(S3):225–235. https://doi.org/10.3989/scimar.2006.70s3225
Silva AC, Ghilardi-Lopes NP (2012) Indicators of the impacts of tourism on hard-bottom benthic communities of Ilha do Cardoso State Park (Cananéia) and Sonho Beach (Itanhaém), two southern coastal areas of São Paulo State (Brazil). Ocean Coast Manag 58:1–8. https://doi.org/10.1016/j.ocecoaman.2011.12.009
Silva ALC, Silva MAM, Dos Santos CL (2009) Morfodinâmica e a estabilidade da praia de Piratininga, Niterói (RJ). Rev Bras Geocienc 39:684–693
Silva ALC, Abreu MLL, Silvestre CP (2012) Dunas costeiras na barreira arenosa holocênica da APA de Maricá no estado do Rio de Janeiro, Brasil. Rev Geonorte Ed Esp 2:367–376
Silva EF, Silva ALC, Silvestre CP et al (2021) Análise da percepção ambiental dos moradores do entorno das lagoas de Piratininga e Itaipu, Niterói (RJ). Rev Bras Educ Ambient 16:446–469
Simões BGS, Puga CA, Junqueira AOR (2024) Temporal variation of rocky shore biota of Guanabara Bay in a long-term context. Braz J Aquat Sci Technol 28:1–7. https://doi.org/10.14210/bjast.v28n2.20662
Southward AJ (1958) The zonation of plants and animals on rocky sea shores. Biol Rev 33:137–177. https://doi.org/10.1111/j.1469-185X.1958.tb01305.x
Stephenson TA, Stephenson A, Du Toit CA (1937) The South African intertidal zone and its relation to ocean currents. Trans R Soc S Afr 24:341–382. https://doi.org/10.1080/00359193709518928
Stephenson TA, Stephenson A (1949) The universal features of zonation between tide-marks on rocky coasts. J Ecol 37:289–305. https://doi.org/10.2307/2256610
Stephenson TA, Stephenson A (1972) Life between tidemarks on rocky shores. WH Freeman, San Francisco
Stevčić Č, Pérez-Miguel M, Drake P, Tovar-Sánchez A, Cuesta JA (2018) Macroinvertebrate communities on rocky shores: impact due to human visitors. Estuar Coast Shelf Sci 207:232–240. https://doi.org/10.1016/j.ecss.2017.11.026
Tsutsumi H, Fukunaga S, Fujita N, Sumida M (1990) Relationship between growth of *Capitella* sp. and organic enrichment of the sediment. Mar Ecol Prog Ser 63:157–162. https://doi.org/10.3354/meps063157
Tubino RA, Monteiro-Neto C, Moraes LES, Paes ET (2007) Artisanal fisheries production in the coastal zone of Itaipu, Niterói, RJ, Brazil. Braz J Oceanogr 55:187–197
Underwood A (2000) Experimental ecology of rocky intertidal habitats: what are we learning? J Exp Mar Biol Ecol 250:51–76. https://doi.org/10.1016/S0022-0981(00)00179-9
Veiga P, Sampaio L, Moreira J, Rubal M (2023) Short-term effects of trampling on intertidal *Mytilus galloprovincialis* beds. Mar Pollut Bull 189:114800. https://doi.org/10.1016/j.marpolbul.2023.114800
Wahlenberg G (1812) Flora Lapponica. Reimer, Berlin
Wickham H, Averick M, Bryan J et al. (2016) Welcome to the tidyverse. J Open Source Softw 4:1686. https://doi.org/10.21105/joss.01686
Zühlke R (2001) Polychaete tubes create ephemeral community patterns: *Lanice conchilega* (Pallas, 1766) associations studied over six years. J Sea Res 46:261–272. https://doi.org/10.1016/S1385-1101(01)00091-0