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Taxonomy and systematics

# Current knowledge of echinoderms (Echinodermata) from the coast of Paraíba, northeastern Brazil

## *Estado actual del conocimiento de los equinodermos (Echinodermata) de la costa de Paraíba, noreste de Brasil*

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**Abstract**

The first record of echinoderms from the state of Paraíba appeared in 1789, yet the systematic survey of the phylum along the coast only began in 2008. New species and several new records have been added since. An extensive literature survey and an analysis of the main Echinodermata collections housed in Brazil yielded 74 species. Our qualitative survey results in up-to-date records of echinoderm species along the littoral of the state, including information on habitat and their occurrence in Conservation Units (UCs). Even though all records are from the intertidal to 35 m, the resulting diversity of species is high when compared to other areas, since it corresponds to 21% of all Brazilian species and to 16% of the species known from the Caribbean Sea. The main habitats used by echinoderms are reefs and rhodolith beds. About 15% of the species are in the Brazilian Red List. A positive result is that 67% of these species occur within UCs in the state. Based on these results, we conclude that the fauna of echinoderms from shallow water is well documented in Paraíba. Finally, we comment on the conservation status of species and indicate future directions for the study of Echinodermata.

*Keywords*: Benthos; Inventory; Shallow reefs; Biodiversity; Conservation; South Atlantic

**Resumen**

El primer registro de equinodermos para el estado de Paraíba ocurrió en 1789. Sin embargo, el estudio sistemático del phylum a lo largo de esta costa no comenzó hasta 2008. Desde entonces, se han agregado especies y registros nuevos. Una amplia revisión de la literatura y un análisis de las principales colecciones de Echinodermata alojadas en

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Brasil dieron como resultado 74 especies. Nuestro estudio cualitativo incluyó registros actualizados con información sobre el hábitat y la presencia de las especies en unidades de conservación (UC). Aunque todos los registros están restringidos desde el intermareal hasta 35 m de profundidad, la diversidad de especies es alta en comparación con otras áreas, ya que corresponde a 21% de todas las especies brasileñas y a 16% de las especies conocidas del mar Caribe. Los principales hábitats utilizados por los equinodermos fueron los arrecifes y los mantos de rodolitos. Alrededor de 15% de las especies están en la Lista Roja brasileña. Un resultado positivo es que 67% de estas especies se encuentra dentro de las UC del estado. Con base en estos resultados, concluimos que la fauna de equinodermos de aguas someras está bien documentada en Paraíba. Finalmente, comentamos sobre el estado de conservación de las especies e indicamos direcciones futuras para el estudio del phylum Echinodermata.

*Palabras clave*: Bentos; Inventario; Arrecifes someros; Biodiversidad; Conservación; Atlántico sur

## Introduction

The littoral region of northeast Brazil (NE Brazil) extends for approximately 3,400 km, which corresponds to 42.5% of the Brazilian coastline (Gondim, Christoffersen et al., 2014). The area is unique, harbouring the largest and the richest reef strip of the Southwestern Atlantic (about 3,000 km) (Amaral & Jablonski, 2005; Leão et al., 2010). The region encompasses 9 coastal states: Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE), and Bahia (BA).

The littoral of the state of Paraíba is heterogeneous, with beaches, dunes, cliffs, restingas, bays, mangroves, and several reefs, that occur linearly along most of the coastline (Branner, 1904; Carvalho, 1982; Mendes & Pinheiro, 2019). The most common reef formations are of sandstone or biological origin (Carvalho, 1982), occurring as beachrocks, fringe reefs, barrier reefs, or permanently submerged reefs. For several years, the marine benthic fauna of this sector of the northeastern coastline remained unexplored. But knowledge has been growing exponentially throughout the last 2 decades (Brito et al., 2013; de Assis et al., 2007; de Assis, Alonso et al., 2012; Dias, 2009; Dias & Gondim, 2016; Dias et al., 2013; Duarte et al., 2014; Gama et al., 2006; Gondim et al., 2011; Lima et al., 2017; Lucena et al., 2017; Mota et al., 2020; Oliveira et al., 2014; Santos & Pinheiro, 2013, 2014; Santos et al., 2008, 2011, 2018). The southern coastline of the state (Pitimbu) was the first site impacted by the recent oil spill that affected the entire northeastern and part of the northern and southeastern coastline of Brazil in September 2019 (Soares, Teixeira, Bezerra, Paiva et al., 2020). This oil spill was considered the most extensive and severe environmental disaster ever recorded in Brazilian history, both for the South Atlantic Ocean basin and for tropical coastal regions worldwide (Soares, Teixeira, Bezerra, Rossi et al., 2020).

Knowledge of the echinoderm fauna in the state of Paraíba can be divided into 2 periods. The first period was characterized by naturalists and researchers, working at the benthic community level, only indirectly included echinoderms in their samples or studies. Much of this material has been deposited in scientific collections. The second period began in 2006, with the establishment of a research group on echinoderm taxonomy in the Invertebrate Laboratory Paulo Young (LIPY), at Universidade Federal da Paraíba (UFPB). This group, initially consisting of Anne Isabelley Gondim and Patrícia Lacouth, under the supervision of Carmen Alonso Samiguel, began their studies on echinoderm biodiversity along the Paraíba coastline based in the Invertebrate Collection Paulo Young (CIPY - UFPB).

Historically, the first records of echinoderms for the littoral of Paraíba were made by Rathbun (1879), based on material collected by J.C. Branner and other members of the Geological Commission of Brazil between 1875 and 1877. In that paper, Rathbun (1879) cited 6 species of echinoderms for Paraíba: 1 Crinoidea [*Antedon* sp., probably *Comactinia echinoptera* (Müller, 1840)], 1 Asteroidea [*Echinaster* (*Othilia*) *echinophorus* (Lamarck, 1816)], and 4 Ophiuroidea [*Ophioderma cinereum* Müller & Troschel, 1842 —as *Ophiura cinérea*; *O. appressum* (Say, 1825) —as *Ophiura appressa*, *Ophiocoma echinata* (Lamarck, 1816), and *Ophiothrix* (*Ophiothrix*) *angulata* (Say, 1825) —as *Ophiothrix violacea*]. Subsequently, echinoderms (mainly ophiurans) were cited only sporadically for the coast of Paraíba by Verrill (1899) (1 sp.), H.L. Clark (1915) (1 sp.), A.M. Clark (1953) (1 sp.), Laborel-Deguen (1963) (4 spp.), Tommasi (1965, 1970) (1 sp. and 5 spp., respectively), Thomas (1973) (1 sp.), Albuquerque (1986) (6 spp.), Young (1986) (7 spp.), and Albuquerque & Guille (1991) (3 spp.). A turning point in the systematic study of the group is provided by Gondim et al. (2008). The authors recorded 31 species of echinoderms for Cabo Branco beach (João Pessoa). Several inventories, new records, and new species have been published since then (Gondim et al., 2010, 2011, 2018; Gondim, Christoffersen et al., 2014; Prata & Christoffersen, 2017;

Prata et al., 2014, 2017; Prata, Manso et al., 2020; Prata, Stevenson et al., 2020). Nevertheless, only 3 papers provide information on the ecology of the group along this coast (de Assis, Bezerra et al., 2012; Gondim, Dias et al., 2014; Lafite et al., 2021).

Among several types of research that provide data for the conservation and management of marine ecosystems, the inventory of biodiversity is a basic requirement (Sloan & Bartier, 2009). The first stage to conserve biodiversity is to identify, describe, map, and measure this diversity (Margules & Pressey, 2000). Under this view, regional evaluations contribute to the knowledge of biodiversity, uncover biogeographic patterns, and characterize ecosystems. Only then is it possible to establish public programs of conservation, especially in a megadiverse country of continental dimensions such as Brazil. Furthermore, qualitative inventories can be more expedient, more cost-effective, and of similar scientific validity to quantitative data for most conservation needs (Mikkelsen & Cracraft, 2001).

Herein, we present a diagnosis of the present status of knowledge of the Echinodermata for the coast of Paraíba. We provide an updated checklist of the echinoderm fauna, with notes on habitat and distribution along this coast. Likewise, we provide and discuss data of composition and similarity of the taxa in the Paraíba reefs, compare this diversity with other northeastern states and seek to answer the question: is the echinoderm fauna of Paraíba still poorly known? We conclude with comments on the state of conservation of species and recommendations for further research.

## Materials and methods

Collection data on Echinodermata are based on literature surveys (published papers from 1879 to 2021) and examination of specimens deposited from the Invertebrate Collection Paulo Young (CIPY-UFPB), Marine Biology Laboratory of Estadual University of Paraíba (UEPB) (LBMar-UEPB), Federal University of Sergipe (LABIMAR-UFS), Museum of Zoology of the Federal University of Bahia (MZUFBA), Museum of Zoology of the University of São Paulo (MZUSP), National Museum of the Federal University of Rio de Janeiro (MNRJ). An extensive review of the literature and the database Brazilian Fauna Taxonomic Catalog-CTFB (Moura 2020), was also used to inventory the number of echinoderms from each northeastern state.

The taxonomic list is organized systematically, according to that contained in the specialized literature and the database World Register of Marine Species: WoRMS (2020), Asteroidea Database (Mah, 2020), Ophiuroidea Database (Stöhr et al., 2020), and Echinoidea Database (Kroh & Mooi, 2020). Santana et al. (2017) concluded that *Ophiothrix* (*Ophiotrix*) *angulata* does not occur in Brazil and proposed that Brazilian specimens corresponded to several new species. Only recently have these new species been described (Santana et al., 2020). Here, we adopted the name "*Ophiothrix* (*Ophiothrix*) *angulata*" or "*O.* (*O.*) *angulata*", in reference to the study material that needs to be revised. In the similarity analysis, we used simply "*O.* (*O.*) *angulata*", while records provided by Santana et al. (2020) were only considered when estimating the total number of species.

The coastline in Paraíba (6º29'S to 7º33'S) is 138 km long, extending from Barra de Camaratuba, in the north, to Acaú, in the south (Fig. 1). Several types of environments are found along this coast, such as mangroves, sandy beaches, and reefs. The subaquatic landscape includes the presence of seagrass, macroalgal banks, rhodolith beds, and patch reefs. To the south of João Pessoa, narrow beaches and small bays are found. The larger beaches occur along the northern sector of the state (Carvalho, 1982). The climate is tropical, warm, and humid, characterized by a dry period (between September and February) and a rainy season (from March to August). Along the coast, tides oscillate from 0.1 to 2.7 m (Souza & Furrier, 2015).

The continental shelf is narrow, shallow, and relatively flat, with a mean width of 30 km, becoming broader in a north-south direction; carbonatic sediments predominate (Barbosa, 1989; Feitosa et al., 2005). The beginning of the continental slope usually occurs between 50 and 60 m (Rocha et al., 1998). Canyons are observed at the outlets of the rivers Goiana, Paraíba, and Mamanguape, being presently disconnected from the continental shelf, but are visible beyond 15 m (Barbosa, 1989). The geomorphological characteristics of the continental shelf, slope, and abyssal plain are presented by Chaves (1979).

Reefs are quite common along the coast (Carvalho, 1982) (Figs. 1, 2). The greatest reef concentration may be observed between Baía da Traição and João Pessoa (Muniz et al., 2000). The width of the reef strip varies from a few meters to 150 m, with lengths of a few dozen meters to several kilometers. They reach depths greater than 60 m (Carvalho, 1982), but the large majority occur at depths of up to 40 m (Rocha et al., 1998). The northern coast, down to the Municipality of Cabedelo, is dominated by sandstone reefs ("arrecifes"), but beyond this region, the sandstone reefs become more patchy and co-occur with coral reefs (Laborel, 1970) (Fig. 2). Local reefs probably follow the structure common in northeastern Brazil, in which the base is arenitic, and the biogenic portion is formed by calcareous algae and vermetids (Melo, 2006). Around João Pessoa, the hermatypic corals are only

scattered over the reef, whereas algae (e.g., *Caulerpa*, *Halimeda*) are predominant; therefore, the name "algal reef" would be more appropriate for these reefs (Guilcher, 1983, 1988). Many of these reef formations were intensely explored over many years to remove calcareous blocks for the construction of churches, monasteries, houses, and the production of lime (Branner, 1904). Branner (1904), Laborel (1970), and Carvalho (1982) provide a detailed characterization of the littoral of the state. Geological information may be obtained in Branner (1902).

Presently there are 6 Conservation Units (UCs) in the state of Paraíba: Parque Estadual Marinho de Areia Vermelha (PEMAV), Área de Proteção Ambiental Naufrágio Queimado (APANQ), Área de Proteção Ambiental da Praia de Jacarapé (APAPJ), Área de Proteção Ambiental de Tambaba (APAT), Área de Proteção Ambiental Barra do Rio Mamanguape (APABRM), and Reserva Extrativista Acaú-Goiana (Resex Acaú-Goiana). Only the first 2 are exclusively marine. These UCs cover 11% of the littoral area.

In order to describe ecological aspects of the inventoried species, point data extracted from their collection labels were analyzed. Graphs indicate habitats (hard and soft substrate, phytal, rhodolith beds, biological substrate, and artificial reefs), and depth ranges (0 to 10 meters; 11 to 29 m; 30 to 50 m) for each echinoderm class along the coast.

The similarity in species composition was analyzed at the local scale (coast of Paraíba) and a regional scale (northeast coast of Brazil). For the coast of Paraíba, the structure of the analyzed reefs was taken into account (type of reef/proximity to coast was used for 4 levels; Table 1). For the northeast coast, it was possible to compare the composition of the echinoderm fauna of the state of Paraíba with that of other states in the region. A presence/absence matrix was built with the species from the analyzed collections and the literature review. This matrix was subject to Euclidean Distance. The analyses were carried out considering a phylum and class approach; they were compared with cluster graphs and nMDS (non-metric multidimensional scaling). Statistical analyses were run in software Primer 6.0.

## Results

We catalogued 74 species of echinoderms from Paraíba: Crinoidea (1 order, 2 families, 3 genera, and 3 species), Asteroidea (3 orders, 7 families, 7 genera, and 12 species), Ophiuroidea (2 orders, 9 families, 17 genera, and 30 species), Echinoidea (4 orders, 5 families, 8 genera, and 8 species), and Holothuroidea (3 orders, 7 families, 14 genera, and 21 species) (Table 2; Fig. 3). Two new records were added for the state: the feather star *Comactinia echinoptera* (Müller, 1840), and the brittle star *Ophiocnida loveni* (Ljungman, 1867).

In terms of number of species, Ophiuroidea and Holothuroidea were the most diverse classes. Within the first, Amphilepidida (21 spp.) was the order with the highest number of species, followed by Ophiacanthida (7 spp.). For Holothuroidea, Dendrochirotida (15 spp.) was the most diverse order, while Holothuriida (3 spp.) and Apodida (3 spp.) were less represented. Among the Asteroidea, Paxillosida (6 spp.) and Valvatida (4 spp.) were most represented, and Spinulosida (2 spp.) was less represented. All orders of Echinoidea were less diverse: Camarodonta and Clypeasteroida with 2 species each, and Cidaroida and Spatangoida with only 1 species each. As expected, Crinoidea was the least diverse class, represented by 3 species and 1 order (Comatulida) (Table 2).

Circa 82% (59 spp.) of the inventoried species occurred in isobaths below 10 m (Fig. 4a). This zone was the most diverse in number of species for all Echinodermata classes. The bathymetric range 11-29 m contained 39 species, compared to 20 species between 30 and 50 m. Regarding classes, Asteroidea and Ophiuroidea presented about the same number of species between 0-10 m and 11-29 m (Fig. 4b). Echinoidea diminished gradually in number of species along each depth range. On the other hand, 95% of Holothuroidea species occurred from the intertidal to 10 m (Fig. 4b). Only 6 sea cucumbers occurred below 10 m, and only 1 between 30 to 50 m (*Holothuria* [*Cystipus*] *pseudofossor* Deichmann, 1930). Species of Crinoidea come from shallow reefs up to 6 m deep. Considering all species with bathymetric data, 14 occurred in all evaluated depths: *Linckia guildingi* Gray, 1840, *Oreaster reticulatus* (Linnaeus, 1758), *Ophiomyxa flaccida* (Say, 1825), *Ophiocoma echinata*, *Ophioderma appressum*, *Ophioderma cinereum*, *Ophiostigma isocanthum* (Say, 1825), *Ophiopsila hartmeyeri* Koehler, 1913, "*Ophiothrix* (*Ophoithrix*) *angulata*", *Ophionereis reticulata* (Say, 1825), *Ophionereis squamulosa* Koehler, 1914, *Eucidaris tribuloides* (Lamarck, 1816), *Lytechinus variegatus* (Lamarck, 1816), and *Tripneustes ventricosus* (Lamarck, 1816).

Hard substrates (sandstone and biological reefs) were the main habitat of echinoderms, followed by rhodolith beds and phytal (Fig. 4c). Ophiuroidea and Holothuroidea were the most diverse taxa in number of species in the first 2 substrate types. Biological substrates (sponges and corals) were also frequently used by these 2 classes. Except for Crinoidea, all the remaining classes were recorded on artificial reefs. Ophiuroidea was most diverse in such substrates, with 3 spp. in shipwrecks, followed by Asteroidea, Echinoidea, and Holothuroidea, all with 1 species from the Cabedelo breakwater. Crinoidea was not

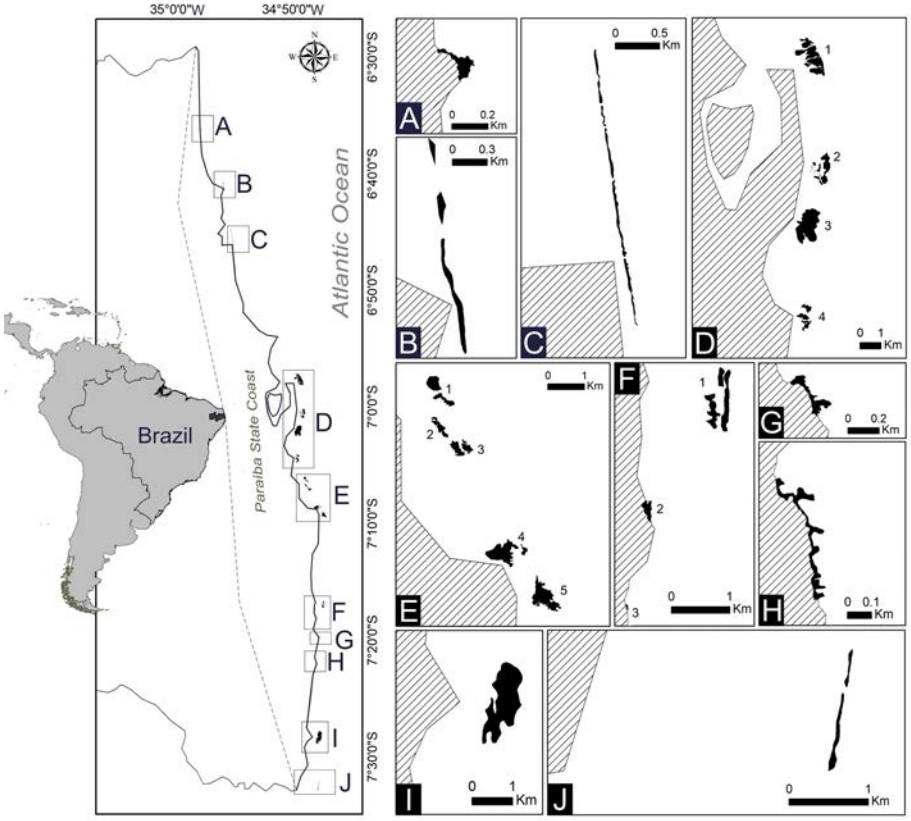


Figure 1. Location of reefs along the coast of Paraíba, Northeastern Brazil. A) Barra de Camaratuba; B) Baía da Traição; C) Barra de Mamanguape; D) Cabedelo (1), Areia Vermelha (2), and Ponta de Campina (3); E) Quebra-Quilha reef (1), São Gonçalo reef (2), Picãozinho reef (3), Cabo Branco (4), and Seixas reef (5); F) Jacumã (1), Carapibus (2), and Tabatinga (3); G) Coqueirinho; H) Tambaba; I) Pitimbu; J) Pedra da Galé.

recorded in soft substrates (sand and mud bottoms). All remaining classes occurred in these substrates, but with a low diversity of species (Fig. 4c).

The similarity in species composition was only considered in relation to the phylum, and specifically for Ophiuroidea and Holothuroidea (Fig. 5). The remaining classes were not considered in this regard due to the small number of species. In general, the composition of the echinoderm fauna is more similar among reefs with similar structures. Most similar groups occur between patch or barrier reefs (Fig. 5a). Similarity increases in reefs of similar type and location, such as Coqueirinho and Carapibus reefs.

Ophiuroidea showed the same patterns of similarity as a function of the type of reef (Fig. 5b). Yet, the location of the reefs was not determinant for the formation of the most similar groups. For example, the reefs of Carapibus and Seixas were the most similar in terms of species composition; they are similar in type (patch reefs), but come from distinct locations (Fig. 5b). Class Holothuroidea was poorly recorded in barrier reefs (sandstone reefs), and thus could not be included in our analysis. The greatest similarity was seen between the reef fauna of Pitimbu and Jacumã, again a case of similar reef patch formations from distinct locations (Fig. 5c). No species of echinoderms occurred in all studied coastal reefs. The brittlestars *Aphipholis squamata* (Delle Chiaje, 1828) and "*O.* (*O.*) *angulata*", and the sea urchin *Echinometra lucunter* (Linnaeus, 1758) were the most common species shared by these areas, occurring in 68%, 63% and 63% of the reefs, respectively. On the other hand, *Tripneustes ventricosus*, *Holothuria* (*Thymiosycia*) *arenicola* Semper, 1868, *Ophiothrix brasiliensis* Santana, Manso, Almeida & Alves, 2020, and *Thyone pawsoni* Tommasi, 1972 were the least common species, occurring in only 1 reef environment.

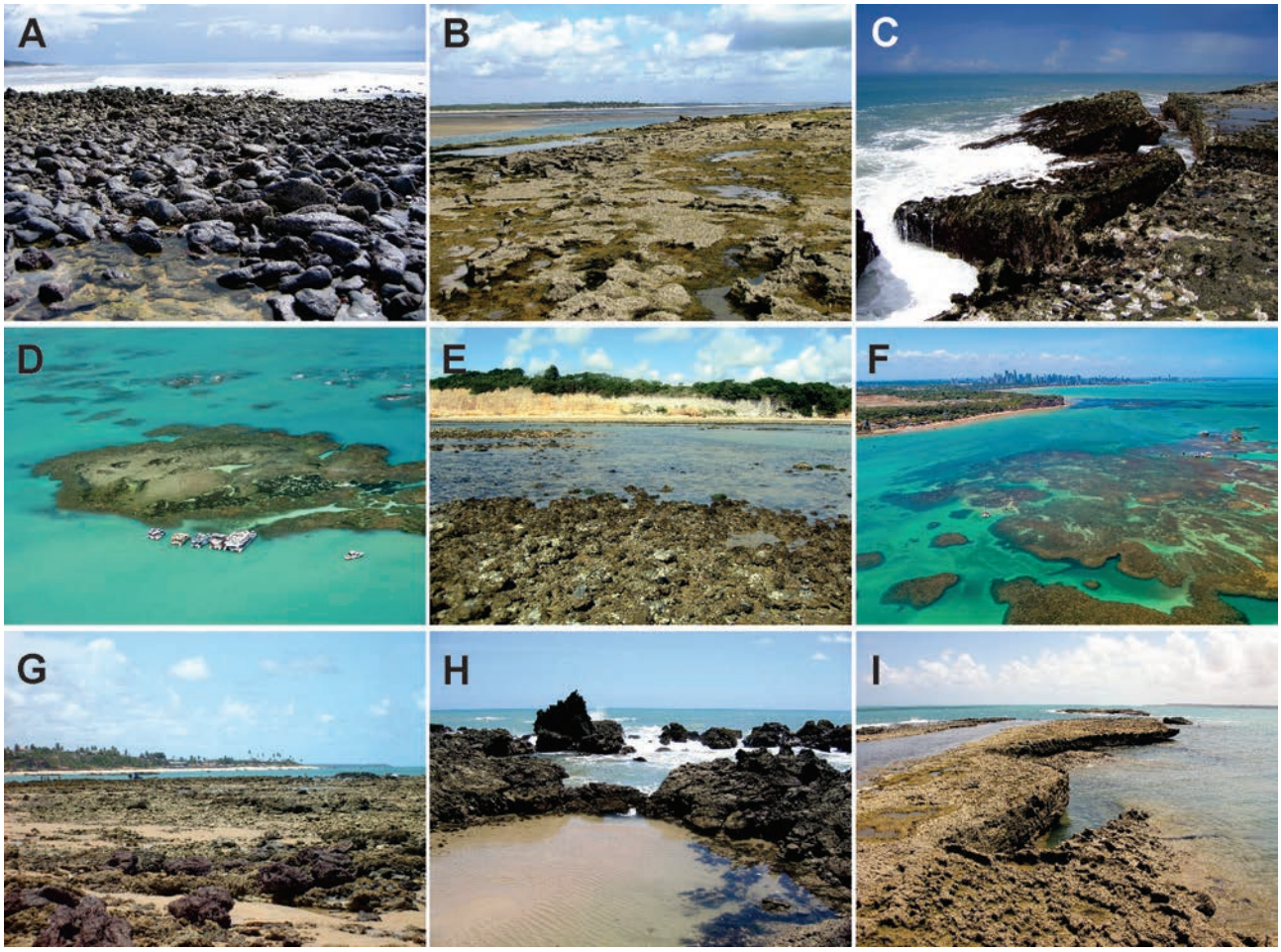


Figure 2. Some shallow-reefs from Paraíba, Northeastern Brazil. A) Barra de Camaratuba, B) Barra de Mamanguape, C) Baía da Traição, D) Aerial view of Picãozinho reef, E) Cabo Branco, F) Aerial view of Seixas reef, G) Carapibus, H) Tambaba, I) Pedra da Galé. Fotos: T.L.P. Dias (Photos 2D, F courtesy of sites Maresia and Paraíba, respectively).

Table 1

Classification used for shallow reefs in Paraíba, Northeastern Brazil.

| Classification | Description |
|---|---|
| Beach patch reef | Fringing reef, mainly beachrocks, located on intertidal zone and subject to exposure during low tides; with several natural pools of diverse sizes, shapes, and depths (Fig. 2a, e, g, h). |
| Beach barrier reef | Sandstone reefs, that begin at intertidal zone, but recede up to 1.67 km from the coast; subject to exposure during low tides, and may form small, shallow natural pools (Fig. 2b, c). |
| Offshore patch reef | Reef with high rates of coral-algae, distant between 0.1 and 1.5 km from coast; mostly submerged (Fig. 2d, f). |
| Offshore barrier reef | Sandstone reefs, that occur between 0.25 and 1.5 km from the beach; they are influenced by rivers, as evidenced by the turbidity of the water in some seasons of the year and the presence of fine muddy sediments covering the rocks; exposed during low tides; shallow natural pools may be present (Fig. 2i). |

Table 2

Taxonomic list of species of echinoderms from Paraíba, with data on occurrence, habitat, and voucher. Localities: AC (Acaú Beach), AT (Atolzinho reef), AVR (Areia Vermelha reef), BC (Barra de Camaratuba beach), BM (Barra de Mamanguape beach), BT (Baía da Traição beach), BB (Bessa Beach), CA (Carapibus Beach), CB (Cabo Branco beach), CBD (Cabedelo beaches), CQ (Coqueirinho beach), JC (Jacarapé beach), JM (Jacumã beach), LC (Lucena beaches), MNB (Manaíra beach), MRE (Mamanguape River Estuary), PC (Picãozinho reef), PCP (Ponta de Campina beach), PH (Penha beach), PNR (Paraíba do Norte River Estuary), PTB (Pitimbú beaches), PS (Pomar das esponjas reef), PTC (Port of Cabedelo), QCB (Breakwater of Cabedelo), QQ (Quebra-Quilha reef), RG (Galé reefs), RS (Seixas reefs), SG (São Gonçalo reef), TB (Tambaú beach), TBB (Tambaba beach), TG (Tabatinga beach). Substrate and habitat: adc (associated with different coral species); atr (artificial reefs – shipwrecks and breakwater); csh (continental shelf between 10 to 35 m); phy (phytal of some algae); rhb (rhodolith beds); sr (submerse reef), srf (shallow coastal reef); sd (sand substrate); sdw (sponge-dwelling); md (mud sediment). Conservation Units of Paraíba littoral: APABRM (APA Barra do Rio Mamanguape), APANQ (APA Naufrágio Queimado), APAT (APA Tambaba), and PEMAV (Parque Estadual Marinho de Areia Vermelha). *Occurrence extracted from Tommasi (1965). **Specimens that need reviewed. ***Occurrence extracted from Santana et al. (2020).

| Taxon | Ocurrence | Ocurrence in Conservation Units | Habitat | Voucher |
|---|---|---|---|---|
| Crinoidea Miller, 1821 | | | | |
| Comatulidae Fleming, 1828 | | | | |
| *Comactinia echinoptera* (Müller, 1840) | PC, QQ, SG | APANQ | phy, scr | UFPB.ECH.49 |
| *Davidaster rubiginosus* (Pourtalès, 1869)* | — | — | — | — |
| Tropiometridae A.H. Clark, 1908 | | | | |
| *Tropiometra carinata* (Lamarck, 1816) | BM, BT, CB, PC, QQ, PS, RG | APABRM, APANQ | scr | UFPB.ECH.1014 |
| Asteroidea de Blainville, 1830 | | | | |
| Astropectinidae Gray, 1840 | | | | |
| *Astropecten alligator* Perrier, 1881 | PCP | APANQ | csh | UFPB.ECH.881 |
| *Astropecten marginatus* Gray, 1840 | CBD, TB | APABRM, APANQ | sd | UFPB.ECH.864 |
| Luidiidae Sladen, 1889 | | | | |
| *Luidia alternata alternata* (Say, 1825) | BM, PCP, BB | APANQ | csh | UFPB.ECH.876 |
| *Luidia clathrata* (Say, 1825) | CBD | APANQ | csh | UFPB.ECH.875 |
| *Luidia ludwigi scotti* Bell, 1917 | BT | — | csh | UFPB.ECH.878 |
| *Luidia senegalensis* (Lamarck, 1816) | CBD, LC, PNRE | — | sd | UFPB.ECH.1865 |
| Echinasteridae Verrill, 1867 | | | | |
| *Echinaster* (*Othilia*) *brasiliensis* Müller & Troschel, 1842 | AVR, BB, CB, RS | APANQ, PEMAV | rhb, scr | UFPB.ECH.138 |
| *Echinaster* (*Othilia*) *echinophorus* (Lamarck, 1816) | AVR, BB, CB, LC, PC, PCP, RS | APANQ, PEMAV | rhb, scr | UFPB.ECH.568 |
| Asterinidae Gray, 1840 | | | | |
| *Asterinides folium* (Lütken, 1860) | CBD | — | rhb | UFPB.ECH.572 |
| Mithrodiidae Viguier, 1878 | | | | |
| *Mithrodia clavigera* (Lamarck, 1816) | BB | — | csh | UFPB.ECH.880 |
| Ophidiasteridae Verrill, 1870 | | | | |
| *Linckia guildingi* Gray, 1840 | BB, BC, CB, CBD, JC, PCP, PTB | APANQ | csh, scr | UFPB.ECH.1159 |

Table 2. Continued.

| Taxon | Ocurrence | Ocurrence in Conservation Units | Habitat | Voucher |
|---|---|---|---|---|
| Oreasteridae Fisher, 1908 | | | | |
| *Oreaster reticulatus* (Linnaeus, 1758) | AC, BT, CBD, JC, LC, PCP, PH, QCB, TB | APANQ | csh, rhb | UFPB.ECH.1251 |
| Ophiuroidea Gray, 1840 | | | | |
| Ophiomyxidae Ljungman, 1867 | | | | |
| *Ophiomyxa flaccida* (Say, 1825) | AC, AVR, BC, CB, LC | APANQ, PEMAV | csh, phy, rhb, scr | UFPB.ECH.64 |
| Ophiocomidae Ljungman, 1867 | | | | |
| *Ophiocoma echinata* (Lamarck, 1816) | AVR, CBD, PCP | APANQ, PEMAV | csh, rhb, scr | UFPB.ECH.216 |
| *Ophiomastix wendtii* (Müller & Troschel, 1842) | BC, BM, CBD, LC, PTB | APANQ | atr, csh | UFPB.ECH.397 |
| *Ophiocomella ophiactoides* (H.L. Clark, 1900) | AT, BB, PC, PTB, RS, SG | APANQ | phy, rhb, scr | UFPB.ECH.34 |
| Ophiodermatidae Ljungman, 1867 | | | | |
| *Ophioderma appressum* (Say, 1825) | AVR, BC, BM, BT, CA, CB, CBD, CQ, JM, PTB, RG, RS, TBB | APABRM, APANQ, APAT, PEMAV | csh, scr, rhb | UFPB.ECH.296 |
| *Ophioderma cinereum* Müller & Troschel, 1842 | AVR, CA, CB, CBD, CQ, JM, RG, RS | PEMAV | csh, scr | UFPB.ECH.116 |
| *Ophioderma januarii* Lütken, 1856 | BC, BT, CB, CBD, PTC, TB | APANQ | csh, scr | UFPB.ECH.271 |
| Amphiuridae Ljungman, 1867 | | | | |
| *Amphiura stimpsonii* Lütken, 1859 | BM, PC, PTB, QQ | APANQ | adc, csh, scr | UFPB.ECH.42 |
| *Amphipholis januarii* Ljungman, 1866 | AVR, BB, BM, BT, CA, CB, CBD, CQ, PS, PTB, PTC, QQ, RG, RS, TBB | APABRM, APANQ, APAT, PEMAV | adc, atr, csh, phy, scr, sr, rhb | UFPB.ECH.50 |
| *Amphipholis squamata* (Delle Chiaje, 1828) | BB, BC, BM, BT, CA, CB, CBD, CQ, RG, RS, SG, PC, PS, PTB, QQ, TBB, TG | APABRM, APANQ, APAT | adc, csh, phy, rhb, scr, sr | UFPB.ECH.43 |
| *Ophiostigma isocanthum* (Say, 1825) | BB, BC, BT, CBD, JC, JM, LC, MNB, PTB | — | csh, rhb | UFPB.ECH.173 |
| *Ophiocnida scabriuscula* (Lütken, 1859) | AVR, BB, BT, CA, CB, CBD, CQ, JM, LC, PCP, RG, RS | APANQ, PEMAV | csh, rhb, scr | UFPB.ECH.174 |
| *Ophiocnida loveni* (Ljungman, 1867) | — | — | sch | — |
| *Microphiopholis atra* (Stimpson, 1852) | CB, MRE | APANQ | csh, rhb, sd | UFPB.ECH.2183 |
| *Microphiopholis gracillima* (Stimpson, 1854) | BB, RS | APANQ | phy, rhb | UFPB.ECH.2202 |
| *Amphiodia planispina* (v. Martens, 1867) | BB, CB, CBD, LC, MNB, PCP, PH, PTB | APANQ | csh, rhb, scr | UFPB.ECH.227 |

Table 2. Continued.

| Taxon | Ocurrence | Ocurrence in Conservation Units | Habitat | Voucher |
|---|---|---|---|---|
| *Amphiodia riisei* (Lütken, 1859) | CB | — | csh | UFPB.ECH.931 |
| *Ophiophragmus luetkeni* (Ljungman, 1872) | BM | APABRM | scr | UFPB.ECH.2279 |
| *Ophiophragmus pulcher* H.L. Clark, 1918 | RS | — | csh, rhb | UFPB.ECH.2231 |
| Ophiopsilidae Matsumoto, 1915 | | | | |
| *Ophiopsila hartmeyeri* Koehler, 1913 | BB, CB, CBD, JC, JM, LC, PH, PTB | — | csh | UFPB.ECH.323 |
| Ophiactidae Matsumoto, 1915 | | | | |
| *Ophiactis lymani* Ljungman, 1872 | BB, BT, CB, PC, PS, PTB, QQ, RG, RS, TBB | APANQ, APAT | adc, phy, scr, sr | UFPB.ECH.58 |
| *Ophiactis quinqueradia* Ljungman, 1872 | BC, BT, CB, CBD, JC, LC, PTB | — | csh, scr, sdw | UFPB.ECH.288 |
| *Ophiactis savignyi* (Müller & Troschel, 1842) | BB, BM, BT, CA, CB, CQ, PC, PS, PTB, QQ, RG, RS, SG | APABRM, APANQ | adc, atr, phy, rhb, scr, sdw, sr | UFPB.ECH.39 |
| Ophiotrichidae Ljungman, 1867 | | | | |
| *Ophiothix* (*Ophiothrix*) *angulata* (Say, 1825)** | AVR, BB, BC, BM, BT, CA, CB, CBD, CQ, JC, JM, LC, RS, RG, PCP, PS, PH, PTB, QQ, TB, TBB, TG | APABRM, APANQ, APAT, PEMAV | adc, atr, csh, rhb, scr, sr | UFPB.ECH.78 |
| *Ophiothrix brasiliensis* Santana, Manso, Almeida & Alves, 2020*** | — | — | — | — |
| *Ophiothrix tommasii* Santana, Manso, Almeida & Alves, 2020*** | — | — | — | — |
| Ophionereididae Ljungman, 1867 | | | | |
| *Ophionereis dolabriformis* John & A.M. Clark, 1954 | BB, CBD, CQ, LC, PTB, TBB | — | csh | UFPB.ECH.749 |
| *Ophionereis reticulata* (Say, 1825) | AVR, CA, BC, BM, BT, CB, CQ, JM, PS, RG, RS, TBB | APANQ, APAT, PEVAV | scr | UFPB.ECH.1139 |
| *Ophionereis squamulosa* Koehler, 1914 | BB, BC, CBD, CQ, JC, LC, PH, PTB, TB | — | rhd | UFPB.ECH.584 |
| Ophiolepididae Ljungman, 1867 | | | | |
| *Ophiolepis impressa* Lütken, 1859 | BC, JM, LC, TB | — | csh | UFPB.ECH.490 |
| *Ophiolepis paucispina* (Say, 1825) | BB, PTB | — | csh, phy, scr | UFPB.ECH.172 |
| Echinoidea Leske, 1778 | | | | |
| Cidaridae Gray, 1825 | | | | |
| *Eucidaris tribuloides* (Lamarck, 1816) | BB, BC, BM, BT, CBD, CQ, JC, JM, LC, PH, PTB, TB | — | csh | UFPB.ECH.1620 |

Table 2. Continued.

| Taxon | Ocurrence | Ocurrence in Conservation Units | Habitat | Voucher |
|---|---|---|---|---|
| Echinometridae Gray, 1855 | | | | |
| *Echinometra lucunter* (Linnaeus, 1758) | AVR, BC, BM, BT, CA, CB, CBD, CQ, JM, PCB, PCP, PTB, RG, RS, TBB, TG | APABRM, APANQ, APAT, PEMAV | scr, phy, rhb | UFPB.ECH.01 |
| Toxopneustidae Troschel, 1872 | | | | |
| *Lytechinus variegatus* (Lamarck, 1816) | BB, BC, BM, BT, CB, CBD, JC, JM, LC, PH, PTB, RG, TB | APANQ | csh, phy, rhb, scr | UFPB.ECH.1158 |
| *Tripneustes ventricosus* (Lamarck, 1816) | BB, BT, PTB | APANQ | csh, scr | UFPB.ECH.1361 |
| Mellitidae Stephanini, 1912 | | | | |
| *Mellita* aff. *quinquesperforata* (Leske, 1778) | BB, BM, BT, CA, CB, CBD, CQ, JM, LC, PCP | APABRM, APANQ | sd | UFPB.ECH.350 |
| *Leodia sexiesperforata* (Leske, 1778) | BT, PCP, PTC | APANQ | sd | UFPB.ECH.1013 |
| *Encope emarginata* (Leske, 1778) | AVR, BM, CB, CBD, LC, PCP, PTC | APABRM, APANQ, PEMAV | sd | UFPB.ECH.615 |
| Brissidae Gray, 1855 | | | | |
| *Brissopsis* sp. | CBD | — | csh | UFPB.ECH.1646 |
| Holothuroidea (Blainville, 1834) | | | | |
| Chiridotidae Östergren, 1898 | | | | |
| *Chiridota rotifera* (Pourtalès, 1851) | AVR, BB, BC, CA, CB, CBD, JM, PH, PS, PTB, RS, TBB | APANQ, APAT, PEMAV | csh, scr, phy, rhb | UFPB.ECH.187 |
| Synaptidae Burmeister, 1837 | | | | |
| *Synaptula hydriformis* (Lesueur, 1824) | BB, CB, PC, RS, SG | APANQ | phy, rhb, scr | UFPB.ECH.161 |
| *Protankyra ramiurna* Heding, 1928 | PTC | — | — | UFPB.ECH.2125 |
| Holothuriidae Burmeister, 1837 | | | | |
| *Holothuria* (*Cystipus*) *pseudofossor* Deichmann, 1930 | CBD | — | csh | UFPB.ECH.2070 |
| *Holothuria* (*Halodeima*) *grisea* Selenka, 1867 | BC, BM, BT, CA, CB, CBD, CQ, JM, PCB, PH, SG, TG | APABRM, APANQ | scr | UFPB.ECH.316 |
| *Holothuria* (*Thymiosycia*) *arenicola* Semper, 1868 | CB | APANQ | scr | UFPB.ECH.1480 |
| Cucumariidae Ludwig, 1894 | | | | |
| *Thyonidium seguroensis* (Deichmann, 1930) | AVR, BB, BC, CB, CBD, PC, PTB, RS, TB | APANQ, PEMAV | rhb, scr | UFPB.ECH.1553 |
| *Parathyone suspecta* (Ludwig, 1875) | AVR, BB, CB, PTB | PEMAV | csh, scr | UFPB.ECH.1216 |
| *Ocnus braziliensis* (Verrill, 1868) | CB | APANQ | scr | UFPB.ECH.1063 |
| Phyllophoridae Östergren, 1907 | | | | |
| *Pentamera paraibanensis* Prata & Christoffersen, 2016 | BB, CB, CBD, CQ, PC, TB | APANQ | phy, rhb, scr | UFPB.ECH.141 |

Table 2. Continued.

| Taxon | Ocurrence | Ocurrence in Conservation Units | Habitat | Voucher |
|---|---|---|---|---|
| *Pentamera pulcherrima* Ayres, 1852 | CBD | — | rhb | UFPB.ECH-2147 |
| *Stolus cognatus* (Lampert, 1885) | AVR, BB, BC, CB, CBD, PCP, RS, TB | APANQ, PEMAV | rhb | UFPB.ECH.854 |
| *Thyone brasiliana* Prata, Manso & Christoffersen, 2020 | BB | — | rhb | UFPB.ECH.2121 |
| *Thyone crassidisca* Miller & Pawson, 1981 | CBD | — | csh, rhb | UFPB.ECH.2113 |
| *Thyone pawsoni* Tommasi, 1972 | RS | APANQ | rhb, scr | UFPB.ECH.1992 |
| *Thyone pseudofusus* Deichmann, 1930 | BB, CBD | — | rhb | UFPB.ECH.2116 |
| Psolidae Burmeister, 1837 | | | | |
| *Lissothuria braziliensis* (Théel, 1886) | CB, RS | APANQ | scr, rhb | UFPB.ECH.1292 |
| Sclerodactylidae Panning, 1949 | | | | |
| *Pseudothyone belli* (Ludwig, 1886) | AT, BB, CB, CBD, TB | APANQ | phy, rhb | UFPB.ECH.146 |
| *Coronatum baiensis* Martins & Souto *in* Martins, Souto & Menegola, 2012 | BB, CBD, TB | — | rhb | UFPB.ECH.2155 |
| *Euthyonidiella occidentalis* (Ludwig, 1875) | AVR, BB, BC, CB, CBD, JM, PCP, PH, PTB, RS, TB | APANQ, PEMAV | rhb, scr | UFPB.ECH.2110 |
| *Euthyonidiella trita* (Sluiter, 1910) | BB | — | rhb | UFPB.ECH.2124 |

The number of echinoderm species recorded in Paraíba (74 spp.) corresponds to 39% of the total number of species known for the entire northeastern region of Brazil, where 191 species are recorded (Table 3). The state of Bahia has the largest number of recorded species, 131 (69% of the total species), followed by Alagoas, with 75 spp. (39%). On the other hand, the smallest species diversity is recorded for the states of Piauí and Sergipe, with 8 and 11 species, respectively.

A dendrogram indicates that the state of Bahia separates from the remaining northeastern states (Fig. 6a-f), except for Crinoidea, in which Bahia groups with others 5 states (Rio Grande do Norte, Sergipe, Paraíba, Alagoas and Ceará), due to their sharing a low number of species (Fig. 6b). Groupings by nMDS share the states of Bahia, Paraíba, Pernambuco, Rio Grande do Norte, Alagoas, and Ceará, based on the composition of echinoderm faunas (Fig. 7a-f).

*Uses, impacts and threats.* From the literature and *in situ* observations, it has been possible to record different uses and moderate populational pressure on echinoderms throughout the state. Basically, echinoderms (mainly Asteroidea and Echinoidea) are used as souvenirs in the confection of zoological artisanal artifacts (Fig. 8). The main threats to this fauna lie in the unplanned use of reef environments, causing alterations or destruction of these habitats, in pollution, and accidental capture during fishing with trawling nets.

Within the phylum, Asteroidea is the group that suffers the greatest threats in the state. It is common to observe the selling of dried specimens of *Oreaster reticulatus* and *Astropecten* spp., that serve as decoration items in shops, hotels, and bars. Young specimens of *Astropecten* spp. are commonly used in the confection of costume jewelry (Fig. 8). *Luidia senegalensis* (Lamarck, 1816) and *Astropecten marginatus* Gray, 1840 are frequently found as part of the bycatch of net trawlings along the beaches. Although accidental captures are common, the number of individuals in these events is low.

Direct pressures are low for class Echinoidea. Yet, echinoid tests are used as decorative items. These animals are also used asexperimental models in scientific research. However, no significant captures or threats were detected for the remaining species in our state. There are no records of uses in the aquarium trade, nor of the fishing of sea urchins and sea cucumbers for local consumption or to supply external markets.

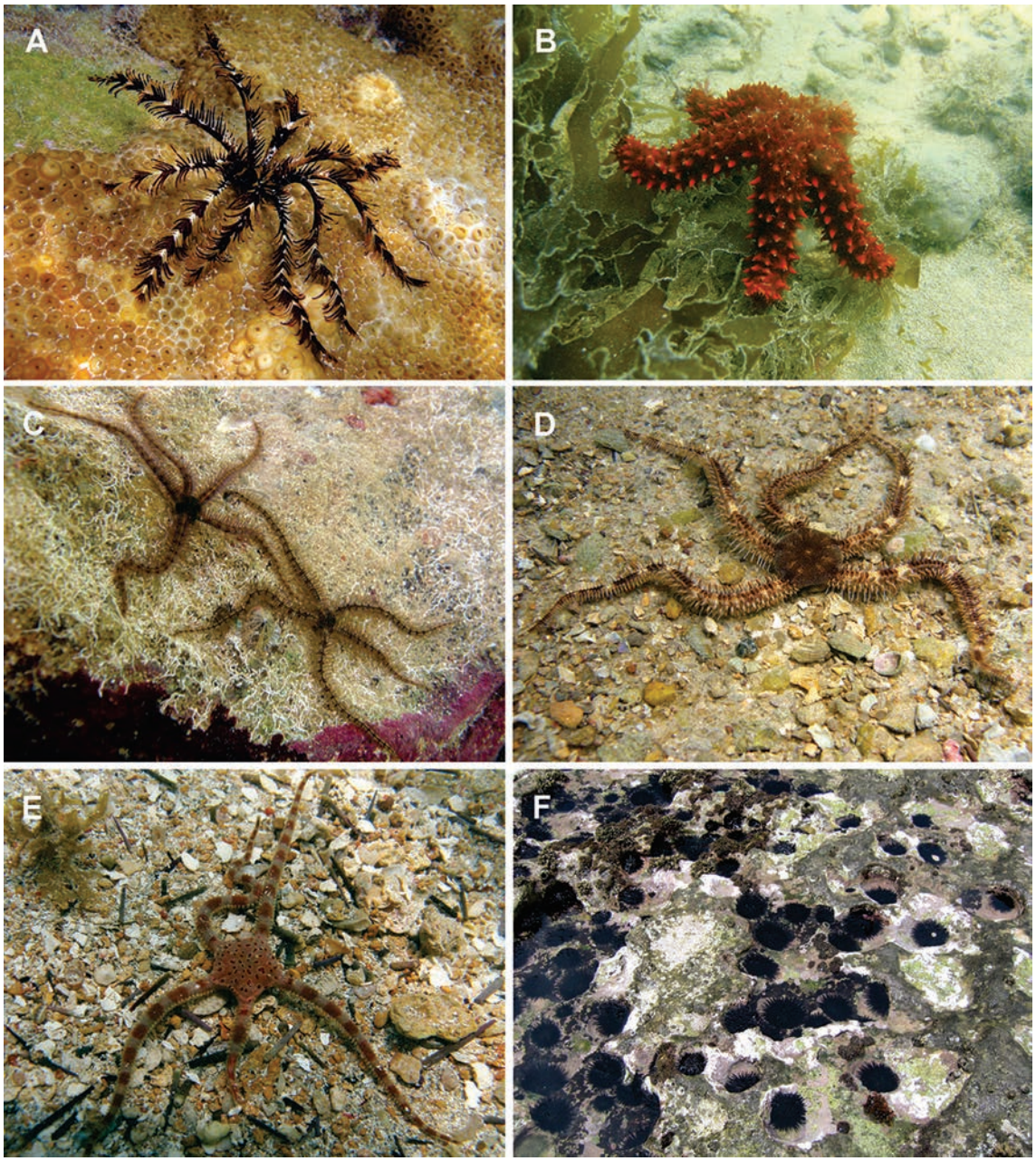


Figure 3. Some species of echinoderms recorded from the Paraíba litoral, Northeastern Brazil. A) The feather stars *Tropiometra carinata*; B) a specimen of sea star *Echinaster* (*Othilia*) *echinophorus* spawing at Cabo Branco reef (João Pessoa); C) specimens of the brittle star "*Ophiothrix* (*Ophiothrix*) *angulata*"; D) *Ophiocoma echinata*; E) *Ophiomyxa flaccida*; F) some specimens of the sea urchin *Echinometra lucunter* at Baía da Traição reef in 2007 (Baía da Traição). Photos: T.L.P. Dias and A.I. Gondim.

## Discussion

Description and cataloguing of the biodiversity is a continuous process. Based on present results, we may consider that the biodiversity of shallow-water echinoderms in Paraíba is well documented. Further, considering the large dimensions of Brazil, and the comparatively short extension of the Paraíba coast, the third smallest in the country, the diversity from the area is high. These species represent 39% of those known for northeastern Brazil,

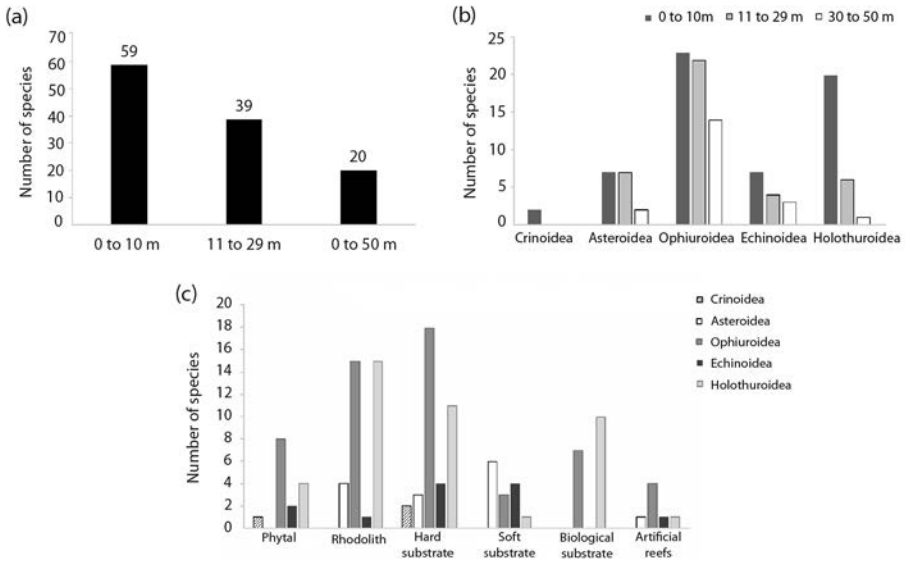


Figure 4. Occurrence of echinoderm species at different bathymetric ranges and habitat in Paraíba coast. a) Number of species of echinoderms by bathymetric ranges; b) number of species of each echinoderm class by bathymetric ranges; c) number of echinoderm species in relation to substrate types (biological substrate = corals and sponges).

Table 3

Number of species of echinoderms arranged by class for each state in Northeast Brazil.

| States | Number of species for taxon | | | | | Total |
|---|---|---|---|---|---|---|
| | Crinoidea | Asteroidea | Ophiuroidea | Echinoidea | Holothuroidea | |
| Maranhão | 8 | 3 | 16 | 3 | 0 | 30 |
| Piauí | 0 | 2 | 2 | 2 | 2 | 8 |
| Ceará | 6 | 7 | 25 | 7 | 4 | 49 |
| Rio Grande do Norte | 1 | 7 | 18 | 8 | 11 | 45 |
| Paraíba | 3 | 12 | 20 | 8 | 21 | 74 |
| Pernambuco | 7 | 12 | 25 | 9 | 9 | 62 |
| Alagoas | 4 | 8 | 27 | 17 | 19 | 75 |
| Sergipe | 1 | 1 | 5 | 4 | 0 | 11 |
| Bahia | 6 | 18 | 60 | 21 | 26 | 131 |
| NE Brazilian coast | 17 | 28 | 74 | 31 | 40 | 191 |

21% of those known for the country (339 spp.), 16% of the Caribbean fauna (433 spp.; Alvarado, 2011), 11% of the Atlantic sector of South America (627 spp.; Pérez-Ruzafa et al., 2013), and 4.8% of Latin America (1,539 spp.; Alvarado & Solís-Marín, 2013). Considering biodiversity, 39% of the species of Ophiuroidea from Northeastern Brazil are compiled, 21% of the Brazilian fauna (134 spp.), and 20% of the species known from the Caribbean Sea (148 spp.; Alvarado, 2011). For Holothuroidea, these numbers are 52%, 30% (69 spp.), and 33% (63 spp.; Alvarado, 2011), respectively. Two species are endemic to the state: *Parathyone paraibanensis* Prata & Christoffersen, 2016 and *Thyone brasiliana* Prata, Manso & Christoffersen, 2020.

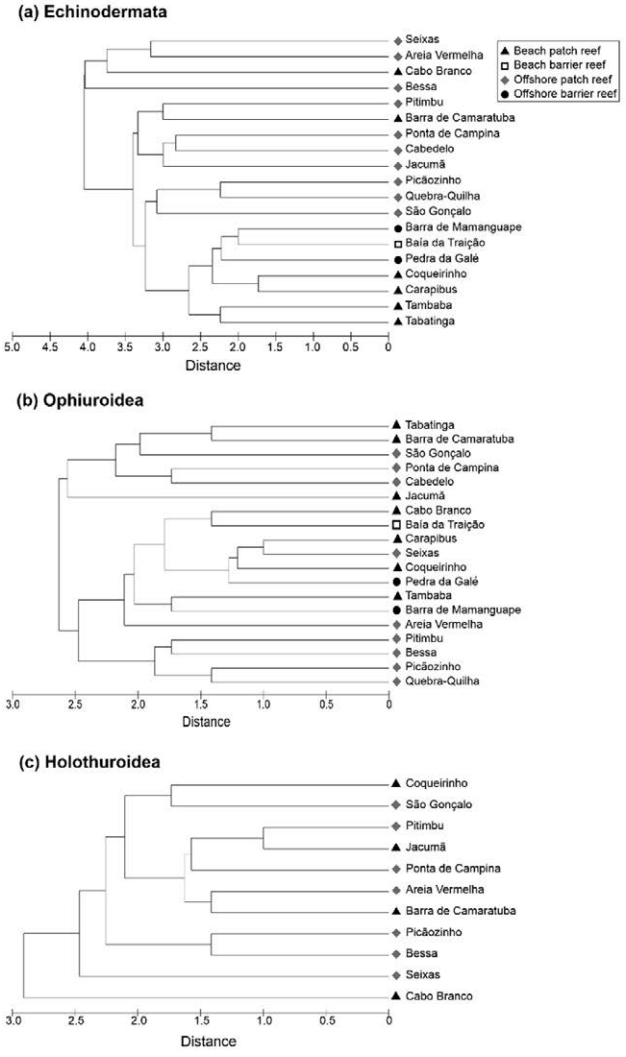


Figure 5. Cluster tree (Euclidean distance) based on species presence/absence Bray-Curtis resemblance matrix for echinoderms between Paraíba shallow-reefs, Northeastern Brazil. A) Echinodermata, B) Ophiuroidea, C) Holothuroidea.

These numbers are relevant when compared to the more diverse areas in the tropical Atlantic Ocean, where intensive sampling has been conducted, such as the Gulf of Mexico (522 species; Pawson et al., 2009) and Caribbean Sea (Alvarado, 2011). The fauna recorded in Paraíba refers mainly to hard substrates (reefs) and rhodolith beds in shallow water, from the intertidal to 35 m in depth. When greater depths and new habitats become better explored, these numbers should increase substantially.

Considering only the composition of echinoderms from shallow reefs in Paraíba, the most common species were *Aphipholis squamata*, "*Ophiothrix* (*O.*) *angulata*", *Ophionereis reticulata*, *Ophiactis savignyi* (Müller & Troschel, 1842), *Ophiocnida scabriuscula* (Lütken, 1859), *Echinometra lucunter*, and *Holothuria* (*Halodeima*) *grisea* Selenka, 1867. These are generally also the most common reef species in other localities of northeastern Brazil, with a few additions (Alves & Cerqueira, 2000; Gondim & Giacometti, 2010; Lima-Verde, 1969; Martins & Martins de Queiroz, 2006; Miranda et al., 2012). It is noteworthy that some species found in the shallow reefs between Pernambuco and Bahia are not found in the coastal reefs of Paraíba. For example, *Eucidaris tribuloides*, a common species in the intertidal zone along the coasts of Pernambuco, Alagoas and Bahia, occurs in Paraíba, restricted to depths greater than 10 m (Gondim et al., 2018). Furthermore, the records of *E. tribuloides* in Paraíba are from 1981, there being no recent records and information on the status of the local populations.

In terms of similarity of the echinoderm fauna from Paraíba reefs, a cluster was observed among areas with similar topological and environmental characteristics. Those areas with similar types of reefs are the most similar in echinoderm composition. A cluster is formed by Barra de Mamanguape, Baía da Traição, and Pedra da Galé, which are very similar regarding topography, biogenic constitution, and availability of microhabitats. However, we believe that these results are due mainly to the availability of microhabitats provided by different types of reefs. The reefs here classified as "barrier reefs" are less complex environments, with few tide pools, and low algal and coralline covering. It is well known that structurally more complex environments offer more habitats and niches, permitting the coexistence of several species and promoting a higher diversity (Beck, 2000; Kerr, 2001; Kostylev et al., 2005; Kovalenko et al., 2012; Matias et al., 2010). However, it is necessary to look at these results with care, because in some cases they could reflect different sampling efforts between areas over time, particularly when we consider the echinoderm classes.

The dendrogram of records in each state in northeast Brazil showed groups shared between closer states that share more similar coastal characteristics. Yet, when each class is considered separately, the groups tend to reflect sampling procedures, and thus are related to the degree of local knowledge of the fauna. Pérez-Ruzafa et al. (2013) analysed biogeographical patterns of echinoderms in Latin America, concluding that similarity between country faunas depends on climatic and trophic conditions and geographical proximity, and that the number of species is highly dependent of the length of the coast. From such a premise, one could expect that the states with highest diversity would be Bahia, Maranhão, Ceará, and Rio Grande do Norte, respectively. When mapping the species

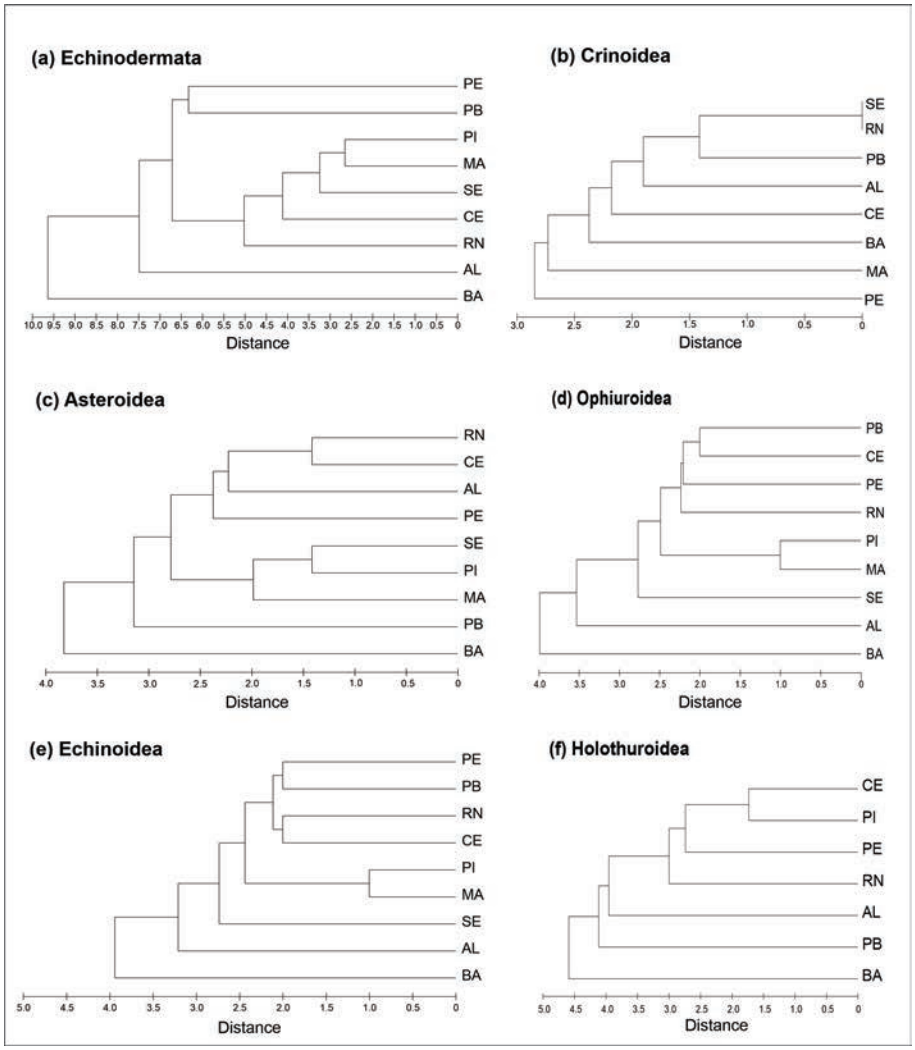


Figure 6. Cluster tree (Euclidean distance) based on species presence/absence Bray-Curtis resemblance matrix for echinoderms from Northeastern Brazil. A) Echinodermata, B) Crinoidea, C) Asteroidea, D) Ophiuroidea, E) Echinoidea, F) Holothuroidea.

every 10 km, Paraíba recorded the highest value (5.1), followed by Alagoas (3.2), Pernambuco (3.2), Bahia (1.4), Piauí (1.1), Rio Grande do Norte (1.0), Sergipe (0.6), and Maranhão (0.4). Thus, the patterns found by Pérez-Ruzafa et al. (2013) are only applicable in part to the northeastern states. The disparity in sampling efforts is an important factor that can influence the interpretation of geographic patterns (Price et al., 1999), species richness, and species similarity. Furthermore, the results generated by the dendrogram and nMDS may be related to sampling efforts in each area, lack of taxonomic expertise, limited funding for research, and limited access to sampling in some area. Local environmental conditions and anthropogenic interference in each sector of the littoral may also influence results.

Throughout the years studying echinoderms, we have noticed reductions in some populations in shallow reefs, and a moderate loss of diversity in these environments. For example, the reef at Cabo Branco, where 31 species of echinoderms have been recorded, displayed an exuberant and diverse fauna up to the middle of 2010 (Dias, 2009; Duarte et al., 2014; Gama et al., 2006; Gondim et al., 2008; Leonel et al., 2012; Lomônaco et al., 2011; Riul et al., 2008; Rosa et al., 1997), with several endemic species (e.g., *Siderastrea stellata* Verrill, 1868, *Voluta ebraea* Linnaeus, 1758). Today, the area is visibly impoverished.

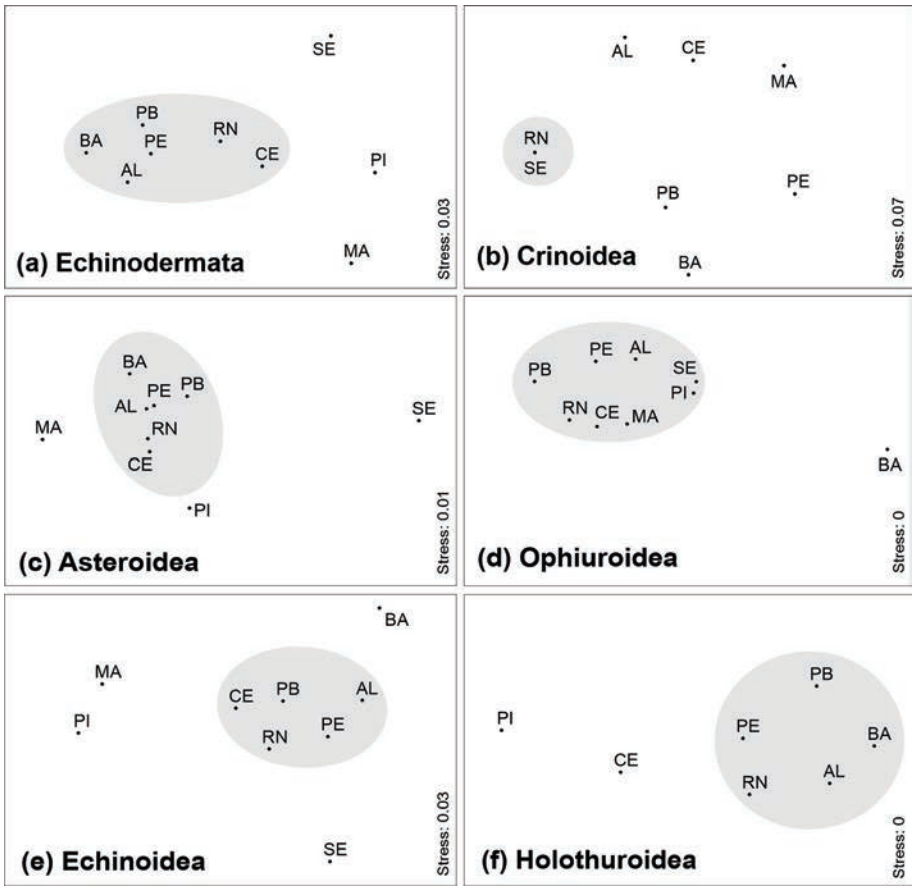


Figure 7. Non-metric multiple dimensional scaling (NMDS) based on species presence/absence Bray-Curtis resemblance matrix for echinoderms between the Northeastern States, Brazil.

Common species in the area, such as *Echinometra lucunter*, *Ophioderma cinereum*, *Echinaster* (*O.*) *echinophorus*, and *Linckia guildingi* are presently rarely observed. Although Cabo Branco reef is a naturally dynamic reef, the erosion of the adjoining cliff has gradually buried a large part of the reef. This process of erosion has been accelerated by increasing constructions in the area, with inadequate use of the soil, deforestation, inadequate maintenance of soil drainage, and circulation of vehicles close to the shoreline at the edge of the cliff (Pinto et al., 2017). Further, the natural pools during low tides are increasingly used for bathing and subsistence fishermen. Only recently (Dec. 28, 2018) this reef has been included in a UC (APANQ).

Cabo Branco is an example of the gradual loss of diversity in recent years. Unfortunately, it is difficult to pinpoint particular culprits. Local stressors (e.g., pollution, coastal acidification) may be responsible, direct anthropic actions (e.g., change or loss of habitats), the activity of pathogens on the populations, or even to anomalous temperatures in sea surface water recorded in the area during the last decade. Ocean warming and ocean acidification are amply recognized stress factors because they affect the physiology, biology, and behavior of echinoderms across life-history stages (Bellucci & Smith, 2019; Brennand et al., 2010; Byrne & Hernández, 2020; Gooding et al., 2009; Wood et al., 2008; Yuan et al., 2016). When associated with a recent case of oil spilling that has affected several beaches in Paraíba, the situation becomes worrisome. Monitoring studies are essential to an understanding of the factors affecting the local echinoderm populations. Echinoderms participate, for example, in the carbon cycle, producing and winnowing vast quantities of the world's seafloor sediments, enhancing the productivity of the benthic biota, through metabolites and their excreta, and acting to increase seawater alkalinity, which contributes to local buffering of ocean acidification (Guillén et al., 2008; Hendler et al., 1995; Lebrato et al., 2010; Purcell et al., 2016).

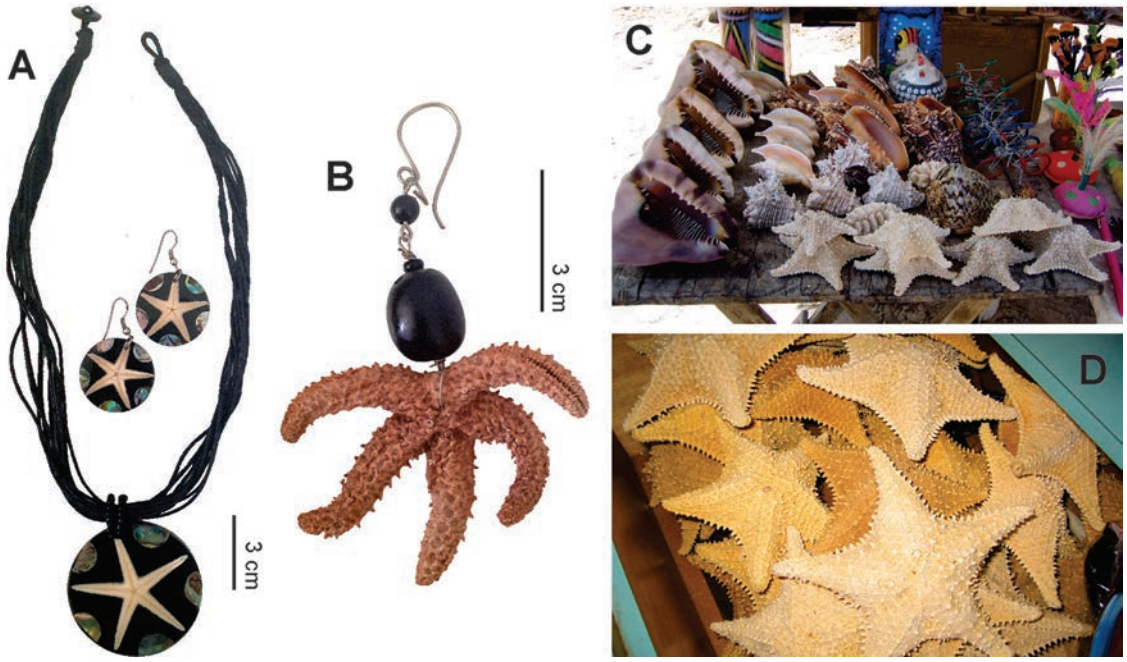


Figure 8. Uses of echinoderm species for the confection of costume jewelry and for ornamental purposes in the State of Paraíba. A) Specimens of *Aspropecten* sp. used in the making of pendants and earings; B) specimen of *Echinaster* (*Othilia*) *echinophorus* used as earings; C) dry specimens of *Oreaster reticulatus* for sale in a beach tent at Coqueirinho beach, Conde; D) dried specimens of *O. reticulatus* for sale in Mercado de Artesanato Paraibano, João Pessoa. Photos: T.L.P. Dias and A.I. Gondim.

On the positive side, about 67% of the species recorded in this study occur in UCs in the state. Yet, they all represent Sustainable Use Units (SNUC, 2002), many with intense touristic exploitation, where surveillance is mostly lacking. Considering that we are beginning a United Nations Decade of Ocean Science for Sustainable Development (2021-2030) (ONU, 2019), geo-referenced historical (literature and collections-based) invertebrate species inventories can be a useful early step in biodiversity knowledge-gathering towards marine area conservation (Sloan & Bartier, 2009).

*Conservation.* Brazil is conservatively estimated to contain more than 13% of the world's biota (Brandon et al., 2005). A large part of this biodiversity is located in marine environments (e.g., mangroves, reefs, rhodolith beds). Such environments are of great biological importance, representing important oases of biodiversity, and functioning as nursery grounds (Donato et al., 2011; Horta et al., 2016; Leão et al., 2016; Schaeffer-Novelli et al., 2000). Yet, these environments, and consequently their flora and fauna, suffer increasing pressure from human activities (e.g., real estate speculation, tourism, pollution, global warming, etc.).

According to the Instituto Chico Mendes de Conservação da Biodiversidade - ICMBIO (2018), the capture of marine invertebrates, directed to consumption, to aquarium trade, or used as bait, are the main threat to this fauna in coastal waters in Brazil. They are followed in importance by pollution of the coastal and marine environment. Presently, 657 species of marine invertebrates are listed in the Brazilian Red List (BRL), of which 38 are echinoderms. Among the categories of threat included in IUCN (The International Union for Conservation of Nature), the species of echinoderms present in the BRL are classified as critically endangered (CR = 1 sp.), endangered (EN = 1 sp.), vulnerable (VU = 8 spp.), and of least concern (LC = 28 spp.).

There have been no specific studies with the objective of evaluating the conservation status of echinoderms in Brazil (Gondim et al., 2018). Data on the conservation status of species may be found in Machado et al. (2008), Ventura et al. (2013, 2018), and Gondim et al. (2018). In Paraíba, Gondim, Dias et al. (2014) pointed out the importance of conserving rhodolith beds for the echinoderm fauna.

In general, data on the status of populations of echinoderms in Paraíba are practically non-existent. Consequently, it is difficult to establish the threatened status over this fauna. As previously mentioned, observations

*in situ* and observations of traditional local communities have recorded reductions in the sizes of these populations. Recently, Gondim et al. (2018) recorded a reduction in the populations of *Echinometra lucunter* and *Lytechinus variegatus* in several areas of Paraíba (e.g., beaches of Cabo Branco, Seixas, Camboinha, Formosa, Jacarapé, among others). This same situation applies to *Ophioderma appressum* and *O. cinereum*, previously common species that are now not often observed on several reefs in our state.

Interestingly all species of Asteroidea recorded in this study are in the BRL. Excepting *Luidia senegalensis*, *Astropecten marginatus*, and *Linckia guildingi*, the remaining occurrences of sea stars throughout the Paraíba state are historical records (with more than 10 years). For example, the most recent record of *Oreaster reticulatus* is from rhodolith beds at a depth of 6 m in 2005 (UFPB. ECH.1871). Since then, the species has not been observed *in situ*. This information is worrisome because the species suffers from the illegal collecting by the aquarium trade (Gasparini et al., 2005; Lunn et al., 2008). When dried they are used in traditional folk medicine, in magicreligious rituals, and are sold, in the hundreds, as a decorative piece (Alves & Dias, 2010; Alves et al., 2006, 2018; Machado et al., 2008; Ferreira et al., 2012, 2013). In the northeast, Dias et al. (2017) recorded several dry specimens of *O. reticulatus* for sale in a beach tent in Coqueirinho beach (Paraíba). Alves et al. (2006) recorded the sale of several dried individuals in the city of Recife (Pernambuco). Martins et al. (2012) recorded the capture of 142 specimens in Bahía de Todos os Santos (Bahia), between 1996 and 2005, for the aquarium trade. In the southeast, Pinheiro et al. (2018) recorded the daily capture of 24 individuals of the species, also to replenish the aquarium trade in Espírito Santo. According to Ventura et al. (2018), populations of *O. reticulatus* are suffering a strong decrease, less than 2,500 adult individuals being estimated as extant. These authors further estimate that a reduction in the order of 30% has occurred in populations from the northeast, where smaller and smaller individuals are being commercialized. The capture of *O. reticulatus* has been prohibited along the Brazilian littoral since 2004, except for scientific purposes (Normative Instruction nº 05/2004 of Ministry of Environment) (Ventura et al., 2018).

*Echinaster* (*O.*) *echinophorus* was one of the commonest species of sea stars in shallow reefs of Paraíba. Presently it is observed only sporadically *in situ*, suggesting a reduction in local populations. This is a widely used species by aquarium enthusiasts, in zoological costume jewelry, and traditional folk medicine (Alves & Dias, 2010; Ferreira et al., 2012; Gurjão & Lotufo, 2018; Gurjão et al., 2018; Machado et al., 2008). Ferreira et al. (2013) recorded that *E.* (*O.*) *echinophorus* and other species of echinoderms are being sold for medicinal purposes in cities far removed from the coast, such as Juazeiro do Norte (Ceará), Caruaru and Santa Cruz do Capibaribe (Pernambuco). This demonstrates that the commercial demand for these organisms is not restricted to coastal cities. Among the reefs in Paraíba, *L. guildingi* is observed in few areas and only sporadically. This species characteristically forms populations with low densities. It is estimated that populations along the Brazilian coast have less than 10,000 adult individuals. Although the capture of this species is rarely documented, their populations are decreasing strongly (Machado et al., 2008). Martins et al. (2012) recorded the collection of *L. guildingi* (437 specimens; a mean of 50 specimens per year) for aquarium trade along the coast of Bahia. The capture of *Echinaster* spp. and *L. guildingi* are also prohibited.

Species of *Astropecten* and *Luidia* suffer mainly from accidental capture in trawling fisheries. Although populational data for the species of these genera are not available, it has been estimated that their populations suffered a reduction of 30% in their area of occurrence (Ventura et al., 2018). Like other sea stars, the capture of both genera is prohibited in Brazil, yet swimmers are very commonly observed capturing specimens of *L. senegalensis* and *A. marginatus*. These individuals sometimes are returned to the sea, but often they are taken home to serve as objects of decoration.

Only 2 species of Holothuroidea [*Synaptula secreta* Ancona Lopez, 1957, endemic to São Paulo, and *Isostichopus badionotus* (Selenka, 1867) —with a record for the northeast] are in BRL. There are no official records of holothurian fisheries in Brazil, but in 2001 about 0.45 tons of dry sea cucumbers were exported to Hong Kong (Machado et al., 2008). In recent years the media has been announcing the apprehension of several kilograms of sea cucumbers in the southeast (e.g., in 2018, 200 kg of sea cucumbers were seized in Angra dos Reis, Rio de Janeiro; in January 2019, fishermen denounced contracts for collecting these animals in Ilha Grande - RJ, that would later be sold in the international trade). In the northeast, Ponte (2017) recorded the fishing of about 200 thousand specimens of *Holothuria* (*H.*) *grisea* on the coast of Ceará during 1 year. Many of these individuals (66.5%) had not attained first sexual maturity (less than 13 cm) and only 33.5% (≥ 13.00 cm) had already reproduced at least once (Ponte & Feitosa, 2019). According to Souza Jr. et al. (2017), sea cucumber collection in Ceará started about 20 years ago, but intensified rapidly over the last 11 years, as a complementary income activity of traditional fisheries. Along the coast of Bahia, approximately 1,300 specimens of *H.* (*H.*) *grisea* were collected during 10 years

for the aquarium trade (mean of 144 individuals annually) (Martins et al., 2012). Although no population data are available for *H.* (*H.*) *grisea*, in a locality in Ceará (a beach close to the village of Bitupitá) a population decline of 98.7% over a period of 4 years has been estimated (Souza Jr. et al., 2017). Gurjão and Lotufo (2018) recorded the illegal selling of holothurians in discussion forums, under the common names "giant sea cucumber", "detritivorous sea cucumber" and "burrowing sea cucumber". So far, there is no record of the capture of these animals along the coast of Paraíba for any purpose. Although *H.* (*H.*) *grisea* is a common species, it does not form dense populations in the study area.

No one species of Crinoidea is considered threatened in Brazil. However *Tropiometra carinata* was the third most captured echinoderm for the aquarium trade in Baía de Todos os Santos (Bahia) between 1996 and 2005. During this period, about 190 specimens were captured annually (Martins et al., 2012). Hadel et al. (1999) cited a significant reduction in the populations of this species in the coast of São Paulo (southeastern of Brazil). Along the coast of Paraíba, the 3 recorded species are not common, and occur in areas abundantly used for touristic activities.

Although the capture of several echinoderms is prohibited in Brazil, there is no inspection and a majority of the population ignores such prohibitions. Artisanal markets commercializing these animals are quite common. Species of sea stars and sea urchins are the main representatives sold in the curiosity trade around the world, being used for decoration or for the confection of artisanal craft in general (Alves et al., 2018). Education programs on the importance of these animals and on the current legislation are fundamental to avoid the withdrawal of these animals from nature.

The largest obstacle for conservation strategies is the lack of information on the status of specific populations. The necessity for research on the biology and ecology of marine organisms is thus essential to reduce the anthropic impacts on echinoderms along our coast.

*General guidelines for the future*

Circa 81% of the species of echinoderms recorded for the coast of Paraíba is concentrated in shallow reefs down to 10 m. Below this depth, there are a few historical records dating mainly from 1981. Records refer basically to Ophiuroidea, Asteroidea, and Echinoidea. There is a complete lack of knowledge of the entire echinoderm fauna from the lower continental shelf, from bathyal and from abyssal waters. Inventories are thus necessary from depths below 10 m. More funds are needed for sampling and for maintaining scientific collections. A continuous formation of new specialists for the study of the group should be forthcoming.

A relevant point is that 99% of the ongoing studies developed along the coast of the State of Paraíba are taxonomical (inventories, new records, and new species descriptions). Biological, ecological and populational studies are virtually nonexistent. Recently, with the joining of the first author to the Postgraduate Program in Conservation and Ecology as a professor (PPGEC-UEPB), the development of research on biology and reproductive ecology of echinoderm species has started in our state (e.g., Cerqueira 2020). Such research is still incipient and needs to be complemented with further studies on the status of these populations.

We know that the incidental capture of echinoderms in trawling nets is common. However, information on the impacts of this activity on echinoderm populations is limited. Another important factor is that during trawling activities, it is common for fishermen to discard captured specimens. Even though many specimens end up returned to the sea, many of them are already dead after long exposure out of the water. Along the coast of Santa Catarina (southern Brazil), for example, Branco et al. (2015) recorded 11 species of echinoderms in the bycatch of seabob shrimp trawl fisheries. These captured species belonged to the sea stars *Astropecten brasiliensis* Müller and Troschel, 1842, *A. marginatus*, *Luidia clathrata* (Say, 1825), *Luidia senegalensis*, *Asterina stellifera* (Möbius, 1859), *Echinaster* (*O.*) *brasiliensis*, 3 echinoids, *Arbacia lixula* (Linnaeus, 1758), *L. variegatus*, *Mellita quinquiesperforata* (Leske, 1778), and 2 brittle stars, *Microphiopholis atra* (Stimpson, 1852) and *Hemipholis cordifera* (Bosc, 1802). Data such as these are not available for the coastline in northeastern Brazil. Studies evaluating the impact of fishing activities on echinoderms are needed along the entire coastline of Brazil.

In short, the most critical points highlighted by our results are: *1)* little knowledge of the fauna below the depth of 10 meters; *2)* the necessity of ecological studies and on monitoring the fauna; *3)* lack of evaluation of the impact of commercial activities (e.g., bycatch and captures for the aquarium trade, for medicinal use, and for use in handicrafts). The database, however, is already constructed (inventories and taxonomical studies). New strategies can now be planned according to local demands and following the recommendations of the scientific community. All research lines indicated herein are indispensable for the attainment of efficient public policies aimed at the conservation of these animals. We stress that in order to close the gaps highlighted herein, there is a demand for organization and financial support.

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