Research Article

# Filling a knowledge gap on the biodiversity of rhodolith-associated Echinodermata from northeastern Brazil

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**Abstract**

Rhodolith beds formed by non-articulated calcareous algae have been recognized as important habitats for a range of organisms. The Brazilian coast is home to one of the largest beds of the Southwestern Atlantic, but the lack of faunal studies in these habitats represents one of our major gaps in the knowledge of Brazilian biodiversity. This study compares the composition, abundance and diversity of echinoderm species associated with rhodoliths in three different isobaths (10, 15 and 20 m) along the coast of the State of Paraíba, Northeastern Brazil. These rhodolith beds provided 2,855 specimens, representing 32 species from four Classes, of which Ophiuroidea was the most numerous. The echinoderm community was significantly different considering the abundance of individuals ($F=452.86$, $p=0.001$) and the number of species ($F=45.14$, $p=0.006$) among the three depths analyzed. Abundance and species numbers decrease with increasing depth. Rhodolith beds in the State of Paraíba are an important habitat for echinoderms, harboring a high diversity and abundance of associated species. Richness and diversity records exceed those found in other coastal areas around the world, indicating that these banks are of special relevance for the conservation of echinoderms in Brazil.

**Keywords:** maërl beds, free-living coralline algae, echinoderm diversity, depth distribution, conservation

Received: 10 October 2013; Accepted 28 November 2013; Published: 24 March 2014

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Cite this paper as: Gondim, A. I., Dias, T. L. P., Duarte, R. C. S., Riul, P., Lacouth, P. and Christoffersen, M. L.. 2014. Filling a knowledge gap on the biodiversity of Rhodolith-associated Echinodermata from northeastern Brazil. *Tropical Conservation Science* Vol.7 (1):87-99. Available online: www.tropicalconservationscience.org

## Introduction

Rhodoliths are free-living forms of non-geniculate coralline red algae (Corallinaceae, Rhodophyta) that form extensive beds worldwide [1]. They occur from the low intertidal zone to depths of 150 m, typically in areas with high luminosity and water motion [2]. These rhodolith beds harbor communities on benthic substrata made up of branching or rounded thalli that collectively create a fragile, structured biogenic matrix over coarse or fine carbonate sediment [3].

Rhodolith beds have been shown to be of great ecological importance to the marine environment, providing a variety of ecological services. They provide a range of microhabitats for their associated fauna and flora, are good indicators of environmental conditions of the ecosystem which they inhabit, protect the associated fauna of the hydrodynamics of marine currents, and help maintain the pH of the sea [4].

Because of their three-dimensionality and rigid structural complexity, rhodolith beds are referred to as habitat modifiers or bioengineers that provide relatively stable microhabitats for other organisms [5]. These include invertebrate epibionts found on the surface of the algae, cryptic animals in crevices of nodules, boring animals in the thallus, and infaunal invertebrates found in sediments accumulated in the nodules. Recent studies in several parts of the world have shown that rhodolith beds may support rich faunal assemblages, including mollusks, crustaceans, polychaetes and echinoderms [e.g. 3, 6-8]. In the Gulf of California, for example, a number of commercially important species are often harvested or are recruited in these beds, such as scallops, shellfish, sea urchins, sea cucumbers and shrimps [9, 10]. The rhodoliths may have different structures, with a complex architecture of branched stems that can directly influence the diversity and abundance of associated taxa [11].

Globally, rhodolith beds are threatened by direct removal of nodules to supply the limestone industry, fishing with benthic trawl nets, and erosion of shorelines causing excessive sedimentation, among other factors. Although these habitats are already recognized as special areas for conservation in the Gulf of California, the United Kingdom and several European countries, in practice they still do not have the importance and necessary priority in conservation initiatives.

Echinoderms are one of the most conspicuous taxa in marine benthic habitats and may play critical ecological roles in coral reef communities [12]. Regarding rhodolith beds, the species richness and diversity of echinoderms inhabiting this ecosystem are still scarce, although some studies have reported them associated with this habitat worldwide [6, 13-15]. Some ecological studies of the sea urchin *Toxopneustes roseus* in rhodolith beds in the Gulf of California found that bioturbation resulting from urchin feeding, movement, and covering activity probably benefits rhodoliths by turning them, contributing to bed integrity and persistence [16]. In the same area, these beds were reported as important sites for juvenile echinoderms [8].

In Brazil, rhodolith beds apparently cover extensive areas of the N-NE Brazilian continental shelf, perhaps being the largest such area in the world [1, 17, 18]. Only in recent decades have studies on rhodolith bed communities increased, mainly focusing on the benthic flora that grow in these beds [19-21]. Faunal communities of ascidians, macroinvertebrates and polychaetes associated with rhodoliths in Brazil were recently surveyed with descriptions of new invertebrate species [22-25].

The objective of this study is to inventory the echinoderm assemblages that use the rhodolith structure as a habitat and discuss the influence of depth on the species composition in algae of three different depths. This baseline assessment of the biodiversity of rhodolith-associated echinoderms will provide a basis for future ecological studies and conservation initiatives.

## Methods

*Study area and sampling*

The study was carried out along the coast of the cities of Cabedelo and João Pessoa in Paraíba, Northeastern Brazil (Fig. 1). The area is located near the easternmost point of the Americas and is considered of high conservation importance [26]. The coast of this state is among the least impacted by exploitation. The rhodolith beds of this area are composed of specimens of *Sporolithon episporum* (M.A. Howe) E.Y. Dawson, *Lithophyllum* sp., *Lithothamnion* $sp_1$ and *Lithothamnion* $sp_2$ [20].

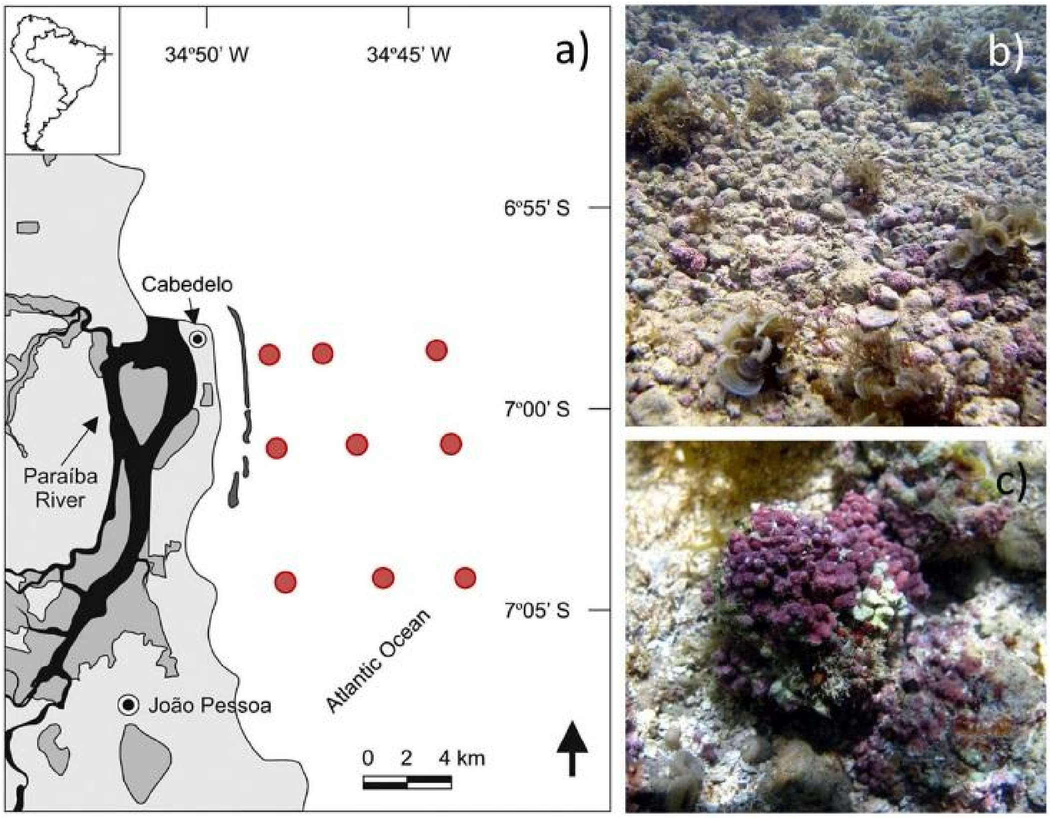


**Fig. 1. (a) Map showing the study area in the coast of Paraíba State, Northeastern Brazil, with collection sites (red dots) along three isobaths of continental shelf. Map adapted from Riul et al. (2009). (b) Underwater partial view of a rhodoliths bed and (c) individual rhodolith. Photos: Thelma Dias © 2009.**

Samplings were carried out during March 2006 in nine collection sites located perpendicularly to the coast at three different depths: 10, 15 and 20 m. For each depth, three rhodolith samplings were obtained, totaling nine samplings. In each site, a square of 100 $m^2$ was demarcated and five quadrat samples (50 x 50 cm) were positioned by chance. The material delimited by the quadrats was collected into plastic bags containing sea water to be analyzed in the laboratory. Data on temperature, salinity and water transparency were obtained with a reversion thermometer, refractometer, and a Secchi disc, respectively.

The samples were fixed in 4% buffered formalin diluted in sea water. Rhodoliths were carefully cleaned under stereomicroscope in order to find the associated echinoderms. The rhodoliths were also broken to access the fauna contained within the nodules. Each echinoderm found was conserved in ethanol at 70% and then deposited in the Echinodermata Section of the Paulo Young Invertebrate Collection, Universidade Federal da Paraíba. Additionally, the echinoderms were identified to species level following the specialized literature [27-31]. Individuals of each species were counted and their density provided as ind.0.25 $m^{-2}$.

*Data analysis*
The echinoderm community structure was characterized by the number of species (S), abundance (N), Shannon-Wiener diversity (H'), Margalef's richness (*d*) and Pielou's evenness (J'). Mean and standard error (SE) was calculated for density. To assess differences in echinoderm abundance among depths we performed an Analysis of Variance (ANOVA) after log (x+1) transformation of data. A Tukey test was used when significant differences were present. For all tests, effects were considered statistically significant at $p<0.05$. Statistical analyses were performed with the software package Biostat 5.3 and Primer 6 & Permanova+.

## Results

A total of 2,855 echinoderms were found associated with the studied beds, representing 32 species from four Classes (Asteroidea, Ophiuroidea, Echinoidea and Holothuroidea) (Appendix 1). Ophiuroidea (brittle stars) was the most abundant Class in number of species (N = 19), followed by Holothuroidea (sea cucumber) (N = 8). Among the species recorded, only 34% are common on the coast of Paraíba State, especially in shallow coastal areas. The remaining 66% area uncommon species, such as the brittle stars *Amphiodia pulchella* (Lyman, 1869) and *Ophiophragmus pulcher* H.L. Clark, 1918, which is first recorded in the coast of the State of Paraíba in the present study (Fig. 2).

In Class Asteroidea (sea star), we found only a single individual of the species *Asterinides folium* (Lütken, 1860), despite its wide geographic distribution and being considered somewhat abundant. Among ophiuroids we highlight *Ophiostigma isocanthum* (Say, 1825), which is uncommon throughout its distribution, occurring in low numbers in the studied banks. The Class Echinoidea (sea urchin) had the lowest number of species and individuals (S=2, N=2), which are considered recruits due to their small size (~5 mm in test diameter). The holothuroids were represented by 8 different genera, including uncommon and small species.

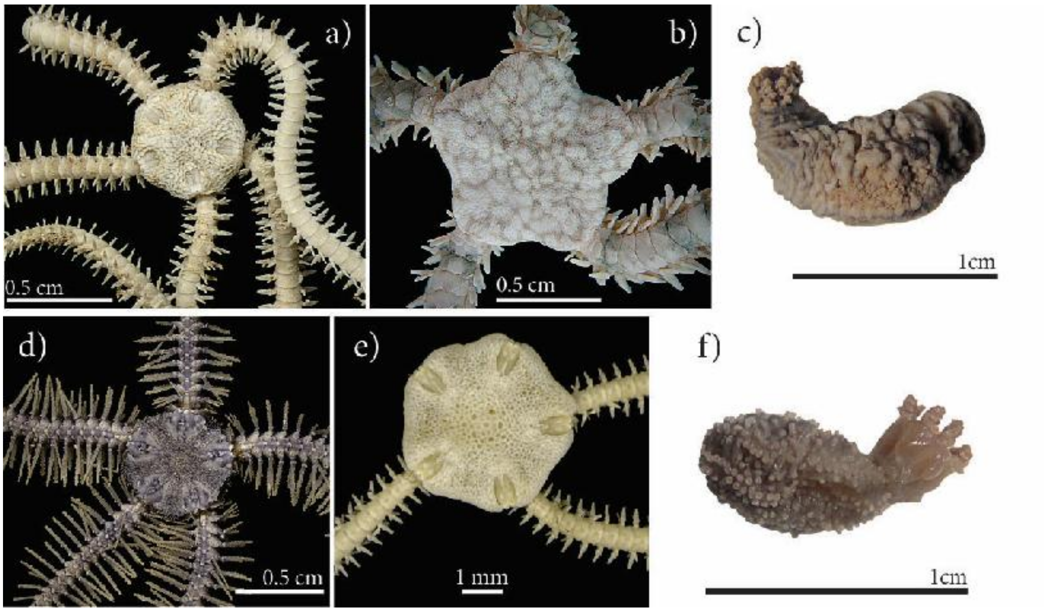


**Fig. 2. Some echinoderm species in the studied rhodolith beds. (a) *Amphipholis januarii*, (b) *Ophionereis reticulata*, (c) *Pseudothyone belli*, (d) *Ophiothrix angulata*, (e) *Amphiodia pulchella,* and (f) *Pentamera pulcherrima*. Photos: Anne Gondim © 2013.**

Relative to abundance, the holothurian *Pentamera pulcherrima* Ayres, 1852 was numerically dominant, accounting for more than 89% of the total (N=2,548), followed by the ophiuroid *Ophionereis reticulata* (Say, 1825), with 2.8% (N=80). The other 30 species were far less abundant and represented nearly 7.9% of the remaining specimens (Fig. 3).

The echinoderm community associated with the studied rhodolith beds was significantly different, considering the abundance of individuals (F=452.86, p=0.001) and number of species (F=45.14, p=0.006) in the three depths analyzed. We observed a decrease in the number of individuals and species with increasing depth. An *a posteriori* test indicated that the isobaths of 10 and 20 m were the most different in species composition and abundance (p <0.01). The isobath of 10 m was highest in number of species (S=22 spp., 68.7% of total), abundance (N=2,347) and richness (*d*=2.70). Comparing the four Classes of Echinodermata recorded, Ophiuroidea was the most species-rich taxon in the three depth ranges, while Asteroidea and Echinoidea occurred only at 10 m (Fig. 4). The Shannon-Wiener diversity was higher in the 20 m isobath (H’=1.81), which also showed higher evenness (J'=0.93) (Fig. 5).

Of the 32 species recorded in rhodolith beds, only three occurred in all three studied isobaths (*Amphipholis januarii*, *Ophiothrix* (*Ophiothrix*) *angulata* and *Pentamera pulcherrima*). The holothurian *P. pulcherrima* was the species with the highest density in the studied beds, reaching 140.1 ind. 0.25m$^{-2}$ in the 10 m isobath and 29.6 ind. 0.25m$^{-2}$ at 15 m. However, at 20 m depth the density of this species had declined abruptly, with only 0.14 ind. 0.25m$^{-2}$ (Appendix 1). Among ophiuroids, *Ophionereis reticulata* was the species with the highest density in the study area (4.07 ind. 0.25m$^{-2}$). This same pattern was observed for most species, such as the holoturoid *Pseudothyone belli*, and ophiuroids *A. januarii* and *Ophionereis* *reticulata*, which showed a decrease in density with increasing depth (Appendix 1). In general, the 20 m isobath showed the lowest density, richness and number of species (Appendix 1, Fig. 5).

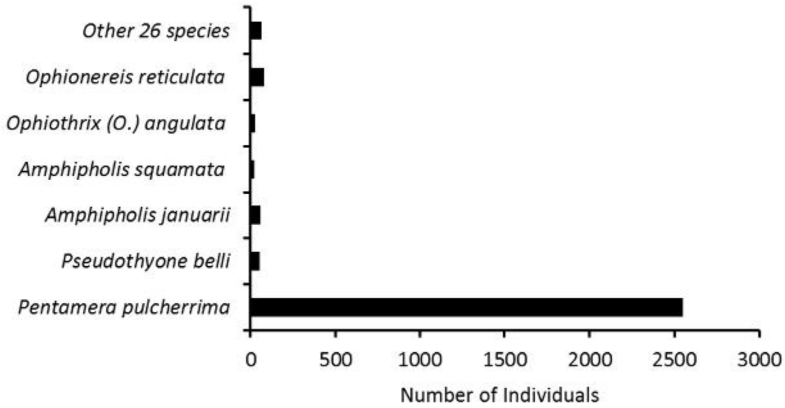


**Fig. 3. Most abundant species of rhodolith-associated echinoderms in Northeastern Brazil.**

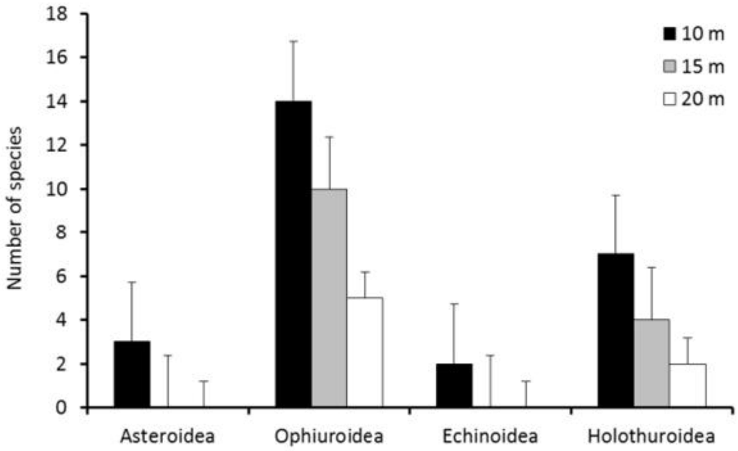


**Fig. 4. Comparison of number of species among the four Classes of Echinodermata found in rhodolith beds of Northeastern Brazil at three depths.**

## Discussion

This study represents the first real contribution to the knowledge of the echinoderm biodiversity of rhodolith beds on the continental shelf of the coast of Paraíba, which is also relevant to Northeastern Brazil. Echinoderms constitute one of the most conspicuous taxa in marine environments, but their biodiversity in the South Atlantic is still insufficiently known, especially in the subtidal Northeast coast. In Brazil, the diversity of echinoderms associated with rhodoliths beds still remains unknown [32]. These cited authors also pointed out that at present, the fauna associated with rhodoliths seems to be the greatest gap in Brazilian biodiversity knowledge.

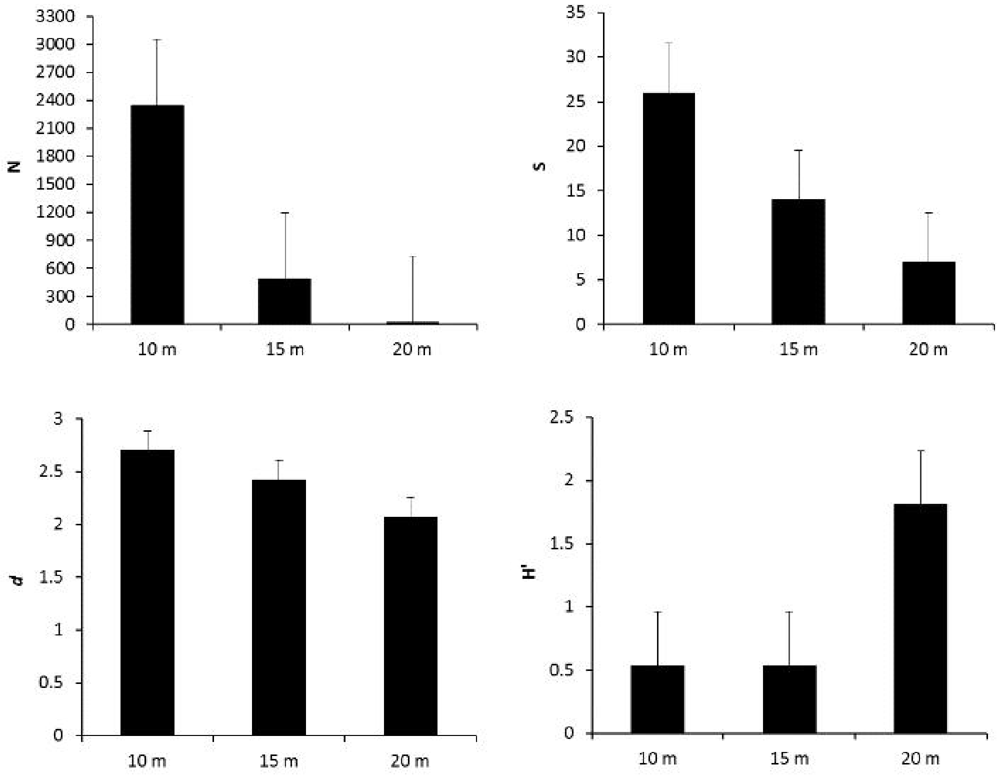


**Fig. 5. Mean values (±SE) for number of individuals (N), number of species (S), Margalef's richness (*d*) and Shannon-Wiener diversity (H') of echinoderms associated with rhodolith beds at three depths in Northeastern Brazil.**

The study revealed a rich echinoderm fauna associated with rhodoliths, composed of small species or young species that reach a larger size as adults, such as the sea urchins *Lytechinus variegatus* and *Echinometra lucunter* and the ophiuroids *Ophiomyxa flaccida* and *Ophioderma apressa*. These species are typically found in shallow coastal reef habitats, where they are usually observed as adults [29].

Representatives of four Classes of Echinodermata were found on the studied beds, with the exception of Class Crinoidea (sea lilies), which was not observed in any other study of echinoderms associated with rhodoliths [e.g. 3, 6, 10, 23]. Crinoids usually live attached to some stable substratum in sheltered habitats [29]. The absence of this class in rhodolith beds may be due to the instability of this habitat, since the individual thallus can be moved by waves, currents, and bioturbation [2, 33].

When compared to the number of species of echinoderms known in other coastal habitats along the coast of Paraíba and in other locations of northeastern Brazil, the biodiversity of echinoderms in studied rhodoliths was curiously high (N=32 species). In the state of Paraíba, 31 species of echinoderms were recorded associated with coastal reefs of Cabo Branco beach [34] and 23 ophiuroids were associated with various biogenic substrates of the continental shelf of Paraíba between the isobaths of 10 and 35 m [31]. In the Areia Vermelha Marine State Park, north coast of the Paraíba state, 16 species of echinoderms were recorded [35], of which 81.25% were found on the studied rhodoliths beds. These data indicate a wide bathymetric distribution of these species in both shallow coastal habitats and deeper areas.

Two species of brittle stars represent new records for the coast of Paraíba, *Amphiodia pulchella* and *Ophiophragmus pulcher*, both small. The first is usually found associated with mud and sand bottoms [30, 36]. Individuals may be found in high densities in poorly oxygenated sediments. In addition, they can be covered by algae, as well as associated with algal fronds. In Brazil *A. pulchella* is usually recorded at low density [29]. *Ophiophragmus pulcher* is an even rarer species along the Brazilian coast, having been recorded herein by a single individual. However, it was found in high numbers in the flats south of Key Biscayne, Florida, where several may be taken in a single handful of *Halimeda* sediment [37]. In Brazil, both species were found previously only in the coasts of Bahia, Rio de Janeiro and São Paulo.

The rhodoliths are also inhabited by the sea stars *Echinaster* (*Othilia*) *echinophorus* and *E. (O.) brasiliensis*, both threatened of extinction along the Brazilian coast [26]. In the studied rhodoliths, the sea stars were represented by juveniles at low densities. These species are common in shallow coastal areas usually associated with living reef environments where they become commercial targets for ornamental purposes [34, 35]. The presence of juveniles of these species in rhodoliths suggests that these habitats may be important as recruitment areas. *E.* (*O.*) *brasiliensis* was also recorded on the rhodolith banks of Arvoredo Marine Biological Reserve, central coast of the state of Santa Catarina, southern Brazil [23].

The sea cucumber *Pentamera pulcherrima* occurred in high density in the studied beds, totaling 140 ind. 0.25 $m^{-2}$ in the 10 m isobath. In other depths analyzed, this species also occurred in high densities, especially at 15 m depth. *P. pulcherrima* can be very common in the areas where it occurs, but previous authors indicate that this species also inhabits sandy bottoms or mud [38]. The high density of *P. pulcherrima* in rhodolith beds can be associated with the presence of sediment accumulated in rhodolith branches or, in the study area, this species can use rhodoliths as a more available habitat than unconsolidated substrates.

The community composition and abundance of echinoderms associated with rhodoliths were significantly different among the three studied isobaths, being richer and more abundant at 10 m depth. This may be related to different factors such as the density and diameter of the nodules and rhodolith vitality, which refers to the living algal tissue coverage on the calcareous matrix. In a study carried out on the northern coast of Bahia, the vitality of rhodolith decreased from 87% at 5 m depth to 17% at 25 m [39]. According to these cited authors, rhodolith vitality is an important factor to be evaluated as it affects the structure of the rhodolith as a substrate. In the study area on the coast of Paraíba, the volume of rhodolith decreased with increasing depth from 10 to 20 m [20]. Furthermore, the rhodoliths tend to decrease in diameter with increasing depth [39]. All these factors, combined with others still unknown, may affect the richness and abundance of the associated fauna. In the specific case of studied echinoderms, only three of the 32 species recorded were present in all three isobaths, suggesting that they are more tolerant of the factors that may be affecting the richness and abundance of the remaining species.

The structure of individual rhodoliths influences abundance patterns in cryptofaunal communities [8]. Intact complex thalli and rhodolith densities are also important factors driving this pattern. The above cited authors emphasize that complex thalli may provide more space, refuge and resources through increased interstitial and interbranch space. Larger, more densely branched or complex rhodoliths support a greater number of cryptofaunal organisms, as evidenced in a study conducted in the Gulf of California [3].

The general abundance of echinoderms in the studied rhodolith beds on the coast of Paraíba (N=2,855) suggests that these banks can be an important habitat for the taxon along the continental shelf, providing substrate and refuge from shallow subtidal to deeper areas. Other studies that reported echinoderms associated with rhodolith beds indicate low abundance of this taxon [3, 10]. However, the true factors that influence patterns of abundance and diversity of echinoderms associated with rhodolith banks need to be investigated in the different regions of these special habitats.

## Implications for conservation

Rhodolith beds studied in the State of Paraíba turned out to be a new and important habitat for echinoderms, harboring high diversities and abundances of associated species, including uncommon forms and species threatened with extinction along the Brazilian coast. Richness and diversities recorded exceed those found in other coastal areas around the world, indicating that these banks are of special relevance to the conservation of echinoderms in Brazil.

The predominance of young specimens reinforces the importance of this habitat as a potential area of recruitment and refuge. The location in shallow areas and increasing human exploitation of natural resources make these banks potentially vulnerable to anthropic impacts. This causes great concern, since only in the last decade have extensive sampling efforts provided a more comprehensive understanding of the distribution of rhodolith beds along the Brazilian coast [32].

In Brazil, rhodoliths beds are still excluded from habitat conservation initiatives, despite their worldwide recognition as true underwater ecosystems. Besides their importance as providers of structural complexity to the continental shelf, rhodolith beds support a rich biodiversity that includes organisms with recognized potential for bioprospection [32]. Thus, these areas need to be urgently prioritized in research programs and initiatives for maintaining their physical integrity, ecological balance, and conservation of their associated biodiversity.

## Acknowledgments

We are grateful to all students of the Department of Systematics and Ecology of the Federal University of Paraíba, who helped in sorting and processing of the studied rhodoliths. This study had the logistic assistance of the Graduate Program in Biological Sciences (Zoology - UFPB) and CAPES (Coordenação de Pesquisa e Ensino), through scholarships awarded to A. I. Gondim and P. Riul. CNPq (Conselho de Desenvolvimento Científico e Tecnológico) is acknowledged for the productivity grant to M. L. Christoffersen.

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**Appendix 1:** Mean density (±se) per sample (ind. 0.25 m$^{-2}$) of Echinodermata (N=32 species) associated with rhodolith beds in northeastern Brazil at three depths.

| Taxa | Depth | | |
|---|---|---|---|
| | **10 m** | **15 m** | **20 m** |
| **Asteroidea (3 spp)** | | | |
| *Asterinides folium* (Lütken, 1860) | 0.07 (±0.07) | - | - |
| *Echinaster (Othilia) echinophorus* (Lamarck, 1816) | 0.14 (±0.10) | - | - |
| *Echinaster (Othilia) brasiliensis* Müller & Troschel, 1842 | 0.14 (±0.10) | - | - |
| **Ophiuroidea (19 spp)** | | | |
| *Amphiodia planispina* (v. Martens, 1867) | - | 0.20 (±0.11) | - |
| *Amphiura* sp. | - | 0.07 (±0.07) | - |
| *Amphiodia* sp. | 0.07 (±0.07) | - | 0.07 (±0.07) |
| *Amphiodia pulchella* (Lyman, 1869) | - | 0.07 (±0.07) | - |
| *Amphipholis januarii* Ljungman, 1866 | 3.40 (±1.62) | 0.20 (±0.11) | 0.27 (±0.12) |
| *Amphipholis squamata* (Delle Chiaje, 1828) | 1.20 (±0.19) | 0.33 (±0.21) | - |
| *Amphipholis* sp. | 0.21 (±0.15) | 0.07 (±0.07) | - |
| *Ophiocnida scabriuscula* (Lütken, 1859) | 0.47 (±0.29) | - | - |
| *Ophiostigma isocanthum* (Say, 1825) | 0.20 (±0.14) | - | 0.20 (±0.14) |
| *Ophiactis savignyi* (Müller & Troschel, 1842) | - | 0.20 (±0.11) | - |
| *Ophiactis* sp. | - | 0.20 (±0.11) | - |
| *Ophiocoma echinata* (Lamarck, 1816) | 0.20 (±0.14) | - | - |
| *Ophioderma apressa* (Say, 1825) | 0.07 (±0.07) | - | 0.07 (±0.07) |
| *Ophiomyxa flaccida* (Say, 1825) | 0.07 (±0.07) | - | - |
| *Ophionereis reticulata* (Say, 1825) | 4.94 (±1.34) | 0.40 (±0.28) | - |
| *Ophionereis squamulosa* Koehler, 1914 | 0.36 (±0.36) | - | - |
| *Ophionereis* sp. | 0.07 (±0.07) | - | - |
| *Ophiophragmus pulcher* H.L. Clark, 1918 | 0.07 (±0.07) | - | - |
| *Ophiothrix (Ophiothrix) angulata* (Say, 1825) | 1.40 (±0.35) | 0.14 (±0.10) | 0.27 (±0.15) |
| **Echinoidea (2 spp)** | | | |
| *Echinometra lucunter* (Linnaeus, 1758) | 0.07 (±0.07) | - | - |
| *Lytechinus variegatus* (Lamarck, 1816) | 0.07 (±0.07) | - | - |
| **Holothuroidea (8 spp)** | | | |
| *Chiridota rotifera* (Pourtalés, 1851) | - | 0.07 (±0.07)- | - |
| *Pentamera pulcherrima* Ayres, 1854 | 140.1 (±47.09) | 29.6 (±10.39) | 0.14 (±0.10) |
| *Phyllophorus (Urodemella) occidentalis* Ludwig, 1875 | 0.14 (±0.10) | | 0.14 (±0.10) |
| *Pseudothyone belli* (Ludwig, 1887) | 3.13 (±1.35) | 2.33 (±1.27) | - |
| *Synaptula hydriformis* Lesueur, 1823 | 0.07 (±0.07) | - | - |
| *Stolus cognatus* (Lampert, 1885) | 0.07 (±0.07) | - | - |
| *Thyonidium seguroensis* (Deichmann, 1930) | 0.20 (±0.11) | 0.40 (±0.22) | - |
| *Thyone* sp. | 0.07 (±0.07) | - | - |