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ORIGINAL RESEARCH

Amphipoda (Crustacea, Peracarida) associated with the octocoral *Carijoa riisei* (Cnidaria, Anthozoa) in estuarine and reef environments of northeastern Brazil

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ABSTRACT. *Carijoa riisei* is a branching colonial octocoral widely distributed in reef and estuarine environments along the coast of Pernambuco, northeastern Brazil. Owing to the structural complexity of its colonies, it provides both habitat and substrate for a diverse assemblage of associated organisms. This study investigated the structure of the amphipod community associated with *C. riisei* in two contrasting environments on the southern coast of Pernambuco: Porto de Galinhas Beach and the Rio Formoso Estuary. Four sampling campaigns were carried out, two at each site, encompassing both the dry and rainy seasons. During each campaign, 12 octocoral colonies were collected, resulting in a total of 48 samples. A total of 26,683 amphipods representing 21 species were recorded. The most abundant species were *Ericthonius brasiliensis* (57.28%), *Laticorophium baconi* (10.93%), *Podocerus brasiliensis* (7.65%), *Monocorophium acherusicum* (7.54%), and *Dulichiella ankeri* (5.89%), which together accounted for 89.22% of all individuals collected. Amphipod abundance in the Rio Formoso Estuary was approximately six times greater than that recorded at Porto de Galinhas. Moreover, *L. baconi* and *M. acherusicum* were exclusively found in the estuarine environment. Comparisons of ecological descriptors revealed significant differences between the two sites, with the estuary exhibiting higher amphipod abundance and diversity. These findings suggest that estuarine conditions, including greater nutrient availability, higher sediment input, and the influence of water flow and reduced light penetration, promote the establishment of more diverse amphipod assemblages associated with *C. riisei*.

Key words: Cnidarians, epibiosis, estuary, beach-rocks, amphipods.

Anfípodos (Crustacea, Peracarida) asociados al octocoral *Carijoa riisei* (Cnidaria, Anthozoa) en ambientes estuarinos y arrecifales del Nordeste de Brasil

RESUMEN. *Carijoa riisei* es un octocoral colonial de estructura ramificada, ampliamente distribuido en ambientes arrecifales y estuarinos a lo largo de la costa de Pernambuco, en el noreste de Brasil. Debido a la complejidad estructural de sus colonias, proporciona refugio y sustrato para una amplia variedad de organismos asociados. Por lo tanto, este estudio tuvo como objetivo analizar la estructura de la comunidad de anfípodos asociada a colonias de *C. riisei* en dos ambientes de la costa sur de Pernambuco: la playa de Porto de Galinhas y el estuario del Río Formoso. Se realizaron cuatro

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campañas de muestreo, dos en cada sitio, abarcando tanto la estación seca como la lluviosa. Durante cada campaña se recolectaron 12 colonias de octocoral, totalizando 48 muestras. Se registró un total de 26.683 anfípodos pertenecientes a 21 especies. Las especies más abundantes fueron *Ericthonius brasiliensis* (57,28%), *Laticorophium baconi* (10,93%), *Podocerus brasiliensis* (7,65%), *Monocorophium acherusicum* (7,54%) y *Dulichiella ankeri* (5,89%), que en conjunto representaron el 89,22% del total de individuos recolectados. El estuario del Río Formoso presentó una abundancia total de anfípodos aproximadamente seis veces mayor que la registrada en Porto de Galinhas. Además, *L. baconi* y *M. acherusicum* se registraron exclusivamente en el ambiente estuarino. La comparación de los descriptores ecológicos reveló diferencias significativas entre ambos sitios, evidenciando una mayor abundancia y diversidad en el estuario. Estos resultados sugieren que las condiciones ambientales estuarinas, como una mayor disponibilidad de nutrientes y sedimentos, así como la influencia de las corrientes de agua y las condiciones de iluminación, favorecen el establecimiento de comunidades de anfípodos más diversas asociadas a *C. riisei.*

Palabras clave: Cnidarios, epibiosis, estuario, *beach-rocks*, anfípodos.

INTRODUCTION

Coastal zones are among the most productive and, at the same time, the most threatened habitats on the planet, harboring numerous plant and animal species that occur exclusively in these environments (David and Stuart 2010). The integrity of these regions is essential for maintaining the natural processes that support biodiversity and the provision of ecosystem services (Fang et al. 2018). Furthermore, the persistence of many species depends on ecological processes occurring along the coastal zone, including reproduction, feeding, and the migration of terrestrial, aquatic and amphibious organisms, as well as nutrient exchange, riverine inputs, and tidal fluxes (Hazlitt et al. 2010; Fang et al. 2018).

This environment encompasses a wide variety of ecosystems, including benthic habitats, which are characterized by their high structural complexity and fundamental role in maintaining marine biodiversity. In these environments, competition for space is intense, and the colonization of previously unoccupied surfaces represents an important ecological strategy, likely serving as the primary driver of epibiosis on living substrates (Wahl 1989). In this context, several benthic organisms, including algae (Boström et al. 2010), octocorals (Goh et al. 1999; de Pádua et al. 2022), sponges (Ribeiro et al. 2003), scleractinian corals (Montano 2020), and hydrozoans (Di Camillo et al. 2017), function as ecosystem engineers by creating biogenic habitats that provide essential ecological functions, such as shelter, modification of abiotic conditions, and food resources, thereby directly influencing the structure and development of associated communities (Sotka et al. 1999; Bruno and Bertness 2001).

Among these organisms, octocorals, cnidarians belonging to the class Anthozoa, are among the most important structural components of coral reef ecosystems, forming dense marine forests that provide substrate, food resources, and shelter for a diverse associated fauna (Buhl-Mortensen and Mortensen 2005; Wicksten and Cox 2011; Sánchez 2016; Soler-Hurtado et al. 2018). *Carijoa riisei*, commonly known as the snowflake coral, is an octocoral native to the Indo-Pacific (Concepción et al. 2010) that has spread aggressively across a wide range of coastal habitats in the Atlantic and Pacific Oceans, threatening tropical ecosystems worldwide, including coral reefs (Galván-Villa and Ríos-Jara 2018; Cárdenas-Calle et al. 2021; Molina-Triana et al. 2022; Vargas and Breedy 2022). However, owing to its arborescent stoloniferous growth form, *C. riisei* also creates structurally complex habitats that support diverse epibiotic communities, including sponges, echinoderms, annelids, crustaceans, and mollusks (Bayer 1956; Neves et al. 2007; Souza et al. 2007; de Pádua et al. 2022). Among these, crustaceans are the most frequently recorded group, with amphipods among the dominant components of the associated fauna (de Pádua et al. 2022; Galván-Villa 2023).

Amphipods constitute one of the most diverse and abundant groups inhabiting marine ecosystems, from shallow waters to deep-sea environments worldwide (Arfianti and Costello 2020a, 2020b). These crustaceans play a key ecological role in marine food webs, serving as an important food resource for a wide range of organisms, including fishes, polychaetes, and other crustaceans (Conlan 1994). They also contribute to nutrient cycling and energy transfer across trophic levels, performing essential functions in maintaining the structure and functioning of marine ecosystems (Karlson et al. 2007; Havermans and Smetacek 2018). However, the occurrence and composition of associated macrofaunal communities, including amphipods, are not determined solely by the characteristics of the host substrate. Environmental factors, such as hydrodynamic conditions and the physicochemical properties of the water column, can directly or indirectly influence the distribution and abundance of benthic species across spatial and temporal scales (Moulaert et al. 2007; Dutertre et al. 2012). These factors regulate fundamental ecological processes, including food availability, larval dispersal, and organismal metabolism, thereby playing a decisive role in shaping the structure of benthic communities (Shanks et al. 2003).

Given the ecological importance of amphipods and the multiple environmental factors that may influence their distribution, this study aimed to investigate the structure of the amphipod community associated with the octocoral *C. riisei* in two contrasting coastal environments of Pernambuco, northeastern Brazil: the reef habitat of Porto de Galinhas Beach and the estuarine environment of the Rio Formoso Estuary. We hypothesized that the structure of the amphipod community associated with *C. riisei* differs between reef and estuarine habitats, with the estuarine environment expected to support higher amphipod abundance, species richness, and diversity due to greater nutrient availability, increased sediment input, and higher resource heterogeneity.

MATERIALS AND METHODS

Study area

Sampling was conducted at two locations along the southern coast of Pernambuco State, northeastern Brazil: Porto de Galinhas Beach (PG) (8° 30′ 04″ S, 35° 00′ 00″ W), Ipojuca, and the Rio Formoso Estuary (RF) (8° 39′ 36″ S, 35° 09′ 00″ W), Rio Formoso (Figure 1). The region has a humid tropical climate, characterized by distinct dry and rainy seasons and a mean annual temperature of approximately 24 °C (CPRH 2001).

Porto de Galinhas Beach is located approximately 64 km south of Recife and is characterized by the presence of near-shore fringing sandstone reefs extending up to 900 m offshore, which promote the formation of natural tidal pools (MMA 2003). Sampling was conducted at Piscina dos Oito, also known as Boca da Barra, a large open tidal pool reaching depths of up to 8 m. The estuarine study area is located in the municipality of Rio Formoso, within the Southern Forest Zone (Mata Meridional) of Pernambuco. Part of the municipality is included within the Guadalupe Environmental Protection Area (Área de Proteção Ambiental –APA), established under State Decree No. 19,635 of March 13, 1997. This protected area occupies the southern portion of the Pernambuco coast and encompasses parts of the municipalities of Sirinhaém, Rio Formoso, Tamandaré, and Barreiros (CPRH 2021).

Sampling design

Two seasonal sampling campaigns, corresponding to the dry and rainy seasons, were conducted at each study site (Porto de Galinhas Beach and the Rio Formoso Estuary), all during low tide. During each campaign, 12 randomly selected colonies of *C. riisei* were sampled, resulting in a total of 48 samples. Each sample was delimited using a 15 × 15 cm PVC quadrat, individually enclosed in a

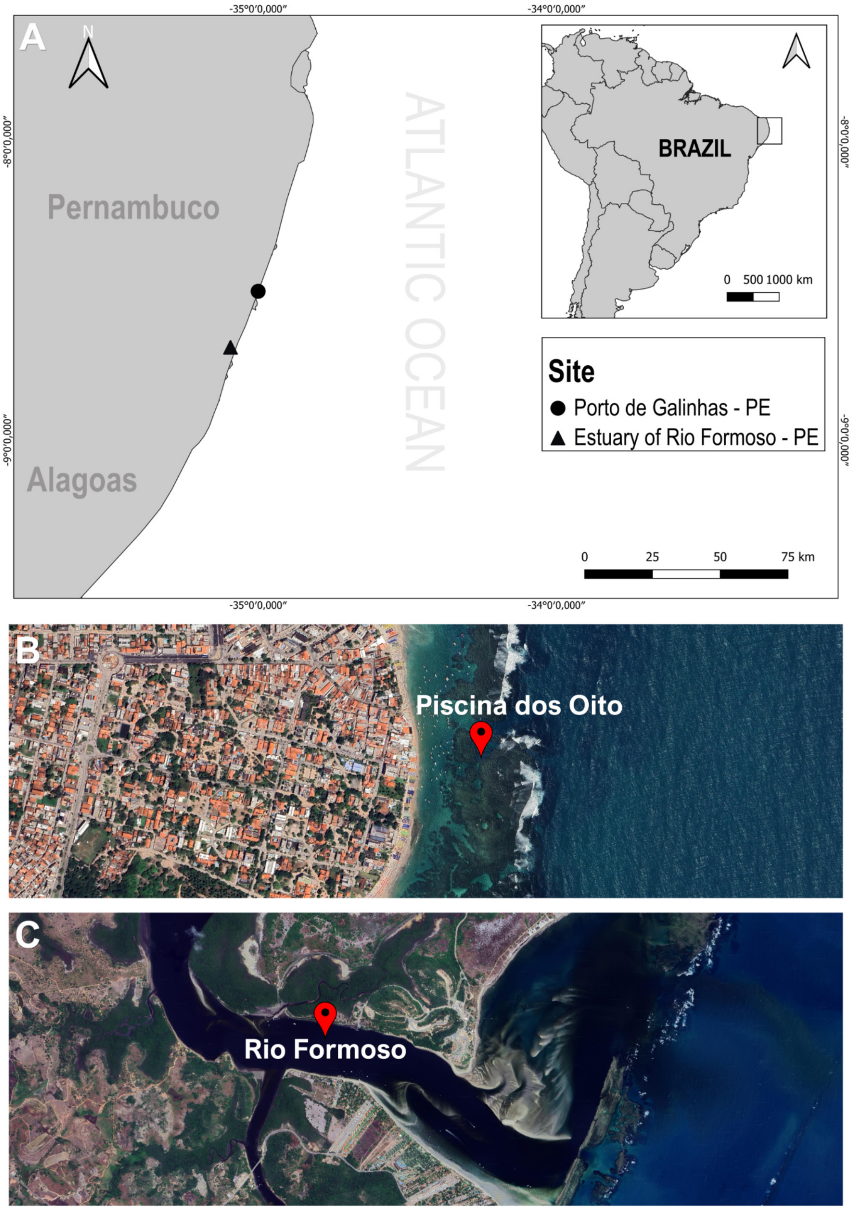

Figure 1. Study sites located on the southern coast of Pernambuco State, northeastern Brazil. A) Map showing sampling locations at Porto de Galinhas and the Rio Formoso Estuary. The inset map indicates the location of the study area within Brazil. B) Satellite image of the sampling site at Piscina dos Oito, Porto de Galinhas. C) Satellite image of the sampling site in the Rio Formoso Estuary. Satellite images were obtained from Google Earth.

polypropylene plastic bag, and immediately fixed in the field with 4% formaldehyde. At Porto de Galinhas Beach, *C. riisei* formed well-defined aggregations along the edges of fringing sandstone reefs at depths of up to 6 m. In contrast, in the Rio Formoso Estuary, colonies were attached to wooden stakes, fish weirs, mangrove roots, and pier pilings at depths of up to 2 m. Sampling at Porto de

Galinhas Beach was carried out in June 2012 (rainy season) and December 2012 (dry season), whereas sampling in the Rio Formoso Estuary took place in July 2012 (rainy season) and February 2013 (dry season).

Sample processing

Laboratory processing was carried out in four stages: colony washing, amphipod sorting and identification, and colony biomass determination. Each of the 48 *C. riisei* colonies was carefully washed individually in a plastic tray to detach the associated amphipods while minimizing damage to diagnostic morphological structures required for species identification. The wash water was filtered through a 250 µm mesh sieve, after which the retained material was preserved in labeled acrylic containers with 70% ethanol. Samples were subsequently sorted under a stereomicroscope, and all amphipods were counted and identified to the lowest possible taxonomic level using identification keys and consultation with taxonomy specialists. Species identifications were carried out at the Carcinology Laboratory of the Museu de Oceanografia Petrônio Alves Coelho, Universidade Federal de Pernambuco (UFPE). To standardize amphipod abundance relative to colony size, the dry biomass (g) of each colony was determined after drying the samples in a drying oven at 50 °C for 72 h, followed by weighing on a precision balance (± 0.01 g).

Statistical analysis

Ecological descriptors, including abundance (N), species richness (S), Pielou's evenness (J'), Shannon-Wiener diversity (H'), and average taxonomic distinctness (Δ+), were initially calculated for each sample based on absolute species abundances using the DIVERSE routine in PRIMER v7. Because colony size varied among samples, abundance values were standardized by the dry biomass of each colony prior to analysis.

A two-factor permutational multivariate analysis of variance (PERMANOVA) was performed to test the effects of Location (fixed factor, two levels: Porto de Galinhas and Rio Formoso) and Period (fixed factor, two levels: dry and rainy) on each ecological descriptor (N, S, H', J', and Δ+). When significant effects were detected, pairwise comparisons were conducted. Homogeneity of multivariate dispersions was assessed using PERMDISP. Prior to analysis, univariate data were square-rooted transformed, and Bray-Curtis similarity matrices were constructed.

Differences in amphipod assemblage structure among locations and seasons were also evaluated using a two-factor PERMANOVA based on the same experimental design, using abundance and species composition. Pairwise tests were performed for significant factors, and PERMDISP was used to assess the homogeneity of multivariate dispersions. Species abundance data were square-root transformed before constructing Bray-Curtis similarity matrices.

Patterns of similarity in amphipod assemblage composition among locations and seasons were visualized using non-metric multidimensional scaling (nMDS). In addition, hierarchical cluster analysis was performed to determine whether samples grouped according to location (Porto de Galinhas or Rio Formoso) or period (dry or rainy). The statistical significance of the resulting clusters was assessed using the Similarity Profile (SIMPROF) test.

The contribution of individual species to similarities within groups and dissimilarities between groups was evaluated using Similarity Percentage Analysis (SIMPER). This analysis identified the species primarily responsible for the observed patterns of similarity within groups and for the dissimilarities among groups detected by the cluster analysis and visualized by the nMDS ordination (Clarke and Warwick 2001).

All statistical analyses were performed using PRIMER v7 (Clarke and Warwick 2001), adopting a significance level of $\alpha = 0.05$.

RESULTS

Species composition and density

A total of 26,681 amphipods belonging to 22 species were identified, of which nine occurred in both environments, three were exclusive to Porto de Galinhas Beach, and 10 were exclusive to the Rio Formoso Estuary (Table 1). Overall amphipod abundance was substantially higher in the Rio Formoso Estuary, where it was approximately six times greater than at Porto de Galinhas Beach. *Ericthonius brasiliensis* (57.28%), *Laticorophium baconi* (10.93%), *Podocerus brasiliensis* (7.65%), *Monocorophium acherusicum* (7.54%), and *Dulichiella ankeri* (5.89%) together accounted for 89.22% of the total abundance. Seasonally, both Porto de Galinhas Beach (PG) and the Rio Formoso Estuary (RF) exhibited a reduction in species richness during the rainy season, with the loss of eight species in PG and seven species in RF relative to the dry season (Table 1).

Ericthonius brasiliensis was the dominant species in both environments, reaching its highest density during the rainy season. *Laticorophium baconi* and *Monocorophium acherusicum* were restricted to the Rio Formoso Estuary and were most abundant during the dry season. At Porto de Galinhas Beach, the ampithoid amphipods *Ampithoe ramondi* and *Cymadusa filosa* were among the dominant species, although *A. ramondi* was recorded exclusively during the dry season.

Ecological descriptors

Significant differences between locations were detected for species richness, abundance, and Shannon-Wiener diversity and average taxonomic distinctness, (PERMANOVA, $p < 0.05$) (Figure 2; Table 2). The effect season was significant for abundance, species richness, Pielou's evenness and Shannon-Wiener diversity (PERMANOVA, $p < 0.05$). Pairwise comparisons revealed significant differences between the dry and rainy seasons in the Rio Formoso Estuary for species richness, abundance, Pielou's evenness, Shannon-Wiener diversity, and average taxonomic distinctness. At Porto de Galinhas Beach, however, seasonal differences were detected only for Shannon-Wiener diversity (Table 2).

Amphipod assemblage structure

A significant interaction between Site and Period was detected, together with significant main effects for both factors (PERMANOVA, $p < 0.05$; Table 3). The nMDS ordination corroborated the PERMANOVA results, revealing clear differences in the composition and abundance of amphipod assemblages between Porto de Galinhas Beach and the Rio Formoso Estuary, as well as between the dry and rainy seasons (Figure 3).

The SIMPER analysis identified the species primarily responsible for the observed dissimilarities among local and periods. *Laticorophium baconi* and *Monocorophium acherusicum* were the main contributors to the differences between the two study sites because they were absent from Porto de Galinhas Beach (Table 4). Likewise, the absence of several species between the dry and rainy periods contributed substantially to the seasonal dissimilarities observed in amphipod assemblage composition (Tables 5 and 6).

DISCUSSION

In the present study, significant differences in species richness, abundance, evenness, and diversity were observed between the amphipod assemblages associated with *C. riisei* in the two habitats investigated (reef and estuarine environments). These differences were primarily driven by the occurrence of species restricted to the estuarine environment (Rio Formoso), which increased the

Table 1. List and number of amphipod species associated with the octocoral *Carijoa riisei* in two environments (Porto de Galinhas and Rio Formoso) during the dry and rainy periods. PG = Porto de Galinhas; RF = Rio Formoso; D = dry period; R = rainy period.

	PG		RF		
Taxon	D	R	D	R	Total
Family Ampithoidae					
Ampithoe ramondi Audouin, 1826	178	0	0	0	178
Pleonexes divisura (Shoemaker, 1933)	3	0	0	2	5
Cymadusa filosa Savigny, 1816	55	88	25	0	168
Family Aoridae					
Grandidierella sp.	0	0	2	0	2
Family Caprellidae					
Caprellidae sp.	0	0	5	2	7
Family Colomastigidae					
Colomastix sp.	0	0	2	0	2
Family Corophiidae					
Laticorophium baconi (Shoemaker, 1934)	0	0	2,248	669	2,917
Monocorophium acherusicum (A. Costa, 1853)	0	0	1,311	636	1,947
Family Hyalidae					
Apohyale media (Dana, 1853)	1	0	0	1	2
Family Ischyroceridae					
Ericthonius brasiliensis (Dana, 1853)	708	2,004	6,591	6,045	15,348
Ischyrocerus sp.	2	0	0	0	2
Family Leucothoidae					
Leucothoe sp. 1	0	0	0	1	1
Leucothoe sp. 2	0	0	704	30	734
Family Maeridae					
Elasmopus sp.	17	0	32	0	49
Elasmopus souzafilhoi Senna, 2011	2	0	61	0	63
Family Melitidae					
Dulichiella ankeri Alves, Johnson and Senna, 2014	1	0	1,512	38	1,551
Family Photidae					
Gammaropsis sp.	0	0	151	10	161
Latigammaropsis sp.	2	0	0	0	2
Photis sp.	0	0	741	0	741
Family Podoceridae					
Podocerus brasiliensis (Dana, 1853)	150	347	1,417	128	2,042
Family Stenothoidae					
Stenothoe sp.	18	134	597	3	752
Stenothoe valida Dana, 1853	0	0	7	0	7
Total	1,137	2,573	15,406	7,565	26,681

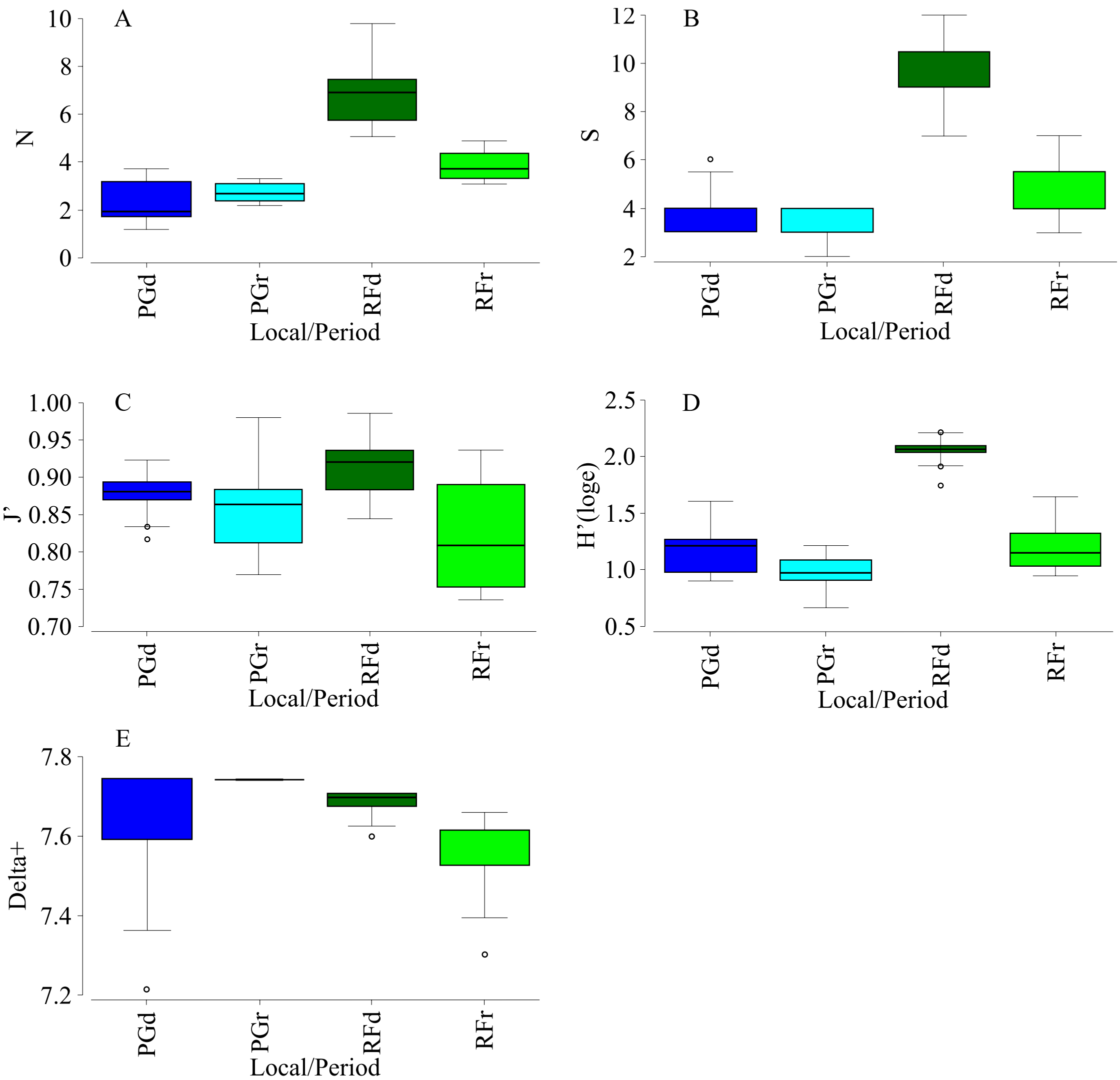

Figure 2. Boxplots of the amphipod assemblage associated with *Carijoa riisei* along the tropical coast of Brazil. Abundance was standardized by biomass (individuals per gram). A) Abundance (N). B) Species richness (S). C) Pielou's evenness (J'). D) Shannon-Wiener diversity (H'). E) Average taxonomic distinctness (Δ+). PGd = Porto de Galinhas, dry period; PGr = Porto de Galinhas, rainy period; RFd = Rio Formoso Estuary, dry period; and RFr = Rio Formoso Estuary, rainy period.

taxonomic complexity and overall diversity of the local assemblage.

Carijoa riisei provides a biogenic substrate that serves as habitat for amphipod communities in both estuarine and reef environments. This octocoral is a generalist suspension feeder that feeds primarily on planktonic organisms, including crustacean and molluscan larvae, diatoms, and suspended organic particles captured by its polyps. Consequently, *C. riisei* typically thrives in environments with high concentrations of suspended particulate matter and continuous to moderate-to-high water flow, conditions that ensure a constant supply of food resources (Lira et al. 2009; Dhivya et al. 2012). Because many of the dominant amphipod species associated with *C. riisei*, particularly members of

Table 2. A) PERMANOVA results for descriptors of the amphipod assemblage associated with *Carijoa riisei* along the tropical coast of Brazil. Abundance (N), species richness (S), Pielou's evenness (J'), Shannon-Wiener diversity (H'), and average taxonomic distinctness (Δ+). df = degrees of freedom; MS = mean squares; Lo = Location (PG and RF); Pe = Period (d and r). Pairwise comparisons following the significant Location × Period interaction. B) Pair-wise tests compare periods (d × r) separately within each Location (PG and RF). Bold values indicate statistical significance ($p < 0.05$).

A

	PERMANOVA					PERMDISP	
Source	Variation source	df	MS	Pseudo-F	P(perm)	F	P(perm)
S	Lo	1	2,584.5	90.59	**0.0001**	16.837	**0.0004**
	Pe	1	1,460.5	51.192	**0.0001**	19.593	**0.0004**
	Lo × Pe	1	592.2	20.757	**0.0001**		
	Res	43	28.53				
	Total	46					
N	Lo	1	3,741.9	119.02	**0.0001**	1.4176	0.2603
	Pe	1	327.1	10.404	**0.0004**	40.34	**0.0001**
	Lo × Pe	1	980.99	31.203	**0.0001**		
	Res	43	31,439				
	Total	46					
J'	Lo	1	0.083985	0.033865	0.857	7.548	**0.019**
	Pe	1	32.135	12.958	**0.0007**	8.9673	**0.0051**
	Lo × Pe	1	12.82	51.691	**0.028**		
	Res	43	2.48				
	Total	46					
H'	Lo	1	1,046.7	72.887	**0.0001**	12.976	**0.0011**
	Pe	1	862.77	60.078	**0.0001**	14.183	**0.0006**
	Lo × Pe	1	236.21	16.448	**0.0005**		
	Res	43	14,361				
	Total	46					
Δ+	Lo	1	4. 5946	9. 8747	**0.0023**	0.35423	0.7482
	Pe	1	0.58444	1. 2561	0.2847	2.5942	0.2652
	Lo × Pe	1	7.7417	16. 639	**0.0001**		
	Res	43	0.46529				
	Total	46					

Table 2. Continued.

B

PAIR-WISE TEST				
Index	Location	Comparison between periods	t	P(perm)
S	PG	d × r	1.9653	0.0764
	RF	d × r	8.3433	**0.0001**
N	PG	d × r	1.8175	0.0873
	RF	d × r	7.9436	**0.0001**
J’	PG	d × r	1.0717	0.2943
	RF	d × r	3.7727	**0.0021**
H’	PG	d × r	2.3597	**0.0292**
	RF	d × r	9.8093	**0.0001**
	PG	d × r	1.8488	0.0933
Δ+	RF	d × r	4.3338	**0.0001**

Table 3. PERMANOVA results compare the structure of amphipod assemblages using Location (2 levels: Porto de Galinhas –PG and Rio Formoso –RF) and Period (2 levels: dry and rainy), both treated as fixed factors. Where df = degrees of freedom and MS = mean squares. Bold values indicate statistical significance ($p < 0.05$).

PERMANOVA analysis					PERMDISP	
Source of variation	df	MS	Pseudo-F	P(perm)	F	P (perm)
Lo	1	24,910	63.674	**0.0001**	0.053606	0.8432
Pe	1	5,130.8	13.115	**0.0001**	48.561	**0.0001**
Lo × Pe	1	6,980.4	17.843	**0.0001**		
Res	43	391.22				
Total	46					

the family Corophiidae, are suspension feeders, their occurrence may be favored in habitats with a continuous supply of suspended food particles. As many of the dominant amphipod species associated with *C. riisei*, particularly members of the family Corophiidae, are suspension feeders, their occurrence may be favored in habitats with a continuous supply of suspended particulate food. In addition, the arborescent architecture of *C. riisei* colonies favor the establishment of amphipod populations by providing structural refuge and a variety of microhabitats that enhance protection from predators, facilitate tube construction, and provide suitable sites for reproduction. According to Kovalenko

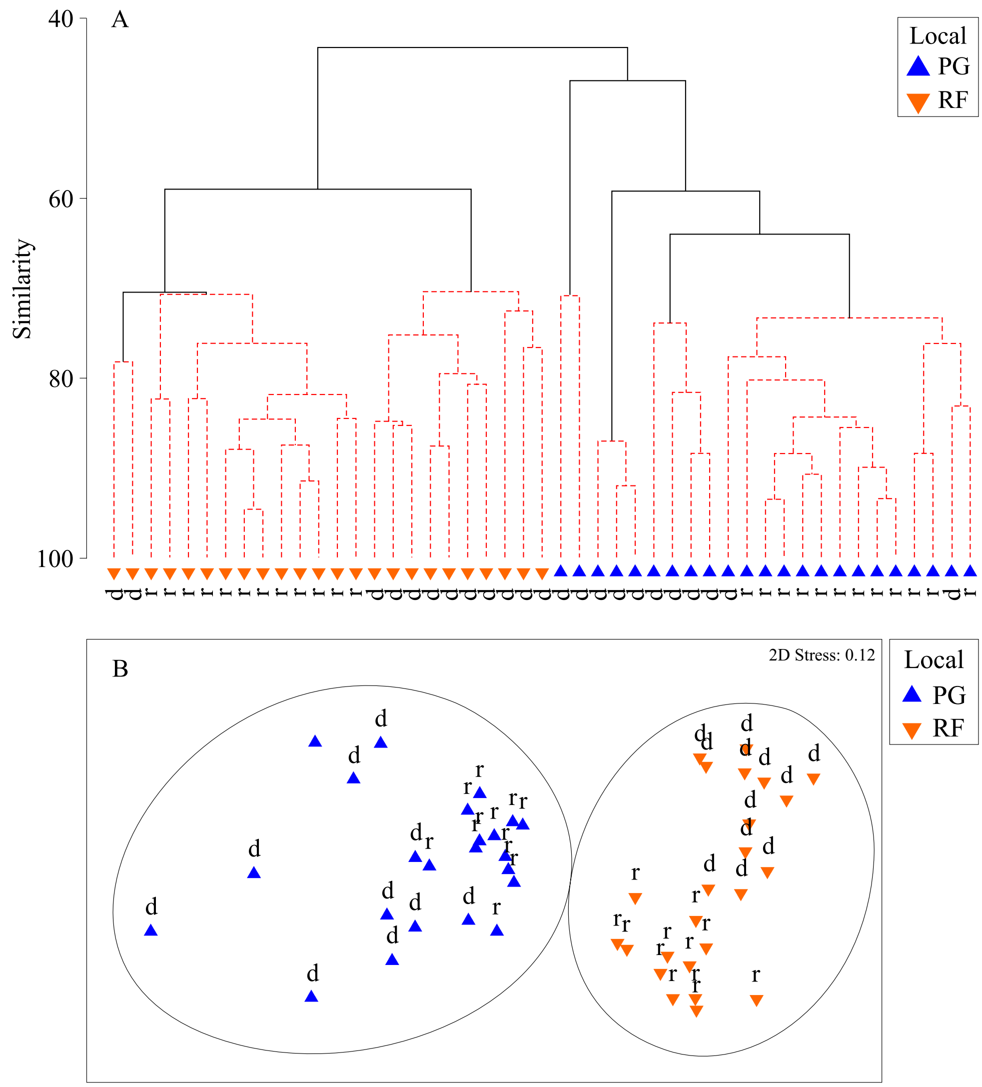

Figure 3. Cluster analysis and non-metric multidimensional scaling (nMDS) based on amphipod abundance data. A) Solid lines in the dendrogram indicate significant differences among groups (SIMPROF test, $P < 0.05$). B) The contour line drawn around each cluster in the nMDS ordination represents the overlap of dendrogram clusters at the selected similarity level (45%). d = dry period, r = rainy period, PG = Porto de Galinhas, Pernambuco, Brazil, and RF = Rio Formoso Estuary, Pernambuco, Brazil.

et al. (2012), habitat heterogeneity is a key factor influencing the structure of biological assemblages. Furthermore, many biogenic substrates have the capacity to generate complex three-dimensional structures that increase habitat complexity and expand the range of ecological niches available to associated organisms (Morrison et al. 2014). Organisms and formations such as kelp forests, mussel beds, oyster reefs, seagrass meadows, and coral reefs are widely recognized as foundation species (Dayton 1972) and ecosystem engineers (Jones et al. 1994), playing a fundamental role in the organization and maintenance of subtidal marine communities (Lindsey et al. 2006). Moreover,

Table 4. SIMPER analysis results showing the percentage contribution of the main amphipod species to the average dissimilarity between the assemblages of Porto de Galinhas (PG) and Rio Formoso (RF). The average dissimilarity between the localities was 57.01%.

	Group PG	Group RF	Average dissimilarity = 57.01			
Species	Av. abund.	Av. abund.	Av. diss.	Diss./SD	Contrib.%	Cum.%
Laticorophium baconi	0	0.83	10.57	3.22	18.55	18.55
Monocorophium acherusicum	0	0.73	9.49	3.57	16.65	35.20
Erichthonius brasiliensis	1.32	1.88	8.67	1.61	15.21	50.41
Podocerus brasiliensis	0.52	0.49	5.46	1.41	9.57	59.98
Stenothoe sp.	0.21	0.26	4.95	1.68	8.68	68.67
Dulichiella ankeri	0.01	0.37	3.92	0.8	6.88	75.55

Table 5. SIMPER analysis results showing the percentage contribution of the main amphipod species to the average dissimilarity between the assemblages of Porto de Galinhas (PG) and Rio Formoso (RF) during the dry period. Where PGd = Porto de Galinhas (dry period) and RFd = Rio Formoso (dry period). The average dissimilarity between locations was 62.21%.

	Dry period					
	Group PGd	Group RFd	Average dissimilarity = 67.21			
Species	Av. abund.	Av. abund.	Av. diss.	Diss./SD	Contrib.%	Cum.%
Laticorophium baconi	0	0.98	10.61	3.29	15.79	15.79
Monocorophium acherusicum	0	0.77	8.34	4	12.41	28.19
Erichthonius brasiliensis	1.08	1.73	8.1	1.41	12.06	40.25
Dulichiella ankeri	0.01	0.66	6.91	1.31	10.28	50.53
Leucothoe sp. 2	0	0.54	5.86	2.55	8.71	59.24
Photis sp.	0	0.53	5.7	1.97	8.48	67.73
Ampithoe ramondi	0.46	0	4.96	2.42	7.38	75.1

the structural complexity of these habitats often provides nursery areas and refugees for juvenile organisms, reducing predation risk and increasing survival rates (Almany 2004). In this context, amphipods exhibited high abundance in both study areas, consistent with their well-documented dominance in mobile epifaunal communities across marine habitats worldwide (Navarro-Mayoral et al. 2024).

Likewise, the arborescent colonies of *C. riisei* increase habitat heterogeneity by creating a complex three-dimensional framework that provides additional attachment surfaces, shelter, and microhabitats for associated fauna. Such structural complexity may provide suitable refuges and microhabitats for amphipods and, therefore, may contribute to their establishment and persistence. However, this potential effect was not directly tested in the

Table 6. SIMPER analysis results showing the percentage contribution of the main amphipod species to the average dissimilarity between the assemblages of Porto de Galinhas (PG) and Rio Formoso (RF) during the rainy period. Where PGr = Porto de Galinhas (rainy period) and RFr = Rio Formoso (rainy period). The average dissimilarity between locations was 47.65%.

	Rainy period					
	Group PGr	Group RFr	Average dissimilarity = 47.65			
Species	Av. abund.	Av. abund.	Av. Diss.	Diss./SD	Contrib. %	Cum. %
Monocorophium acherusicum	0	0.69	10.55	3.92	22.14	22.14
Laticorophium baconi	0	0.69	10.54	3.14	22.12	44.26
Erichthonius brasiliensis	1.55	2.03	9.19	1.84	19.29	63.55
Podocerus brasiliensis	0.62	0.23	6.16	1.46	12.94	76.49

present study, which focused on differences in amphipod assemblages between reef and estuarine habitats.

Notwithstanding, in addition to substrate availability and structural characteristics, other environmental factors may contribute to the organization of macrofaunal assemblages. The SIMPER analysis revealed differences in amphipod assemblage composition between the two environments, with dissimilarities mainly driven by the absence of several species from the reef habitat (Porto de Galinhas). *Laticorophium baconi*, *Monocorophium acherusicum*, *Grandidierella* sp., *Colomastix* sp., *Leucothoe* sp. 1, *Leucothoe* sp. 2, *Gammaropsis* sp., *Photis* sp., and *Stenothoe valida* were exclusively recorded in the Rio Formoso Estuary.

According to Bousfield (1973), *L. baconi* and *M. acherusicum* show a preference for environments with moderate to low salinity, which may explain their exclusive occurrence in the Rio Formoso Estuary observed in the present study. Species of the family Corophiidae are tubicolous and widely distributed along the Atlantic coast of the Americas and are frequently associated with estuarine sandy substrates and environments characterized by moderate to low salinity conditions (Bousfield 1973). These ecological preferences may also explain their higher affinity for *C. riisei* colonies in Rio Formoso, which presented a greater amount of sediment retained among the branches compared with colonies from Porto de Galinhas, where sediment accumulation around branches and polyps was considerably lower.

Species of the genus *Leucothoe* are commonly associated with marine sponges, mollusks, ascidians, and bryozoans (Bousfield 1973; Cantor et al. 2009). Similarly, some colomastigid and leucothoid amphipods may occur within host-associated structures, such as tubes or respiratory cavities of invertebrate hosts (LeCroy 2004). In the present study, leucothoid amphipods were exclusively recorded in *C. riisei* colonies from Rio Formoso, where colonies frequently exhibited sponge overgrowth on their branches. The presence of these epibiotic sponges may therefore explain the occurrence of leucothoids and colomastigids associated with *C. riisei* in the estuarine environment.

Species of the genera *Grandidierella* and *Colomastix* were recorded exclusively in the estuarine environment and showed among the lowest abundances observed in the present study. Their low occurrence may be related to competitive interactions with more abundant species that monopolize available space and resources, such as *Ericthonius brasiliensis*. Species of *Grandidierella* are commonly associated with brackish, estuarine, and coastal waters worldwide (Wongkamhaeng et al. 2020). Although numerous records exist for this genus in marine habitats, occurrences in hypersaline environments are relatively scarce, with only a few reports available in the literature (Wongkamhaeng et al. 2012). Species of *Colomastix* are commonly associated with invertebrate hosts and may occur within tubes or respiratory cavities of host organisms (Bousfield 1987). As commensals, colomastigids are frequently associated with marine sponges, and their suspension-feeding behavior may favor their establishment in sponge-dominated habitats. The occurrence of *Colomastix* exclusively in Rio Formoso may therefore be related to the presence of epibiotic sponges growing on *C. riisei* colonies in this environment. In contrast, *Ampithoe ramondi*, *Ischyrocerus* sp., and *Latigamaropsis* sp. were recorded exclusively at Porto de Galinhas Beach and during the dry season. This pattern may be associated with seasonal differences in environmental conditions, particularly water quality. During the rainy season, increased freshwater input into the estuarine system results in higher turbidity, sediment resuspension, and greater concentrations of suspended particulate matter, potentially altering nutrient availability and light conditions and negatively affecting species associated with the octocoral. Representatives of *Ampithoe ramondi* are generally herbivorous and predatory, tube-dwelling, and commonly associated with green algal beds. This species has also been recognized as an important trophic resource for fishes and as a potential structuring component of *Sargassum* beds along the southeastern Brazilian coast (Jacobucci and Leite 2006).

Some species were also particularly abundant in the present study, as observed for *Podocerus brasiliensis*. Members of this species are suspension feeders and detritivores, constituting free-living epifaunal organisms that occur mainly in environments with moderate salinity, although some brackish-water records have been reported (Bousfield 1973). *Ericthonius brasiliensis* was the most abundant species recorded in both environments. This species belongs to the family Ischyroceridae, whose representatives are commonly tube builders associated with hydroids and other branched substrates. Their tubes are constructed using sediment particles and secreted materials, providing protection and attachment sites. Individuals of this group are frequently found in bays, estuarine mouths, and shallow coastal waters. Studies addressing associations between amphipods and macroalgae have also reported *E. brasiliensis* as a highly abundant species in phytal habitats, particularly within *Sargassum* beds (Jacobucci and Leite 2006; Htaik 2023; Kanhai et al. 2023). In these environments, their high densities may influence the overall structure of amphipod assemblages by affecting community attributes such as abundance, dominance, and diversity. According to the results, *Ericthonius brasiliensis* exhibited broad ecological plasticity, occurring in both reef and estuarine environments. This species was originally described from Rio de Janeiro and is considered native to Brazil. It has a wide geographic distribution, with records from the Atlantic Ocean and the Mediterranean Sea (Myers and McGrath 1984) and has more recently been recognized as one of the most successful amphipod invaders worldwide (Zettler 2021). Although *E. brasiliensis* occurred in both environments, it was significantly more abundant in the estuarine habitat. This pattern may be related to environmental conditions characteristic of estuarine systems, such as greater nutrient availability and higher concentrations of suspended particulate matter (Gameiro et al. 2004). Additionally, *C. riisei* colonies provide elevated and structurally complex substrates that may enhance feeding opportunities for this species. Therefore, the combination of favorable environmental conditions and the availability of suitable habitat provided by *C. riisei* colonies likely contributed to the high abundance of *E. brasiliensis* observed in the estuary.

Apohyale media was represented by only two individuals in the present study, both collected during the dry season in the reef environment.

Poore (2004) reported that *A. media* and *Hyale nigra* were the most abundant species across all macroalgal substrates investigated, highlighting the common dominance of the family Hyalidae in this habitat, particularly on foliose algae exposed to wave action and desiccation stress. The predominantly herbivorous feeding strategy of *A. media* suggests that this species may prefer substrates other than *C. riisei*. Therefore, the occurrence of these two individuals on octocoral colonies may represent occasional habitat use. Alternatively, their presence may be related to the high abundance of macroalgae in reef environments, where algal assemblages can become dominant components of the benthic community (Fong and Paul 2011), potentially increasing the availability of resources for herbivorous organisms.

This study demonstrated that the estuarine environment has a greater potential to support more abundant, species-rich, and diverse amphipod communities, possibly due to higher nutrient and sediment availability, as well as the distinct hydrodynamic and light conditions characteristic of this habitat. Although the estuarine environment exhibited higher values of abundance, richness, and diversity, significant differences were also detected in amphipod assemblage composition between the reef and estuarine habitats. Despite some overlap in species composition between environments, the observed differences indicate that local environmental conditions may play an important role in shaping amphipod assemblages associated with *C. riisei*. The complex three-dimensional architecture of *C. riisei* may provide suitable refuges and microhabitats for associated fauna, potentially contributing to the establishment and persistence of amphipod populations; however, this potential effect was not directly tested in the present study. Therefore, the differences observed between environments are more appropriately interpreted in the context of variation in local environmental conditions, which may influence the availability of food resources, sediment input, and other habitat characteristics.

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Conflicts of interest

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Author contributions

Stella M. F. de Pádua: conceptualization, formal analysis, investigation, resources, writing-original draft preparation, writing-review and editing. Liliana do Carmo Nascimento: conceptualization, investigation, resources, writing-original draft preparation. Jesser F. Souza-Filho: resources, writing-original draft preparation. Mônica L. Botter-Carvalho: formal analysis. Paula Braga Gomes: methodology, writing-original draft preparation, writing-review and editing, supervision. Carlos

D. Pérez: conceptualization, methodology, writing-original draft preparation, supervision, funding acquisition. All authors have read and agreed to the published version of the manuscript.

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