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**INTERAÇÃO MACROFAUNA X MACROALGAS EM RECIFES COSTEIROS
COMO INDICADOR DE URBANIZAÇÃO NA COSTA PERNAMBUCANA**

Recife

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Dissertação apresentada ao Programa de Pós-Graduação em Oceanografia da Universidade Federal de Pernambuco, como requisito parcial para obtenção do título de mestre em Oceanografia.

Área de concentração: Oceanografia Biológica

Orientador: Prof. Dr. José Souto Rosa Filho.

Orientador: Prof. Dr. Edson Régis Tavares Pessoa Pinho de Vasconcelos.

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RESUMO

A urbanização é um dos principais problemas presentes em zonas costeiras, acarretando em diversos impactos em comunidades recifais, como a perda de riqueza e diversidade de espécies e a simplificação de habitat. Comunidades bentônicas são reconhecidas como bioindicadores de impactos antropogênicos, especialmente a macrofauna e as macroalgas. Portanto, este estudo teve como objetivo caracterizar as comunidades macrobênticas associadas às macroalgas em praias do litoral de Pernambuco com diferentes graus de urbanização e utilizar a relação macrofauna X macroalgas como indicador de urbanização. Para tal, foram coletadas amostras da macrofauna epifítica associadas a *Gelidium* spp., *Gelidiella acerosa* e *Palisada perforata* em seis praias em diferentes graus de urbanização no litoral pernambucano, bem como foram coletados os parâmetros ambientais (compostos nitrogenados, fosfato, turbidez, salinidade, clorofila e temperatura) a fim auxiliar na caracterização desses ambientes. Atributos morfológicos das macroalgas também foram medidos através da dimensão fractal. Em regiões altamente urbanizadas foram registradas maiores concentrações de nutrientes, como nitrito e fosfato. A complexidade estrutural das macroalgas não variou significativamente entre os níveis de urbanização e períodos sazonais, tendo uma baixa explicação sobre a macrofauna. A estrutura da macrofauna variou significativamente entre os graus de urbanização e período sazonal. A abundância da macrofauna foi maior em áreas urbanizadas. Diversidade e riqueza de espécies foram menores nas áreas altamente urbanizadas, reforçando a hipótese de utilização da macrofauna como uma ferramenta para bioindicação de perturbações ambientais antrópicas, como a urbanização.

Palavras-chave: bioindicadores; macrofauna epifítica; complexidade; regiões tropicais.

ABSTRACT

Urbanization is one of the main problems in coastal areas, causing various impacts on reef communities, such as loss of species richness and diversity and habitat simplification. Benthic communities are recognized as bioindicators of anthropogenic impacts, especially macrofauna and macroalgae. Therefore, the aim of this study was to characterize the macrobenthic communities associated with macroalgae on beaches on the coast of Pernambuco with different degrees of urbanization and to use the macrofauna X macroalgae relationship as an indicator of urbanization. To this end, samples of the epiphytic macrofauna associated with *Gelidium* spp., *Gelidiella acerosa* and *Palisada perforata* were collected from six beaches with two degrees of urbanization on the Pernambuco coast, as well as environmental parameters (nitrogen compounds, phosphate, turbidity, salinity, chlorophyll and temperature) in order to help characterize these environments. Morphological attributes of the macroalgae were also measured using fractal dimension. Higher concentrations of nutrients, such as nitrite and phosphate, were recorded in highly urbanized regions. The structural complexity of the macroalgae did not vary significantly between levels of urbanization and seasonal periods, with a low explanation for the macrofauna. The structure of the macrofauna varied significantly between the degrees of urbanization and seasonal period. Macrofauna abundance was higher in urbanized areas. Diversity and species richness were lower in highly urbanized areas, reinforcing the hypothesis that macrofauna can be used as a tool for bioindicating anthropogenic environmental disturbances, such as urbanization.

Keywords: Bioindicators; epiphytic macrofauna; complexity; tropical regions.

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1 INTRODUÇÃO

Áreas costeiras são ricas em recursos como minérios e estoques pesqueiros (Pires-Filho e Cycon, 1987), além de oferecerem diversas atividades como o turismo e o comércio (Neumann et al., 2015). Devido a sua alta produtividade, essas regiões têm sido intensamente ocupadas ao longo dos anos, com uma densidade populacional muito alta em comparação a outros ambientes (Small e Nicholls, 2003). Cerca de 50% da população mundial vive num raio de 200 km da costa e três quartos das megacidades do mundo estão situadas ao longo da costa (Yang et al., 2019). A utilização e exploração das zonas costeiras tem conduzido a várias alterações ambientais e socioeconômicas (Neumann et al., 2015), o que tem gerado uma grande pressão sobre os vários ecossistemas que as constituem (Zheng et al., 2020).

Dentre os ecossistemas costeiros, os ambientes recifais são conhecidos por apresentar alta importância social, ecológica e econômica devido aos serviços ecossistêmicos prestados, como proteção costeira, berçário, pesca e turismo (Moberg e Folk, 1999; Spalding et al., 2017; Brathwaite et al., 2021). Assim como nas regiões costeiras, os recifes sofrem diversos impactos devido à intensa e desordenada ocupação humana (Guimaraens et al., 2014). Essas regiões são de fácil acesso aos banhistas, o que intensifica os impactos da ação antrópica, como o pisoteio (Soares e Fujii, 2012). A urbanização resulta em diversos impactos nos ecossistemas recifais: a construção de estruturas artificiais que podem atuar como vetores para a dispersão de espécies invasoras e causar simplificação do habitat (Oricchio et al., 2019; Todd et al., 2019), contaminação química, aumento dos níveis de turbidez e nutrientes na água e acúmulo de resíduos sólidos (Burt, 2014; Mayer-Pinto et al., 2015).

O aporte de nutrientes provenientes de efluentes domésticos e industriais é um dos principais estressores para as comunidades bentônicas, o que pode se traduzir em desequilíbrio, simplificação de habitat e perda de resiliência e biodiversidade da comunidade recifal (Vasconcelos et al., 2019; Leite et al., 2020).

A descarga de efluentes urbanos em quantidades superiores à capacidade de depuração das massas de água pode causar vários impactos na biota (Ulloa et al., 2017). No bentos, a eutrofização e o enriquecimento orgânico podem afetar as comunidades macroalgal e zoobentônica (Jessen et al., 2015). Os ambientes eutróficos podem apresentar um aumento da biomassa de macroalgas (Glibert e Burford, 2017) e, assim, favorecer certos taxa, afetar a estratégia reprodutiva de certos invertebrados e até causar extinções locais (Grall e Chauvaud, 2002). A poluição da água e dos sedimentos, sobrepesca e pisoteio são um problema crítico e comum nas cidades costeiras e podem afetar os organismos marinhos ao nível dos indivíduos,

populações, comunidades e ecossistemas (Santos et al., 2015; Nichols et al., 2019; Todd et al., 2019).

As comunidades bentônicas são reconhecidas como bioindicadores, devido à sua sensibilidade à poluição, por serem sésseis ou terem baixa mobilidade e facilidade de coleta, além de refletirem condições ambientais anteriores e atuais a que foram submetidas (Huguenin et al., 2019; Leite et al., 2020). Dentre as comunidades bentônicas, a comunidade de macroalgas tem potencial bioindicador de urbanização, pois são sensíveis à poluição orgânica e as espécies podem alterar suas populações em decorrência da poluição (Vasconcelos et al., 2019; Santos et al., 2020).

As macroalgas são um dos principais componentes das comunidades da zona intertidal e estão divididas em três grandes grupos, com base nos seus pigmentos fotossintéticos Phaeophyceae (castanho), Chlorophyta (verde) e Rhodophyta (vermelho) (Zilberberg et al., 2016). As comunidades de algas marinhas macroscópicas desempenham um importante papel ecológico nos recifes, sendo um elo importante na cadeia alimentar, atuando na produtividade primária, acumulação e ciclagem de nutrientes, além de servir como habitat, berçário e alimento para a fauna marinha (Schermer et al., 2013; Santos et al., 2020).

Responsáveis por aumentar a complexidade estrutural dos ambientes recifais, as macroalgas proporcionam ambientes tridimensionais que abrigam tanto uma fauna quanto algas epífitas (Kovalenko et al., 2012). Fatores como a forma e complexidade de estruturas das macroalgas são importantes pois podem determinar os padrões diversidade, abundância e tamanho das comunidades epifíticas (Ape et al., 2018; Duarte et al., 2020), onde macroalgas com maior complexidade estrutural estão relacionadas com comunidades epifíticas mais diversas (Hauser et al., 2006).

O ambiente fital foi introduzido por Remane (1933) para designar uma nova seção do ambiente marinho além do ambiente pelágico e bentônico; sendo o fital um ecossistema composto por fundos vegetados, especialmente macrófitas, vegetações de marismas e angiospermas (Robertson e Weis, 2005; Ranjitham et al., 2008; Checon et al., 2023). O fital é formado por uma gama de organismos que colonizam o macrofitobentos, onde as macrófitas atuam como substrato abrigando tanto a flora quanto fauna associados (Nascimento e Rosso, 2007). Devido à complexidade das interações, o ambiente fital é considerado um ecossistema (Lopes Filho, 2007; Bezerra, 2011). Por conta de suas características, o ecossistema fital suporta uma grande diversidade de invertebrados marinhos (Edgar, 1983), compostos principalmente pela microfauna, meiofauna e macrofauna (Lopes Filho, 2007), além de vertebrados de importância comercial (Fulton et al., 2020; Christie et al., 2022). A macrofauna fital é

abundante e diversificada (Tano et al., 2016; Saarinen et al., 2018), constituída principalmente por anfípodes, isópodes, moluscos gastrópodes e poliquetas (Corte et al., 2012; Queiroz e Dias, 2014; Hamdy et al., 2018). Estas comunidades são reguladas por fatores abióticos como a hidrodinâmica e a ação das ondas (Hovel et al., 2002; Jacobucci e Leite, 2002) e pela complexidade estrutural das macroalgas (Chemello e Milazzo, 2002). Além disso, as perturbações antropogênicas podem também afetar negativamente a comunidade do fital (Cardoso et al., 2004).

Com relação as macroalgas, a urbanização pode levar a alterações na composição e estrutura da comunidade (Fowles et al., 2018) e redução da riqueza de espécies (Portugal et al., 2016). Espécies oportunistas, de crescimento rápido e de pequeno porte, como as algas turfosas e filamentosas, podem dominar regiões com elevada pressão antropogênica, inibindo o crescimento de algas com maior complexidade estrutural (Fowles et al., 2018). Locais enriquecidos organicamente apresentam maiores coberturas de taxa oportunistas como *Ulva* spp. (Arévalo et al., 2007) e menores coberturas de algas pardas, que contribuem para a complexidade dos ecossistemas costeiros (Bellgrove et al., 2017).

Esses estressores antropogênicos resultantes da urbanização também podem levar a diversos impactos sobre a macrofauna bentônica associada a macroalgas, como o aumento da abundância e densidade de espécies tolerantes e oportunistas (Vinagre et al., 2016; Mosbahi et al., 2019), redução da abundância, riqueza e diversidade da comunidade (Augusto et al., 2023) e até mesmo a extinção local de espécies (Hubbard et al., 2014). Alguns táxons oportunistas podem responder positivamente às maiores taxas de matéria orgânica comumente encontradas em ambientes urbanizados (Fitch e Crowe, 2012; Corte et al., 2022). Além disso, a urbanização também pode resultar na bioacumulação de metais pesados (Cabrinini et al., 2018) e na contaminação por microplásticos (Hashim et al., 2024).

No Brasil, os estudos sobre a macrofauna associada ao fital começaram com Boffi (1972) e Tararam e Wakabara (1981). Posteriormente, Jacobucci e Leite (2002), Leite e Turra (2003), Tanaka e Leite (2003) e Leite et al. (2021) deram continuidade desenvolvendo estudos especialmente focados na macrofauna epifítica de *Sargassum* spp. Autores como Thomaz et al. (2008) e Ramos et al. (2010) também realizaram trabalhos com a macrofauna associada a macrófitas no sudeste do Brasil. No nordeste brasileiro também foram desenvolvidos estudos com a comunidade da macrofauna epifítica, especialmente moluscos e poliquetas (Cunha et al., 2013; Barbosa et al., 2020; Craveiro & Rosa Filho, 2024). Apesar da maioria dos trabalhos serem realizados em áreas continentais também já foram feitos estudos com a macrofauna do fital em ilhas oceânicas (Jacobucci et al., 2006). Ainda que existam estudos a respeito de

impactos antropogênicos sobre a macrofauna epifítica (Vinagre et al., 2016; Mosbahi et al., 2019), até o momento não existem trabalhos no Brasil relatando os efeitos decorrentes da urbanização sobre esse grupo de organismos.

Ao longo da costa do Nordeste brasileiro, no litoral de Pernambuco, especialmente nas praias localizadas na Região Metropolitana do Recife, há uma forte pressão antrópica, resultante de uma grande e desordenada ocupação urbana, gerando impactos sobre as comunidades recifais (Sousa e Concentino, 2004). Esses recifes têm sido impactados pela sobrepesca, pisoteio, processos de engorda de praia e descarga de nutrientes, alterando a diversidade das comunidades de macroalgas (Guimaraens et al., 2021). No entanto, pouco se sabe sobre esses impactos na fauna epifítica e como a urbanização interfere na complexidade estrutural das macroalgas. Levando em consideração esses fatores, a macrofauna associada ao fito pode refletir os impactos da exposição a ambientes poluídos, o que reforça a necessidade de realização de estudos nesta temática.

1.1 OBJETIVOS

1.1.1 Objetivo Geral

Caracterizar as comunidades macrobentônicas associadas a macroalgas em praias do litoral sul de Pernambuco com diferentes graus de urbanização e utilizar a relação macrofauna x macroalgas como indicador de impactos ambientais.

1.1.2 Objetivos específicos

- Identificar alterações na complexidade estrutural de *Gelidium* spp.; *Gelidiella acerosa* e *Palisada perforata* em praias com diferentes graus de urbanização;
- Descrever a estrutura das comunidades macrobentônicas em diferentes macroalgas: *Gelidium* spp.; *G. acerosa* e *P. perforata* em praias com diferentes níveis de urbanização;
- Identificar alterações temporais (período seco e chuvoso) na estrutura das comunidades macrobentônicas em diferentes macroalgas e praias;
- Utilizar a interação macrobentos x macroalgas como indicador biológico dos impactos da urbanização sobre as comunidades biológicas costeiras.

1.2 ESTRUTURA DA DISSERTAÇÃO

A dissertação está estruturada na forma 1 artigo, intitulado “EPIPHYTIC MACROFAUNA AS A BIONDICADOR OF URBANIZATION ON THE COAST OF BRAZIL NORTHEASTERN” que aborda os impactos da urbanização sobre a estrutura da macrofauna epifítica, considerando variações sazonais (estação seca e chuvosa) e espaciais (grau de urbanização), que será submetido à revista *Marine Pollution Bulletin*.

2 ÁREA DE ESTUDO

O estado de Pernambuco possui uma população de 9.058.931 habitantes e ocupa uma área de 98.067,877km², sendo a 11^a maior densidade demográfica do Brasil (IBGE, 2022). Apenas 32,81% da população tem acesso à coleta de esgoto, dos quais 72,32% são tratados adequadamente (TCE/PE). O litoral de Pernambuco está localizado na província biogeográfica do Atlântico Tropical Sudoeste, e na ecorregião Nordeste do Brasil (Spalding et al., 2007).

O regime de marés é considerado mesotidal semidiurno, com as alturas médias variando entre 1.5 e 2m (Pereira et al., 2016), a plataforma continental possui 155 km de extensão e 35 km de largura (Barcellos et al., 2020).

De acordo com a classificação de Köppen (1928), o clima é tropical quente e úmido (As'), com uma estação chuvosa de abril a setembro e uma estação seca de outubro a março (Domingues et al., 2017). A precipitação média anual é de 1600mm (Bezerra et al., 2021) e a temperatura média anual do ar é de 25°C (Domingues et al., 2017). A temperatura superficial anual da água do mar está entre 26 e 27°C e a salinidade média está em torno de 36 (Domingues et al., 2017; Schettini et al., 2017). O litoral tem predominância de praias arenosas e apresenta uma característica morfológica típica das praias da região nordeste do Brasil, os recifes de arenito (beachrocks), geralmente alinhados paralelamente à costa (Martins et al., 2016; LaboreL-Deguen., 2019). Essas estruturas podem aflorar durante a maré baixa, e são povoadas por macroalgas e diversos invertebrados marinhos (Horta et al., 2001).

As amostras foram coletadas em seis praias (figure. 1) classificadas por Vasconcelos et al. (2019), de acordo com seu nível de urbanização, como Alta urbanização - Pina (Recife), Boa Viagem (Recife), Piedade (Jaboatão dos Guararapes) ou Baixa urbanização - Enseada dos Corais (Cabo de Santo Agostinho), Toquinho (Ipojuca) e Carneiros (Tamandaré). As praias do Pina (8° 5'19.79"S; 34°52'44.82"W), Boa Viagem (8° 7'28.62"S; 34°53'44.99"W) e Piedade (8°10'43.76"S; 34°54'55.69"W) estão localizadas na Região Metropolitana do Recife (PE) e são marcadas por intensa pressão antrópica, como a presença de muros de contenção, redes de esgoto, intenso fluxo de banhistas e longa extensão de edificações (Araújo et al., 2007; Almeida et al., 2008; Dias Filho et al., 2011). As praias do litoral sul: Enseada dos Corais (8°19'2.45"S; 34°56'52.19"W), Toquinho (8°34'40.84"S; 35° 2'10.33"W) e Carneiros (8°42'8.98"S; 35° 4'38.22"W) são menos densamente povoadas e possuem, em sua maioria, casas de veraneio (Araújo et al., 2007). Além das pressões antrópicas, algumas praias da região do litoral de Pernambuco também são marcadas por um intenso processo de erosão, o que levou a construção

de diversas estruturas artificiais para contenção do avanço do mar, especialmente na região metropolitana do Recife (Pereira et al., 2016).

Figura 1 - Áreas de estudo ao longo do litoral de Pernambuco



A: Pina; B: Boa Viagem; C: Piedade; D: Enseada dos Corais; E: Toquinho; F: Carneiros.
Fonte: O Autor (2024).

3 ARTIGO 1 – EPIPHYTIC MACROFAUNA AS A BIOINDICADOR OF URBANIZATION ON THE COAST OF BRAZIL NORTHEASTERN



ARTIGO A SER SUBMETIDO À REVISTA MARINE POLLUTION BULLETIN

ABSTRACT

Urbanization is one of the main problems in coastal areas, causing various impacts on reef communities, such as loss of species richness and diversity and habitat simplification. Benthic communities are recognized as bioindicators of anthropogenic impacts, especially macrofauna and macroalgae. Therefore, the aim of this study was to characterize the macrobenthic communities associated with macroalgae on beaches on the coast of Pernambuco with different degrees of urbanization and to use the macrofauna X macroalgae relationship as an indicator of urbanization. To this end, samples of the epiphytic macrofauna associated with *Gelidium* spp., *Gelidiella acerosa* and *Palisada perforata* were collected from six beaches with two degrees of urbanization on the Pernambuco coast, as well as environmental parameters (nitrogen compounds, phosphate, turbidity, salinity, chlorophyll and temperature) in order to help characterize these environments. Morphological attributes of the macroalgae were also measured using fractal dimension. Higher concentrations of nutrients, such as nitrite and phosphate, were recorded in highly urbanized regions. The structural complexity of the macroalgae did not vary significantly between levels of urbanization and seasonal periods, with a low explanation for the macrofauna. The structure of the macrofauna varied significantly between the degrees of urbanization and seasonal period. Macrofauna abundance was higher in urbanized areas. Diversity and species richness were lower in highly urbanized areas, reinforcing the hypothesis that macrofauna can be used as a tool for bioindicating anthropogenic environmental disturbances, such as urbanization.

Keywords: Bioindicators; epiphytic macrofauna; complexity; tropical regions.

1 Introduction

Coastal regions have seen increased population growth in recent years (Small and Nicholls, 2003), with 50% of the world's population residing within 200 km of shorelines and three-quarters of the world's megacities situated along the coast (Yang et al., 2019), especially due to the ecosystem services provided by estuarine environments, coral reefs and macroalgae beds, such as fisheries, tourism, recreational activities and coastal protection (Barbier, 2017; Macreadie et al., 2017 Woodhead et al., 2019). This high population density leads to a series of impacts on the ecosystems that make part of coastal zones (Zheng et al., 2020).

Increasing urbanization in regions near the sea has several impacts on coastal ecosystems, such as the construction of artificial structures that facilitate the dispersal of invasive species and simplify the habitat (Oricchio et al., 2019; Todd et al., 2019). In addition, there is chemical contamination, increased turbidity and nutrients in the water, and solid waste pollution (Burt, 2014; Mayer-Pinto et al., 2015). The input of nutrients from domestic and industrial effluents is one of the main stressors for benthic communities, resulting in imbalance, habitat simplification and loss of resilience and biodiversity (Vasconcelos et al., 2019; Leite et al., 2020). Water and sediment pollution, overfishing and trampling are a critical and common problem in coastal cities and can affect marine organisms at the level of individuals, populations, communities and ecosystems (Santos et al., 2015; Nichols et al., 2019; Todd et al., 2019).

Benthic communities are efficient as bioindicators due to their sensitivity to pollution, low mobility and ease of sampling, reflecting past and present environmental conditions (Huguenin et al., 2019; Leite et al., 2020). Bioindicators are essential tools in ecological studies, as they allow anthropogenic impacts on ecosystems to be monitored and evaluated (Parmar et al., 2016).

Macroalgae are particularly useful for indicating urbanization, as they respond to changes caused by organic pollution, which can alter their populations (Vasconcelos et al., 2019; Santos et al., 2020). Seaweed communities play a crucial ecological role on reefs, contributing to primary productivity, nutrient cycling, and providing habitat, nursery grounds, and food for marine fauna (Schermer et al., 2013; Santos et al., 2020).

By enhancing the structural complexity of reef environments, macroalgae create three-dimensional habitats that support both marine fauna and epiphytic algae (Kovalenko et al., 2012). The shape and complexity of macroalgal structures are key factors in determining the diversity, abundance, and size patterns of epiphytic communities (Kovalenko et al., 2012; Ape

et al., 2018; Duarte et al., 2020). The ecosystem where macrophytes act as a substrate is called Phytal (Robertson and Weis, 2005; Ranjitham et al., 2008; Checon et al., 2023).

In macroalgae, urbanization can lead to changes in community composition and structure (Fowles et al., 2018) and a reduction in species richness (Portugal et al., 2016), with less structurally complex algae inhibiting the growth of more structurally complex algae (Fowles et al., 2018). In epiphytic macrofauna, urbanization can lead to an increase in the abundance and density of tolerant and opportunistic species (Vinagre et al., 2016; Mosbahi et al., 2019), a reduction in the abundance, richness and diversity of the community (Augusto et al., 2023) and even the local extinction of species (Hubbard et al., 2014). Some opportunistic taxa can respond positively to the higher rates of organic matter commonly found in urbanized environments (Fitch and Crowe, 2012; Corte et al., 2022).

In Brazil, studies on the macrofauna associated with fital began with Boffi (1972) and Tararam and Wakabara (1981). Subsequently, Jacobucci and Leite (2002), Leite and Turra (2003), Tanaka and Leite (2003) and Leite et al. (2021) continued to develop studies especially focused on the epiphytic macrofauna of *Sargassum* sp. In northeastern Brazil, studies have been carried out on the epiphytic macrofauna community, especially molluscs and polychaetes (Cunha et al., 2013; Barbosa et al., 2020; Craveiro & Rosa Filho, 2024). Although there are studies on anthropogenic impacts on epiphytic macrofauna (Vinagre et al., 2016; Mosbahi et al., 2019), little is known about these impacts on epiphytic fauna and how urbanization interferes with the structural complexity of macroalgae. Taking these factors into account, the macrofauna associated with fital may reflect the impacts of exposure to polluted environments.

Therefore, this study aimed to characterize the macrobenthic communities associated with macroalgae on beaches along the coast of Pernambuco with different degrees of urbanization and to use the macrofauna X macroalgae relationship as a bioindicator of environmental impacts.

2. Material and methods

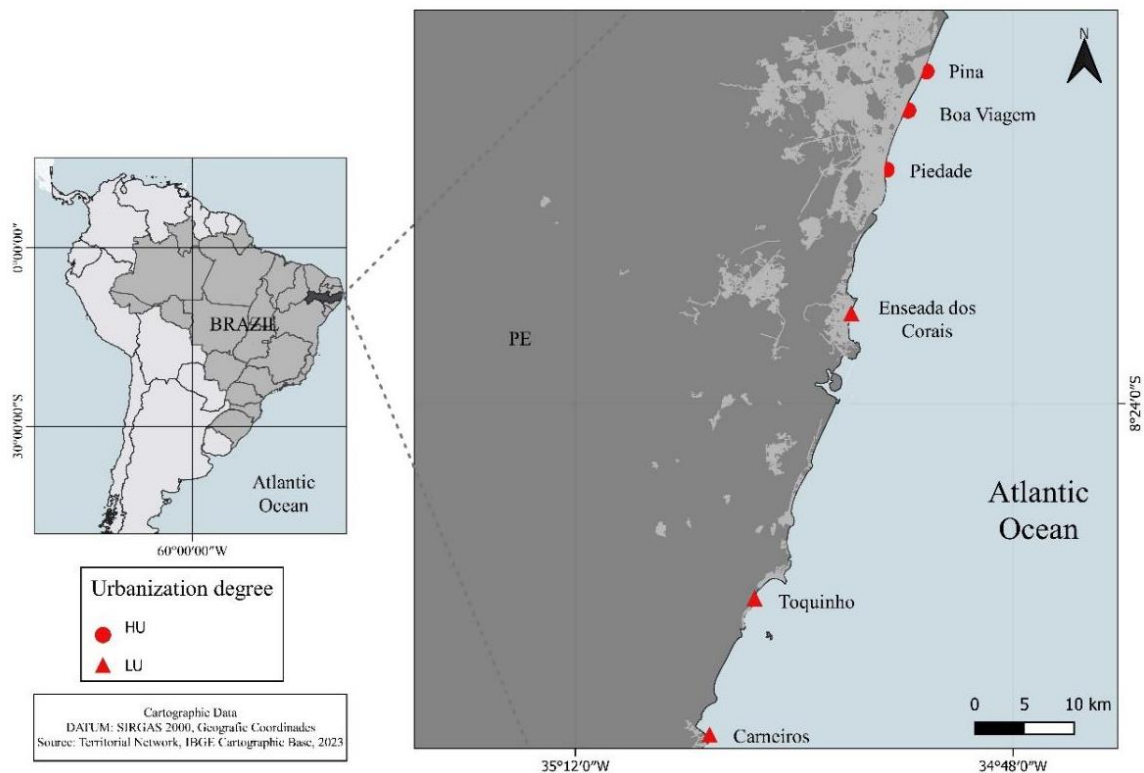
2.1 Study Area

The Pernambuco state has a population of 9,058,931 inhabitants and occupies an area of 98,067.877km², with the 11th highest population density in Brazil (IBGE, 2022). Only 32.81% of the population has access to sewage collection, of which 72.32% is adequately treated (TCE /PE). The coast of Pernambuco is located in the biogeographical province of the Tropical Southwest Atlantic, and in the Northeast ecoregion of Brazil (Spalding et al., 2007).

According to the Köppen classification (1928), the climate is tropical hot and humid (As'), with a rainy season from April to September and a dry season from October to March (Domingues et al., 2017). The average annual rainfall is 1600mm (Bezerra et al., 2021) and the average annual air temperature is 25°C (Domingues et al., 2017). The annual surface temperature of the sea water is between 26 and 27°C and the average salinity is around 36 (Domingues et al., 2017; Schettini et al., 2017). The coastline has a predominance of sandy beaches and displays a morphological feature typical of beaches in the northeastern region of Brazil, the sandstone reefs (beachrocks), usually aligned parallel to the coast (Martins et al., 2016; LaboreL-Deguen., 2019).

The samples were collected in six beaches (figure. 1) classified by Vasconcelos et al. (2019), according with their level of urbanization, as High urbanization (HU) - Pina (Recife), Boa Viagem (Recife), Piedade (Jaboatão dos Guararapes) or Low urbanization (LU) - Enseada dos Corais (Cabo de Santo Agostinho), Toquinho (Ipojuca) and Carneiros (Tamandaré). The beaches of Pina, Boa Viagem and Piedade are marked by intense anthropogenic pressure, such as the presence of retaining walls, sewage systems, an intense flow of bathers and a long stretch of buildings (Araújo et al., 2007; Almeida et al., 2008; Dias Filho et al., 2011). The beaches on the south coast (Enseada dos Corais, Toquinho and Carneiros) are less densely populated and mostly have houses for summer use (Araújo et al., 2007).

Figure 1 - Map of sampling sites along beaches on the coast of Pernambuco with different degrees of urbanization. HU: High urbanization; LU: Low urbanization.



2.2 Field procedures

Sampling took place in June/July 2022 (rainy season) and January 2023 (dry season). Samples (six per beach – nearly 100 ml of macroalgae) of *Gelidiella acerosa* (Forssk.) Feldmann & Hamel, 1934; *Palisada perforata* (Bory de Saint-Vincent) K.w.Nam, 2007 and *Gelidium* spp.. were taken in the intertidal zone during low spring tide using a spatula. The macroalgae were chosen based on the fact that these species occur all through the year, are widely distributed, belong to the same morphofunctional group (Rhodophytes) and have a similar architecture (corticated) (Soares and Fujii, 2012; Ferreira et al., 2022; Craveiro and Rosa Filho, 2024). The samples were fixed in 4% saline formalin. Parallel with the collection of macroalgae, water samples were taken (four samples per beach) to determine the concentration of nutrients and chlorophyll *a*. Temperature and turbidity were measured using a multiparameter probe Horiba U50

2.3 Laboratory procedures

In the laboratory the samples were washed through a 300 µm mesh under running water to separate the macrofauna. The macroalgae were then dried and weighed, and all the

macrofauna were collected and identified. After identification, the organisms were preserved in 70% ethanol.

The water samples were filtered through a 47mm glass microfiber filter (GF/C) using a vacuum pump. From the filtered seawater, 300 ml aliquots were made in order to determine the concentrations of nitrite, nitrate, ammonia, phosphate and chlorophyll *a*. The concentration of chlorophyll *a* and nutrients was obtained using a spectrophotometer. The concentration of nitrite and nitrate was determined based on García-Robledo et al. (2014), ammonia (Bower & Holm-Hansen, 1980), phosphate (Grasshof et al., 1983) and chlorophyll *a* (UNESCO, 1966).

2.4 Macroalgae structural complexity

In the laboratory, three fronds of each macroalgae sample were scanned using an HP Deskjet 2600 printer. The scanned images were then transformed into black and white and transferred to the ImageJ® program. After taking the scans, the macroalgae were dried and weighed individually on a 0.0001g precision scale. The structural complexity of the macroalgae was defined based on morphological attributes: height, dry weight and area and perimeter of the fronds as proposed by Chemello & Milazzo (2002); on the fractal dimension of the area (Da) and perimeter (Dp) (McAbendroth et al., 2005) and by means of the interstitial space index - IHV (Dibble et al., 1996; Dibble & Thomaz, 2006). From the photos, using ImageJ ® software, it was possible to measure height, Da and Dp using the *Box Count plugin*.

2.5 Data analysis

Sample completeness, species richness (total number of species), abundance (number of individuals per 10 g dry weight of macroalgae) and diversity (Hill number - Chao et al., 2020) were calculated for each fauna sample. The morphological attributes of the macroalgae (height, IHV, Da and Dp) and environmental variables of seawater were compared between degrees of urbanization (HU and LU) and seasonal period (Dry and Rainy season) (fixed factors) using two-way Permutational Analysis of Variance (PERMANOVA) (degree of urbanization and seasonal period). The structure of the macrofauna communities and the structural complexity of the macroalgae were compared using two-way (degree of urbanization and season) PERMANOVA. Distance-based linear models (DistLM) were used to correlate the structural complexity of the macroalgae and the fauna. To visualize the multivariate patterns of the macrobenthic communities in the different algae, seasonal periods and degrees of urbanization, Canonical Analysis of Principal Coordinates (CAP) was used (Anderson & Willis, 2003). For the analyses, similarity matrices were constructed using the Bray-Curtis

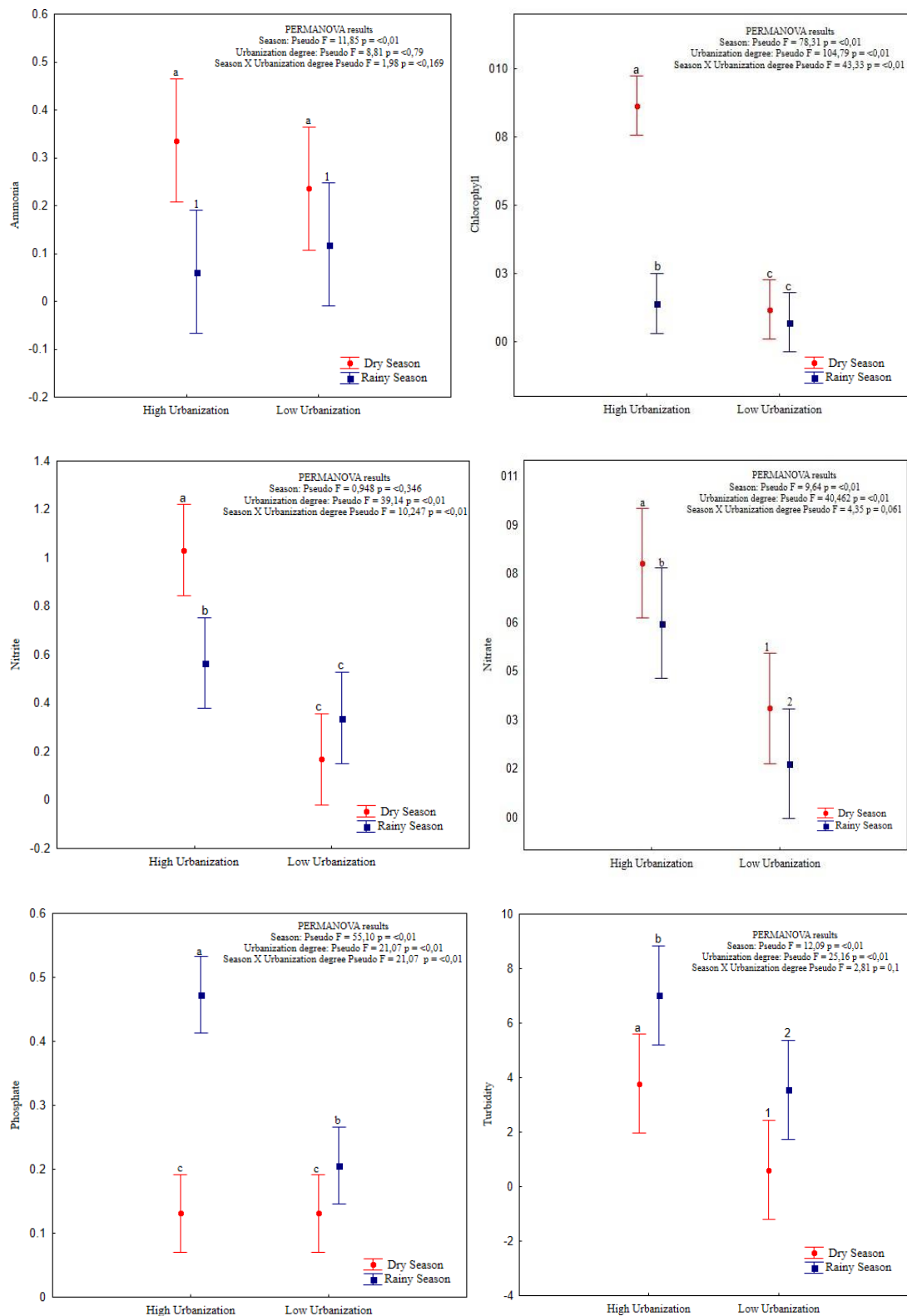
similarity index for fauna (data transformed by square root) and Euclidean distance for the morphological attributes of the algae and environmental variables (data transformed by fourth root and $(\log x + 1)$). All analyses were carried out using PRIMER 6 +PERMANOVA (Anderson et al., 2008) and STATISTICA 12 software, considering a 5% significance level.

3. Results

3.1 Environmental variables

There was significant variation between seasons for all environmental parameters except nitrite (figure 2), and generally higher values being recorded during the dry season (except turbidity and phosphate). Significantly higher values of chlorophyll *a*, nitrate, phosphate and turbidity were in general recorded in HU beaches (figure 2). The set of environmental parameters varied significantly among seasons and degrees of urbanization (with interaction between factors) (table 1). In the CAP graph (δ^2 CAP1: 0.89; δ^2 CAP2: 0.72 - 97.917% of samples correctly classified) (figure 3) it is possible to observe four groups, corresponding combinations of degrees of urbanization and seasons.

Figure 2 - Environmental parameters (mean $\pm$ standard deviation) from sandy beaches on the tropical Brazilian coast.



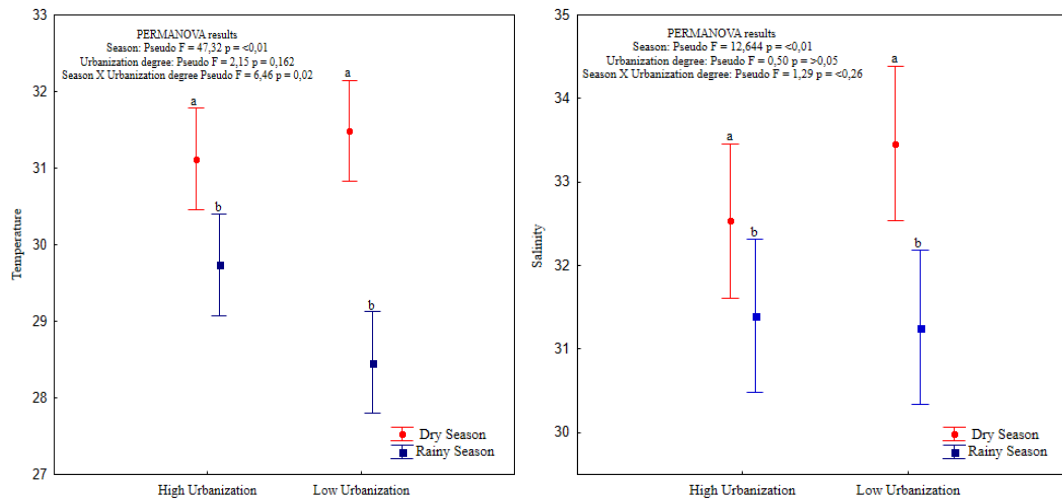


Table 1 - PERMANOVA results for environmental parameters from sandy beaches on the tropical Brazilian coast.

Source of variation	DF ¹	SS ²	MS ³	Pseudo-F	p(permutation) ⁴	Unique permutations
UD ⁵	1	79.6	79.6	19.29	< 0.01	998
SEA ⁶	1	85.83	85.83	20.8	< 0.01	999
UD x SEA	1	28.99	28.99	7.03	< 0.01	998
Res	44	181.59	4.13			
Total	47	376				

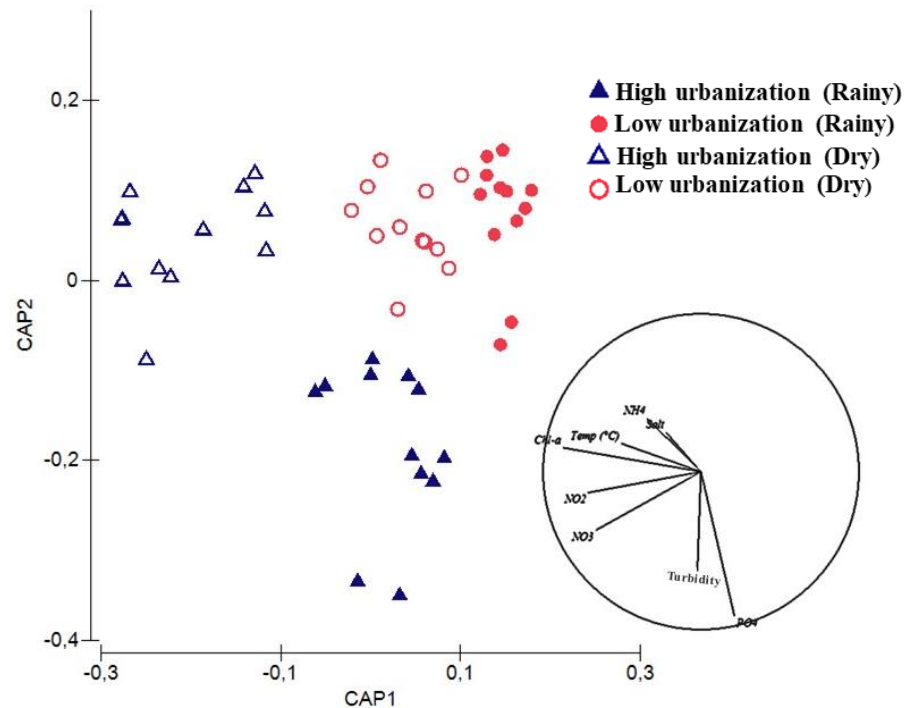
Pair-wise tests

Rainy season			Dry season		
Groups	t	P(permutation)	Groups	t	P(permutation)
HU, LU	2.88	< 0.01	HU, LU	4.57	< 0.01

High urbanization			Low urbanization		
Groups	t	P(permutation)	Groups	t	P(permutation)
Rainy,Dry	4.15	< 0.01	Rainy,Dry	3.32	< 0.01

¹ DF: Degree of Freedom, ² SS: Sum of Squares, ³ MS: Mean Square, ⁴ p(permutation): p value after permutation, ⁵UD: Urbanization degree. ⁶ SEA: Season

Figure 3 - Plot of CAP for environmental variables. The vectors represent variables with more than 50% of correlation (Spearman) with the axes.



3.2 Macroalgae Structure Complexity

In general, the morphological attributes of macroalgae did not vary significantly between seasons and degrees of urbanization (table 2). Exceptions were the height in *Gelidium* spp., that significantly higher in the dry season in both degrees of urbanization (table 2) and the values of fractal dimension of area (Da) in *Palisada perforata* that were significantly higher in the dry season in the low urbanization beaches (table 2). In the HU beach's height, Da and Dp behaved similarly for the 3 macroalgae, with the highest values recorded in the dry season (table 2). In general, the morphological attributes of the macroalgae showed significant variation only between collection sites. The structural complexity of the macroalgae did not vary significantly between the degrees of urbanization and seasons (table 3).

Table 2 –Morphological attributes (mean $\pm$ standard deviation) of macroalgae from sandstone reefs on the tropical Brazilian coast. The letters indicate the results of pair-wise test carried out after significant PERMANOVA results.

		High urbanization ^a		Low urbanization ^b	
		Dry	Rainy	Dry	Rainy
<i>Gelidium</i> spp.	Height	2.74 $\pm$ 0.62	2.45 $\pm$ 0.98	3.18 $\pm$ 1.06	62.2 $\pm$ 1.14
	IHV	87.43 $\pm$ 47.36	75.99 $\pm$ 35.01	93.72 $\pm$ 152.5	154.73 $\pm$ 200.3
	Da	1.59 $\pm$ 0.05	1.56 $\pm$ 0.08	1.6 $\pm$ 0.06	1.62 $\pm$ 0.08
	Dp	1.58 $\pm$ 0.04	1.57 $\pm$ 0.05	1.59 $\pm$ 0.06	1.56 $\pm$ 0.11
<i>Palisada perforata</i>	Height	4 $\pm$ 1.14	3.53 $\pm$ 0.81	3.67 $\pm$ 0.86	3.69 $\pm$ 1.03
	IHV	39.43 $\pm$ 22.18	42.67 $\pm$ 22.03	42.56 $\pm$ 32.85	33.41 $\pm$ 19.72
	Da	1.64 $\pm$ 0.05	1.58 $\pm$ 0.06	1.63 $\pm$ 0.05^a	1.57 $\pm$ 0.07^b
	Dp	1.49 $\pm$ 0.06	1.48 $\pm$ 0.05	1.49 $\pm$ 0.07	1.49 $\pm$ 0.05
<i>Gelidiella acerosa</i>	Height	3.73 $\pm$ 1.08	3.01 $\pm$ 0.98	4.19 $\pm$ 0.96	4.22 $\pm$ 1.36
	IHV	79.77 $\pm$ 37.28	80.14 $\pm$ 32.23	89.28 $\pm$ 39.85	79.52 $\pm$ 40.41
	Da	1.46 $\pm$ 0.13	1.41 $\pm$ 0.15	1.46 $\pm$ 0.12	1.47 $\pm$ 0.10
	Dp	1.45 $\pm$ 0.11	1.44 $\pm$ 0.13	1.47 $\pm$ 0.12	1.51 $\pm$ 0.10

IHV:p>0,05, DA: p< 0,01 DP:p>0,05 and Height: p<0,05

Table 3 - PERMANOVA results for structural complexity of macroalgae from coastal sandstone reefs on the tropical Brazilian coast.

<i>Gelidium</i> spp.						
Source of variation	DF ¹	SS ²	MS ³	Pseudo-F	p(permutation) ⁴	Unique permutations
UD ⁵	1	3.61	3.61	0.26	0.92	826
SEA ⁶	1	30.17	30.17	3.17	0.05	999
UD x SEA	1	16.25	16.25	1.71	0.21	998
Res	199	516.52	2.60			
Total	211	844				
<i>Palisada perforata</i>						
UD ⁵	1	3.23	3.23	0.23	0.89	336
SEA ⁶	1	48.04	48.04	2.57	0.1	999
UD x SEA	1	4.65	4.65	0.25	0.89	999
Res	200	655.36	3.28			
Total	211	844				
<i>Gelidiella acerosa</i>						
UD ⁵	1	40.73	40.73	1.17	0.17	60
SEA ⁶	1	7.46	7.46	0.62	0.57	998
UD x SEA	1	10.89	10.89	0.90	0.45	998
Res	203	608.65	3.00			
Total	214	856				

¹ DF: Degree of Freedom. ² SS: Sum of Squares. ³ MS: Mean Square. ⁴ p(permutation): p value after permutation.

⁵UD: Urbanization degree. ⁶ SEA: Season

3.3 Macrofauna structure

A total of 26,642 individuals were identified, belonging to the phyla Cnidaria, Platyhelminthes, Mollusca, Annelida, Arthropoda, Nemertea and Echinodermata, with dominance of Amphipoda and Polychaeta. The abundances were significantly higher on HU beaches (table 4). Sample completeness for richness ($q=0$), abundant species ($q=1$) and dominant species ($q=2$) were 100%. In all macroalgae the species richness and diversity (abundant and dominant species) were higher in the dry season, and lowest on reefs with a high degree of urbanization during the rainy season (table 5). The structure of the communities in all macroalgae varied significantly between the degrees of urbanization and seasons (significant interaction between factors for *G. acerosa* and *P. perforata*) (table 6). The structure of macrofaunal communities in *P. perforata* and *G. acerosa* varied significantly between HU and LU beaches in the dry and rainy periods, as well as there was significant variation between degrees of urbanization in the dry and rainy seasons (table 7). In the CAP graph, it is possible to identify 3 groups for *G. acerosa* (δ^2 CAP1: 0.77; δ^2 CAP2: 0.67 - 81,944% of samples correctly classified) (figure 4A) and *P. perforata* (δ^2 CAP1: 0.63; δ^2 CAP2: 0.56 - 73.611% of samples correctly classified) (figure 4B) and 2 groups for *Gelidium* sp (δ^2 CAP1: 0.75; δ^2 CAP2: 0.32 - 61.111% of samples correctly classified) (figure 4C).

Table 4 - Abundance (mean $\pm$ standard deviation) of the macrofauna in macroalgae from sandstone reefs on the tropical Brazilian coast, with results of PERMANOVA.

	High urbanization		Low urbanization		Pair - Wise
	Dry	Rainy	Dry	Rainy	
<i>Gelidium</i> spp.	24.29 $\pm$ 8.04	15.63 $\pm$ 8.75	16.47 $\pm$ 6.63	15.81 $\pm$ 4.93	HU=LU D>R HUD>HUR=LUR=LUD
<i>Palisada perforata</i>	34.31 $\pm$ 12.93	21.44 $\pm$ 5.99	25.30 $\pm$ 6.18	21.76 $\pm$ 7.35	HU=LU D>R HUD>HUR=LUR=LUD
<i>Gelidiella acerosa</i>	23.28 $\pm$ 5.19	19.21 $\pm$ 5.99	21.47 $\pm$ 6.91	13.31 $\pm$ 6.34	HU>LU D>R HUD=HUR=LUR=LUD

¹ HU: High urbanization. LU: Low urbanization. ³D: Dry season. R: Rainy season.

Table 5 - Diversity profile of the macrofauna in macroalgae from sandstone reefs on the tropical Brazilian coast. C: Sample completeness. q=0 (species richness). q=1 (diversity of common species). q=2 (diversity of dominant species).

<i>Gelidium spp.</i>				
	C	q=0	q=1	q=2
HUD	100%	29.0	9.80	7.43
LUD	100%	30.0	13.71	10.02
HUR	100%	26.0	8.86	5.44
LUR	100%	30.0	11.43	7.40
<i>Palisada perforata</i>				
HUD	100%	28.0	6.50	3.86
LUD	100%	28.0	7.20	4.39
HUR	100%	22.0	7.40	4.98
LUR	100%	26.0	7.65	4.22
<i>Gelidiella acerosa</i>				
HUD	100%	27.0	11.09	7.66
LUD	100%	38.0	9.71	5.92
HUR	100%	22.0	9.47	6.82
LUR	100%	26.0	9.52	6.47

HUD: High urbanization (Dry season). LUD: Low urbanization (Dry season). HUR: High urbanization (Rainy season). LUR: Low urbanization (Rainy season). C: Sample completeness.

Table 6 - PERMANOVA results for the macrofauna of macroalgae from coastal sandstone reefs on the tropical Brazilian coast.

<i>Gelidium spp.</i>						
Source of variation	DF ¹	SS ²	MS ³	Pseudo -F	p(perm) ⁴	Unique permutations
UD	1	8697.9	8697.9	4.74	< 0.01	998
SEA	1	7820.1	7820.1	4.26	< 0.01	999
UD x SEA	1	3074.1	3074.1	1.7	0.07	998
Res	68	124800	1835.3			
Total	71	144390				
<i>Palisada perforata</i>						
Source of variation	DF ¹	SS ²	MS ³	Pseudo -F	p(perm) ⁴	Unique permutations
UD	1	6345.9	6345.9	4.83	< 0.01	999
SEA	1	11040	11040	8.41	< 0.01	998
UD x SEA	1	5203.9	5203.9	3.96	< 0.01	999
Res	68	89266	1312.7			
Total	71	1.12E+05				
<i>Gelidiella acerosa</i>						
Source of variation	DF ¹	SS ²	MS ³	Pseudo -F	p(perm) ⁴	Unique permutations

UD	1	9955.2	9955	6.78	< 0.01	998
SEA	1	11814	11814	8.04	< 0.01	999
UD x SEA	1	6342	6342	4.32	< 0.01	996
Res	68	99899	1469			
Total	71	1.28E+05				

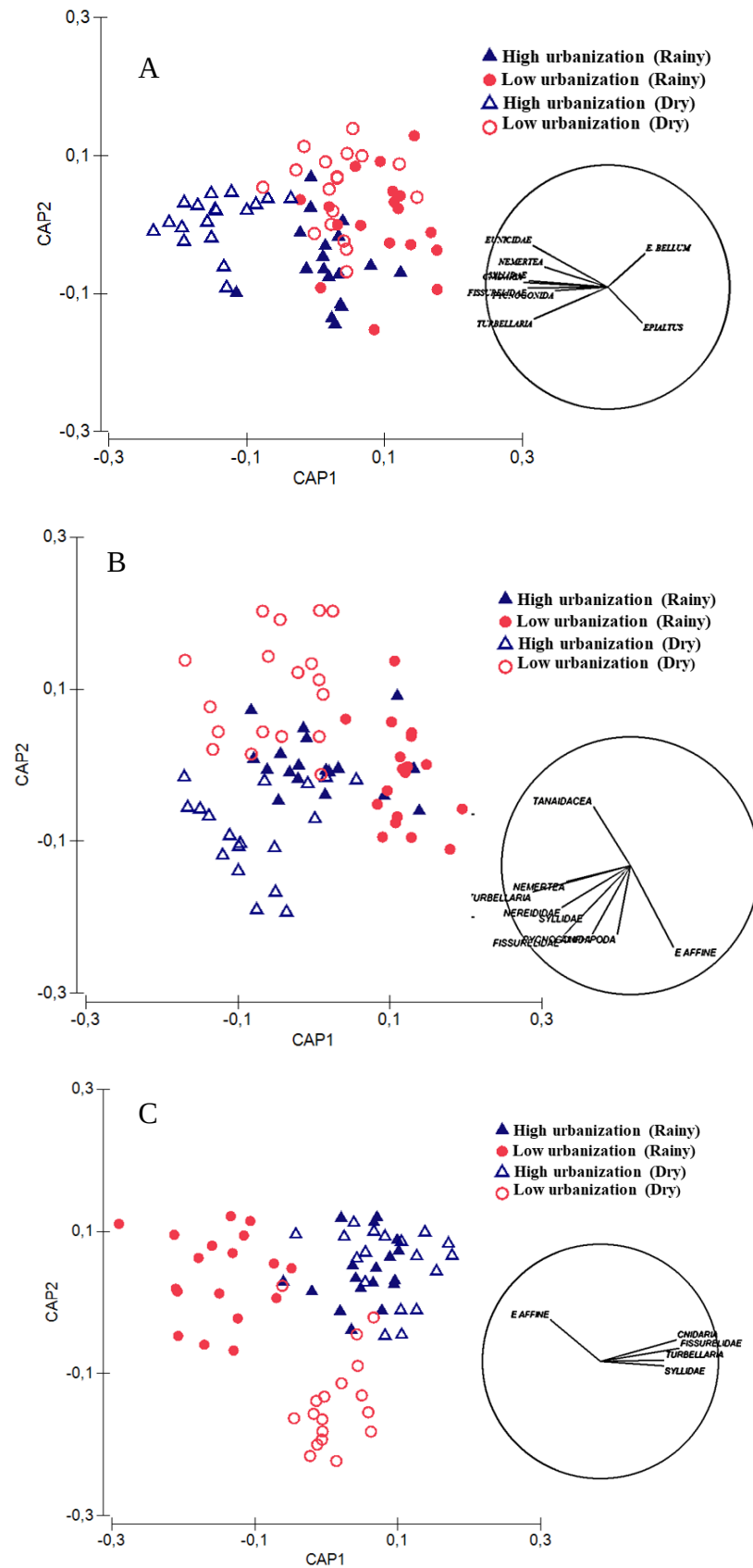
¹ DF: Degree of Freedom. ² SS: Sum of Squares. ³ MS: Mean Square. ⁴ p(permutation): p value after permutation. ⁵ Mean resemblance within/between groups. *: p < 0.05. UD: Urbanization degree. ⁶ SEA: Season

Table 7 - Result of Pairwise tests (for the macrofauna of macroalgae from coastal sandstone reefs on the tropical Brazilian coast.

<i>Palisada perforata</i>					
Rainy season			Dry season		
Groups	t	P(permutation)	Groups	t	P(permutation)
HU, LU	1.45	0.04	HU, LU	2.65	< 0.01
High urbanization			Low urbanization		
Groups	t	P(permutation)	Groups	t	P(permutation)
HUR, HUD	2.51	< 0.01	LUR, LUD	2.47	< 0.01
<i>Gelidiella acerosa</i>					
Rainy season			Dry season		
Groups	t	P(permutation)	Groups	t	P(permutation)
HU, LU	2.57	< 0.01	HU, LU	2	< 0.01
High urbanization			Low urbanization		
Groups		P(permutation)	Groups	t	P(permutation)
HUR, HUD	1.87	< 0.01	LUR, LUD	2.84	< 0.01

HUD: High urbanization (Dry season), LUD: Low urbanization (Dry season), HUR: High urbanization (Rainy season), LUR: Low urbanization (Rainy season).

Figure 4 - Canonical analysis of principal coordinates (CAP) of the macrofauna associated with the macroalgae. The vectors represent the components that best explain the formation of the groups.



A: *Gelidium* spp.; B: *Palisada perforata*; C: *Gelidiella acerosa*.

3.3.1 Macrofauna structure x morphological attributes of macroalgae and environmental variables

The best models fitted for the relation between macrofauna and environmental characteristics explained 10 and % of variation in *G. acerosa*, *Gelidium* sp, and *P. perforata* respectively. The variables that best explained the variation in the epifauna of *Gelidium* spp and *G. acerosa* (table 8) was turbidity and temperature in *P. perforata* (table 8). All models fitted for the relationship between the macrofauna and the structural characteristics of macroalgae explained less than 5% of the variance.

Table 8 - Best models fitted for the relationship between environmental variables and the macrofauna of macroalgae from coastal sandstone reefs on the tropical Brazilian coast.

<i>Gelidium</i> spp.			
AIC: 360.26	R ² : 0.27	RSS: 287.4	
Variable	Pseudo-F	P	Prop. (%)
Turbidity	4.88	<0.01	9
Phosphate	2.61	0.01	5
Ammonia	2.61	0.01	4
Salinity	1.88	< 0.01	3
Nitrite	.007	0.02	3
<i>Palisada perforata</i>			
AIC: 351	R ² : 0.19234	RSS: 60899	
Variable	Pseudo-F	P	Prop. (%)
Temperature	4.95	<0.01	9
Salinity	2.55	< 0.01	4
Chlorophyll <i>a</i>	2.27	0.02	4
Nitrate	1.99	0.05	3
<i>Gelidiella acerosa</i>			
AIC: 358.12	R ² : 0.17298	RSS: 73639	
Variable	Pseudo-F	P	Prop. (%)
Turbidity	3.94	<0.01	10
Salinity	5.15	<0.01	7

4. Discussion

4.1 Environmental parameters

Most environmental parameters responded significantly to seasonal climate variations.

In northeastern Brazil the climate is driven by the Intertropical Convergence Zone (ITCZ), which migrates meridionally during the year and controls rainfall and wind regimes (Nimer 1979; McGregor & Nieuwolt 1998). The Pernambuco coast has a Tropical Atlantic climate with annual rainfall around 2000 mm, with a dry season from October to March and a rainy season between April and ends in September (Domingues et al., 2017). Following rainfall changes the coastal river regimes also change seasonally, with maximum flow immediately after the months of maximum rainfall (Silva et al., 2009a; Schettini et al., 2016). These seasonal changes in rainfall and river flow are essential to understanding biological processes in the coastal zone, since in tropical and subtropical areas the rainfall regime is among the most important drivers of hydrological characteristics and primary productivity in coastal areas (Sassi, 1991; Silva, et al., 2009b).

The water temperature was maximum in the dry season and the minimum in the rainy season, a seasonal pattern already described for the continental shelf of northeastern Brazil (Domingues et al., 2017; Schettini et al., 2017). Similar to the temperature, salinity had a seasonal pattern of changes, with maximum in the dry season, as already recorded by other authors in the region (Koenig & Macêdo, 1999; Cordeiro et al., 2014). In the rainy season, when rainfall is maximum and rivers flow are maximum, the greater freshwater intrusion results in lower salinities. Chlorophyll *a* concentrations were higher during the dry season, when nutrient concentrations were also maximum. Other studies in the northeastern region of Brazil found this association between low rainfall and high chlorophyll *a* (Feitosa et al., 1999; Cordeiro et al., 2014).

High temperature associated with nutrient availability directly affects the phytoplankton, promoting increased growth and reproduction rates, resulting in higher chlorophyll concentrations (Silva et al., 2017). The lower phosphate concentrations recorded during the dry season may also be a consequence of phytoplankton growth, since this nutrient is used by these organisms (Lomas et al., 2014). Barradas et al (2012) and Silva et al (2021) point out that higher nutrient concentrations during the dry season may be related to an increase in the intensity of tourist activity in coastal regions, which ends up increasing anthropogenic pressures and consequently the input of nutrients into these environments. On the other hand, higher concentrations of phosphate and turbidity were recorded during the rainy season, when maximum river flow occurs. Feitosa et al (1999) found in the Pina Basin indicate that during the rainy season there is a greater intrusion of freshwater into coastal ecosystems, increasing suspended particulate matter as well as concentrations of phosphate and other nutrients.

Nutrient concentrations were significantly higher in highly urbanized regions. Highly urbanized environments are characterized by the high input wastewater and sewage to water bodies, resulting in increase of nutrient concentrations (Gray et al., 2002). In the Northeast region of Brazil, other studies have already shown a positive correlation between nutrient levels and urbanization (Feitosa et al., 199; Santos et al., 2020). Some important coastal rivers, such as the Capibaribe and Jaboatão rivers have their margins very urbanized and are well known by their high input of nutrients to the coastal area (Collier et al., 2019; Silva et al., 2019). The profile of environmental parameters in highly and sparsely urbanized regions reinforces the impacts of urbanization in these environments, especially the presence of domestic sewage effluent, which contributes to an increase in nutrient concentrations.

4.2 Macroalgae Structure

The morphology of macroalgae can change in response to several factors, including hydrodynamic forces, light, temperature, nutrient availability, life history, and biological interactions such as herbivory (Diaz-Pulido et al., 2007). Despite changes in water chemistry in urbanized environments, no significant variations in morphological characteristics of macroalgae were observed across seasonal periods and levels of urbanization, except for height in *Gelidium* spp. and *Da* in *Palisada perforata*, which were significantly greater during the dry season.

Several studies (Terlizzi et al., 2002; Orfanidis et al., 2003; see Areces et al., 2015) have identified the genus *Gelidium* as an opportunistic taxon, with populations thriving in urbanized areas and even showing higher densities near sewage outfalls (May, 1985). Opportunistic macroalgae such as *Gelidium* spp. benefit from environments with elevated organic loads, which allow for rapid nutrient uptake (Bellgrove et al., 2017). Therefore, *Gelidium* spp. may have benefited from the higher nutrient concentrations during the dry season, particularly in highly urbanized beaches, facilitating increased growth. In subtropical areas *Gelidium corneum* (as *sesquipedale*) shows frond elongation seasonal pattern: high during spring and summer, and low in the winter (Santos, 1994). *Da* (Dimension area) indicates how the perception of surface area might change with scale, while *Dp* relates to the nature of the gaps between the plant parts (McAbendroth et al, 2005). *Palisada perforata* (previously classified as *Laurencia papillosa*) has already shown higher growth rates at higher temperatures and in the presence of higher nutrient concentrations (Tsai et al., 2005). In addition, *P. perforata* has already been recorded in different reef microhabitats (Vasconcelos et al., 2021), which demonstrates the plasticity of this alga due to habitat and seasonal variation. Surface area is an important factor in the efficient

assimilation of nutrients by macroalgae (Hein et al., 1995). Therefore, it is possible to hypothesize that the higher Da values in *P. perforata* may be related to a more efficient nutrient assimilation strategy in highly urbanized areas, especially during the dry season, when the nutrient load was higher.

(Diaz-Pulido et al., 2007).

Although they did not vary significantly, higher values for height, Da and Dp were recorded during the dry season in the highly urbanized regions. These results are in line with those of Rodrigues (2018) where greater structural complexity was found in *Sargassum* during the summer months. The highest temperatures and nutrient concentrations were also found during the dry season. Temperature and luminosity act positively on metabolic processes such as photosynthesis and respiration, favoring vegetative growth, increased complexity and biomass of macroalgae (Boulos et al., 2007; Rodrigues, 2018; Marinho, 2020).

Despite the higher concentrations of nutrients in the urbanized beaches, Brazilian legislation (CONAMA N° 357/2005) does not define which nutrient concentrations are characteristic of a eutrophic environment, which makes it difficult to determine the trophic state of these environments, especially for coral reef areas. It makes it possible to hypothesize that the higher organic and inorganic nutrient loads in the highly urbanized regions was not enough to significantly alter the structural complexity of the macroalgae. Although the species studied did not demonstrate the effect of urbanization on structural complexity, macroalgae communities in northeastern Brazil have already satisfactorily demonstrated the effect of urbanization (Portugal et al., 2016; Vasconcelos et al., 2019), which demonstrates that the same species can respond in different ways to human impact depending on the scale studied.

4.3 Macrofauna communities

Invertebrates belonging to the phylum Cnidaria, Platyhelminthes, Mollusca, Annelida, Nemertea, Arthropoda and Echinodermata were recorded in all macroalgae and areas. Amphipoda and Polychaeta were the most abundant taxa, as found in other studies about epiphytic macrofauna on macroalgae (Guerra-García et al., 2011a; Tano et al., 2016; Leite et al., 2021). Vegetated ecosystems, such as macroalgae beds, are known to support a greater abundance, richness and diversity of marine invertebrates compared to non-vegetated ecosystems (Sheridan, 1997; Serrano & Preciado, 2006; Hamdy et al., 2018). These environments provide refuge from predators (Hauser et al., 2006) and mitigate environmental conditions, since macroalgae soften hydrodynamic action (Hendriks et al., 2009; Hamdy et al., 2018) and prevent desiccation by retaining water even during low tide (Serrano & Preciado,

2006). In addition to abiotic factors, macroalgae can also positively affect biotic factors. Some species of polychaetes seek out the phytal environment for food, either to feed on the organic matter retained in the vegetation (Frojan et al., 2005; Ramos, 2010; Carvalho et al., 2017) or to feed directly on the macroalgae or associated epiphytic algae (Oliver et al., 1996; Gambi et al., 2000; Raffaelli, 2000).

The dominance of amphipods in macroalgae has already been documented in other studies (Jacobucci & Leite, 2002; Guerra-García et al., 2011b; Rosa Filho et al., 2024). These organisms have several morphological adaptations that favor their development in macroalgae, such as they are covered by an exoskeleton that protect them from desiccation and chelated or hook-shaped appendages that provide greater adhesion to macroalgae stalks (Fenwick, 1976; Jacobucci et al., 2019). The success of amphipods in macroalgae is also related to the diversity of feeding strategies and habitat selection that these organisms present, with some amphipod species having the ability to present more generalist diets when necessary (Leite et al., 2021). In addition to these factors, the increase in the abundance of amphipods may also be a response to the habitat in which they are found, since these organisms respond positively to increases in the structural complexity and biomass of macroalgae (Lewis & Stoner, 1983; Carvalho et al., 2017).

Polychaetes, along with amphipods and molluscs, are commonly described as dominant organisms in the seaweed phytal (Tano et al., 2016). The dominance of polychaete species was already recorded in rhodophytes (Hamdy et al., 2018; Craveiro & Rosa Filho, 2024), and pointed out that complex algae such as *Gelidiella acerosa* favour the establishment and survival of dense polychaete populations. Polychaetes have a very diverse feeding, reproductive and survival strategies (Giangrande, 1997; Cunha et al., 2013; Fauchald & Jumars, 1979; Jumars et al., 2015), which ultimately allows them to succeed in almost all marine environments, particularly on those as morphologically complex as seaweeds (Hadiyanto et al., 2024). Algal coverage enhances habitat variation, supporting a higher number of polychaete species than less complex habitats (Giangrande, 1988; Chemelo & Milazzo, 2002). As shown by Antoniadou & Chintiroglou (2006) and Craveiro & Rosa Filho (2024), polychaetes can use macroalgae as feeding area, whether the animals are carnivorous, herbivorous or deposit feeders, since algae can be directly consumed, they accumulate detritus on branches, holdfast or blades, or even support dense populations of prey. Also, the reproduction of some species of polychaete are modulated by the presence of macroalgae which stimulate the recruitment or provide nutrient-rich food for juveniles (Oliver et al., 1996; Bazterrica et al., 2014).

The species richness and diversity were lowest in the rainy season, and on the high urbanization beaches. During the rainy season there is a general increase in the physical stress generated by greater intensity of winds and waves and a reduction in salinity (Silva et al., 2009a; Melo et al., 2013; Schettini et al., 2016). Hydrodynamics make the rocky intertidal zone one of the most physically stressful environments on the planet (Jensen & Denny, 2016) and is one of the most important environmental drives of benthic communities in coastal hard bottoms (Koehl, 1984; Burel et al., 2022). The physiological stress resulting from low salinity results in lower abundance, diversity and richness of macrofauna in coastal and estuarine areas (Braga et al., 2013; Melo et al., 2013; Palmer et al., 2016; Lowe et al., 2022). On the other hand, higher salinity during the dry months favors the reproduction in marine animals (Alves et al., 2023; Rosa Filho et al., 2024), as well as a greater food supply for herbivores, since epiphytic algae increase their populations during the dry season and can act as a food source for epiphytic fauna (Viejo, 1999; Gambi et al., 2000; Zheng et al., 2015).

Decreases in species richness have already been recorded as response to urbanization in beaches (Augusto et al., 2023). Also, the presence of bathers and the coastal occupation in beaches act negatively in species richness and abundance (Corte et al., 2022). In the present study, the structure of the macrofauna responded in a similar way to other studies about the effect of anthropogenic disturbances on macrofauna, with higher abundance, but lower diversity and richness, in highly urbanized areas (Pearson & Rosenberg, 1978; Fitch & Crowe, 2012). Lower richness and diversity are usually associated with the exclusion of species that are more sensitive to impact (Hubbard et al., 2014; Orlando et al., 2020). The exclusion of sensitive species is followed by the monopolization of resources by tolerant species, which results in higher macrofaunal abundances in impacted environments (Pearson & Rosenberg, 1978; Johnston & Roberts, 2009).

The abundance of macrobenthos was significantly higher on highly urbanized beaches. Higher abundances of macrofauna in impacted environments are related to the presence of opportunistic species (Ganesh et al., 2014), higher loads of organic matter commonly present in urbanized regions can act as a food source for macrofauna, allowing for higher abundances (Pearson & Rosenberg, 1978; Savage et al., 2002; Nasi et al., 2023), especially species tolerant of environments with anthropogenic disturbances.

The dominance of amphipods in impacted areas are not common, since these taxa and other crustaceans are commonly regarded as sensitive to contamination (Cesar et al., 2002; De-La-Ossa-Carretero et al., 2012; Navarro-Barranco et al., 2020). However, the low taxonomic resolution used in the present study difficult comparisons with other studies, where the majority

of amphipods were identified at the species level, especially due to the fact that some amphipod species respond differently to pollution, sometimes being more tolerant to impacts (De-La-Ossa-Carretero et al., 2012). One possible hypothesis is that the composition of amphipods in the areas studied is made up of these species that are tolerant to contamination, which allowed the higher abundances recorded in the highly urbanized areas. In addition, other authors have found higher abundances of amphipods near impacted areas and hypothesized that the higher abundances were due to the increased structural complexity of the habitat due to the presence of macroalgae (Vinagre et al., 2016). In highly urbanized environments, the algae were more complex, although not significantly, a factor that may also have contributed to the higher abundances of amphipods found in this study.

The abundance of polychaetes was considerably higher in highly urbanized areas. This pattern has already been recorded for other benthic communities in disturbed environments (Cabral-Oliveira et al., 2013; Schmidt et al., 2017; Mosbahi et al., 2019). Some species of polychaetes are known to respond positively to environmental impacts, increasing their abundance and/or biomass (Dean, 2008; Weis et al., 2017). The increased load of organic matter commonly present in impacted environments can act as an additional food source for deposit-feeding polychaete species (Santi & Tavares, 2009). Some polychaete families and species have adaptations that allow them to capture organic matter more efficiently, such as long grooved palps, which can favor them in impacted environments (Santi & Tavares, 2009) and also may take advantage of less stressful conditions because of its ability to feed as omnivore, predator, suspension feeder and deposit feeder (Cardoso et al., 2007).

In addition, some families, such as Syllidae, may have species that behave in completely different ways in the presence of environmental impact (Giangrande et al., 2005), which highlights the importance of taxonomic resolution in order to correctly assess the level of anthropogenic disturbance in the environment. Furthermore, as with amphipods, the increase in the abundance of these organisms may be an indirect response to the effect of nutrient enrichment on macroalgae, as hypothesized by Hamdy et al. (2023). This would be in line with the findings of Craveiro and Rosa Filho (2024), where polychaetes respond directly to variations in the structural complexity of macroalgae. Therefore, the higher abundances of polychaetes found could be both an indirect response to nutrient enrichment of the macroalgae and a direct response of the polychaetes to a greater food supply.

The variables that best explained the variation in the epifauna were turbidity and temperature, and the structural characteristics of macroalgae had a few power of explanation of macrofauna. Phytoplankton blooms can increase the abundance of macrofauna, since they can

act as a source of organic matter for benthos (Zhang et al., 2015), which may have happened in this study, since the highest chlorophyll *a* values coincide with the highest abundances recorded for macrofauna and higher temperatures. Raghunathan et al (2003) point out that higher turbidity rates inhibit phytoplankton production. Therefore, a possible hypothesis is that the higher turbidity reduced the availability of organic matter for the macrofauna, limiting their abundance especially during the rainy season.

Although structural complexity is commonly cited as having an influence on macrofauna (Craveiro & Rosa Filho, 2024), other factors are equally influential in modulating epiphytic fauna, such as substrate quantity (biomass) (Torres et al., 2015), algae chemistry (Fernandes et al., 2021), biological processes such as predation, epiphyte quantity, and food availability (Russo, 1990; Cacabelos et al., 2010), and physical factors like landscape surrounding, hydrodynamics, and desiccation (Schreider et al., 2003; Torres et al., 2015). Moreover, methods for measuring structural complexity utilize two-dimensional photographs, thereby disregarding the three-dimensional structure that macroalgae exhibit, potentially leading to structure overlap and thus neglecting the true complexity of macroalgae (Gee & Warwick, 1994; McAbendroth et al., 2005; Alves, 2020). Therefore, in the present study, it is possible that the low explanatory power of macroalgae structural complexity on macrofauna results from the influence of biological and physical factors, as well as the methods used not fully capturing the structural complexity of macroalgae.

In conclusion, this study contributes to the understanding of the responses of macrofauna and benthic communities to environmental disturbances. Environmental parameters satisfactorily reflected the degree of urbanization of the beaches studied. The highly urbanized environments had higher nutrient loads, which reinforces the role of urbanization in nutritional enrichment in coastal areas.

Macroalgae structural complexity did not respond significantly to urbanization and Only height and Da of *Palisada perforata* and *Gelidium* spp. significantly varied between seasons. The macrofauna responded to the impacts of urbanization, with an increase in abundance and a decrease in species richness and diversity in the highly urbanized areas. Therefore, macrofauna can be used satisfactorily as a bioindicator of anthropogenic disturbances. Despite this, taxonomic resolution is an important factor in accessing environmental impacts, since species within the same group can respond to environmental impact in different ways.

Chlorophyll *a* and turbidity were the variables that best explained the variation in the epifauna. This was probably due to the relationship that these variables have with food

availability and its effect on the macrofauna. The low explanation of the structural complexity of the macrofauna is probably related to these factors, since food availability probably played a more important role in structuring the macrofauna.

The differences in the responses of macrofauna and macroalgae to the factors studied may be due to differences in scale, since the fauna was studied at a population and community level, while the macroalgae was studied at a morphological level. However, studies on morphological scales between macroalgae and macrofauna are necessary in order to better understand the effects of structural complexity on macrofauna and their relationship with environmental disturbances.

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4 CONSIDERAÇÕES FINAIS

A urbanização costeira impacta negativamente a estrutura da macrofauna epifítica de ambientes tropicais, aumentando as abundâncias mas em contrapartida diminuindo a riqueza e diversidade de espécies nos locais altamente urbanizados. Sendo assim, com base no presente estudo, é possível concluir que a macrofauna epifítica funciona como um bioindicador de urbanização na costa do nordeste brasileiro. Além disso, também foi possível constatar que a macrofauna epifítica responde a padrões de variação sazonal, onde a urbanização também segue esse mesmo padrão. Certamente as maiores ofertas de alimentos em regiões altamente urbanizadas favorecem as espécies tolerantes e oportunistas e em contrapartida afetam negativamente as espécies sensíveis. Esses padrões revelam a importância da resolução taxonômica em estudos que objetivam acessar impactos ambientais, uma vez que diferentes espécies de um mesmo grupo podem responder de maneiras completamente distintas a uma mesma fonte de impactação ambiental.

De forma semelhante a macrofauna a concentração dos nutrientes inorgânicos também demonstrou satisfatoriamente o gradiente de urbanização. Maiores concentrações de compostos nitrogenados e fosfato foram registradas nas áreas altamente urbanizadas. O lançamento de efluentes carregando águas eutrofizadas diretamente no ambiente marinho resulta em maiores concentrações desses compostos.

Diferente da macrofauna e dos nutrientes, a complexidade estrutural das macroalgas não respondeu significativamente à urbanização, e apenas a altura e a Da de *Palisada perforata* e *Gelidium* spp. variaram significativamente entre as estações do ano.

Diferenças na disponibilidade de alimentos provavelmente foi um dos fatores de maior importância para estruturação da macrofauna epifítica, especialmente considerando os padrões que a clorofila e a turbidez apresentaram no presente estudo.

As diferenças nas respostas da macrofauna e das macroalgas aos fatores estudados podem ser devidas a diferenças de escala, uma vez que a fauna foi estudada ao nível da população e da comunidade, enquanto as macroalgas foram estudadas ao nível morfológico. No entanto, são necessários estudos em escalas morfológicas entre macroalgas e macrofauna para compreender melhor os efeitos da complexidade estrutural sobre a macrofauna e a sua relação com as perturbações ambientais.

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**ANEXO A - ABUNDANCE OF EPIPHYTIC MACROFAUNA (IND.10G-1 OF DRY MACROALGAE)
ON SANDY REEFS OFF THE BRAZILIAN TROPICAL COAST.**

Results are represented as mean $\pm$ standard deviation.

Taxa	High urbanization		Low urbanization	
	Dry	Rainy	Dry	Rainy
Cnidaria				
Anthozoa spp.	59.7 $\pm$ 80.3	16.6 $\pm$ 30	10.8 $\pm$ 24.4	3.6 $\pm$ 7.7
Platyhelminthes				
Turbellaria spp.	116.9 $\pm$ 107.9	64 $\pm$ 101.6	40.2 $\pm$ 43.6	11.5 $\pm$ 18.8
Mollusca				
Polyplacophora	1.5 $\pm$ 3.5	0.2 $\pm$ 0.9	1.9 $\pm$ 3.9	4.9 $\pm$ 25.3
Nudibranchia	1.7 $\pm$ 4.2	1.2 $\pm$ 3.9	0.1 $\pm$ 0.5	0
Fissurellidae	89.9 $\pm$ 114.3	15.9 $\pm$ 26.4	9.4 $\pm$ 13.4	3.9 $\pm$ 10.9
<i>Costoanachis</i> spp.	0	0.1 $\pm$ 1	0	0
<i>Mitrella</i> spp.	0	0	0.2 $\pm$ 1.2	0
<i>Caecum</i> spp.	0.9 $\pm$ 3.1	1.8 $\pm$ 7.2	19.9 $\pm$ 66.4	9.2 $\pm$ 25.5
<i>Haminoea antillarum</i>	0.1 $\pm$ 1.1	0.4 $\pm$ 1.9	0.2 $\pm$ 1.2	0.3 $\pm$ 1.4
<i>Alaba incerta</i>	0	0	0	0.1 $\pm$ 0.7
<i>Pinctada imbricata</i>	4.9 $\pm$ 11.8	0	2.5 $\pm$ 6.8	0
<i>Rissoina</i> spp.	0	0.2 $\pm$ 1.2	0	0
<i>Eullithidium affine</i>	25.8 $\pm$ 40.7	17 $\pm$ 19.6	7.1 $\pm$ 19.3	54 $\pm$ 86.4
<i>Eullithidium bellum</i>	0	0	2.6 $\pm$ 7	7.5 $\pm$ 19.2
Annelida				
Nereididae	53.1 $\pm$ 72.1	48.9 $\pm$ 86.9	38.3 $\pm$ 59.5	24.2 $\pm$ 26.6
Syllidae	130.4 $\pm$ 93.1	49.8 $\pm$ 65.6	53.6 $\pm$ 53.9	42.8 $\pm$ 62.9
Eunicidae	16.4 $\pm$ 16.1	7.9 $\pm$ 10.4	7.1 $\pm$ 10.8	5.9 $\pm$ 10.8
Spionidae	0.1 $\pm$ 1.1	0	0.1 $\pm$ 0.4	0.1 $\pm$ 0.5
Phyllodocidae	0.6 $\pm$ 2.7	0	0.1 $\pm$ 0.4	0.4 $\pm$ 1.8
<i>Eulalia</i> sp.	0.3 $\pm$ 1.6	0.7 $\pm$ 2.7	0.1 $\pm$ 0.7	0
Polynoidae	0.2 $\pm$ 1	1 $\pm$ 3.7	0.2 $\pm$ 1.4	1.4 $\pm$ 2.8
Orbiniidae	3.9 $\pm$ 16.6	1.3 $\pm$ 5.8	1.5 $\pm$ 10.1	1.2 $\pm$ 6.3
Cirratulidae	1.3 $\pm$ 4.1	1 $\pm$ 4.6	0.3 $\pm$ 1.1	0.5 $\pm$ 1.9
Sabellidae	0.4 $\pm$ 1.6	0	0.4 $\pm$ 1.5	0.9 $\pm$
Capitellidae	0.1 $\pm$ 0.4	0	2 $\pm$ 6.3	0
Ampharetidae	0.7 $\pm$ 2.4	0	0	0
Hesionidae	0.1 $\pm$ 0.7	0	0	0.1 $\pm$ 0.4
Lumbrineridae	2.1 $\pm$ 9.5	0	3.4 $\pm$ 12.1	0

Terebellidae	4.3 ± 8.4	4.9 ± 20.7	2.3 ± 6.2	1.2 ± 3.4
Sipuncula	2.5 ± 6.6	6.5 ± 13.5	6.4 ± 15.1	7.3 ± 13.9

Arthropoda

Amphipoda	262.5±533.2	124 ±113.4	91.3±94.2	117.2±223.3
Tanaidacea spp.	24.2 ±42.6	12.2±21.2	153.3±270.8	16.9±42
Caprellidae	8.9 ±33.8	0	2.6±11.5	0
Isopoda	7.9±21.3	2.7 ±10	9.4±30	1.1±2.4
Ostracoda	0	0	5.7±19.1	4.5±19.6
Cumacea	0	0.1 ±0.7	0	0.3 ±1.5
Pycnogonida	13.5±28.6	1.8± 5	3.1±9	0.6±1.8
Paguroidea	0	0	0.3±1.1	0.2±1.4
Chironomidae	0	0	7.6 ±33	0
<i>Epialtus spp.</i>	1.5±3.2	6.9±8	3.4±6.2	4.6±8.4

Nemertea

Nemertea spp.	10.4 ±13.8	0.7 ±3.5	5.7 ±15.2	0.3 ±2.4
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Echinodermata

Ophiuroidea	3.9 ± 10.1	1.4 ± 3.7	3.4 ± 10	6 ± 17
Holothuria	0	0.2 ± 1.2	0.3 ± 1.5	0.4 ± 1.7
Echinoidea	0	0.1 ± 0.7	0	0

**ANEXO B - ABUNDANCE OF EPIPHYTIC MACROFAUNA (IND.10G-1 OF DRY
MACROALGAE) PER MACROALGAE SPECIES ON SANDY REEFS OFF THE
BRAZILIAN TROPICAL COAST**

Results are represented as mean $\pm$ standard deviation.

Taxa	<i>Gelidium spp.</i>		<i>Palisada perforata</i>		<i>Gelidiella acerosa</i>	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
Cnidaria						
Anthozoa spp.	48.78 $\pm$ 90.22	4.86 $\pm$ 7.65	19.02 $\pm$ 48.32	7.93 $\pm$ 22.08	37.89 $\pm$ 39.49	17.53 $\pm$ 30.88
Platyhelminthes						
Turbellaria spp.	61.33 $\pm$ 95.82	30.99 $\pm$ 64.07	117.74 $\pm$ 103.92	38.39 $\pm$ 87.29	56.68 $\pm$ 52.08	43.86 $\pm$ 80.55
Mollusca						
Polyplacophora	1.21 $\pm$ 2.67	0.98 $\pm$ 2.80	2.12 $\pm$ 5.05	5.82 $\pm$ 30.88	1.79 $\pm$ 2.92	0.84 $\pm$ 2.13
Nudibranchia	0.29 $\pm$ 1.00	0.25 $\pm$ 1.50	1.76 $\pm$ 4.87	0.61 $\pm$ 3.68	0.65 $\pm$ 1.59	0.94 $\pm$ 2.94
Fissurellidae	50.02 $\pm$ 115.32	5.87 $\pm$ 12.32	67.08 $\pm$ 99.79	9.17 $\pm$ 16.60	31.77 $\pm$ 34.27	14.72 $\pm$ 29.50
<i>Costoanachis spp.</i>	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.20 $\pm$ 1.20
<i>Mitrella spp.</i>	0.24 $\pm$ 1.44	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00
<i>Caecum spp.</i>	23.01 $\pm$ 80.99	8.10 $\pm$ 19.29	1.54 $\pm$ 6.13	1.21 $\pm$ 7.29	6.69 $\pm$ 9.98	7.29 $\pm$ 25.61
<i>Haminoea antillarum</i>	0.21 $\pm$ 1.27	0.78 $\pm$ 2.32	0.21 $\pm$ 1.28	0.29 $\pm$ 1.72	0.08 $\pm$ 0.50	0.00 $\pm$ 0.00
<i>Alaba incerta</i>	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.13 $\pm$ 0.77	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00
<i>Pinctada imbricata</i>	1.46 $\pm$ 4.41	0.00 $\pm$ 0.00	3.75 $\pm$ 12.65	0.00 $\pm$ 0.00	5.98 $\pm$ 9.64	0.00 $\pm$ 0.00
<i>Rissoina spp.</i>	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.25 $\pm$ 1.51	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00
<i>Eullithidium affine</i>	14.66 $\pm$ 22.73	20.71 $\pm$ 43.54	27.39 $\pm$ 50.11	53.93 $\pm$ 75.30	7.20 $\pm$ 9.37	31.94 $\pm$ 69.08
<i>Eullithidium bellum</i>	2.42 $\pm$ 7.96	1.88 $\pm$ 6.44	0.50 $\pm$ 1.72	5.52 $\pm$ 20.15	1.00 $\pm$ 3.21	3.82 $\pm$ 12.12
Annelida						
Nereididae	22.76 $\pm$ 41.62	24.89 $\pm$ 29.78	98.87 $\pm$ 83.54	69.96 $\pm$ 100.25	15.53 $\pm$ 17.37	14.78 $\pm$ 15.89
Syllidae	94.75 $\pm$ 91.01	44.43 $\pm$ 67.98	69.58 $\pm$ 69.18	38.16 $\pm$ 53.33	111.56 $\pm$ 89.91	56.27 $\pm$ 70.02
Eunicidae	14.51 $\pm$ 14.66	4.20 $\pm$ 7.11	5.63 $\pm$ 6.84	5.04 $\pm$ 9.59	15.10 $\pm$ 17.92	11.57 $\pm$ 12.83
Spionidae	0.00 $\pm$ 0.00	0.10 $\pm$ 0.62	0.22 $\pm$ 1.30	0.00 $\pm$ 0.00	0.09 $\pm$ 0.52	0.00 $\pm$ 0.00
Phyllodocidae	0.21 $\pm$ 0.88	0.36 $\pm$ 1.49	0.28 $\pm$ 1.69	0.68 $\pm$ 3.17	0.54 $\pm$ 2.78	0.28 $\pm$ 1.67
<i>Eulalia spp.</i>	0.00 $\pm$ 0.00	0.28 $\pm$ 1.16	0.56 $\pm$ 2.00	0.68 $\pm$ 3.17	0.07 $\pm$ 0.45	0.10 $\pm$ 0.62
Polynoidae	0.29 $\pm$ 1.74	1.49 $\pm$ 3.53	0.15 $\pm$ 0.90	1.25 $\pm$ 4.00	0.21 $\pm$ 0.93	0.84 $\pm$ 2.01
Orbiniidae	0.45 $\pm$ 1.67	0.62 $\pm$ 2.09	5.99 $\pm$ 22.83	1.27 $\pm$ 7.64	1.70 $\pm$ 6.02	1.82 $\pm$ 7.00
Cirratulidae	0.62 $\pm$ 2.65	0.97 $\pm$ 2.68	0.55 $\pm$ 2.68	1.29 $\pm$ 5.49	1.20 $\pm$ 3.69	0.10 $\pm$ 0.58
Sabellidae	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.67 $\pm$ 2.07	1.02 $\pm$ 3.69	0.51 $\pm$ 1.61	0.37 $\pm$ 2.24
Capitellidae	0.08 $\pm$ 0.46	0.00 $\pm$ 0.00	0.28 $\pm$ 1.18	0.00 $\pm$ 0.00	2.69 $\pm$ 7.58	0.00 $\pm$ 0.00
Ampharetidae	0.34 $\pm$ 2.06	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.69 $\pm$ 2.24	0.00 $\pm$ 0.00
Hesionidae	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.14 $\pm$ 0.84	0.10 $\pm$ 0.58

Lumbrineridae	3.02 ± 11.47	0.00 ± 0.00	4.17 ± 13.63	0.00 ± 0.00	1.12 ± 6.24	0.00 ± 0.00
Terebellidae	2.11 ± 4.29	1.12 ± 3.23	3.46 ± 7.65	3.05 ± 6.45	4.20 ± 9.46	4.88 ± 24.86
Sipuncula	3.27 ± 7.49	11.26 ± 17.68	5.86 ± 15.71	3.87 ± 7.45	4.09 ± 11.02	5.61 ± 13.08

Arthropoda

Amphipoda	66.40 ± 79.57	94.31 ± 98.80	373.43 ± 626.02	196.99 ± 266.38	90.97 ± 92.34	70.51 ± 70.58
Tanaidacea spp.	21.88 ± 47.78	9.10 ± 17.26	151.20 ± 279.22	25.95 ± 50.28	93.31 ± 194.48	8.51 ± 18.52
Caprellidae	5.17 ± 14.71	0.00 ± 0.00	0.46 ± 1.94	0.00 ± 0.00	11.69 ± 40.96	0.00 ± 0.00
Isopoda	14.32 ± 36.28	4.20 ± 11.90	6.31 ± 21.68	0.32 ± 1.34	5.34 ± 14.66	1.19 ± 3.42
Ostracoda	1.33 ± 5.65	3.63 ± 15.60	0.76 ± 3.29	3.12 ± 18.70	6.49 ± 22.60	0.00 ± 0.00
Cumacea	0.00 ± 0.00	0.13 ± 0.83	0.00 ± 0.00	0.29 ± 1.72	0.00 ± 0.00	0.12 ± 0.74
Pycnogonida	9.22 ± 31.53	1.24 ± 2.98	8.27 ± 17.10	0.67 ± 2.47	7.40 ± 12.30	1.61 ± 5.30
Paguroidea	0.24 ± 1.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.17 ± 1.01	0.29 ± 1.73
Chironomidae	0.00 ± 0.00	0.00 ± 0.00	10.68 ± 39.97	0.00 ± 0.00	0.67 ± 4.01	0.00 ± 0.00
<i>Epialtus spp.</i>	1.57 ± 3.70	4.40 ± 7.52	2.28 ± 4.55	5.44 ± 8.80	3.53 ± 6.29	7.46 ± 8.20

Nemertea

Nemertea spp.	6.56 ± 11.12	0.88 ± 3.23	11.16 ± 20.53	0.71 ± 4.25	6.47 ± 9.78	0.00 ± 0.00
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Echinodermata

Ophiuroidea	6.11 ± 12.93	4.85 ± 9.61	0.97 ± 2.86	5.40 ± 19.01	3.79 ± 10.86	0.76 ± 2.43
Holothuria	0.29 ± 1.74	0.15 ± 0.87	0.00 ± 0.00	0.41 ± 1.89	0.13 ± 0.77	0.32 ± 1.35
Echinoidea	0.13 ± 0.83	0.13 ± 0.83	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00