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Biodiversity assessment using BRUVS in a port area of Pernambuco, northeast Brazil

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ABSTRACT

Located in the second-largest estuary in Pernambuco, Brazil, the Suape Port Industrial Complex (CIPS) and its surroundings are regions of high environmental and economic importance that experience the effects of constant anthropogenic action. To understand the interference of these acts and the marine environment in this area, to identify its taxonomic diversity and abundance, and to guide management and mitigation measures for the fauna and marine ecosystem of this location, using the non-lethal baited remote underwater video system (BRUVS) method, between July 2021 and October 2022, we conducted a survey of the fauna in the coastal zone of the CIPS area, with a sampling area of 180 km^2 and 800 sampling points. Among the 118 species identified, the most abundant were *Haemulon aurolineatum*, *Decapterus macarellus*, and *Caranx crysos*, with a greater association of individuals in the sand/gravel + phytobenthos substrate, sand/gravel, and limestone formation. Although no non-significant differences were observed in the diversity of species by lunar phase, the relative abundance was greater during the new moon. When evaluating the depth gradients, those with the highest relative abundance and diversity were observed in the extracts at 20–25 and 25–30 m.

Keywords: BRUVS; Coastal ecosystem; Ichthyofauna.

Avaliação da biodiversidade utilizando BRUVS em uma área portuária de Pernambuco, nordeste do Brasil

RESUMO

Localizado no segundo maior estuário de Pernambuco, Brasil, o Complexo Industrial Portuário de Suape (CIPS) e seu entorno são regiões de alta importância ambiental e econômica que sofrem os efeitos da constante ação antrópica. Utilizando o método não letal de sistema de vídeo subaquático remoto com isca (BRUVS), para entender a interferência desses atos no ambiente marinho, identificar sua diversidade e abundância taxonômica e orientar medidas de manejo e mitigação desse ecossistema, foi aplicado um esforço amostral entre julho de 2021 e outubro de 2022 para realizar o levantamento da fauna na zona costeira da área do CIPS, com área amostral de 180 km^2 e 800 pontos amostrais. Entre as 118 espécies identificadas, as mais abundantes foram *Haemulon aurolineatum*, *Decapterus macarellus* e *Caranx crysos*, com maior associação de indivíduos no substrato areia/cascalho + fitobentos, areia/cascalho e formação calcária. Embora não tenham sido observadas diferenças significativas na diversidade de espécies por fase lunar, a abundância relativa foi maior durante a lua nova. Ao avaliar os gradientes de profundidade, aqueles com maior abundância relativa e diversidade foram os extratos de 20–25 e 25–30 m.

Palavras-chave: BRUVS; Ecossistema costeiro; Ictiofauna.

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INTRODUCTION

The advent of new technologies has enabled the exploration of environments with fewer extractive samples or without anthropogenic interference (Santana-Garcon et al., 2014). Thus, as the marine environment has a greater sensitivity to stress, studies have been conducted with equipment that provides highly accurate results and generates less interference to the environment, including non-lethal methods of investigating fauna, particularly for organisms threatened by extinction and areas vulnerable to exploitation (MacNeil et al., 2020; Trobbiani et al., 2021).

Among the methods currently used to survey fauna and characterize habitats, the baited remote underwater video system (BRUVS) is an efficient and increasingly popular alternative for environmental studies because of its low cost, ease of use, and comprehensiveness in comparing biological data. Additionally, this technique can be used without the presence of scholars in aquatic environments, and species need not be captured (Trobbiani et al., 2021), making it advantageous for both research and the environment.

Due to its usual variability, BRUVS has been used to analyze populations in more sensitive environments, such as environmental protection areas (APA) and other forms of conservation units (CUs), as well as to infer data on the parameters of environments with high anthropogenic activity; thus, it can be used to survey fauna and estimate relative abundance in these environments (Reis-Filho et al., 2019). The management and conservation of these environments are aimed at protecting them; consequently, there is a tendency to decrease the use of research methods that interfere with ecosystems due to the increasing anthropogenic pressure in these environments. Thus, BRUVS is an efficient alternative for conducting studies in these sensitive areas or those with varying degrees of degradation (MacNeil et al., 2020).

Over the last decade, surveys employing the BRUVS methodology have been conducted more frequently in Brazil. In the northern and northeastern parts of the country, scholars have evaluated the associative effects of species and environments with applications in freshwater, estuarine, and marine ecosystems (Schmid et al., 2017; Schmid & Giarrizzo, 2019; Schmid et al., 2020). Additionally, scholars have investigated environments with anthropogenic pressure, such as the connectivity between marine environments in an urban region in the northeast (Reis-Filho et al., 2019; Rolim et al., 2019). However, in the metropolitan region of Recife (RMR), Pernambuco, Brazil, the second-largest urban area in the northeast, this methodology was used to understand the diversity of marine species that are adversely affected by anthropogenic pressure owing to increasing urbanization (Bezerra et al., 2022). This ecosystem has suffered from the impacts of anthropogenic activities over the last 40 years (Castello, 2010; Jales et al., 2013).

The coastal zone of the RMR suffers from various anthropogenic effects resulting from urban expansion. Decree Nos. 15,750 and 6,025 proposed on August 8, 1992 and January 22, 2007, respectively, were aimed at accelerating industrial growth and development, and had the following consequences in the south region of the RMR: silting of mangroves and wetlands, dredging of estuaries, sediment dispersion, and a greater flow of boats, thus altering the parameters of submerged and emerging aquatic ecosystems (Magarotto & Costa, 2018; Magarotto et al., 2020). This region is of great ecological and socioeconomic importance due to the presence of the second-largest estuary and largest port complex in the state (Suape, 2023).

South of the state of Pernambuco, the port area of the Suape Port Industrial Complex (CIPS), located in the municipalities of Cabo do Santo, Agostinho, and Ipojuca, is of great importance to the state and ranks as the second largest industrial port in northeastern Brazil (Conexos, 2023). CIPS is one of the main exporters of national economic and technological development owing to its loading and unloading. It is a place with high industrial development and continuous anthropogenic activity characterized by constant changes to submerged and emerging geography (Suape, 2023). However, the actual consequences of such landscape changes in the region are unknown, and few qualitative and quantitative studies have been conducted to investigate the diversity of underwater fauna in port areas.

Understanding the marine environment of port areas and interference of anthropogenic activities requires data to fill the gaps in such an unexplored environment that is constantly changing. Moreover, the taxonomic diversity must be identified to understand and guide management and mitigation measures for the fauna and marine ecosystem of this location. This coastal environment is of great ecological importance, serving as a spawning, growth, and feeding area for local and migratory species, exhibiting an interdependence between living beings and the environment, with great taxonomic variety and biological complexity (Ferreira & Maida, 2006; Jales et al., 2013). Accordingly, the objective of this study was to survey the marine fauna using BRUVS to elucidate the biodiversity of the CIPS, with the goal of providing subsidies for the implementation of measures aimed at conserving the species in this region.

MATERIAL AND METHODS

Study area

The study was conducted in the second largest port complex in northeastern Brazil (Conexos, 2023), namely, the CIPS, located in Pernambuco, south of the RMR (08°23’41.2”S – 34°57’09.6”W). The CIPS is located in a tropical region and has a humid tropical climate, with an annual average temperature of 25°C and average annual rainfall of more than 2,000 mm, concentrated between April and July (Suape, 2023). It was established in the second largest hydrographic basin in Pernambuco, which is used for industrial, agricultural, and urban supply. The prevailing winds in this region are from the east and southeast and seasonally from the northeast. The tidal regime is semi-diurnal, and the average variations are 2.04 and 0.91 m in syzygy and quadrature, respectively (Suape, 2023).

Sampling was conducted in an area of 180.97 km^2, close to the port in the municipalities of Cabo de Santo Agostinho and Ipojuca, including the anchorage area of the vessels operating at the CIPS (Fig. 1).

Collections and analysis

Data were collected between July 2021 and October 2022 as part of the Marine Megafauna Research and Monitoring Project in the Suape Port Area (MEGAMAR; Professor Fábio Hazin). Fifty expeditions were conducted in the CIPS area, with each expedition prospecting 16 sampling points, encompassing the lunar phases of new, crescent, full, and waning moon. The sampling points were randomly predetermined using the ArcGIS 10.8 software, totaling 800 georeferenced points for sampling, based on the methodology described by Global FinPrint (2024) for underwater video image acquisition by BRUVS.

At 800 points, at the time of launching the BRUVS, abiotic parameters were collected, namely, empirical estimate of cloud cover percentage, water transparency (visibility using the Secchi disk), depth (using the vessel’s echosounder), pH, salinity, dissolved oxygen, and seawater surface temperature (using the Lutron, WA, 2015 multiparameter).

BRUVS comprised a tubular metal structure in a trapezoidal shape, wherein a front rod was attached to a bait box, and the top of the trapezoid was coupled to the equipment for capturing videos at the resolution of 4 K (Cappo et al., 2006; Mallet & Pelletier, 2014; Whitmarsh et al., 2016). *Harengula clupeola* and *Opisthonema oglinum* were used in the bait box to generate a plume of lipids from these species to attract species adjacent to the structure. The recording time for each BRUVS was 90 min from submersion to emersion, following the methodology proposed by Global FinPrint. The equipment was inserted at different depths ranging from 1.4 to 32.0 m within the area of influence of the port, thus establishing a gradient to infer the influence of depth on the composition of aquatic fauna (Reis-Filho et al., 2019; Whitmarsh et al., 2016).

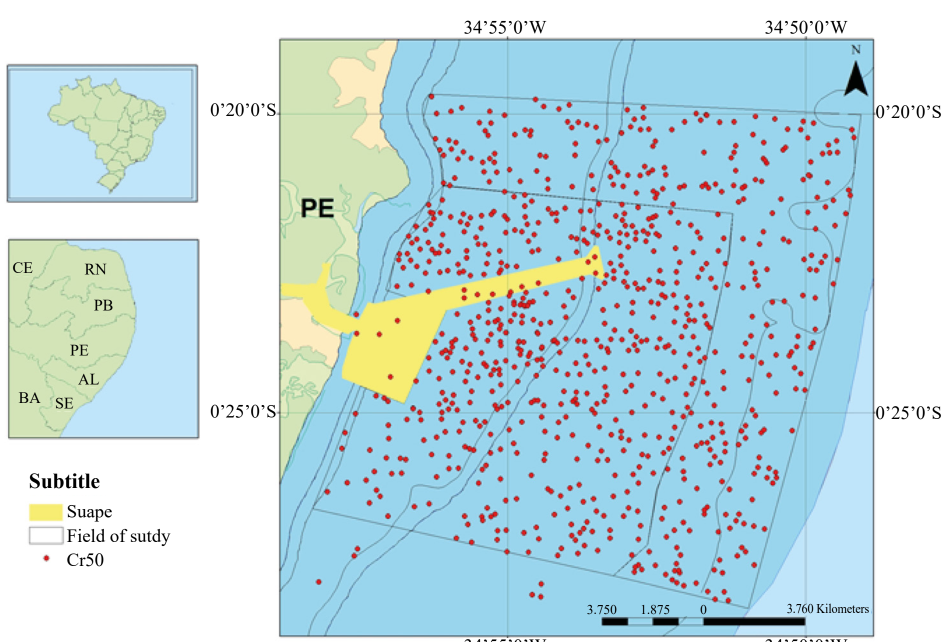

Figure 1. Coastline of the municipality of Cabo de Santo Agostinho, Pernambuco, Brazil. The points in red correspond to the data collection sites.

The fauna recorded in the images produced by BRUVS were analyzed to identify the species to the lowest possible taxonomic level, based on the literature available for identifying tropical species (Sampaio & Nottingham, 2008; Cerqueira et al., 2021; Barbosa et al., 2022). To understand the efficiency of quantitative sampling in terms of the amount of sampling conducted, we analyzed the species accumulation curve characterized by the sum of new species per collection point until the stabilization of the asymptotic curve, which denotes the stability and sampling contemplation during this study (Schilling & Batista, 2008).

Considering the characterization of the habitats recorded in BRUVS, the types of substrates present in the images of the sampled areas were quantified, and their classification was listed into three different types: sand/gravel, sand/gravel + phytobenthos, and limestone formation based on the methodology described by Lins-Oliveira et al. (2021).

To assess absolute abundance, the maximum number (Nmax) of individuals of the same species recorded during each frame (second of filming) at each sampling point was calculated. To establish the relative abundance of species, Nmax was calculated per effort of hours recorded ($MaxN{\cdot}h^{-1}$), as this parameter is important for determining the most representative species and families (MacNeil et al., 2020).

The analysis of relative abundance by family and species was conducted by summing up the $MaxN{\cdot}h^{-1}$ values for each category, computing the observation time of the first five species in each category. For the substrate class, $MaxN{\cdot}h^{-1}$ was summed up, estimating which class would have the highest relative abundance.

For the entire lunar cycle evaluated during the sampling period, the variation in species was quantified to understand the influence of lunar phases on species diversity, as well as the prevalence of species per lunar phase. For the analyses of depth, extracts were created by grouping the depths every 5 m to quantify the greatest relative abundance by the sum of $MaxN{\cdot}h^{-1}$ and diversity by the sum of species.

To perform the analyses of multivariate abiotic data, moon phases, types of substrates, depths, temperatures, visibility, and cloud cover were used as explanatory variables in relation to species occurrence responses. To assess the degree of similarity in species distribution, the multivariate technique of non-metric multidimensional scaling (nMDS) was applied, based on the Bray-Curtis similarity matrix, with observation points considered as sampling units. The relative effort ($MaxN{\cdot}h^{-1}$) was square root-transformed to reduce the dominance effect in the samples. Differences between factors were tested using the multivariate technique analysis of similarities (ANOSIM) (Clarke, 1993), and the items that discriminated the groups were evaluated using the SIMPER routine (Clarke, 1993). All analyses were performed using the R software (R Core Team, 2022), and the Vegan package (Oksanen et al., 2024) was used for multivariate analyses. However, the variables were transformed using $\sqrt{x}$ to normalize them, adopting the significant level of $p < 0.05$. All the analyses were conducted using the R Development Core Team software (2023).

RESULTS

During the period from July 2021 to October 2022, 1,185 h of underwater videos were recorded, covering the dry (lowest rainfall index) and rainy (highest rainfall index) seasons, wherein the *in-situ* sea surface temperature (SST) varied between 24.4 and 31.5°C. Being in a tropical region, the study area experiences significant cloud cover, which affects underwater visibility during filming.

The underwater images were recorded between the depths of 1.4 and 32.0 m. Within this range, seven taxonomic subclasses were identified: Ambuloasteroidea, Coleoidea, Discomedusae, Eumalacostraca, Teleostei, Elasmobranchii, and Reptilia, belonging to 118 different taxa, with 16,639 individuals recorded (Table 1).

The cumulative curve of species over the 800 collection points (Fig. 2) showed a tendency to stabilize from site 200, with stabilization at site 600, indicating that the species for the sampling period and area using the BRUVS sampling method were covered, making the line asymptotic.

Considering the recorded families, 53 families were counted, the most representative being Carangidae (SNmax = 5,519 and $MaxN{\cdot}h^{-1}$ = 4.66), Haemulidae (SNmax = 3.774 and $MaxN{\cdot}h^{-1}$ = 3.18), Lutjanidae (SNmax = 1,282 and $MaxN{\cdot}h^{-1}$ = 1.08), Clupeidae (SNmax = 1,077 and $MaxN{\cdot}h^{-1}$ = 0.91), and Serranidae (SNmax = 638 and $MaxN{\cdot}h^{-1}$ = 0.54) (Fig. 3).

Among all the species recorded during the sampling period, the most abundant ones in the underwater images were as follows: *Haemulon aurolineatum* (SNmax = 2,598 and $MaxN{\cdot}h^{-1}$ = 2.19), *Decapterus macarellus* (SNmax = 1.264 and $MaxN{\cdot}h^{-1}$ = 1.07), *Caranx crysos* (SNmax = 1.125 and $MaxN{\cdot}h^{-1}$ = 0.95), *Decapterus sp.* (SNmax = 1.118 and $MaxN{\cdot}h^{-1}$ = 0.94), and *Lutjanus synagris* (SNmax = 1.072 and $MaxN{\cdot}h^{-1}$ = 0.90) (Fig. 4).

Among the 800 collection points, we identified the type of substrate at 703 points because of environmental factors, such as the turbidity of water or fixation of the device that drifted and recorded the sea surface. At the evaluated points, we observed that 61.0, 38.4, and 0.6% of the records were collected at sites with substrates predominantly comprising sand/gravel + phytobenthos ($MaxN{\cdot}h^{-1}$ = 1,170.83; 108 taxa), sand/gravel ($MaxN{\cdot}h^{-1}$ = 552.61; 78 taxa), and limestone formation ($MaxN{\cdot}h^{-1}$ = 10.17; 10 taxa), respectively (Fig. 5).

Table 1. Subclasses, families, species and the maximum number observed (MaxN) sum of species recorded by baited remote underwater video system (BRUVS) (total N = 16,639) in the Suape Port Industrial Complex port area*.

Subclass	Family	Species	Sum of MaxN	Status IUCN
Ambuloasteroidea	Astropectinidae	*Astropecten marginatus* (Gray, 1840)	1	
Coleoidea	Loliginidae	*Sepioteuthis sp.*	4	
	Octopodidae	*Octopus sp.*	3	
Discomedusae	Ulmaridae	*Aurelia aurita* (Linnaeus, 1758)	36	
Elasmobranchii	Aetobatidae	*Aetobatus narinari* (Euphrasen, 1790)	15	EN
	Cacharhinidae	*Carcharhinus acronotus* (Poey, 1860)	1	EN
	Dasyatidae	*Hypanus berthalutzae* (Petean, Naylor & Lima, 2020)	166	VU
		Hypanus guttatus (Bloch & Schneider, 1801)	50	NT
		Hypanus marianae (Gomes, Rosa & Gadig, 2000)	17	EN
		Hypanus sp.	26	
	Ginglymostomatidae	*Ginglymostoma cirratum* (Bonnaterre, 1788)	5	VU
	Gymnuridae	*Gymnura altavela* (Linnaeus, 1758)	1	EN
	Mobulidae	*Mobula alfredi* (Krefft, 1868)	1	VU
	Rhinobatidae	*Pseudobatos percellens* (Walbaum, 1792)	2	EN
Eumalacostraca	Diogenidae	*Calcinus sp.*	28	
	Palinuridae	*Panulirus sp.*	12	
	Portunidae	*Callinectes sp.*	2	
Reptilia	Cheloniidae	*Caretta caretta* (Linnaeus, 1758)	9	VU
		Chelonia mydas (Linnaeus, 1758)	9	EN
		Eretmochelys imbricata (Linnaeus, 1766)	2	CR
		Lepidochelys olivacea (Eschscholtz, 1829)	4	VU
Teleostei	Acanthuridae	*Acanthurus bahianus* (Castelnau, 1855)	29	LC
		Acanthurus chirurgus (Bloch, 1787)	32	LC
		Acanthurus coeruleus (Bloch & Schneider, 1801)	3	LC
		Acanthurus sp.	43	
	Albulidae	*Albula sp.*	2	
		Albula vulpes (Linnaeus, 1758)	93	NT
	Aulostomidae	*Aulostomus maculatus* (Valenciennes, 1841)	5	LC
	Balistidae	*Balistes capriscus* (Gmelin, 1789)	14	VU
		Balistes sp.	1	
		Balistes vetula (Linnaeus, 1758)	174	NT
	Bothidae	*Bothus lunatus* (Linnaeus, 1758)	2	LC
		Bothus ocellatus (Agassiz, 1831)	131	LC
		Bothus sp.	136	
	Carangidae	*Caranx bartholomaei* (Cuvier, 1833)	945	LC
		Caranx crysos (Mitchhill, 1815)	1,089	LC
		Caranx hippos (Linnaeus, 1766)	24	LC
		Caranx ruber (Bloch, 1793)	10	LC
		Caranx sp.	129	
		Chloroscombrus chrysurus (Linnaeus, 1766)	376	LC
		Decapterus macarellus (Cuvier, 1833)	1,264	LC
		Decapterus punctatus (Cuvier, 1829)	391	LC
		Decapterus sp.	1,118	
		Elagatis bipinnulata (Quoy & Gaimard, 1825)	2	LC
		Selene vomer (Linnaeus, 1758)	20	LC
		Seriola lalandi (Valenciennes, 1833)	1	LC
		Seriola rivoliana (Valenciennes, 1833)	6	LC

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Continuation.

Subclass	Family	Species	Sum of MaxN	Status IUCN
	Chaetodontidae	*Chaetodon sedentarius* (Poey, 1860)	2	LC
		Chaetodon striatus (Linnaeus, 1758)	58	LC
	Clupeidae	*Harengula clupeola* (Cuvier, 1829)	141	LC
		Opisthonema oglinum (Lesueur, 1818)	906	LC
	Cyclopsettidae	*Syacium micrurum* (Ranzani, 1842)	38	LC
		Syacium papillosum (Linnaeus, 1758)	18	LC
		Syacium sp.	52	
	Dactylopteridae	*Dactylopterus volitans* (Linnaeus, 1758)	2	LC
	Diodontidae	*Diodon sp.*	1	
		Diodon holocanthus (Linnaeus, 1758)	1	LC
	Echeneidae	*Echeneis naucrates* (Linnaeus, 1758)	26	LC
		Echeneis sp.	2	
	Ephippidae	*Chaetodipterus faber* (Broussonet, 1782)	3	LC
	Epinephelidae	*Alphestes afer* (Bloch, 1793)	13	LC
		Cephalopholis fulva (Linnaeus, 1758)	179	LC
		Epinephelus itajara (Lichtenstein, 1822)	1	VU
		Epinephelus marginatus (Lowe, 1834)	1	VU
	Fistulariidae	*Fistularia petimba* (Lacepède, 1803)	3	LC
		Fistularia tabacaria (Linnaeus, 1758)	26	LC
	Gerreidae	*Eucinostomus argenteus* (Baird & Girard, 1855)	68	LC
		Eucinostomus lefroyi (Goode, 1874)	9	LC
		Eucinostomus sp.	554	
	Haemulidae	*Anisotremus virginicus* (Linnaeus, 1758)	16	LC
		Haemulon atlanticus (Carvalho, Marceniuk, Oliveira & Wosiacki, 2020)	220	LC
		Haemulon aurolineatum (Cuvier, 1830)	2,586	LC
		Haemulon macrostomum (Günther, 1859)	1	LC
		Haemulon melanurum (Linnaeus, 1758)	8	LC
		Haemulon parra (Desmarest, 1823)	44	LC
		Haemulon plumierii (Lacepède, 1801)	418	LC
		Haemulon sciurus (Shaw, 1803)	6	LC
		Haemulon sp.	229	
		Haemulon squamipinna (Rocha & Rosa, 1999)	209	LC
		Orthopristis rubra (Cuvier, 1830)	5	LC
		Orthopristis scapularis (Fowler, 1915)	15	
		Pomadasys ramosus (Poey, 1860)	3	
		Pomadasys sp.	2	
	Holocentridae	*Holocentrus adscensionis* (Osbeck, 1765)	83	LC
	Labridae	*Bodianus pulchellus* (Poey, 1860)	1	LC
		Bodianus rufus (Linnaeus, 1758)	10	LC
		Halichoeres brasiliensis (Bloch, 1791)	5	DD
		Halichoeres dimidiatus (Agassiz, 1831)	22	LC
		Halichoeres poeyi (Steindachner, 1867)	72	LC
		Halichoeres sp.	161	
		Xyrichtys novacula (Linnaeus, 1758)	1	LC
	Lutjanidae	*Lutjanus analis* (Cuvier, 1828)	32	NT
		Lutjanus chrysurus (Bloch, 1791)	26	DD
		*Lutjanus jocu (*Bloch & Schneider, 1801)	12	DD
		Lutjanus sp.	8	
		Lutjanus synagris (Linnaeus, 1758)	1,072	NT
		Ocyurus chrysurus (Bloch, 1791)	126	DD
	Malacanthidae	*Malacanthus plumieri* (Bloch, 1786)	26	LC
	Microdesmidae	*Ptereleotris randalli* (Gasparini, Rocha & Floeter, 2001)	31	LC

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Continuation.

Subclass	Family	Species	Sum of MaxN	Status IUCN
	Monacanthidae	*Aluterus monoceros* (Linnaeus, 1758)	16	LC
		Aluterus schoepfii (Walbaum, 1792)	1	LC
		Aluterus scriptus (Osbeck, 1765)	14	LC
		Aluterus sp.	1	
		Cantherhines macrocerus (Hollard, 1853)	2	LC
		Monacanthus ciliatus (Mitchhill, 1818)	8	LC
		Stephanolepis hispida (Linnaeus, 1766)	63	
		Stephanolepis setifer (Bennett, 1831)	2	LC
	Mullidae	*Pseudupeneus maculatus* (Bloch, 1793)	271	LC
	Muraenidae	*Gymnothorax funebris* (Ranzani, 1839)	1	LC
		Gymnothorax sp.	7	
		Gymnothorax vicinus (Castelnau, 1855)	17	LC
	Opistognathidae	*Opistognathus sp.*	2	
	Ostraciidae	*Acanthostracion quadricornis* (Linnaeus, 1758)	3	LC
		Acanthostracion sp.	3	
		Lactophrys trigonus (Linnaeus, 1758)	87	LC
	Paralichthyidae	*Paralichthys brasiliensis* (Ranzani, 1842)	3	LC
	Pomacanthidae	*Holacanthus ciliaris* (Linnaeus, 1758)	1	LC
		Holacanthus tricolor (Bloch, 1795)	5	LC
		Pomacanthus paru (Bloch, 1787)	14	LC
	Pomacentridae	*Abudefduf saxatilis* (Linnaeus, 1758)	7	LC
		Stegastes sp.	1	
	Rachycentridae	*Rachycentron canadum* (Linnaeus, 1766)	3	LC
	Scaridae	*Sparisoma axillare* (Steindachner, 1878)	334	DD
		Sparisoma radians (Valenciennes, 1840)	1	LC
		Sparisoma sp.	11	
	Scombridae	*Scomberomorus brasiliensis* (Collette, Russo & Zavala-Camin, 1978)	15	LC
		Scomberomorus cavalla (Cuvier, 1829)	1	LC
		Scomberomorus regalis (Bloch, 1793)	68	LC
		Scomberomorus sp.	33	
		Thunnus sp.	2	
	Serranidae	*Diplectrum formosum* (Linnaeus, 1766)	630	LC
	Sparidae	*Calamus calamus* (Valenciennes, 1830)	6	LC
		Calamus penna (Valenciennes, 1830)	28	LC
		Calamus pennatula (Guichenot, 1868)	72	LC
		Calamus sp.	17	
	Sphyraenidae	*Sphyraena barracuda* (Edwards, 1771)	151	LC
		Sphyraena picudilla (Poey, 1860)	455	LC
	Synodontidae	*Synodus foetens* (Linnaeus, 1766)	2	LC
		Synodus intermedius (Spix & Agassiz, 1829)	5	LC
		Synodus synodus (Linnaeus, 1758)	2	LC
		Trachinocephalus myops (Forster, 1801)	14	LC
	Tetraodontidae	*Lagocephalus laevigatus* (Linnaeus, 1766)	15	LC
		Sphoeroides greeleyi (Gilbert, 1900)	2	LC
		Sphoeroides sp.	30	
		Sphoeroides spengleri (Bloch, 1785)	218	LC
		Sphoeroides testudineus (Linnaeus, 1758)	4	LC

*International Union for Conservation of Nature (IUCN) status: EN) endangered, DD) data deficient, VU) vulnerable, NT) near threatened, CR) critically endangered, LC) least concern.

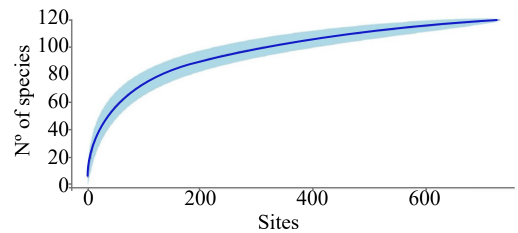

Figure 2. Cumulative curve of species over the 800 sites recorded by the baited remote underwater video system (BRUVS) in the Suape Port Industrial Complex port area.

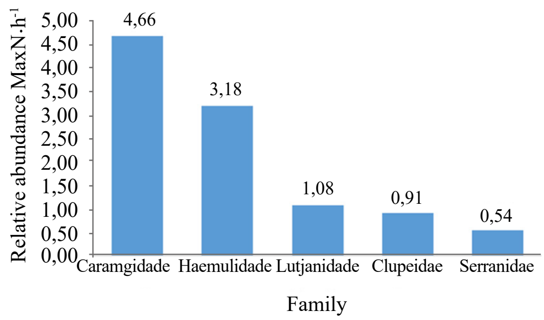

Figure 3. Relative family abundance per hour (MaxN·h^{-1}) of the five families with the most records in the Suape Port Industrial Complex port area.

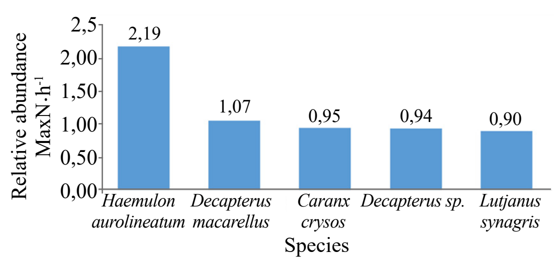

Figure 4. Relative abundance of species per hour (MaxN·h^{-1}) of the five most recorded species in the Suape Port Industrial Complex port area.

The individuals with the greatest presence in the sand/gravel substrate were *H. aurolineatum*, *O. oglinum*, and *Diplectrum formosum*, with total numbers of 764, 307, and 287, respectively; and those in the sand/gravel + phytobenthos substrate were *H. aurolineatum*, *D. macarellus*, and *C. crysos*, with total numbers of 1,658, 1,070, and 800, respectively. However, individuals with the greatest presence in the limestone formation substrate were *H. aurolineatum*, *L. synagris*, and *Haemulon squamipinna*, with total numbers of 12, eight, and three, respectively. Species grouping was 38% higher in the sand/gravel + phytobenthos substrate than in the sand/gravel substrate.

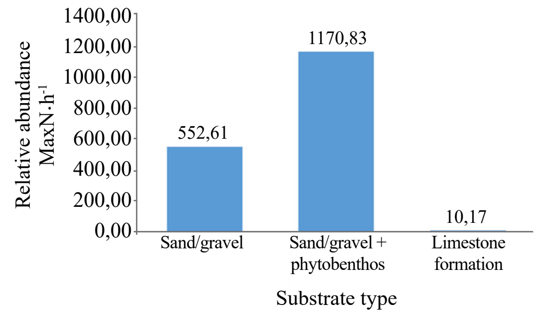

Figure 5. Relative abundance of species per hour (MaxN·h^{-1}) by substrate recorded in the Suape Port Industrial Complex port area.

The phase with the greatest species diversity was the waning phase, followed by the full and crescent phases, with the same number of individuals identified, and the crescent phase was the least representative, with 73, 69, and 62 taxa, respectively (Fig. 6). However, when assessing the lunar phase with the greatest abundance, the new moon was the most representative, with 338 MaxN·h^{-1}, followed by the full, waning, and crescent phases, with 276, 242, and 238 MaxN·h^{-1}, respectively (Table 2).

Analysis of the presence of species at different depths showed that extracts at depths greater than 15 m had greater diversity than those at shallower depths, with more significant records between depths of 25 and 30 m (Fig. 7). The sum of MaxN·h^{-1}

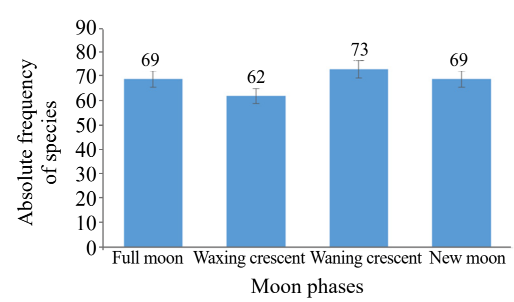

Figure 6. Relative abundance by substrate recorded in the Suape Port Industrial Complex port area (total N = 118 and standard deviation = ± 4.5).

Table 2. Sum of MaxN h^{-1} per lunar phase recorded by baited remote underwater video system (BRUVS) (total MaxN·h^{-1} = 1185) in the Suape Port Industrial Complex port area.

Line labels	Sum of MaxN·h^{-1}	SD of MaxN·h^{-1}
Full moon	276	± 0.52
Waxing crescent	238	± 0.48
Waning crescent	242	± 0.55
New moon	338	± 0.59

MaxN·h-1: relative abundance of species per hour; SD: standard deviation.

per species in the extracts at 25–30 m also showed the presence of species at greater depths (Table 3).

The arrangement obtained from the nMDS, combined with the ANOSIM results, showed a high overlap in species distribution among the evaluated factors (Fig. 8), with significantly low contributions to the dissimilarity between groups from the effects of depth (R = 0.15; $p < 0.05$), substrate type (R = 0.15; $p < 0.05$), visibility (R = 0.11; $p < 0.05$), cloud cover (R = 0.03; $p < 0.05$), moon phase (R = 0.02; $p < 0.05$), and temperature (ANOSIM R < 0.01; $p < 0.05$) (Table 4). The SIMPER routine indicated that Haemulidae, Lutjanidae, and Carangidae were the main contributors to the group similarity across all evaluated factors (Table 5).

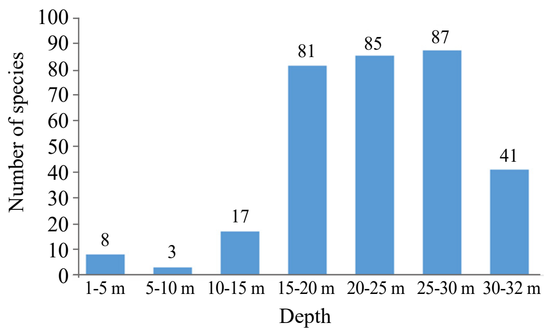

Figure 7. Relative abundance by depth recorded in the Suape Port Industrial Complex port area (N total = 118).

Table 3. Sum of MaxN h^{-1} per depth extract recorded by baited remote underwater video system (BRUVS) (total MaxN·h^{-1} = 1,185) in the Suape Port Industrial Complex port area.

Depth (m)	Time (MaxN·h^{-1})	SD
1–5	3,14	± 1.1
5–10	0,86	± 0.0
10–15	14	± 0.8
15–20	250	± 10.9
20–25	408	± 8.4
25–30	416	± 7.2
30–35	91	± 5.5

MaxN·h-1: relative abundance of species per hour; SD: standard deviation.

DISCUSSION

During the analysis, we noticed that atmospheric pressure influenced the filming times, causing different recording durations because of depth variations, thus directly interfering with the equipment's recording autonomy. The influence of

Table 4. Table of dissimilarity and significance between groups of abiotic data: moon phase, cloud cover, substrate type, depth, temperature and visibility, in relation to the species identified in the Suape Port Industrial Complex port area.

Factor	R	p-value
Depth	0.15	0.001
Bottom_type	0.15	0.001
Visibility	0.11	0.001
Cloud_coverage	0.04	0.015
Moon_phase	0.03	0.003
Temperature	0.00	0.453

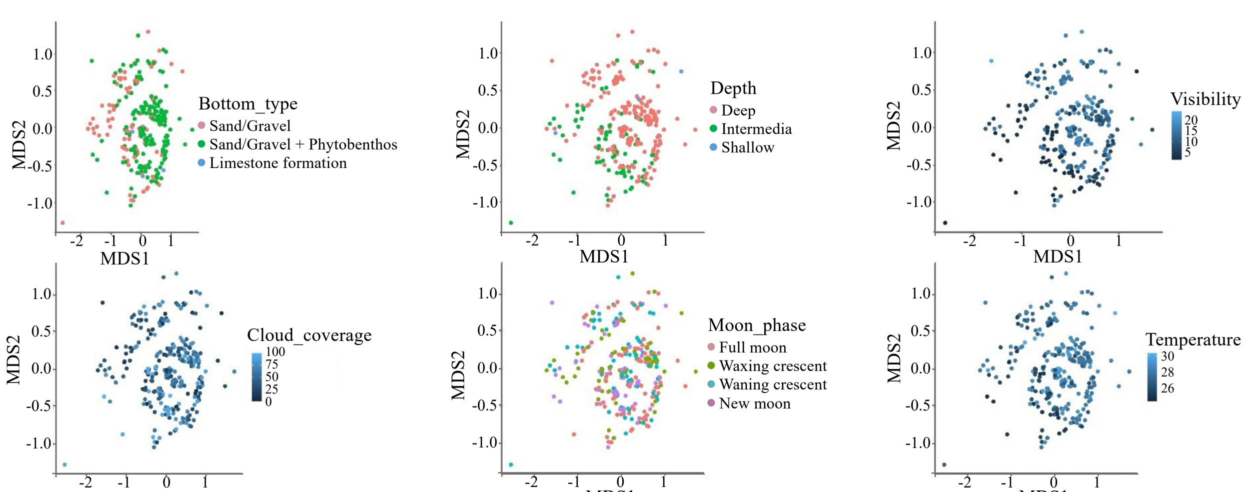

Figure 8. Cluster analysis for significance of abiotic data: moon phase, cloud cover, substrate type, depth, temperature and visibility, in relation to the species identified in the Suape Port Industrial Complex port area.

Table 5. Table of similarity between groups of abiotic data: substrate type, depth, in relation to the species identified in the Suape Port Industrial Complex port area.

Species	Sand *vs.* phytobenthos	Phytobenthos *vs.* limestone	Sand *vs.* limestone	Shallow *vs.* deep	Shallow *vs.* interm	Deep *vs.* interm
Haemulon aurolineatum	0.22660	0.28122	0.25700	0.45641	0.18415	0.24149
Lutjanus synagris	0.38997	0.54384	0.48651	0.16700	0.36096	0.39305
Caranx crysos	0.53746	0.43366	0.67615	0.31537	0.60769	0.53952
Diplectrum formosum	0.62460	0.63166	0.59015	0.65986	N/R	0.62339
Caranx bartholomaei	0.69188	0.69358	N/R	0.58173	0.49491	N/R
Eucinostomus sp.	N/R	N/R	0.74757	N/R	0.70401	0.69595

N/R: no data.

pressure was also reported by Bocchi et al. (2000) and Brain et al. (2023), wherein the higher the pressure, the shorter is the battery time, thus resulting in shorter filming times at greater depths with 90 min as the filming standard.

Monthly sampling over the course of one year proved to be important for sample homogenization, considering the characteristics of different abiotic and climatic periods, wherein species are aggregated by different environmental associations, thus recording species that are influenced by the period of terrestrial translation. According to Gaston and Spicer (2004), the biological diversity of an environment can be demonstrated by the stability of the cumulative curve of the species sampled in the region (Schilling & Batista, 2008), reaching its sampling peak with the stability of the curve.

The CIPS area experiences significant interference from sediment deposition from the estuaries present in the region and from the constant traffic of large vessels that remove particles from the substrate. These factors are amplified by the regimes of northeast currents in summer and southeast currents in winter (Marques & Oliveira, 2016). This dynamic is similar to that reported by Lins-Oliveira et al. (2021): the coarser particles that constitute the sand (portion with the highest incidence in the coastal zone) tend to decant more quickly; however, owing to the intense dynamics of sedimentary flow, this phenomenon is attenuated, thus creating a marine plume along the samples, making it difficult to visualize the species (Falcão-Filho et al., 2016).

The association of species by substrate is evident from the number of species recorded in each type of sediment, with sand/gravel + phytobenthos being greater than sand/gravel, as well as from the Nmax of each species being more expressive in the sand/gravel + phytobenthos substrate compared with that in sand/gravel substrate (Harvey et al., 2013). This association has been evidenced in other studies (Gaston & Spicer, 2004; Pinheiro & Castello, 2010; Reis-Filho et al., 2019); namely, when there is a decrease in the presence of primary producers, there is a decrease in the diversity and abundance.

According to Nassongole et al. (2019), the balance of the aquatic community is related to the type of composition of the substrate it resides in, as well as the distribution, feeding habits of fish and nutrient recycling (Pereira, 2000). Animals that feed on plankton, macro- and micro-algae have a direct relationship with the substrate and are important for resilience, important biomass for the trophic chain and the development of marine ecosystems (Bonaldo, 2010). In addition to their socio-economic importance, carnivorous fish also act as ecosystem control agents, maintaining levels of equity between the communities at the base of the trophic chain (Pet et al., 2006).

The higher number of taxa in the assemblage of individuals in this study can be explained by the longer sampling time compared with studies using the same methodology (Pinheiro & Castello, 2010; Reis-Filho et at., 2019; Rolim et al., 2019; Schmid et al., 2020; Bezerra et al., 2022). Previous studies in the coastal zone of Recife were conducted in environments with less anthropogenic action (Fischer et al., 2009; Oliveira, 2012; Bezerra et al., 2022), applying observation efforts of 180 to 7,254 min and observing 65 to 97 taxa. In contrast, in our study, the sample size was large (71,100 min), wherein 17 taxa were recorded, thus expanding our knowledge of the underwater diversity of the port and coastal areas of Recife.

Among the main species recorded, *D. macarellus*, *C. crysos*, *L. synagris*, and *H. aurolineatum* together account for 3% of the total fish caught in Brazil, with 15,000 tons caught annually, as recorded in Brazil's fishing statistics bulletins according to Ministry of Fishing and Aquaculture (MPA) data (MPA, 2010, 2011, 2012). However, these species are of socioeconomic importance to the region's artisanal subsistence fishery; in this context of food security, *L. synagris* is on the International Union for Conservation of Nature (IUCN) list of threatened species. Therefore, these species must be preserved for the region's fishermen, especially those adjacent to CIPS, whose economies are based on tourism and fishing.

In the faunal composition of the evaluated region, the species that were aggregated in shoals were the most representative (*H. aurolineatum*, *D. macarellus*, *C. crysos*, *Decapterus sp.*, and *L. synagris*), which is consistent with the results of previous studies in the region (Fischer et al., 2009; Oliveira, 2012; Schmid et al., 2020; Bezerra et al., 2022). Moreover, we identified 74 species that were not reported by Bezerra et al. (2022) in an area close to that of our study. However, despite the presence of estuaries, we did not identify individuals, such as *Centropomus spp.*, *Sciades spp.*, and *Megalops atlanticus*, which are common in fishing landings and sport fishing in adjacent regions.

According to Batista et al. (2020) and Pereira et al. (2020), these individuals are present in the estuarine zones of northeastern Brazil. This absence can be explained by the movement of vessels and dredging of the estuary, thus causing changes in the estuary and marine substrate through the deposition of sediments in irregular areas, changing the ecology of the coastal environment (Sousa, 2024), causing the migration of these individuals to areas with better environmental conditions, providing homeostasis.

In addition to the ichthyofaunal inventory, which was the subject of this study, we identified four of the five species of sea turtles present in Brazil. These species are listed as threatened animals in the National List of Endangered Species of Brazilian Fauna and IUCN Red List of Threatened Species. In Brazil, the most notable threats to chelonians are irregular occupation of the coast, sea pollution, boat traffic, and mineral extraction (ICMBio, 2011), all of which are present in the study area. Carvalho et al. (2021) highlighted the ecological importance of sea turtle conservation, and Sarmiento (2013) reported the important role of these species in coastal communities, thus facilitating socioeconomic development through ecotourism. Furthermore, the study area is rich in nutrients from the estuaries present there, thus being a foraging area for sea turtle species. According to Hamann et al. (2010) and Silva (2023), these areas should be monitored to support local and international conservation efforts.

The elasmobranchs recorded in this study are characterized as top-of-the-chain individuals belonging to the megafauna, which directly suffer from anthropogenic interference in the environment; thus, more than one-third of the elasmobranch species are on the IUCN Red List of Threatened Species (Camhi et al., 1998; Lessa et al., 1999; Hazin et al., 2000). Among other factors, this is ascribed to the destruction of essential habitats for the species, coupled with inefficient management and conservation policies that do not mitigate illegal fishing or accidental catches. Therefore, the conservation of coastal and estuarine environments, which are used as nurseries and feeding grounds, is essential for the balance of the trophic chain as elasmobranchs are trophic regulators.

Among the elasmobranchs, stingrays were the largest representatives and with the greatest distribution in the sampled area. Among the 10 species recorded, nine are threatened with extinction at some level in the IUCN, and are within the 50 species planned implemented by the National Action Plan for the Conservation of Sharks and Endangered Marine Stingrays (PAN Sharks). Therefore, it is necessary to mitigate the impacts on marine elasmobranchs threatened with extinction in Brazil and their environments, for short-term conservation purposes, given the rapid population decline (Pinto, 2023).

Although previous studies based on the methodology of capture in regions adjacent to CIPS at greater depths have recorded elasmobranch species responsible for incidents with swimmers (Hazin et al., 2013; Hazin et al., 2000), despite the presence of elasmobranchs in the sampled region, recording the individuals associated with incidents was not possible, even with the occurrence of two incidents with swimmers and sharks in July 2021 during the sampling period (SEMAS, 2023). The lack of records of such individuals in the sampled area may be related to the biology of these animals, which are large cosmopolitan migrators from the Atlantic Ocean (Hazin et al., 2013; Coletto et al., 2019).

Silva et al. (2023) state that it is essential to detect the regions with the highest density of megafauna occurrence and critical habitats for the species, as well as the main degradation zones and fishing activity, aiming to establish inclusive and efficient management to mitigate impacts on threatened species, and, therefore, highlighting the importance of spatial assessments by region and the importance of developing conservation plans based on participatory and integrated assessments to enable assertive and more effective actions (Scherer & Nicolodi, 2021).

The lunar phase can alter the composition of fish assemblages in a given region due to its influence on sea and light incidence regimes (Quinn & Kojis, 1981; Rooker & Dennis, 1991), which is amplified in the equatorial zone by lunar gravitational pull. However, no relationship was observed between the annual variation of the species and different periods of lunar incidence due to the homogeneity between the results in the lunar phases. This result was also reported by Reis-Filho et al. (2010) in another region of northeastern Brazil.

Depth is a segregator of species because of depth variations to the physical permeability of seawater, with the penetration of sunlight, thus limiting the diversity and abundance in photic depth extracts (Lins-Oliveira et al., 2021), as reported by Reis-Filho et al. (2019), who observed greater abundance and diversity in the meso- and infralittoral transition regions. However, Bezerra et al. (2022) observed greater diversity in the infralittoral region, as corroborated in this study, recording a greater number of species in the neritic and euphotic regions between 20 and 30 m. This can be explained by the association between primary producers and greater settling of sediments containing organic matter for the development of the former.

The evaluation of the data by the multivariate analysis methods, ANOSIM and SIMPER, showed high overlap of species according to abiotic factors. However, separately, the abiotic data had little influence on the presence of species; the type of substrate by depth was more significant for shoal species. This fact corroborates the trend described in the work developed by Betito (1999), that strategist individuals have a greater biomass and flock behavior, thus having greater significance for the data analyzed.

Furthermore, Reis-Filho et al. (2019) described in an analysis of a coastal region in northeastern Brazil that the sum of the factors is the explanatory association for the presence of species, something that was also described by scholars in a coastal environment in southern Brazil (Pinheiro & Castello, 2010). Thus, the equity of environmental parameters is fundamental to perpetuate the biological diversity of the environment (Gaston & Spicer, 2004).

According to Scherer and Nicolodi (2021), the coastal and marine zone must be understood as a continuous flow of interdependent systems. Thus, the management of the coastal zone and marine ecosystems must be integrated, sharing knowledge, instruments and decisions. Industrialization, maritime transport and tourism, combined with disorderly development, can impact the management of coastal zones. For this reason, it is very important to update public policies and local territorial management tools, ensuring the sustainable use of coastal ecosystems (Prearo Junior et al., 2021), thus guiding the constant port expansion.

The premise for territorial management and administration must be that what occurs in the terrestrial environment mutually influences the marine environment (Van Assche et al., 2020). Therefore, effluents, sediments, and contaminants simultaneously flow into the sea through the river basin and can promote significant changes in the marine environment (Coccossis et al., 1999; Nicolodi et al., 2009; Mulazzani & Malorgio, 2017). Therefore, more recent proposals for marine spatial planning defined in Ehler (2021) as ecosystem-based ocean management, or in Ehler and Douvere (2009) as a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas, tend to assist measures of environmental interaction with anthropic actions (Ehler, 2021), thus assisting port development.

CONCLUSION

The study area showed a great diversity of species along the coastal platform, even with continuous interference in the environment because of anthropogenic activities in the port. Despite the presence of chelonians as indicators of marine conservation, the port region showed low records of top-of-the-chain individuals, indicating an environmental imbalance caused by constant anthropogenic action.

There is a need for satellite monitoring of endangered species to understand their use of the area and their protection, as well as monitoring the coastal ecosystem to mitigate the growth of degradation in this sensitive environment, exposed to dredging and continuous changes in hydrological flow. However, there is a need for new prospecting in deeper regions to understand the absence of species that commonly use similar regions, since they may have migrated to deeper regions because of port flow, due to their lack of registration in the applied study effort.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

All data sets were generated or analyzed in the current study.

AUTHORS' CONTRIBUTIONS

Writing – original draft: Garciov-Filho, E.B.; **Writing – review & editing:** Garciov-Filho, E.B., Soares, A.P.C., Branco Nunes, I.S.L., Bezerra, N.P.A.; **Data curation:** Garciov-Filho, E.B., Soares, A.P.C., Roque, P.C.G., Fischer, A.F.; **Formal analysis:** Garciov-Filho, E.B., Soares, A.P.C., Roque, P.C.G., Fischer, A.F.; **Project administration:** Santos, J.C.P., Oliveira, P.G.V.; **Funding acquisition:** Santos, J.C.P., Oliveira, P.G.V.; **Validation:** Oliveira, P.G.V.; **Final approval:** Garciov-Filho, E. B.

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