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DIMÍTRI DE ARAÚJO COSTA



**ENVIRONMENTAL EDUCATION AND THE ECOLOGICAL-TAXONOMIC
STUDY OF MARINE INVERTEBRATES ASSOCIATED WITH
RHODOLITHS/MAËRL BEDS IN TROPICAL COAST**

**“EDUCAÇÃO AMBIENTAL E O ESTUDO ECOLÓGICO-TAXONÔMICO DOS
INVERTEBRADOS MARINHOS ASSOCIADOS AOS BANCOS DE
RODOLITOS/MAËRL NA COSTA TROPICAL”**

João Pessoa, Paraíba, Brazil
Matosinhos, Porto, Portugal
March 2020

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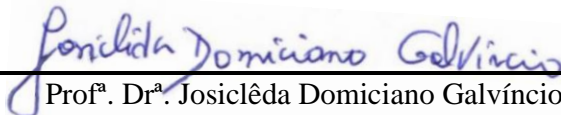
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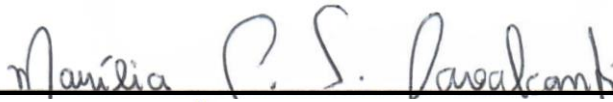
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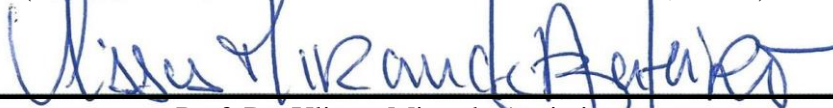
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DEDICATION

Education does not make us educable.

It is our awareness of being unfinished that makes us educable.

(Paulo Freire)

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ABSTRACT. This thesis aimed to provide students from public elementary schools in the Northeast Brazil with a differentiated and innovative way of teaching, using Environmental Education to raise their awareness for the protection of local coastal marine environments. The rhodolith/maërl beds are among the local potential environments to use for that purpose, since they are highly abundant on the Brazilian northeast coast, but still poorly known in the region. As such, the thesis also aimed to contribute to improve the knowledge of this habitat, with respect to local abundance, associated invertebrate communities, ecological importance and the impact of environmental constraints. The study was conducted in two schools in João Pessoa and Mataraca municipalities, in the State of Paraíba, integrating non-formal education, through a sequential program of practical activities, with traditional formal education. The efficiency of the program was tested with a questionnaire. In general, the integrated teaching was effective, since at the end of the program more than 80% of the students responded according to the concepts taught, demonstrating an improved level of ocean literacy. Regarding the rhodolith beds, a literature review was carried out, that confirmed their worldwide distribution and ecological importance, including for the balance of coastal ecosystems and maintenance of marine life. As a further research, the first taxonomic study of the invertebrates associated with rhodoliths was carried out on the beaches of Miramar (municipality of Cabedelo), Seixas (João Pessoa) and Maceió (Pitimbu). Sixty species were collected and identified, from different taxa. Of these, 53 were new records for the beaches under study, some of which may even be new species and/or endemic to rhodoliths. Finally, the rhodolith beds of these beaches, subjected to different anthropogenic impacts, were characterized, from the rhodoliths' abundance, morphology, growth form, as well as the associated invertebrates, according to the environmental factors assessed at the study sites. In general, Seixas Beach presented the greatest abundance of rhodoliths, and diversity and abundance of associated invertebrates, a result related to the high levels of calcium carbonate in the region, since this is an essential component for the development of calcareous algae. Maceió beach had the lowest abundance of these organisms, mainly associated with the high level of contamination by thermotolerant coliforms and lower water transparency. The invertebrate communities were also analysed from a functional perspective. Miramar and Seixas beaches were similar, where biodiffusors, with free and slow movement and predators predominated; whereas in Maceió Beach these attributes were practically absent, with individuals with limited movement, limited sediment remobilization and suspended feeding. These differences were analysed according to habitat characteristics, whose rhodolith-invertebrate interaction may be more beneficial in Seixas and Miramar beaches.

Keywords: Environmental awareness; Coralline algae; Biodiversity; Tropical zone; New taxonomic records; Marine ecology.

RESUMO. A presente tese objetivou proporcionar aos alunos de escolas públicas primárias do Nordeste do Brasil uma forma diferenciada e inovadora de ensino, usando a Educação Ambiental para sensibilizá-los para a proteção dos ambientes marinhos costeiros locais. Dentre as potencialidades locais para estudo, estão os bancos de rodolitos/maërl, altamente abundantes na costa nordestina brasileira, porém ainda pouco conhecidos na região. Como tal, a tese também objetivou contribuir para melhorar o conhecimento deste habitat, no que respeita a abundância local, comunidades de invertebrados associada, importância ecológica e impacto de condicionantes ambientais. O estudo foi realizado em duas escolas nas cidades de João Pessoa e Mataraca, no Estado da Paraíba, integrando o ensino não-formal, através de programa sequencial de atividades práticas, com o ensino formal tradicional. A eficiência do programa foi testada com um questionário. Na generalidade, o programa integrado de ensino foi efetivo, dado que no fim do programa mais de 80% dos alunos responderam de acordo com os conceitos transmitidos, demonstrando melhoria ao nível da literacia dos oceanos. Em relação aos bancos de rodolitos, foi realizada uma revisão acerca dos mesmos, sendo possível constatar a sua ampla distribuição a nível mundial e importância ecológica, incluindo o equilíbrio dos ecossistemas costeiros e manutenção da vida marinha. Como aprofundamento destas pesquisas, foi realizado o primeiro estudo taxonômico dos invertebrados associados aos rodolitos na região nordeste, nas praias de Miramar (no município de Cabedelo), Seixas (João Pessoa) e Maceió (Pitimbu). Foram coletadas e identificadas 60 espécies de diferentes taxa. Destas, 53 foram novas ocorrências para as praias em estudo, das quais algumas poderão ser novas espécies e/ou endêmicas associados aos rodolitos. Finalmente, os bancos de rodolitos destas praias com diferentes níveis de impacto antrópico foram caracterizados, desde abundância, morfologia, forma de crescimento, bem como fauna associada (invertebrados) em função dos fatores ambientais avaliados no local. No geral, a Praia do Seixas apresentou maior abundância de rodolitos, e diversidade e abundância dos invertebrados associados, resultado este relacionado aos altos níveis de carbonato de cálcio na região, um componente essencial para o desenvolvimento das algas calcárias. A Praia de Maceió apresentou a menor abundância destes organismos, associado sobretudo à contaminação elevado por coliformes termotolerantes e menor transparência da água. Os invertebrados foram também analisados numa perspectiva funcional. As praias de Miramar e Seixas foram similares, onde predominaram organismos biodifusores, com movimento livre e devagar, e predadores; ao passo que na Praia de Maceió estes atributos foram praticamente ausentes, predominando organismos de movimento limitado, com remobilização do sedimento limitada e com alimentação em suspensão. Estas diferenças foram analisadas de acordo com as características do habitat, cuja interação rodolito-invertebrados poderá ser mais benéfica nas praias de Seixas e Miramar.

Palavras-chave: Sensibilização ambiental; Algas coralináceas; Biodiversidade; Zona tropical; Novos registros taxonômicos; Ecologia marinha.

GENERAL INTRODUCTION

Environmental Education in the school context

Formal education encompass teaching in the educational system, usually inside a classroom linked to official institutions (Dib 1988, Biesdorf 2011, Bruno 2014). The traditional method usually practiced in these institutions tends to relegate students to the role of spectators in the teaching/learning process, which results in two structural problems: 1) teaching requires formalisms and preconditions for the understanding of the subsequent contents; 2) the traditional approach withhold the use of alternative forms of education (Nathan 2012). Yet, during expository classes from the traditional method, the teacher can incentive the participation of students (e.g. questions and dynamic exercises), improving the process of teaching (by the teacher) and learning (by the students). This can also occur through non-formal education practices, which generally occur outside the official educational institutions, in both urban and rural spaces, and where one learns through ‘daily life’ routines and sharing experiences (Gohn 2014). Indeed, non-formal education, that includes alternative methodologies, is becoming more necessary where formal education has been unable to educate the people, for e.g., to enhance skills and competence in the literacy (Kedrayate 2012), and to raise awareness environmental.

Embracing a non-formal and more dynamic approach where the teacher tends to use data from other areas of knowledge, aggregating complementary information, lead to broaden the learning outlook of the students. Among the subjects amenable to this integrated approach are the ‘transdisciplinary subjects’ (Nash 2008, Godemann 2008, Reyers et al. 2010), such as Environmental Education (EE). These are indissociably and extensively related to society in the proposition of problem solutions and resolution. Indeed, EE aims to change behaviour and direct practices for the preservation of the environment as a whole, using biological, ecological, chemical, physical, geographical, and mathematical concepts, among others. According to the classical definition, ‘Environmental education’ is aimed at “producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution” (Stapp 1969, p. 31). Along the decades of 1980 and 1990 the EE concept was developed and directed joint with ‘sustainability’ (Tilbury 1995, Câmara et al. 2018), arising from the necessity of changing the human paradigm towards the environment. Sustainability may be defined as “a certain compromise among environmental, economic, and social goals of

community, allowing for wellbeing for the present and future generations” (Ciegis et al. 2009, p. 32).

The promotion of EE have been considered for the formulation of sustainable development objectives (Ojala 2013), and according to the ‘2030 Agenda for Sustainable Development’, quality education is a priority to contribute to the preservation of oceans (SDGs 2020). The aim is to stimulate social well-being in equilibrium with a viable natural environment, and with an economy sufficient for the survival of humans (Ciegis et al. 2009, Griggs et al. 2013). So, including the EE practice in schools involving early grades, might be essential to awaken and sensitize students towards environmental well-being, and may thus contribute to building a society tuned into the sustainability goals.

Despite the recognized importance of implementing EE in schools to arouse environmental awareness in the medium-long run, this kind of practice is not always implemented. Yet, there have been several reports where the use of practical ludic activities as non-formal education in the traditional system, may facilitate learning and direct behavioural changes in consonance with EE (Rios & Brewer 2014, Branco et al. 2015). The professors are encouraged to apply these alternative activities and adapt them to the local reality of students, developing activities in the context within which they live, such as promoting field lessons, laboratory activities, developing theatre presentations, the elaboration of literary texts, games, among others. Such experiences are efficient in promoting learning in students in the most diverse subjects, such as the Sciences (Rios & Brewer 2014, Branco et al. 2015). In the long run, these help to promote environmental citizenship of the human population, considering that children and young people are precursors for sustainable behaviours for humanity as a whole.

Environmental Education in Brazil

In Brazil, one of the most important promoters of Education is Paulo Freire, whose work focused on promoting quality education also for the poor and working class children and their communities (O’Cadiz et al. 2018), through of a reform of the traditional Brazilian educational system. Within his work, Freire also included teaching proposals of EE, linking its principles with the human species being interdependent from nature, inseparable from its existence, in an understanding of a systemic-dynamic world (Dickmann & Carneiro 2012). This imply in a development of an ecological conscience, which not only identifies problems, but reflects on non-predatory actions,

that is, sustainable alternatives for the environment of life as a whole (Dickmann & Carneiro 2012, Freire 2018).

Within this perspective, Brazil, a country that is rich in biodiversity, and with a coastal environment reaching 8,500 Km in territorial extension (MMA 2020), must incentivize, by means of public policies, the use of practical instruments for EE to promote the protection of these littoral environments.

Coastal ecosystems, rhodolith/maërl beds and associated fauna

The so-called coastal ecosystems occur along the margins of the continental platforms of all global continents. They are characterized by a high diversity and elevated biological productivity (Burke et al. 2001). Coastal ecosystems include, for example, estuaries, coral reefs, coastal wetlands, rocky and sandy beaches (CBD 2019). These environments provide essential ecosystem services for human well-being, namely: a) provisioning resources, such as fish and shellfish biomass and production, offshore wind and wave energy, pharmaceutical products, among others; b) regulation & maintenance, such as climate regulation (e.g. through carbon sequestration), nutrient cycling and regulation, waste remediation, sediment formation; and c) cultural, such as tourism, education and spiritual values (Lau 2013, Barbier 2017). Given these essential services, these ecosystems attract a majority of the human population, with 40% of the worldwide human populations inhabiting these environments (MEA 2005). As such, they are particularly vulnerable to anthropic changes (Ruttenberg & Granek 2011).

Rhodolith beds, known as maërl in Europe (Foster 2001), are one of the habitats that may be found along with coastal environments (Fig. 1), being well represented worldwide (Krayesky-Self et al. 2017). They are formed by corallinaceous, non-geniculate red algae (Nelson 2009), which belong to the Order Corallinales (Guiry & Guiry 2020). They present great external morphological variability, having different outer shapes and distinct growth modes. They provide a three-dimensional environment that helps in the recruitment of young stages and enhances the survival of several organisms. In this context, rhodolith banks may be considered biodiversity hotspots (Mittermeier et al. 2011, National Geographic Society 2019). Indeed, rhodolith beds harbour a high diversity of marine invertebrates (Peña et al. 2014, Costa et al. 2019) and fishes (Gagnon et al. 2012), serving as a refuge for young specimens (Schnerer et al. 2010), such as echinoderms (Prata et al. 2017), annelids, crustaceans molluscs, sipunculids, among others.



Figure 1. Rhodolith beds in the coast from the State of Paraíba, Northeast Brazil. Photo: Massei, K.

Brazil has the largest coastal extension of rhodolith beds in the world (Amado-Filho et al. 2012). On the other hand, the extension of these banks, their associated communities, and the main anthropic pressures to which these environments are subject, are still little known in tropical regions. In fact, large-scale anthropic pressures, such as petroleum surveys and leakages, platform constructions, traffic of vessels, extraction of commercial species associated with the rhodoliths (Horta et al. 2015), effluent discharges, fishing activities (Horta et al. 2016), and tourism (Costa et al. 2019), without adequate management, have promoted a reduction of biological populations, resulting in environmental instability. With the aim of promoting the conservation/preservation of rhodolith banks, it is fundamental to know what exists and what may affect the habitat and the associated biodiversity. In this way, taxonomy – the field of science that proposes to identify, name, and group species into supraspecific taxonomic groups, within an evolutionary context, using morphological and/or

molecular characteristics – is fundamental for the study of unknown organisms and monitoring diversity. In the marine environment, there is a large biodiversity to be uncovered, as it is estimated that 50-80% of all life forms are present in the oceans (Marine Bio 2019). In addition to the 232,300 valid species (WoRMS Editorial Board 2020), there may remain about 25 million species yet to be discovered (Marine Bio 2019), 10% of which represent marine invertebrates (Mather 2013).

The correct identification of organisms is essential for the most diverse types of studies, involving ecology, zoology, pharmacology, toxicology, genetics, physiology, among others. Thus, taxonomists provide successive revisions and comparative studies of close taxa to corroborate the correct names of each individual species and of each proposed taxon. In studies of environmental impact, for example, the identification provided by specialists in each taxonomical group helps to adequately directing public managers in their efforts towards minimizing negative anthropic impacts over these environments. In the present study, the focus was on the marine invertebrates associated with rhodoliths occurring along the coast of the State of Paraíba. The effort should contribute to our knowledge of the local diversity and should be helpful in future programs of environmental monitoring.

Motivation

The present study aims to stimulate the implementation of EE in public schools of Northeastern Brazil, using alternative tools based on the local context of each school. We chose to focus on incrementing ocean literacy in our students, using, as examples, local marine ecosystems, such as the abundant rhodolith beds, and choosing less charismatic species (charismatic, e.g. pets and the popularly prettier ones), and thus less known, such as local invertebrate fauna. The study involved two phases: 1) helping teachers in teaching Science in the fundamental grades of public schools, integrating theoretical information with ludic activities, using local environmental examples with the aim of awakening the students sensitivity for the preservation of their coastal ecosystems; 2) deepening the knowledge on the taxonomy and ecology of the rhodolith beds and associated marine invertebrates, since these are extremely abundant in the region, yet less known habitats of the public in general.

Regarding the first phase, the work was conducted in public schools in Northeastern Brazil in classes at the fundamental level. In this region, teaching quality is generally considered lower in public schools when compared to private schools

(Casarin et al. 2012, Oliveira et al. 2013), which have more resources and infrastructures. Differences in teachers' salaries and motivation might also compromise learning by students (Santos 2010). However, alternative non-formal practices, easily applied using the local context and by integrating different subjects could considerably improve the learning process. As such, we decided to implement these alternatives in two schools, from the 7th grade class of the fundamental cycle. We chose, among schools located near the coast, one from the capital city of the State of Paraíba (municipality of João Pessoa), the State School "Padre Roma", and another in the municipality of Mataraca, the Municipal school "Cônego José Vital Ribeiro Bessa". The present project evolved as a response to emergent worries arising in society towards promoting the awareness of students towards the protection of the environment.

As a result of integrating practical activities with traditional teaching methods of EE, it is possible to enhance the sensitivity of students towards the protection of natural environments, among which of coastal habitats and its biological communities. This acquires special relevance, since as mentioned earlier, Brazil has an extensive coastal line and a lot of the population living on the municipalities where the first part of the study took place depend on the sea directly or indirectly. Yet, in order to increase environmental perception, it is also necessary to gain knowledge of the habitats under focus.

Following the above assumptions, the second phase of this project consisted in contributing to increase knowledge about a coastal habitat, that is widespread in the Paraíba beaches, yet, still poorly known in this region – the rhodoliths and their associated invertebrate communities. Thus, a general review information about rhodoliths was performed, regarding the worldwide geographical distribution, diversity, associated biota, main impacts, and other aspects relating to these ecosystems. Then, we studied these habitats and the associated diversity of marine invertebrates from three beaches along the coast of the State of Paraíba (Barra de Camaratuba Beach – Mataraca municipality, Seixas Beach – João Pessoa municipality, and Maceió Beach – Pitimbu municipality), at depths of 1.5 m (designated as 'shallow') and 4.0 m ('deep'). These beaches are subject to different anthropogenic impacts. We started by identifying and compiling the taxonomic information about the marine invertebrates associated with rhodoliths of tropical beaches and to study the main drivers of the diversity and community composition from the different beaches, subjected to different impacts. The

idea was to investigate aspects that may influence the distribution, shape, and associated fauna of rhodoliths in these tropical regions.

PhD timeline

Within the 4 years of doctorate, 2 and a half years were carried out in Brazil, consisting of: data collection in the marine environments studied, and preliminary analyses of results obtained in schools. In the remaining period, the final analyses of the data took place in Portugal, at the Interdisciplinary Centre of Marine and Environmental Research (CIIMAR), under the supervision of Dr^a. Marina Dolbeth, with the final result of the concluded PhD thesis.

Interdisciplinarity

In accordance with the interdisciplinarity of the Post-Graduation Program of Development and Environment (PRODEMA, UFPB, Brazil), this thesis is based on the following disciplines: Education, Environmental Sciences, Zoology, Botany, Ecology, Chemistry, Geography, and related ones.

Objectives and hypothesis of the Thesis

- General objective

This thesis aims to improve environmental education practices, literacy and awareness in public schools in the Northeast Brazilian region, using rhodolith beds as case study and contribution for their understanding regarding: i) associated fauna (taxonomy), ii) ecological importance and iii) the impact of environmental drivers.

- Specific objectives and hypotheses

- 1) To prove the effectiveness of integrating new learning methodologies for engaging the youth in the protection of coastal environments through participatory and dynamic activities in public elementary schools;
- 2) To compile the knowledge on the biological characteristics and ecological distribution, importance and vulnerability of rhodoliths/maërls beds through a revision of the available bibliography at a global scale;
- 3) To develop the first complete taxonomic study of the marine invertebrates associated with the rhodoliths beds considering 3 beaches in the Northeastern Brazilian coastal area.

- 4) To characterize and study the ecological relationships of rhodolith beds in the 3 beaches, its associated invertebrate fauna and environmental drivers.

The hypotheses related to these objectives are the following:

- H1) The integration of non-formal learning methods with traditional methods is efficient for the assimilation of knowledge and to enhance the awareness of young scholars;
- H2) Through the literature review it was established that the rhodoliths/maërl beds present a worldwide distribution and provide essential ecosystem services, yet are vulnerable to the climate changes and anthropogenic activities;
- H3) Rhodoliths/maërl beds from the Northeast Brazilian coastal area encompass several new records and undescribed marine invertebrate species.
- H4) The rhodoliths/maërl and associated fauna are ecologically interlinked and affected by anthropogenic environmental drivers.

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CHAPTER I

IMPROVING ENVIRONMENTAL AWARENESS AND OCEAN LITERACY WITH SCHOOL ACTIVITIES IN THE TROPICS



IMPROVING ENVIRONMENTAL AWARENESS AND OCEAN LITERACY WITH SCHOOL ACTIVITIES IN THE TROPICS

Abstract. This work proposed to raise the awareness of students regarding the importance of marine invertebrates and of their environments in a capital and a town school, from Northeast Brazil. For this purpose, practical activities, such as visits to the local aquarium, field classes, laboratory classes, didactic collections, production of *cordel* chapbooks, theatre presentations, and organization of science fairs, were undertaken. A questionnaire was applied to evaluate the perception, before and after these ludic activities, whose questions were organized as different topics “Concepts, Importance, Pollution, and Management”. Before the activities, both schools showed difficulties in understanding the topics being taught. Still, the students from the capital school had a higher level of knowledge than the ones from town school. After the activities, both schools revealed a clear improvement in the understanding of the topics under consideration.

Keywords: Brazilian Northeast; elementary public schools; playfulness; environmental sciences; environmental education; awareness.

INTRODUCTION

Within Science teaching in elementary education, Biology represents the largest portion of what is taught during the school year, the main topic centring around the biosphere. In the scope of formal education (that is, at school), this is where most people (especially children) have their first contact with these contents. Thus, elementary schools have a great social responsibility because they have the mission of educating responsible citizens for the future (Hands, 2008, Gerdes, Durden, & Poppe, 2013). The inclusion of marine biology contents, in particular, acquires special importance as to promote the sensibility to preserve/conservate marine ecosystems (Kind 2009), bearing in mind that a great part of the population lives within coastal areas (UN). Yet, when teaching the marine environment and its fauna, the focus is usually on the vertebrates (e.g. fish, reptiles, mammals), while the remaining groups, such as invertebrates (e.g. annelids, crustaceans, molluscs) are often neglected or mentioned superficially. These organisms represent circa 92% of the known marine biodiversity (Bouchet 2006, Guerra et al. 2011). Schools curricula do not take into account an adequate consideration of the marine biological diversity (Lindemann-Matthies et al. 2009, Dalelo 2012) and interdisciplinary (Drake & Reid 2018), nor of its ecological importance from an environmental and from a socio-economical perspective. Indeed, these contents are not

always addressed in such a way as to improve ocean literacy (Guest et al. 2015), in line with the UN's sustainable development goals. According to the '2030 Agenda for Sustainable Development', quality education is a priority to contribute to the preservation of oceans (SDGs 2020).

Marine invertebrates are extremely important for human well-being (Haines-Young & Potschin 2010, Daw et al. 2011), as promoters of several essential ecological functions in the ecosystems (e.g. biological production, habitat formation and modification, nutrition dynamics, recycling) (Balmford & Bond 2005), and for associated ecosystem services, such as food production, biochemical products, waste decomposition or climate regulation, among others (Kellert 1993, Lavrado 2006, Haines-Young & Potschin 2010). Indeed, for the Brazilian coast, marine invertebrate resources represent subsistence for the maintenance of many fishermen communities and available resources for the fishing industry (e.g. shrimp fishing industry, (Nishida et al. 2006, Begossi et al. 2011)), which highlights the importance of contextualizing socio-ecological aspects in teaching (Araújo-de-Almeida 2010).

In the Brazilian context, teaching is still very focused on the idea of memorization, lacking an adequate contextualization (e.g. different taxa are presented in a synthetic way, without addressing their ecological relevance, nor their evolution), and based on textbooks with outdated methodologies (Carneiro 2009, Santos 2010, Azevedo et al. 2016). Contents are usually taught using traditional oral presentations, which may hinder learning. Furthermore, the workload is badly planned by public managers, and teachers are insufficiently prepared to implement a more adequate curriculum, which becomes an obstacle for the learning process (Brynard & Netshikhophani 2011). Therefore, it becomes necessary to make an effort to integrate various fields of knowledge (Alghamdi 2017), mainly in the elementary school curriculum (Bacon 2018), in which students are on the high stage of brain development, e.g. thinking more complexly, understanding parts of a scientific concept, thinking symbolically and abstractly (Gerdes et al. 2013).

To implement the former objectives in teaching, practices developed in Environmental Education (EE) can be useful, such as facilitation mechanisms and conscientization processes for the education of citizens based on environmentally sustainable development. Such actions should encourage the protection of ecosystems, promoting the improvement of environmental awareness. EE is a fundamental module to be inserted into basic education. It shelters several concepts that lead the human

being to a reflection as a social being and of his interaction with the surrounding fauna and flora (Sauvé 2005, Brasil 2012).

A way to apply EE in the elementary schools may be through the integration of ludic activities, in order to promote the learning process (Istrate 2017). Altogether, such an action represents a good opportunity to explore the interdisciplinary understanding of the contents pertinent to marine biology. There are several examples of ludic activities known to motivate learning and knowledge acquisition: a) production of texts to improve the assimilation of topics taught (Genlott & Grönlund 2013); these can activate creativity, mainly when the texts are made with local literature and realities close to the students' daily lives; b) theatrical representations, that promote greater social interaction among students in a shared learning perspective (Ejiofor & Ken-Aminikpo 2016); c) field classes and visits to aquariums/museums, where students have greater contact with marine life and its environment, particularly in their local living area, and may facilitate the raising of environmental awareness (Zeichner 2010, Packer & Ballantyne 2010, Fleischner et al. 2017); d) science fairs, in which the social interaction, building of mock-ups or basic science, with presentations for the general public (including teachers and students) that may awaken a greater interest to learn complex subjects (Jaworski 2013). These practices help to promote ocean literacy and consequently help to sensitize students, in the long run of their lives (Chawla & Cushing 2007), for the economic and social benefits that these resources may represent for society (Guest et al. 2015). This becomes essential in this era that highlights the importance of the oceans for human well-being, as well as their vulnerability (Chen & Tsai 2016).

In face of the above, this study aimed to improve the environmental awareness of students from elementary schools and to promote different learning possibilities. The study focused on the role of the marine invertebrates in their environmental context, but also on notions regarding the importance of preserving marine environments, impacts from human action and local management. As case studies, we used two Brazilian public schools to compare the effectiveness of the learning program. We combined theoretical and ludic approaches as an alternative way to motivate the student to learn and incorporate acquired knowledge into their daily life.

METHODS

Study area

The present study occurred at two municipalities from Northeast Brazil, João Pessoa and Mataraca, located in the state of Paraíba in Brazil (Fig. 1), during May to December 2017, along the full lective year. João Pessoa is the capital of the State, located on the coast, with more of 809,000 inhabitants and 70.8% of households having adequate sanitary sewage (IBGE Cidades-João Pessoa 2020). Mataraca is a municipality town, located in the North of Paraíba, from about 10.6 km from the coast. It has about 8,430 inhabitants, yet only 4.1% of the households have adequate sanitary sewage (IBGE Cidades-Mataraca 2020). In both municipalities, the schooling rate in elementary school (between 12 to 16 years) is higher than 96%. The GNP (‘Gross National Product’) is generally higher in the Mataraca region than in João Pessoa, yet the average minimum wage is higher in the capital João Pessoa. The program activities were planned and implemented at these two municipalities, at the State School “Padre Roma” (João Pessoa) and Municipal School “Cônego José Vital Ribeiro Bessa” (Mataraca) (Fig. 1).

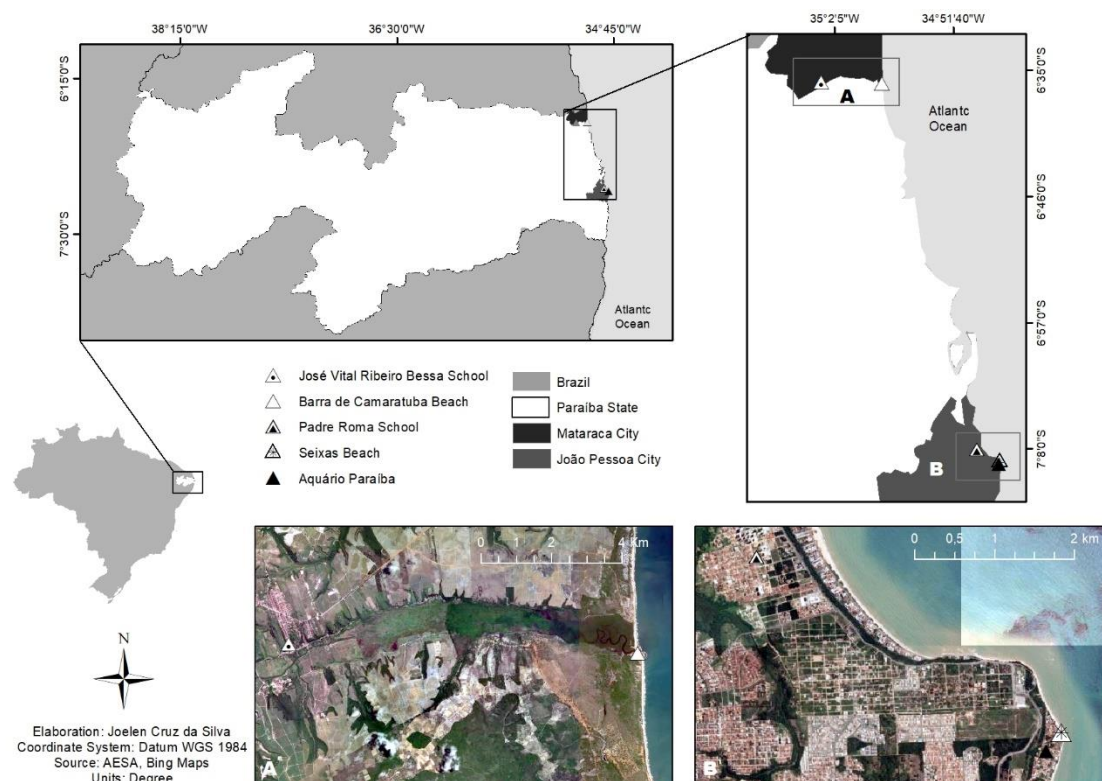


Figure 1. Locations of the schools, beaches’ field classes and “Aquário Paraíba”, in the Paraíba State, Northeast Brazilian.

The school “Padre Roma” has a total of approximately 350 students, with 16 classes, 6 of which are primary, 9 are secondary, and 1 of specialized educational assistance for deaf students (Escol.as 2020a, Melhor Escola 2020a). The school “José Vital Ribeiro Bessa” has a total of 230 students, with 23 primary classes (Escol.as 2020b, Melhor Escola 2020b).

Methodological approach

The activities were organized to accommodate a wide range of possibilities and followed a sequence: from indoor to outdoor activities, and from more-scientifically driven activities to artistic ones (Fig. 2). Initially, a meeting was held with the director and teachers of each school, to explain the details of the project and the planned activities. This initial meeting allowed an understanding of the main difficulties of teachers and students regarding traditional teaching and served to implement suggestions from teachers concerning our plan of activities. Afterward, the project was presented to students of the 7th elementary school class, within the discipline of Sciences.



Figure 2. Sequence of the planned practical activities during the project, from May to December 2017, with the indication of the indoor and outdoor activities and the more creative ones. Photos: Pereira, A.R.; Costa, D.A.; Silva, F.A.; Massei, K.; Arruda, K.B.

A semi-structured questionnaire (with open and closed questions) consisting of 24 questions (Supplementary material 1A, 1B) was initially given to students before the activities planned, hereafter mentioned as First Application (1st App), to evaluate their initial perception (in order to check what the students know) regarding the theme of marine zoology, ecology and broad environmental related topics. After the 1st App, we implemented the sequential activity program (Fig. 2), starting with classes (formal education method) taught by researchers. The topics were the same as the questionnaire: zoology, ecology, marine invertebrates, coastal ecosystems, environmental preservation, EE, pollution, and management. From these initial approaches, we moved for the outdoor activities (Fig. 2).

The outdoor activities consisted in a visit to the marine aquarium - “Aquário Paraíba”, located in João Pessoa city, at Seixas Beach. The aquarium is also a research institute dedicated to marine life conservation, which simultaneously promotes ocean literacy to schools and the general public. There, students had contact with the living marine organisms that inhabit the coast of the State of Paraíba. For each school region, we also conducted a field class: at Seixas Beach for students of João Pessoa city, and at Barra de Camaratuba Beach for students in Mataraca city. The beach classes focused on the coastal habitats (e.g. rhodoliths) and on the invertebrates inhabiting the intertidal region, where their ecological importance was explained, including for the environment and value for human well-being. Additionally, biological samples were collected following standard scientific procedures. The samples were taken into the laboratory schools, where students processed and identified the invertebrates collected and started a reference didactic invertebrate collection (laboratory activities, Fig. 2).

Afterwards, and working together with teachers from different subjects (Sciences, Portuguese and Arts), students moved on to more artistic activities: they elaborated *cordel* texts (Slater 1982, Lira 2003, Silva 2007), which are traditional small books typical in Northeastern Brazil. They verse on popular poems and drawings on a particular subject. These manuscripts aimed to emphasize the marine invertebrates from the coast of the State of Paraíba and how each animal would communicate in a literate sense (Zooliterature, (Churchman 1987, Genlott & Grönlund 2013, Uehara 2016)). These *cordel* compositions allows us to explore the ecological, trophic and morphological importance of the marine fauna, besides other aspects related to their characteristics and importance to humans. For the cover of the “*cordel*” chapbook, students attended a workshop on woodcuts of their drawings on marine invertebrates,

with foam trays to produce the covers. All covers were then exposed and voted by the teachers, managers and school employees, to select the official cover of the *cordel* chapbook (Fig. 2, selected poems by students in Supplementary material 2).

A theatre presentation was then developed by students, in which each student chose and represented a marine invertebrate and created a dramatic story together with the help of the teachers, following the method known as ‘pedagogical theatre’ or ‘play-building’ (Burton 2011, Curtis et al. 2013).

Finally, students organized a Science Fair for the general public in an Open School Day, which consisted in 1) marine zoology expositions, where the marine invertebrates were exposed and their importance explained to the visitors, 2) exposition of the “cordel” chapbooks produced; 3) presentations of workshops on the recognition of the animals of Brazilian currency banknotes [“Real” (R\$)]; 4) presentation of a theatre performance to other students, teachers, board and staff of each school.

After the whole sequence of the former recreational activities, students performed the same written questionnaire presented at the beginning of the program, hereafter mentioned as Second Application (2nd App), to evaluate the efficacy of the knowledge acquisition about the proposed theme – marine zoology, environmental preservation and ocean literacy.

The study and questionnaires were approved by the Ethics Committee of the Federal University of Paraíba (CEP/CCS/UFPB) n° 95666617.6.0000.5188 (Supplementary material 3), according “*Resolução 466/12/CONEP/CNS/MS*” from the Brazilian Health Ministry.

Efficiency of the implemented activity program

The questionnaire given to students before and after the activity program (1st and 2nd App) had 24 questions (Supplementary material 1A, 1B). The expected answers were closed for some questions – answer were yes, no, or absent (Questions 1, 3-8, 10, 17, 19, 22), semi-structured from selected options (Questions 9, 11, 20, 21, 24), and open questions (Questions 2, 12-16, 18, 23). The questions were organized into four main topics for the statistical descriptive analysis (which were only performed due to the low ‘n’ value and the open question): 1) Concept definitions (Questions 1-7, 12-14), 2) Importance to Nature and human well-being (Questions 8-11), 3) Pollution (Questions 15-Q17, Q20-Q21), and 4) Environmental Management (Questions 18-19, 22-24).

In the questions dealing with concepts we included all the definitions from biological terms, usually transmitted in the elementary school programs (base knowledge), such as zoology, invertebrates, marine invertebrates, common and scientific taxonomic names, habitat, mangrove and environment. The second group of questions referred to the view of students on the level of importance of marine invertebrates to both Nature and Human well-being, including the reasons for that importance. The Pollution group of questions refers the evaluation to the student knowledge regarding the concept of environmental pollution, with given examples, its consequences for the marine environment, and for marine invertebrates in general. Finally, the environmental management group of questions aimed to understand the level of perception of students on ways for preservation/conservation of the marine ecosystem and invertebrates, both by them as part of their local community, and by Brazilian government actions. Their view on the role EE was also evaluated. For the descriptive analysis, these groups of questions were analysed as average and range percentages and as a function of 1) absent answers (for students who did not answer), 2) answer “No/Do not know/Wrong/Vague” (for negative responses, or those lacking coherence), 3) incomplete (with missing information) or 4) complete (fully correct according to what was taught in the class). For the closed questions, the expected answer was considered as complete (e.g., for question 8 - importance to nature -, the answer “yes” was considered as complete).

RESULTS

Overview of the activities and students' general feedback

The activity program was applied to a 7th grade-class in one of the selected classes in elementary schools. A class with a total of 17 students participated in the program from the capital school (“*Padre Roma*”), with ages varying from 13 to 16, average of 13.9 ± 1.5 years old. In the town school (“*José Vital Ribeiro Bessa*”), 25 students participated in the project, with ages varying from 12 to 16, average of 13.4 ± 3.2 years old.

The activity program was implemented in both schools before any formal teaching regarding the subjects by teachers. The answers of the students in the 1st App thus reflect their knowledge based on notions taught in previous grade-classes (<6th grade) and on their life-experiences. During the theoretical lectures by researchers, students from the capital school were more participant and demonstrated a better

knowledge on the subjects being taught, from a formal perspective (e.g. terms, definitions) compared to students from the town school. Indeed, this was expressed in the 1st App, where students from the capital had more correct answers than the town ones (Table 1), particularly for the concept questions (Fig. 3).

Table 1. Mean and range (minimum and maximum) percentages (%) of student's answers organized by the main topics for of capital and town schools, before and after the programmed activities (1st and 2nd App).

	Capital Before	Capital After	Town Before	Town After
<i>Concepts (Q1-Q7, Q12-Q14)</i>				
No Answer (NA)	13.2 (0 - 41.2)	0.7 (0 - 5.9)	23.5 (8.0 - 40.0)	6.5 (0 - 28.0)
No/Do not know/Wrong/Vague	38.2 (0 - 88.2)	11.8 (0 - 58.8)	51.0 (12.0 - 80.0)	3.0 (0 - 12.0)
Incomplete answer	37.3 (0 - 64.7)	9.8 (0 - 17.6)	24.0 (0 - 56.0)	2.7 (0 - 8.0)
Complete answer	20.6 (0 - 64.7)	80.1 (41.2 - 94.1)	7.5 (0 - 24.0)	88.5 (60.0 - 96.0)
<i>Importance (Q8-Q11)</i>				
N.A.	14.7 (5.9 - 17.6)	1.5 (0 - 5.9)	16.0 (0 - 24.0)	0
No/Do not know/Wrong/Vague	39.7 (23.5 - 58.8)	4.4 (0 - 11.8)	40.0 (0 - 60.0)	0
Incomplete answer	32.4 (23.5 - 47.1)	17.6 (0 - 47.1)	31.0 (0 - 100)	13.0 (0 - 32.0)
Complete answer	13.2 (5.9 - 29.4)	76.5 (47.1 - 94.1)	13.0 (0 - 32.0)	87.0 (68.0 - 100)
<i>Pollution (Q15-Q17, Q20-Q21)</i>				
N.A.	14.7 (11.8 - 23.5)	0	32.0 (16.0 - 40.0)	0
No/Do not know/Wrong/Vague	7.4 (0 - 11.8)	0	26.0 (12.0 - 40.0)	0
Incomplete answer	76.5 (70.6 - 88.2)	13.2 (5.9 - 23.5)	41.0 (24.0 - 64.0)	5.0 (0 - 12.0)
Complete answer	1.5 (0 - 5.9)	86.8 (76.5 - 94.1)	1.0 (0 - 4.0)	95.0 (88.0 - 100)
<i>Management (Q18-Q19, Q22-Q24)</i>				
N.A.	14.7 (5.9 - 35.3)	1.5 (0 - 5.9)	12.0 (0 - 40.0)	3.0 (0 - 12.0)
No/Do not know/Wrong/Vague	29.4 (0 - 64.7)	7.4 (0 - 17.6)	43.0 (0 - 92.0)	7.0 (0 - 16.0)
Incomplete answer	32.4 (5.9 - 64.7)	1.5 (0 - 5.9)	15.0 (0 - 32.0)	2.0 (0 - 8.0)
Complete answer	23.5 (0 - 82.4)	89.7 (82.4 - 100)	30.0 (0 - 100)	88.0 (76.0 - 100)

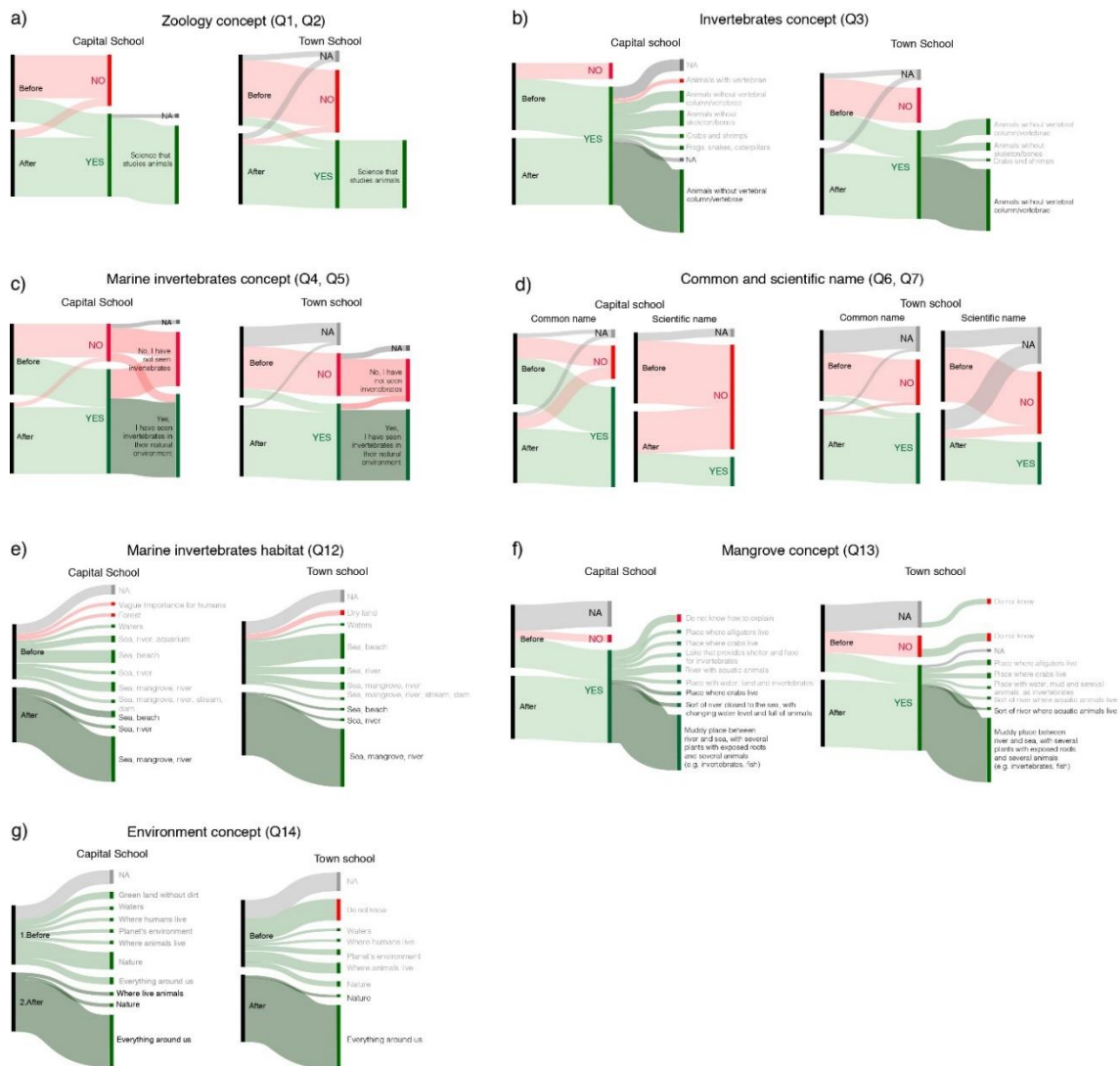


Figure 3. Questionnaire answers of the students regarding ‘Concepts’ topic, organized per time, before (1st App) and after (2nd App) the activities program for each school; grey: NA (no answer); red: ‘No/don’t know/wrong’ answers; green: corrected/expected answers. Figures made with rawgraphs.io.

The students from the Mataraca city (town school) showed more contact with the marine environment (where the field classes were held), as many of their parents are fishermen and use the fishing resources to feed and trade the surplus fish. These students, therefore, demonstrated greater sensitivity with the protection of the beach in which they live, with the considerable increase in the level of correct answers in the 2nd App (Table 1).

In general, all students participated actively in the programmed activities designed to improve and motivate their learning about marine ecology. This was particularly evident for the town school, where the access to the sort of activities

proposed is not as common. After the programmed activities, the answers of students reveal a significant improvement regarding all the topics being taught, when comparing 1st and 2nd App questionnaires, detailed in the next section. The average of expected/completed responses, comparing both applications, increased from 1.5-24% to 77-89% in capital school, and from 1-30% to 88%-95% in the town school (Table 1). In the four topics (concepts, importance, pollution, and management) students enhanced the answers according to the aim of this study, yet this was particularly evident for the pollution group of questions (Table 1).

Specificities in the students' answers

The concept questions related the actual definition of terms and their understanding, by providing examples of such terms, understanding what an invertebrate is and providing examples. As mentioned, in the 1st App, the capital school had a better background on these definitions than the town school (Table 1, Fig. 3a-g). Still, some concepts were harder to define than others, such as the zoology and scientific invertebrate names (Fig. 3a, d). As for the other concepts, some students were able to provide definitions, but not examples (e.g. invertebrates and marine invertebrates definitions and examples, Fig. 3b-d) or provided incomplete answers (Fig. 3b, c; e-g). This queries the actual understanding of such definition by the student, particularly relative to their application in the environment. After the program activities and in the 2nd App, these problems become less evident, as most students were able to provide definitions and relate them the actual examples in Nature. For instance, students were able to identify and provide examples of different main taxonomical groups and species belonging to those taxa, such as crustaceans (e.g. crabs and shrimps), polychaetes (e.g. bristleworms, ragworms), molluscs (e.g. seashells) and echinoderms (e.g. sea stars, sea cucumbers). Even for the scientific names, students were already able to provide names for some species of polychaetes (e.g. *Hermodice carunculata*, *Hesione splendida*), echinoderms (e.g. *Amphipholis squamata*, *Ophioderma apressa*), crustaceans (e.g. *Ocypode quadrata*, *Cardisoma guanhumi*) and molluscs (e.g. *Aplysia* sp., *Crassostrea rhizophorae*).

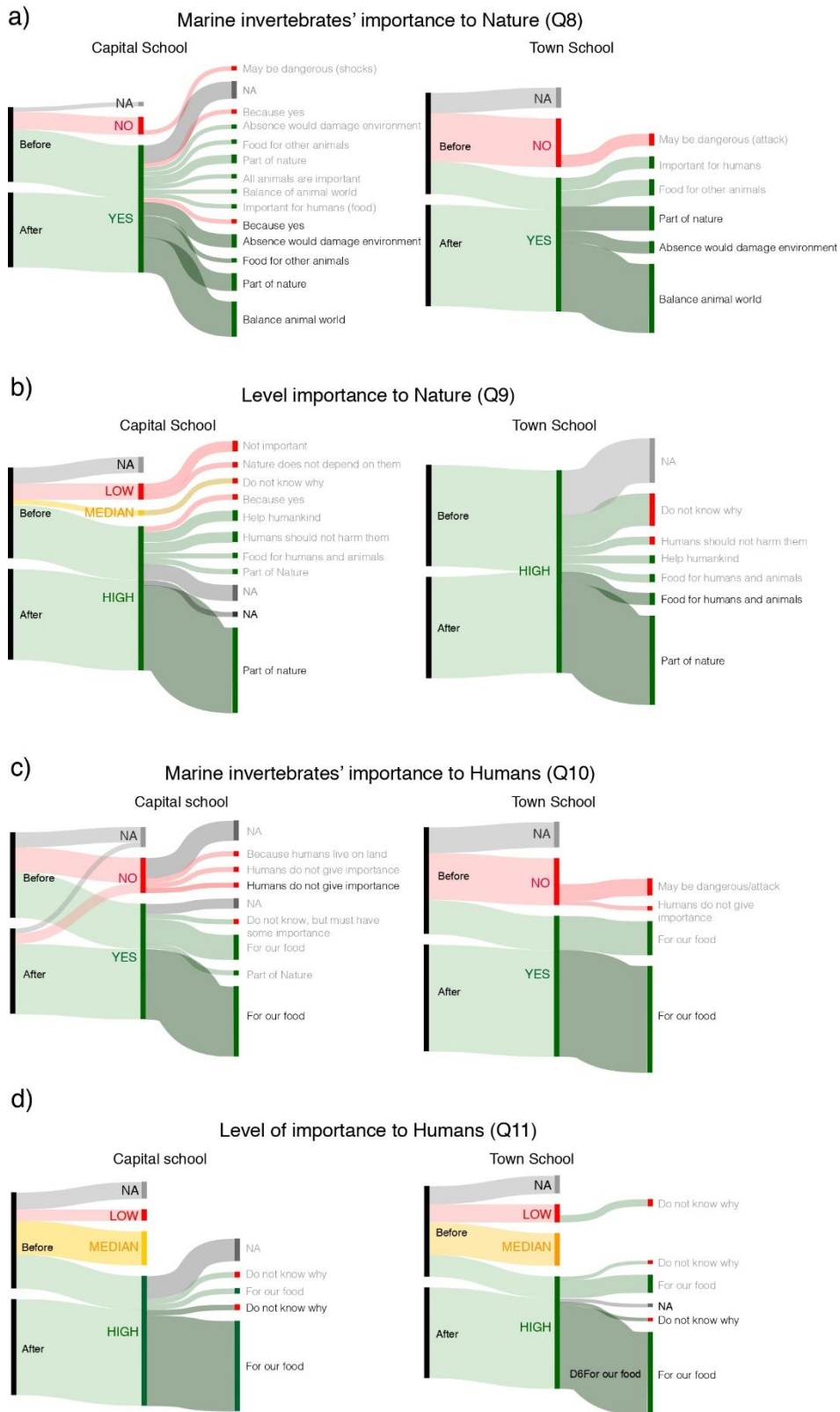


Figure 4. Questionnaire answers of the students regarding ‘Importance’ topic, organized per time, before (1st App) and after (2nd App) the programmed activities for each school; NA (in gray): no answer; red: ‘No/don’t know/wrong’ or ‘low importance’ answers; yellow: ‘median importance’ answers; green: corrected/expected or ‘high importance’ answers; grey: no answer. Figures made with rawgraphs.io.

The second group of questions was directed towards understanding the importance of marine invertebrates for the environment in which they live (ecological perspective, Fig. 4a, b), and to how these organisms can be useful to human society (social perspective, Fig. 4c, d). In the 1st App, although most pupils recognize that marine invertebrates are important, they were not able to present reasons for this. Answers were thus often contradictory or vague, such as “important for our food”, “because yes” or “do not know why” (Fig. 4a-d). Concerning specifically the level of importance for Nature, pupils from the town school always linked their answers to an anthropogenic view (i.e., considering the actual benefits for humans, such as food provision) (Fig. 4b). In the 2nd App, students from both schools enhanced their answers as a function of the taught contents (Fig. 4a-d). Yet, considering the level of this importance, students living in the capital showed a slightly better performance than the town students (Fig. 4d).

Questions that deal with pollution mention concepts, consequences, and means of avoiding the degradation of coastal ecosystems, including of the animals that live in them. Students from the capital had more difficulty in formulating answers within this theme, both in the 1st App and in the 2nd App (Table 1, Fig. 5a-e). These issues were important for evaluating the perception on the consequences of anthropic actions on the marine environment. At the end of the project, a considerable improvement was observed in the answers in the 2nd App, in accordance with the concepts transmitted during the program of activities. In fact, when requested to provide examples of the types of pollution, the students answered in accordance with what was taught in the class and in the field (e.g., atmospheric, aquatic, radioactive, visual pollution) (Fig. 5b).

Students were questioned about how to protect coastal ecosystems, including the invertebrates living in them, aiming to assess their critical reasoning on preservation and conservation, in personal and government contexts (Table 1, Fig. 6a-c). In the 1st App, the town students presented a slightly better level of performance (30.0%) relative to the students living in the capital (23.5%). Notwithstanding, in the 2nd App the students from the capital obtained a larger percentage of complete answers (Table 1, Fig. 6c). Regarding to the government care in the 2nd App, most students from both schools affirmed the idea that there is an environmental legislation or the protection of the environment, but that public legislators do not apply the rules as expected (Fig. 6b).

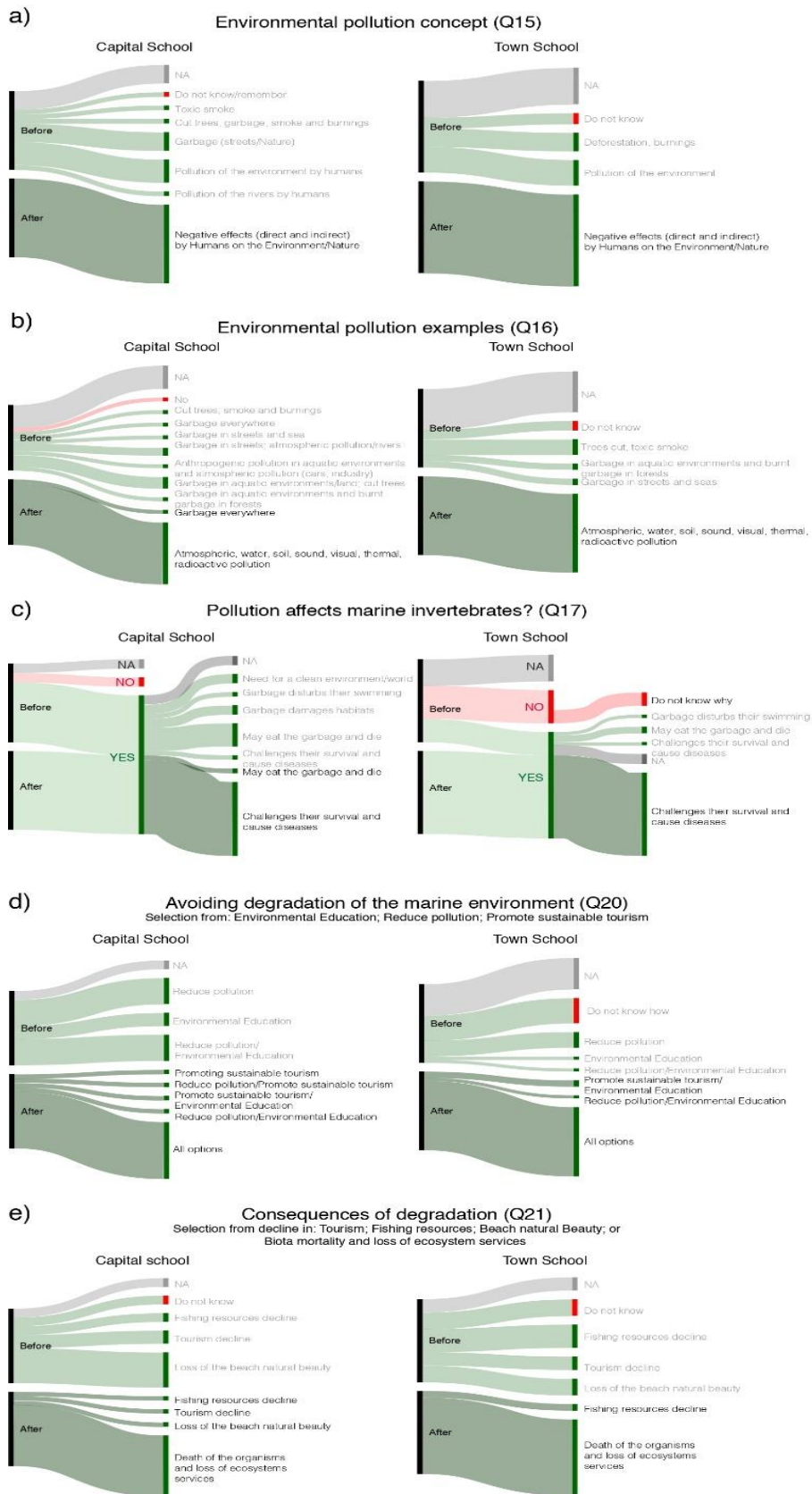


Figure 5. Questionnaire answers of the students regarding ‘Pollution’ topic, organized per time, before (1st App) and after (2nd App) the programmed activities for each school; grey: NA - no answer; red: ‘No/don’t know/wrong’ answers; green: corrected/expected answers. Figures made with rawgraphs.io.

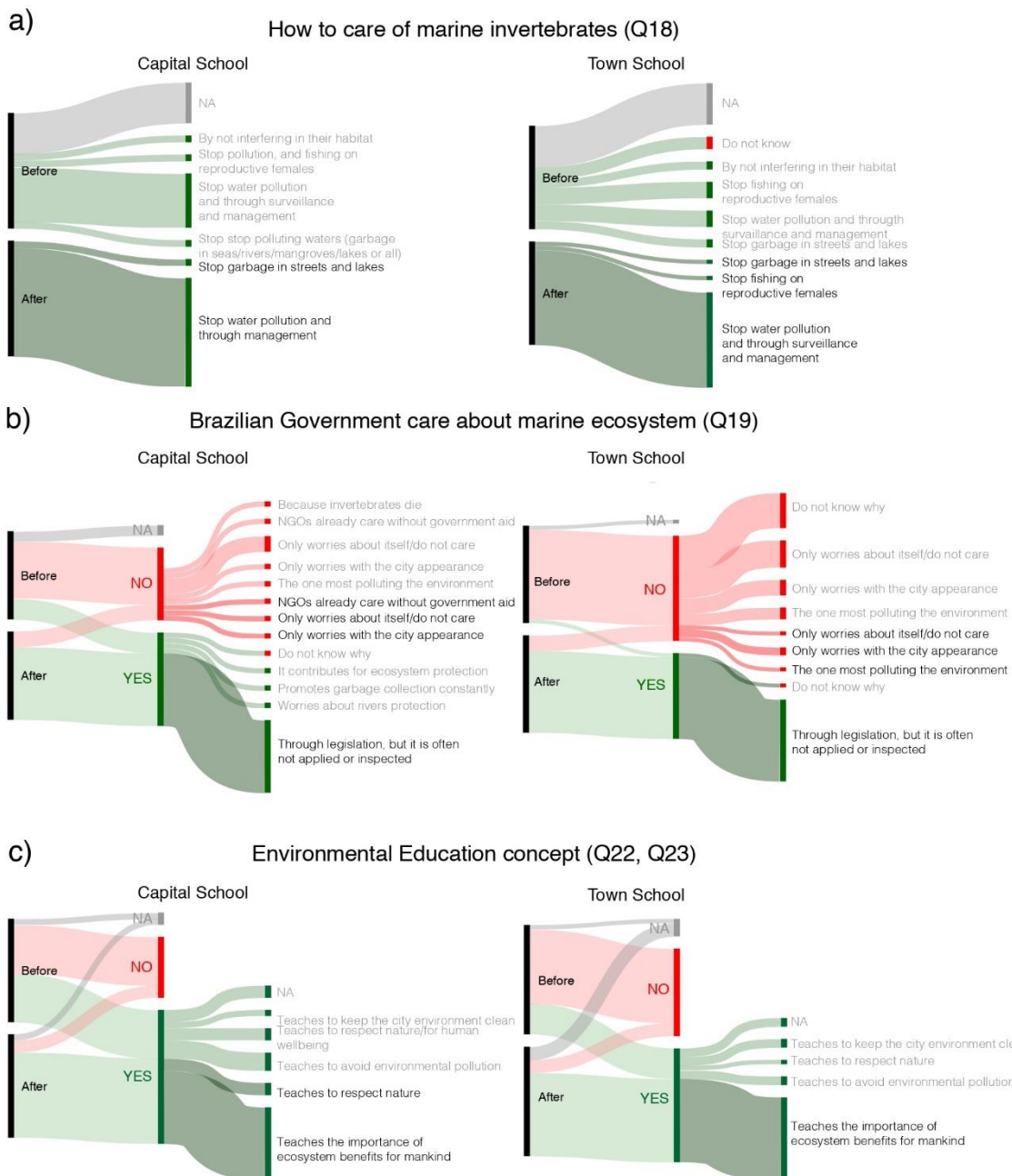


Figure 6. Questionnaire answers of the students regarding ‘Management’ topic, organized per time, before (1st App) and after (2nd App) the programmed activities for each school; grey: NA - no answer; red: ‘No/don’t know/wrong’ answers; green: corrected/expected answers. Figures made with rawgraphs.io.

DISCUSSION

Overview of the efficiency of the activities program

The use of the Science discipline for teaching environmental concepts within environmental education may improve the environmental awareness of the students, educating individuals worried about protecting ecosystems. Under this perspective, the introduction of more integrative teaching practices, such as those that combine

theoretical and ludic activities, may be more efficient in relation to traditional teaching (Souza e Silva & Delacruz 2006, Selander 2008, Healey et al. 2010, Hayes et al. 2013). These provide motivation and enthusiasm, abilities that enhance the teaching-learning process (Amaral et al. 2014). This study has effectively shown that the help provided by researchers to teaching activities and the ludic activities proposed effectively facilitated learning in daily activities, justifying their introduction into formal teaching. Practical activities should be introduced with the traditional teaching, thus enriching the cycle of teaching, research, and extension activities, being important for education in Brazilian learning institutions (Castro & De Alves 2017). These methods are now emerging also in public schools in the country, particularly in the Northeastern region, where there is a noted discrepancy in the quality between public and private teaching.

In the present paper, the use of questionnaires proved efficient to evaluate deficiencies in environmental perception by the students, before and after the application of activities. It thus became possible to outline strategies to improve the teaching of the proposed subjects (Amin & Khan 2009). The 1st App allowed directing the focus of the educators, giving more emphasis on contents that are considered more difficult by the pupils. The 2nd App allowed us to verify the progress of the students in their learning process (Amaral et al. 2014). It was also observed that within the scope of the correct answers (e.g. concept questions), some students responded beyond what was taught in the classroom, which may be the result of their enthusiasm for research in other sources the contents (e.g. internet, books, newspaper, TV).

Environmental education, as well as actions for the management and sustainability in the context of social responsibility are effective ways for raising environmental awareness of the community (Powell & Ham 2008, Lucrezi et al. 2017, Mutanga et al. 2017, Smit et al. 2017, Sutcliffe & Barnes 2018). In this context, this study is included in the fourth objective of the ‘Sustainable Development Goals’ (SDGs 2020). Such an action may promote permanent changes in attitudes towards the conservation of nature. Therefore, students should be motivated in the process of teaching-learning in Marine Zoology and Ecology in the context of EE. Such initiatives should encourage protection of coastal ecosystems, promoting improvements in environmental awareness in practical actions as applied to their daily routines.

Although control groups were not established within each school in order to compare the effectiveness of the learning process, the present study also allowed to emphasize the differences in teaching supposedly existing between a school lying in the

capital with a less urban school (farther away from the capital city). Capital school has more resources to invest in education, so we expected that these students would find it easier to learn the subjects and would present the best results. However, a tendency for increased motivation was detected in the school located in the town, despite they mostly never had the opportunity of frequenting more dynamic classes during their school years. Furthermore, the town students had more contact with coastal environments, mainly due to their dependency on its fishing resources, as many of their parents are fishermen. Thus, in the end, both schools obtained very similar results relating to the learning of concepts transmitted along this project and when related to the importance of beach where they live in.

Adequacy of the teaching methodology used

The addition of alternative and integrative activities to the traditional teaching model brings benefits to the cognitive learning of the students. In this study, we verified potential actions that may help in this process, which we detail here. Despite the low representativeness of schools, it was possible to verify some of the reality of public schools in the Northeast from Brazil, which have similar teaching characteristics and financial resources available throughout this Brazilian region.

In the context of practical courses, the visit to the local marine aquarium, together with marine researchers, provide students with a unique experience. Most students were not familiar with the local marine animals, nor were familiar with the expressive diversity present in their region. Thus, this visit allowed the observation of living organisms, their identification and aroused a sentiment of protection towards the animals living in the ocean (Furtado et al. 2018). Such feelings may promote changes in long-term attitudes in society as a whole (Ballantyne & Packer 2011).

Field classes were considered essential for the process of teaching/learning. They represent another opportunity of direct contact with both local fauna and environments under study (Farmer et al. 2007). Visiting the coastal environments allowed the students to observe the habitat in which the animals studied during theoretical classes actually live. This also helps understanding the influence that oceans have for our well-being, and comprehending the consequences of our actions in these environments (Markos et al. 2017). In the present study, students became conscious of the importance of conserving the beaches they commonly used for recreational activities and for fishing. They came to understand how these actions benefit both nature and their

future and that of their families. These outdoor classes were also an opportunity for the students to understand the essential role of researchers in investigating these themes.

The use of laboratory classes was important to awaken scientific and investigative abilities, to learn in more detail the importance of invertebrates, and to continue the scientific practices begun during the field classes. Such activities, conducted by teachers, with the use of directed studies (Figueiredo et al. 2016), for example, on the identification and sorting of animals collected along the beaches, help sharpen the curiosity of the students, and thus contribute to sediment the subjects taught in the classroom (Tarhan & Sesen 2010). Thus, more investment in the lab infrastructure, mainly in public schools, may significantly advance the quality of teaching. Supplementing the sorting and identification practices, the building of didactic reference collections helps students to change organization behaviours, with beneficial effects on other disciplines as well.

Indoor activities were complemented with other creative activities, such as combining literature with dramaturgy. The production of “cordel” chapbooks (Supplementary material 2) represents a cultural aspect present in the daily life of the students along the last centuries (a result of the strong European influence originating in the Iberian Peninsula). Such literary endeavours, through the production of popular poems, permitted the students to learn about the characteristics of marine invertebrates in the context of empathy, compassion, and affective relationship (Uehara 2016), by contextualizing the Zooliterature (Churchman 1987, Genlott & Grönlund 2013). Although the use of this type of text for the creation of popular accounts of the daily cultural life is largely used in Northeastern Brazilian, mainly in inland cities, their use in the school context is underexplored. In this study, the students became enthusiastic with the production of their own “cordel” texts. At the same time, this expedient helped them to retain information relating to the importance of marine invertebrates in the local context. We recommend more incentives for students to produce this type of texts. They should be included in the programmed Curriculum, in combination with other subjects, such as Portuguese (within the context of Popular Literature), Arts, Sciences, and others.

Furthermore, theatrical presentation is an alternative way for improving environmental awareness. These activities stimulate both senses and perception of students, promoting the ‘incorporation’ of concepts and increasing the performance of factual acts, through action and reaction, emotion and knowledge (Berbert et al. 2007).

In the present study, the use of marine animals lying close to local communities accrue the common sense of the students and serve as motivators for the development and creation of a theatrical play. In addition to these artistic activities, Science fairs in the schools may awaken in students the opportunity of applying the empirical method for the development of scientific research projects, promoting the refinement of their abilities, such as of scientific literacy (Tortop 2013). In the present study, teachers from other subjects, such as Arts and Portuguese, with the help of scientific researchers, cooperated with the development of the ‘theatre of marine invertebrates’. Such a theatrical endeavour, together with the taxonomical exposition of several zoological groups, and a workshop for the recognition of the animals present in Brazilian banknotes, awakened in students a sense of creativity and a propensity for teamwork.

In view of the probable inefficiency in the traditional didactic teaching of Sciences in Brazilian public schools, especially in the context of zoology, the application of practical and innovative kinds of teaching (Marble 2007), such as creative games, theatre, field classes, or educational computer programs (Araújo-de-Almeida 2010, Rafael Medeiros et al. 2012, Silva & Del Corso 2016), represent efficient methods for the motivation of students, as incentives of creativity, and for awakening critical scientific thinking. Such activities must be offered during the entire school year, in addition to traditional teaching lectures.

Suggestions to teaching’ methodology in Brazilian public schools

The Brazilian Ministry of Education establishes the National Curriculum Guidelines (“Diretrizes Curriculares Nacionais-DCNs”) directed to all teachers and educational institutions, so that, the contents are taught in a standardized way throughout Brazil. According DCNs, environmental education should be taught integrated in all subjects. Despite the effort, this suggestion has led to the discouragement of teachers, since it becomes unclear and highly subjective how to incorporate EE in the curricula. Thus, EE could be taught as a separate subject, in the same way as Mathematics, Science or Portuguese, for example. Such a disciplinary subject could be an important from elementary education to university education. This proposal is in line with the ‘Proposed Bill 221/2015’ (Federative Republic of Brazil 2015) (which amends Law 9795/1999-“National Environmental Education Policy” (Federative Republic of Brazil 1999)), with the final objective of making environmental education a mandatory subject. EE aims to educate citizens aware of their role in social welfare (Brasil 2012)

and may generate in each student a potential transformer of knowledge, capable of creating a more balanced society in the use of nature as a sustainable resource.

CONCLUSIONS

The integration of traditional expositions in the classroom, integrated with more ludic practices, has provided students an effective way of learning about marine invertebrates and the ecosystems in which they live. The development of “cordel” chapbooks, theatre presentations, didactical zoological collections, screening of the collected invertebrates in beach classes, and direct participation during expository classes, expanded learning perspectives for students. These activities improved their environmental perception for the preservation of coastal ecosystems and allowed to promote Environmental Education in the elementary schools.

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Supplementary material 1A. Semi-structured questionnaire (Portuguese/original version) applied to the students.



**UNIVERSIDADE FEDERAL DA PARAÍBA
CENTRO DE CIÊNCIAS EXATAS E DA NATUREZA
PROGRAMA REGIONAL DE PÓS-GRADUAÇÃO EM DESENVOLVIMENTO E
MEIO AMBIENTE**

**QUESTIONÁRIO: INOVAÇÕES NO ENSINO DE ZOOLOGIA E EDUCAÇÃO
AMBIENTAL EM ESCOLAS PÚBLICAS AO LONGO DO LITORAL DO
ESTADO DA PARAÍBA**

ESCOLA:

IDADE: _____ TURMA: _____ TURNO: _____ SÉRIE: _____

1) Você conhece o significado da palavra zoologia? SIM () NÃO ()

2) Se sim, defina e dê exemplos.

3) Você já ouviu falar em animais invertebrados?

SIM () Defina: _____

NÃO ()

4) E, em invertebrados marinhos, já ouviu falar? SIM () NÃO ()

5) Se sim, já teve a oportunidade de ver ou encontrar um invertebrado marinho em seu ambiente natural? SIM () NÃO ()

6) Você saberia identificar um invertebrado marinho pelo nome popular?

SIM () Qual (is)? _____

NÃO ()

7) Você saberia identificar um invertebrado marinho pelo nome científico?

SIM () Qual(is)? _____

NÃO ()

8) Você acredita que os invertebrados marinhos possuem alguma importância para a natureza? SIM () NÃO ()

Por quê? _____

9) Se sim, qual o nível de importância desses animais para a natureza?

POUCA () MÉDIA () MUITA ()

Por quê? _____

10) Você acredita que os invertebrados marinhos possuem alguma importância para o ser humano?

SIM () NÃO ()

Por quê? _____

11) Se sim, qual o nível de importância desses animais para o ser humano?

POUCA () MÉDIA () MUITA ()

Por quê?

12) Onde podemos encontrar os invertebrados marinhos?

13) Você já ouviu falar na palavra “Mangue”? Saberá explicar o que é, e qual sua importância para a natureza e para os seres humanos?

14) Para você, o que é Meio Ambiente?

15) Na sua opinião, o que é Poluição Ambiental?

16) Quais tipos de poluição ambiental você conhece? Dê exemplos.

17) Você acredita que a poluição pode causar danos aos invertebrados marinhos?

SIM () NÃO ()

Por quê? _____

18) De que maneira você acha que deve cuidar dos invertebrados marinhos?

19) Em sua cidade, você acredita que os governos (municipal e estadual) têm se preocupado com a proteção dos ecossistemas marinhos?

SIM () NÃO ()

Por quê? _____

20) Qual seria a melhor forma para evitar a degradação dos ambientes marinhos?

DIMINUIR A POLUIÇÃO ()

PROMOVER O TURISMO SUSTENTÁVEL ()

EDUCAÇÃO AMBIENTAL ()

OUTRA FORMA ()

Qual? _____

21) Qual a pior consequência da degradação ambiental nos ambientes marinhos?

DIMINUIÇÃO DO TURISMO ()

DIMINUIÇÃO DE RECURSOS PESQUEIROS ()

PERCA DA BELEZA NATURAL DA PRAIA ()

OUTRA CONSEQUÊNCIA ()

Qual? _____

22) você já ouviu falar em Educação Ambiental?

SIM () NÃO ()

23) Se SIM, diga o que é, na sua opinião?

24) O que você achou desse questionário?

SEM IMPORTÂNCIA ()

POUCO RELEVANTE ()

MUITO IMPORTANTE ()

Por quê? _____

Muito Obrigado (a), por sua colaboração!

Supplementary material 1B. Semi-structured questionnaire (English version).



UNIVERSIDADE FEDERAL DA PARAÍBA
CENTRO DE CIÊNCIAS EXATAS E DA NATUREZA
PROGRAMA REGIONAL DE PÓS-GRADUAÇÃO EM DESENVOLVIMENTO E
MEIO AMBIENTE

QUESTIONNAIRE: INNOVATIONS IN THE TEACHING OF ZOOLOGY AND
ENVIRONMENTAL EDUCATION IN PUBLIC SCHOOLS ALONG THE
COAST OF THE STATE OF PARAÍBA

SCHOOL:

AGE: _____ CLASS: _____ SHIFT: _____ SERIES: _____

1) Do you know the meaning of the word zoology? YES () NO ()

2) If yes, define and provide examples.

3) Have you already heard of invertebrate animals?

YES () Define: _____

NO ()

4) And marine invertebrates, have you heard of them before? YES () NO ()

5) If yes, have you had the opportunity to see or find a marine invertebrate in its natural environment? YES () NO ()

6) Would you know how to identify a marine invertebrate by its popular name?

YES () Which animals? _____

NO ()

7) Would you know how to identify a marine invertebrate by its scientific name?

YES () Which animals? _____

NO ()

8) Do you believe that marine invertebrates are of some importance for nature?

YES () NO ()

Why? _____

9) If yes, what level of importance would you give to these animals for nature?

LITTLE () MEDIUM () MUCH ()

Why? _____

10) Do you believe that invertebrate animals are of some importance for human beings?

YES () NO ()

Why? _____

11) If yes, what level of importance would you give to these animals for human beings?

LITTLE () MEDIUM () MUCH ()

Why? _____

12) Where can we find marine invertebrates?

13) Have you already heard of the word “Mangrove”?

14) For you, what is Environment?

15) In your opinion, what is Environmental Pollution?

16) Which are the types of environmental pollution that you know of? Give examples.

17) Do you believe that pollution may cause damage to marine invertebrates?

YES () NO ()

Why? _____

18) In which way do you think we should care for marine invertebrates?

19) In your city, do you believe that the government (municipal and state) are worried with the protection of marine ecosystems?

YES () NO ()

Why? _____

20) Which would be the best way to avoid the degradation of marine environments?

PROMOTE SUSTAINABLE TOURISM ()

ENVIRONMENTAL EDUCATION ()

OTHER FORM ()

WHICH?

21)What is the consequence of environmental degradation of marine environments?

REDUCING FISHERIES RESOURCESS ()

LOSS OF BEAUTY OF BEACH ()

OTHER CONSEQUENCE ()

Which?

22) Have you already heard of Environmental Education?

YES () NO ()

23) If yes, what is it, in your opinion?

24) What is your opinion of this questionnaire?

WITHOUT IMPORTANCE ()

LITTLE RELEVANT ()

VERY IMPORTANT ()

Why? _____

Many thanks for your collaboration!

Supplementary material 2. ‘Cordel’ texts produced by the students.

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Josina Danielle – Bolsista UFPB
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Amaury Ramos Pereira/Professor de Ciências
Outubro de 2017.

“Por vezes sentimos que aquilo que fazemos não é
senão uma gota de água no mar. Mas o mar seria
menor se lhe faltasse uma gota”.

Madre Teresa de Calcutá

APOIO:



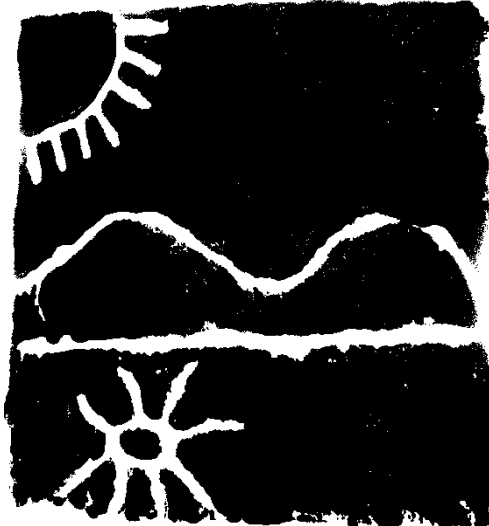
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CRIE O HÁBITO DE LEITURA
OFEREÇA UM CORDEL A UM AMIGO.

ZOOLOGIA, MAR E POESIA

Alunos (as) do 7º ano
João Pessoa e Mataraca / PB



Xilogravura: Caio Henrique

Orientadores:

Amaury Ramos, Ana Elizabeth Lira,
Denise Nascimento e Dimítri de Araújo Costa

Estrelas que não estão no céu – Yasmine Cavalcante

Gosto muito de sonhar.
No meu sonho preferido,
Eu sou estrela-do-mar
Sem estrela ter nascido!
E seu poder de encantar
É muito bem merecido.

Quando a lua vem beijar
A praia, na maré cheia,
Não há quem não se encante
Com as estrelas na areia
Só se não tiver seu sangue
Correndo dentro da veia

Eu não admiro os humanos
Que jogam lixo no mar
Botam a culpa nos rios
Por que agem sem pensar?
Eu já vou me despedindo
Pra você não irritar

Me despedindo vou já
A maré está subindo
Mas um alerta vou dar
O mundo tá sucumbindo
Preservem o meio ambiente
Porque ele tá sumindo

Arrecifes de corais - Maria Eduarda Araújo

Vou começar meu cordel
Pedindo sua atenção
Pois o assunto tratado
Pede consideração
Vou falar sobre corais
Com linda coloração

Contando sigo então
Pois em Porto de galinhas
Vemos esta maravilha
Que é das costas marinhas
A jóia mais preciosa
Mas só em águas limpinhas

Os peixes lá vão pastar
Na vegetação presente
Atraindo predadores
Maiores do que contente
Acabam sendo fígados
Saem do meio ambiente

Esta grande criatura
Do mundo em que vivemos
A maior da natureza
De tudo que conhecemos
Um ser entre muitos seres
O bom daquilo que vemos

Nome de Gente – Jonatha Leonardo

Mora um animado polvo
Entre as algas marinhas
Às vezes, se sente só
Entre as águas limpinhas
Aqui embaixo da água
Vive catando alguinhas

Tem arma pra atacar
Quando está em perigo
É muito bom pra mirar
Porém não matar inimigo
Mas gosto dele porque
Depois pode ser amigo

Seu nome parece gente
E é muito bonitinho
Na panela sou gostoso
Sempre muito bem fritinho
Humanos são desumanos
Porque querem meu finzinho

Eu nunca andei de trenó
Sou um animal marinho
Aqui embaixo da água
Eu nunca estive sozinho
Gosto muito de brincar
Tenho sempre amiguinho

Paguro ou caranguejo – Ana Kelly

Olá, eu sou o paguro
Sempre me sinto inseguro
Moro no fundo do mar
Lá é meu porto seguro
Longe dos meus companheiros
Eu me sinto imaturo

Na limpeza do aquário
Eu até sou um orgulho
Me sinto todo feliz
Se alguém dá um mergulho
Não permito a sujeira
Nem sequer um pedregulho

Paguro ou caranguejo
Tenho o corpo muito mole
Me abrigo dentro das conchas
Para ver se não me engole
Fico todo chateado
Se mexem na minha prole

Quando já estou adulto
Troco logo a carapuça
Se encontro uma sobrando
Logo, logo enfio a fuça
De repente já me acho
Parecendo uma dentuça

O peixe que não é boi – Yago Soares

Oi, meu nome é peixe-boi
Vou apresentar meu lar
Não é piscina nem terra
Mas sim o fundo do mar
Sempre gostei de arroz
Como pra me empanturrar

Embaixo d'água não durmo
Porque querem atacar
E se vou adormecer
Não consigo escapar
Preciso achar uma forma
De minha vida salvar

Sou um animal mamífero
De grande porte e de corpo
Para minha segurança
Fundo do mar é meu porto
A reprodução é lenta
Porque eu sou muito gordo

Finalizando o cordel
Não sei se você gostou
Não sei se fiz muito bem
Porque sou um sonhador
Minha vida segue em frente
Levando só meu amor.

Caranguejo, bichinho esquisito – Edvan Silva

Eita que bicho esquisito
Seu nome rima com queijo
Anda pra frente pra trás
O seu nome é caranguejo
Igual trem desgovernado
Assim que vejo, desejo

Querido *Ucides cordatus*
Se vê em todo lugar
Nos mangues pelo Brasil
É fácil de encontrar
Pois só nesse ecossistema
O animal vai procriar

A fêmea sobrecarrega
Em uma procriação
Média sessenta mil ovos
Se é que eu tenho noção
E nos animais mais jovens
Pode ter variação

Para ficar forte é bom
Comer uma caldeirada
Moqueca de caranguejo
De sobremesa a cocada
Leve também um bombom
Enquanto pega a estrada.

A Lagosta – Davy Silva

Dizem que a lagosta é
Muito rica em vitamina
Seu valor alimentício
Em muitas mesas anima
Antes era classe baixa
Agora é de gente fina

Só se fala na lagosta
Onde mora o pescador
Pois a pescaria dela
Apresenta mais valor
Hoje é para presidente
Delegado e senador

Hoje estão abandonando
Os peixes na pescaria
Entretidos na lagosta
Pescam de noite e de dia
É esta a pura razão
De tamanha carestia

O preço duma lagosta
Que agora se apresenta
Como uma coisa enfadonha
Que todo mundo lamenta
Custava vinte reais
Agora custa sessenta!

Ouriço do mar – Caio Henrique

Vivo debaixo das pedras
Bem quieto a transpirar
Anoiteceu minha casca
Logo começa a brilhar
Nunca mexo com ninguém
Pra água não baldear

Me mexo ao anoitecer
Para ninguém suspeitar
Na enchente da maré
Mereço é me esbaldar
Para no embalo das ondas
Chegar ao fundo do mar

Eu sou pontudo e em mim
Ninguém pode se encostar
Porque em poucos segundos
Dedos começam inchar
Não moro em apartamento
Pois é no fundo do mar

Um recado pra humano
Agora eu vou repassar
Parem já de poluir
O planeta vamos salvar
Sou poeta animal
Querido ouriço do mar

Supplementary material 3. Project Approval Report by the Ethics Committee.

UFPB - CENTRO DE CIÊNCIAS
DA SAÚDE DA UNIVERSIDADE
FEDERAL DA PARAÍBA



PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Relação entre a Educação Ambiental Formal e o Estudo Taxonômico-Sistemático dos Invertebrados Marinhos

Pesquisador: DIMITRI DE ARAUJO COSTA

Área Temática:

Versão: 2

CAAE: 95666617.6.0000.5188

Instituição Proponente: UNIVERSIDADE FEDERAL DA PARAIBA

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.924.592

Apresentação do Projeto:

Trata-se de analisar o projeto de tese de doutorado do Programa de Pós-graduação em Meio Ambiente PRODEMA do doutorando DIMITRI DE ARAUJO COSTA sob a orientação do Professor Dr. Reinaldo Farias Paiva de Lucena do Centro de Ciências da Saúde da Universidade Federal da Paraíba.

Objetivo da Pesquisa:

Objetivo Principal: Este projeto busca desenvolver a educação ambiental dentro do contexto taxonômico-sistemático dos invertebrados marinhos da costa paraibana, e usá-lo como ferramenta propulsora de conscientização ambiental em escolas públicas de ensino fundamental.

Objetivo Secundário:

- Desenvolver formas de promoção da educação ambiental e ensino da zoologia nas escolas de ensino fundamental;
- Avaliar a percepção ambiental dos alunos pesquisados;
- Pesquisar e apresentar uma metodologia de ensino que motive os alunos para o aprendizado de zoologia de invertebrados e educação ambiental;
- Propor um programa continuado de educação ambiental e ensino da zoologia junto às escolas, enfatizando a importância da preservação/conservação dos ecossistemas costeiros.

Endereço: UNIVERSITARIO S/N

Bairro: CASTELO BRANCO

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Continuação do Parecer: 2.924.592

Considerações sobre os Termos de apresentação obrigatória:

O projeto em tela se encontra bem instruído de acordo com a Resolução 466/12 do Conselho Nacional de Saúde.

Recomendações:

Recomenda-se manter a metodologia proposta.

Conclusões ou Pendências e Lista de Inadequações:

Sem pendências.

Considerações Finais a critério do CEP:

Certifico que o Comitê de Ética em Pesquisa do Centro de Ciências da Saúde da Universidade Federal da Paraíba – CEP/CCS aprovou a execução do referido projeto de pesquisa.

Outrossim, informo que a autorização para posterior publicação fica condicionada à submissão do Relatório Final na Plataforma Brasil, via Notificação, para fins de apreciação e aprovação por este egrégio Comitê.

Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

CHAPTER II

RHODOLITHS ('MAËRLS') BEDS: A GLOBAL VIEW ON ITS ECOLOGICAL IMPORTANCE



RHODOLITHS ('MAËRLS') BEDS: A GLOBAL VIEW ON ITS ECOLOGICAL IMPORTANCE

Abstract. Rhodoliths (or 'maërls') are colonial aggregations containing at least 50% of non-articulate coralline red algae. They form extended banks in the benthic region of several ocean floors worldwide. This work presents a bibliographic review of the rhodoliths beds, focusing on their distribution, diversity, morphology, ecology, biota associated, main climate change and anthropogenic impacts and current conservation schemes. Generally, rhodoliths are present in a wide range of geographic and bathymetric distribution, being found in the photic zone from the intertidal region to depths of 270 m. Different families of rhodoliths, within the Corallinales order, display well-marked patterns of distribution in temperate and tropical regions. Rhodolith beds have large morphological variability, providing a unique biogenic habitat, favourable for several marine fauna, in particular, invertebrates such as polychaetes, bivalves, and echinoderms. In addition, they harbour a holobiont microbiota composed of viruses, bacteria, and small eukaryotes. Both the rhodoliths' morphology and the external environmental factors are considered as the main factors controlling faunistic communities in rhodolith beds. Climate change impact, in particular, those associated to changes in carbonate content and pH may seriously compromise the viability of the rhodoliths, as a consequence of the high levels of dissolution of their calcite and magnesium structures. Despite the importance of rhodoliths as unique biotopes in the world, they are also suffering from several anthropogenic pressures, from dredging, tourism, overexploitation, among others. Efforts for their protection are greatly limited, which reinforces the need for monitoring rhodolith beds, study their associated communities and evaluate environmental impacts in programs aiming at their conservation and management.

Keywords: Corallinales; Climate changes; Bioengineers; Algae reefs.

INTRODUCTION

Rhodoliths are colonial nodules aggregations of unattached coralline algae (Fig. 1) (Bosence 1983, Darrenougue et al. 2013), which contain calcium carbonate (CaCO_3) in their structure (Krayesky-Self et al. 2017), being important sinks of this chemical substance (Amado-Filho et al. 2012b). Generally, a biogenic nodule is classified as a "rhodolith" when more than 50% of its volume is formed by the coralline red algae. Otherwise, the biogenic structure is named a "coating" (Steneck 1986, Foster 2001, Sañé et al. 2016).



Figure 1. Rhodolith beds in the coast from the State of Paraíba, Northeast Brazil. Photo: Massei, K.

Another name originating in Brittany (northwest coast of France) for these biogenic structures, both living and dead, is “maërl” (Lemoine 1910, Bosence 1983, Grall & Hall-Spencer 2003). The term maërl is used mainly in studies along the European Atlantic coast, while the term rhodolith is more common worldwide (Bosellini & Ginsburg 1971, Foster 2001, Peña & Bárbara 2007). Rhodoliths have also been termed as “algaliths”, defined as non-articulate granules or as nodules of the size of pebbles (“oncoids”) originating from algae that secrete carbonates (Leeder 2011). Other designations have also been used over time, with many vernacular and scientific terms (Riosmena-Rodríguez 2017), which have contributed to hamper their delimitation, such as “boxwork rhodoliths”, “coatings”, “nucleated rhodoliths”, “gravels”, “nodules”, “rhodolites/rhodoliths”, “prâlines”, “algal balls”, “marls/maërlls”, “coralline algal nodules”, “oncoliths/onkoids”, “rhodoids”, “algal-encrusted grains”, “rubbles”, “unattached branches”, “glagla” (Mazzullo & Cys 1983, Steneck 1986, McCoy & Kamenos 2015, Forever-Príncipe 2018).

Nowadays, the terms rhodoliths or maërl are considered synonyms (Birkett et al. 1998, Steller et al. 2003, Riosmena-Rodríguez et al. 2016), and are the most common ones. The term “rhodolith” was created when its paleoecological value was understood, in order to designate the specific type of redstone (Bosellini & Ginsburg 1971, Peña 2010). Indeed, the low growth rate of the rhodolith (between 0.01 to 5.0 mm per year) (Bosence & Wilson 2003, Blake & Maggs 2003, Rivera et al. 2004, Steller et al. 2007) combined with its carbonatic nature, and consequent good conservation in fossil deposits has turn them into reliable indicators in paleoenvironmental and paleoecological studies (Braga & Bassi 2007, Kamenos et al. 2008b, 2009, Bassi et al. 2009). Fossil evidence indicates that these coralline algae have been around in the world for at least 55 million years (Erickson-Davis 2014).

The rhodoliths, as biogenic aggregations may contain an organic or inorganic nucleus, which may be monospecific or multispecific regarding the composition of coralline algae. Indeed, several non-articulate species may be responsible for the formation of extensive rhodolith beds in the oceanic floors (Aguado-Giménez & Ruiz-Fernández 2012, Villas-Bôas et al. 2014, Riosmena-Rodríguez 2017). In some cases, other organisms may be equally, or even more important constructors than coralline algae. For example, the “for-algaliths” are formed mainly by benthic foraminiferans, together with coralline algae (Prager & Ginsburg 1989, Aguirre et al. 2012). The laminar thalli of coralline algae may also embed the tubes of serpulid polychaetes into the nodules (Aguirre et al. 1993, 2012).

DISTRIBUTION AND RHODOLITHS-FORMING ALGAE

The rhodoliths-forming algae are among those groups attaining the largest geographic distribution range (Fig. 2), bathymetric and climatic amplitudes. They occupy a large latitudinal range in the oceanic photic region, occurring from the intertidal zone to depths of 270 meters (Bosence 1983, Littler & Littler 1984, Foster 2001, Riosmena-Rodríguez 2017). For this reason, rhodoliths have been considered adequate for studies on thermogeography, as the growth and reproduction rates of corallinaceous algae increases in warmer water temperatures, in a process of ‘thermal control’ (Adey & Steneck 2001).

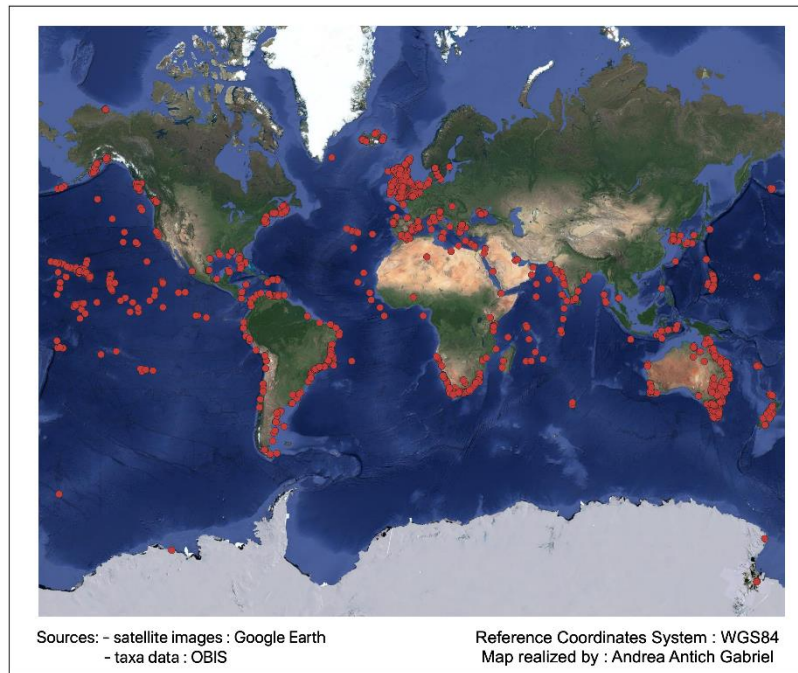


Figure 2. Map indicating the distribution of rhodoliths (Order Corallinales) in the world, based on information from OBIS – Ocean Biogeographic Information System. Satellite images: Google.

In the North and Central region of America, the rhodolith beds occur from Gulf of Alaska (Prince William Sound) to Gulf of Mexico (Bosence 1983, Foster 2001, Konar et al. 2006, Hernandez-Kantun et al. 2017), exclusive to the habitats at 50–90 m depth on the continental shelf offshore Louisiana and Texas (Fredericq et al. 2019). On the Pacific coast of the southern hemisphere, these algae are distributed from the Gulf of California to the South of Chile (Henriques et al. 2012). On the Atlantic coast of the southern hemisphere, there are extensive rhodolith beds. On the Brazilian coast, rhodolith beds potentially represent the largest depositional area of CaCO_3 in the world (about 2×10^{11} tons) (Milliman & Amaral 1974, Amado-Filho et al. 2012a), mainly in Abrolhos Bank region (in Northeast Brazilian) (Amado-Filho et al. 2012a). Recently, rhodolith beds were discovered in the coral reef systems off the mouth of the Amazon River, extending from the French Guiana to the State of Maranhão (Brazil), coverage of one thousand kilometres in length and 50 km in width (Moura et al. 2016).

In Europe, these algae may be found in the Atlantic coast, i.e., in Galicia (Peña 2010), Iceland, Norwegian Sea, Baltic Sea, North Sea, United Kingdom, Iberian Peninsula and Canarian Islands (Hernandez-Kantun et al. 2017, OBIS 2020) and in the Mediterranean coasts (BIOMAERL Team 1999, Peña 2010), e.g., in Marseille and Corsica (France), Sardinia (Italy), and in the Aegean Sea (European Red List of

Habitats 2016). Scotland has to the most extensive maërl beds in this continent, with fossil records from 8,000 years old (Natura 2019).

In the African continent, these corallinaceous living unattached algae are common in the Gulf of Guinea (e.g. Príncipe's island), South Africa, ranging from depths of 5m up to 30m (Peña et al. 2014b, Maneveldt et al. 2016, Forever-Príncipe 2018). Fossil rhodolith formations and sedimentary features evidence in Pleistocene interglacial periods are found in the Gulf of Aden, Northeastern Ethiopia (Braga et al. 2018) and in the Cape Verde islands (Johnson et al. 2017).

In Asia, there are few reports of these non-geniculate red algae from India to Russia (Teichert et al. 2012, Teichert 2013, Rösler et al. 2015, Kato et al. 2017), mostly found in Japan, both as living and dead rhodoliths beds (Matsuda & Iryu 2011).

Finally, in Oceania, rhodolith beds create a stable substrate conditions on the Great Australian Bight shaved shelves (Ryan et al. 2007), representing the primary successional coral-reef building stage for damaged reefs (Perry et al. 2012, Pereira-Filho et al. 2015, Harvey et al. 2016). There are also rhodoliths in New Zealand, e.g. in North Island (Nalin et al. 2007). The cores of these rhodoliths beds have approximately 6,500 years old (Marshall et al. 1998), for processes of building, erosion, burial, and recolonization (Martin et al. 1993).

Regarding the algae composition, the non-geniculate red coralline rhodoliths-forming algae represent the third-largest group in Rhodophyta, belonging to the order Corallinales, with circa of 600 valid morphospecies (Table 1) (Brodie & Zuccarello 2007, Horta et al. 2016, Guiry & Guiry 2020). From this order, the families Corallinaceae and Lithophyllaceae have a large distribution over the entire globe (Table 1; Fig. 3B, E). The families Lithothamniaceae, Spongitaceae, and Hydrolithaceae predominate in the temperate region, while the families Porolithaceae and Mastoporaceae are more representative in the tropical region (Table 1; Fig. 3) (OBIS 2020).

Table 1. Groups of rhodoliths-forming algae of the Order Corallinales, with the indication of the accepted genera. Source: (Guiry & Guiry 2020).

Family	Number of known genera/species	Genera	Main distribution
Corallinaceae	20 genera 150 species	<i>Alatocladia</i> <i>Aquirrea</i> <i>Arthrocardia</i> <i>Bossiella</i> <i>Calliarthron</i> <i>Chamberlainium</i> <i>Chiharaea</i> <i>Corallina</i> <i>Cornicularia</i> <i>Crusticorallina</i> <i>Duthiophycus</i> <i>Ellisolandia</i> <i>Eolithoporella</i> <i>Jania</i> <i>Johansenia</i> <i>Masakiella</i> <i>Paraphyllum</i> <i>Parvicellularium</i> <i>Pneophyllum</i> <i>Pseudolithothamnium</i>	Global
Hydrolithaceae	3 genera 29 species	<i>Adeylithon</i> <i>Fosliella</i> <i>Hydrolithon</i>	Temperate region
Lithophyllaceae	7 genera 212 species	<i>Amphiroa</i> <i>Ezo</i> <i>Lithophyllum</i> <i>Lithothrix</i> <i>Paulsilvella</i> <i>Tenarea</i> <i>Titanoderma</i>	Global
Lithothamniaceae	2 genera 107 species	<i>Lithothamnion</i> <i>Phymatolithon</i>	Temperate region
Mastoporaceae	4 genera 14 species	<i>Lesueuria</i> <i>Lithoporella</i> <i>Mastophora</i> <i>Metamastophora</i>	Tropical region
Porolithaceae	5 genera 31 species	<i>Dawsoniolithon</i> <i>Floiophycus</i> <i>Harveyolithon</i> <i>Metagoniolithon</i> <i>Porolithon</i>	Tropical region
Spongitaceae	3 genera 55 species	<i>Neogoniolithon</i> <i>Spongites</i> <i>Rhizolamiella</i>	Temperate region

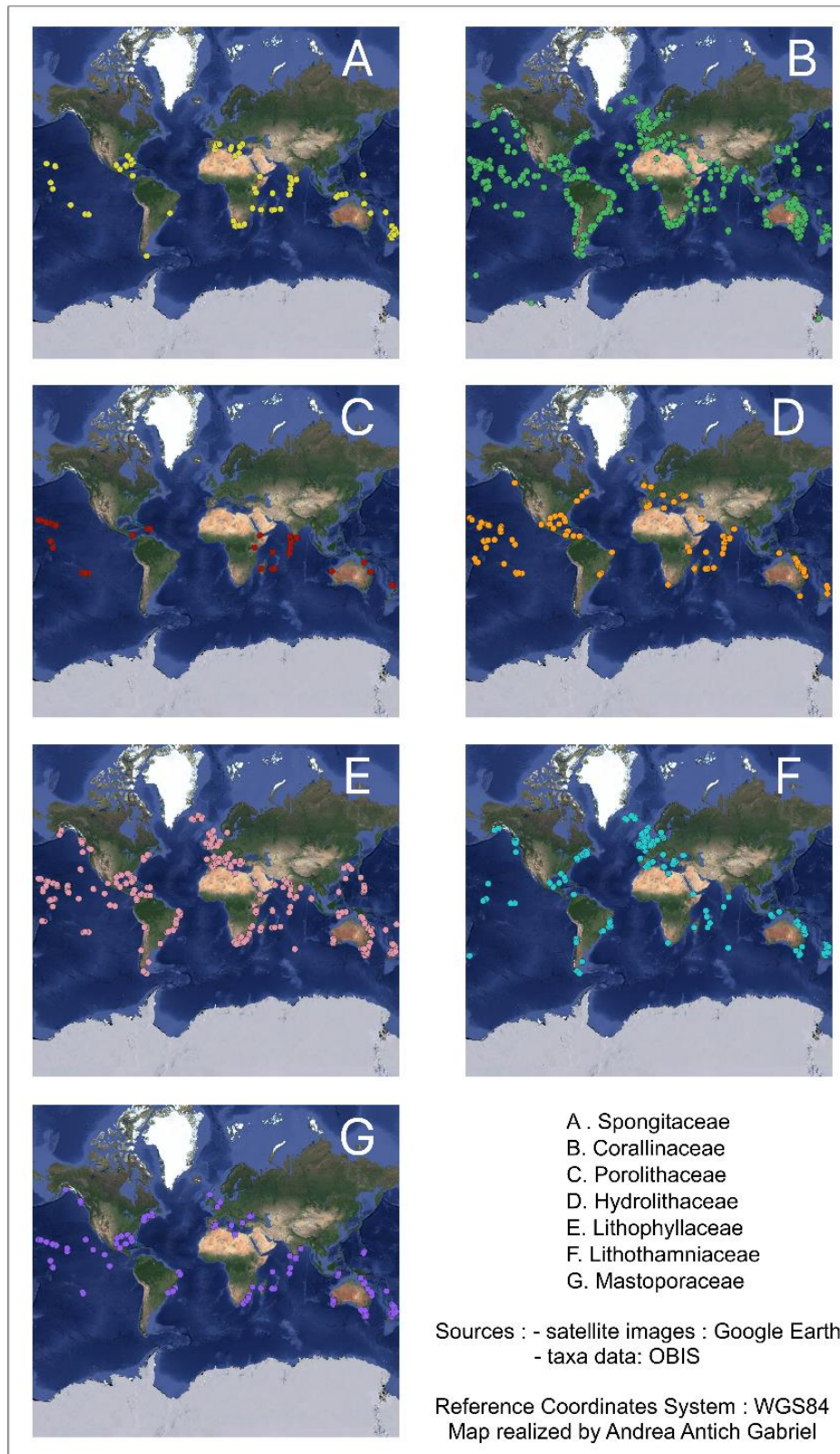


Figure 3. World geographic distribution of the families of rhodoliths-forming algae from the Order Corallinales, based on information from OBIS – Ocean Biogeographic Information System. Satellite images: Google.

In temperate regions, rhodolith beds are abundant mainly in Europe, where the species *Lithothamnion corallioides* (P.Crouan & H.Crouan) P.Crouan & H.Crouan 1867, *Lithothamnion glaciale* Kjellman 1883, and *Phymatolithon calcareum* (Pallas) W.H.Adey & D.L.McKibbin ex Woelkerling & L.M.Irvine 1986 predominate (Birkett et al. 1998, BIOMAERL Team 1999, Grall & Hall-Spencer 2003). The ecological niches of *L. corallioides* and *P. calcareum* are relatively narrow and subject to controlled environmental factors, such as wave action, seabed currents and the combined effects of depth, light accessibility and water quality in general. From these, the seabed currents, resulting from rivers, tides, salinity differentials and wave action, are one of the main physical drivers that affect the distribution of the previous species. Usually, these coralline algae are better adapted to oceanographic low-energy conditions (generally do not occur subjected to strong wave action), more commonly found in coves and bays (Birkett et al. 1998).

The species composition of rhodoliths is also highly influenced by the water temperature, particularly in the North Atlantic (Adey & Adey 1973). For example, the absence of *L. corallioides* in Scotland has been associated with the low temperatures in winter, that do not allow the survival of this species (ideal value between 2 and 5 °C) or because the temperatures do not remain high during a time sufficient for the annual growth of the species (Birkett et al. 1998). On the other hand, the species *L. glaciale* appears to be limited to regions to the north of the British Isles (Birkett et al. 1998), requiring low temperatures for reproduction (<9°C, e.g. (Hall-Spencer 1994)).

GENERAL MORPHOLOGICAL CHARACTERISTICS OF THE RHODOLITHS

Hydrodynamism and light are crucial factors determining the morphology and the phytal composition of rhodoliths and, consequently, of the heterogeneity of rhodolith beds (Sciberras et al. 2009). Rhodoliths are generally more abundant in areas with moderate to high-energy currents (except for the *L. corallioides* and *P. calcareum* mentioned above) (Birkett et al. 1998, Dias 2000). However, they may present a great morphological polymorphism, which is correlated with hydrodynamism: size, shape and the pattern of ramification of the rhodoliths are mainly depend on the local hydrodynamics (Foster 2001, Aguado-Giménez & Ruiz-Fernández 2012). On the other hand, the species composition of rhodolith beds often depends also on the light penetration and depth, temperature of the water, sedimentation, salinity and water

quality (Birkett et al. 1998), among other factors. This complexity of conditions frequently results in sporadic and irregular patterns of rhodoliths' distribution in the ocean floor (Aguado-Giménez & Ruiz-Fernández 2012), where the rhodolith beds become intercalated with sandy bottoms, creating mosaics within the marine realms (García-Sanz et al. 2014).

Regarding morphology, the rhodoliths may be classified into Boxwork, Unattached branches, and Pralines (Fig. 4), e.g. (Basso 1998, 2012, Basso et al. 2009, Sañé et al. 2016):

- Boxwork: multispecific and irregular nodules, with internal spaces filled by sediment, and nucleus consisting of a small pebble or biogenic remnant;
- Unattached branches: monospecific rhodoliths devoid of a macroscopic nucleus, and possibly characterized by a high degree of protuberance;
- Pralines: compact mono(oligo)specific nodules, with a lytic or biogenic nucleus, with strongly developed protuberances on surface.

Rhodoliths of the pralines type may further be classified according to their growth pattern: Encrusting-warty, Lumpy and Fruticose (Fig. 4) (Woelkerling et al. 1993, Sañé et al. 2016):

- Warty growth: branches vary from cylindrical to compact, with usually radial organization;
- Lumpy growth: protuberances are expanded, occurring contiguously and in great numbers, being rarely branched;
- Fruticose growth: branches notably separated from each other.

The complexity created by the accumulation of the rhodolith nodules of various shapes (i.e. spherical and elliptical shapes of distinct sizes, from a few millimetres to several centimetres) provides shelter and protection for other species, both fauna and flora. The associated flora also increases the complexity of the rhodolith that functions as a micro-ecosystem (Figueiredo et al. 2007) and may harbor different fauna. This micro-ecosystem may be essentially dependent on indirect positive interactions (e.g. mutualism, commensalism), involving successions of positive interspecific interactions, a phenomenon known as “facilitation cascades” (Thomsen et al. 2010). This process is applied in communities hierarchically organized, therefore, in which a basal habitat

former (typically a large primary producer, e.g., the rhodolith) creates living space for an intermediate habitat former (e.g., an algal epiphyte) that in turn creates living space for the focal organisms (e.g., polychaetes, echinoderms, molluscs, and crustaceans).

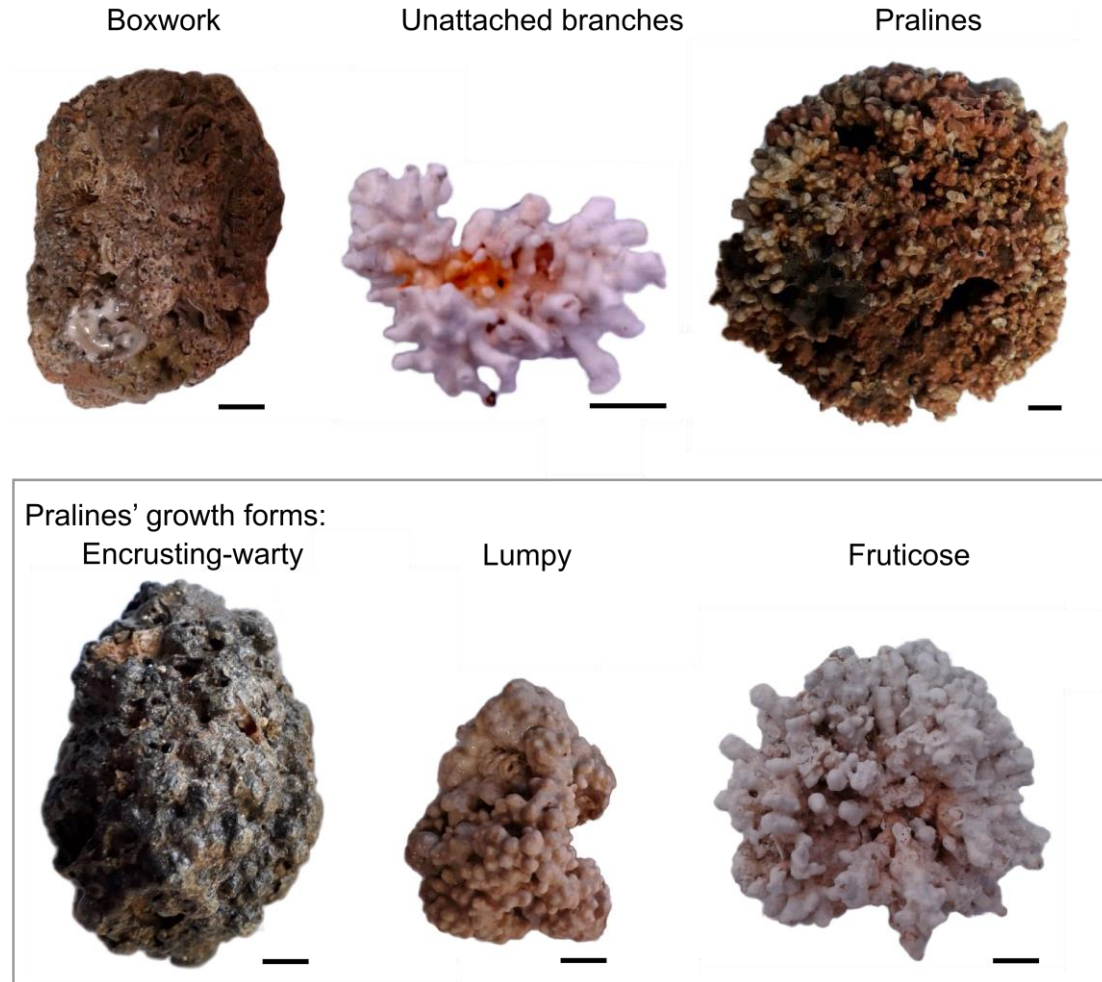


Figure 4. Morphology of the rhodoliths and praline’s growth forms collected along the coast of the Brazilian Northeast State of Paraíba; scale: 1 cm. Adapted from: (Sañé et al. 2016). Photos: Costa, D.A.; Pereira, A.R.; Silva, F.A.; Silva, M.P.

ECOLOGICAL IMPORTANCE AND ASSOCIATED BIOTA

Rhodoliths are bioengineers (‘biological builders’ or ‘ecosystem engineers’), supplying a three-dimensional habitat with irregular shapes (Sciberras et al. 2009, Basso et al. 2016) and providing food for several marine species. Regarding habitat, the rhodolith furnishes refuge and protection for the associated fauna, against physical perturbations, predation and allows competitive exclusion (due to the variability of niches provided) (Horta et al. 2016, Prata et al. 2017). In effect, rhodoliths have been identified as places of recruitment of marine species, providing refuge for the initial stages of development

of commercially important fishes (Riosmena-Rodríguez 2017), and for several species of marine invertebrates (Hinojosa-Arango & Riosmena-Rodríguez 2004, Figueiredo et al. 2007, Riul et al. 2009, Scherner et al. 2010, Costa 2016, Riosmena-Rodríguez 2017), such as polychaetes, bivalves, molluscs and echinoderms (Gagnon et al. 2012, Prata et al. 2017, Perry & Tyler-Walters 2018). The inner space of a rhodolith may further contain particulate organic matter for filtering organisms, and may provide microphytobenthos for herbivorous scavengers (Berlandi et al. 2012).

Organisms that inhabit rhodoliths may be categorized into endobionts and ectobionts. The endobiota lives inside the rhodoliths, being represented mainly by the following taxonomic groups: Polychaeta, Echinodermata, Mollusca, and Sipuncula. The ectobiota inhabits the surface of these algae, belonging mainly to Crustacea and Cnidaria.

Both the morphological characteristics of the rhodolith and the environmental characteristics in which they are found represent the main factors controlling the faunistic communities associated with rhodoliths beds (Hall-Spencer 1998, De Grave 1999). Typically, associated fauna abundance and diversity may increase with the heterogeneity and size of the rhodolith (Steller et al. 2003, Kamenos et al. 2004, Figueiredo et al. 2007, Steller & Cáceres-Martínez 2009). Yet, studies confirming this hypothesis are still incipient (Otero-Ferrer et al. 2019).

From an environmental perspective, rhodolith beds play an important function in maintaining the marine levels of pH (Bosence & Wilson 2003, Martin et al. 2007), as a result of the high concentration of carbonates that accumulate in their skeletons. Furthermore, rhodoliths are important for climate regulation processes as intervening in the global cycles of different chemical elements. For example, the biogenic gas dimethylsulphide (DMS) has “an important role in the Earth’s albedo, and thus climate regulation, through the formation of aerosols and cloud condensation nuclei” (N. Kamenos et al., 2008, p. 61).

In addition, the production of calcium carbonate and dissolved organic carbon promotes the proliferation of other organisms within the ecosystem (Van der Heijden & Kamenos 2015). A set of organisms formed by viruses, bacteria, and small eukaryotes, when associated with rhodoliths, act as an ecological unit, denominated as holobiont (Hester et al. 2016), whose function is intimately related to the associated microbiome (Cavalcanti et al. 2018). This symbiotic microbiota may respond rapidly to changes in the environmental conditions, providing an efficient mechanism for acclimatization, via

processes of adaptation (i.e. phenotypic plasticity). For instance, under elevated seawater temperature and partial pressure of carbon dioxide ($p\text{CO}_2$), specific host-associated microorganisms may decrease or increase in abundance, changing the holobiont fitness and function (Webster & Reusch 2017). However, the effects that certain climate change drivers, such as ocean acidification, on the holobiont community are still unknown (Cavalcanti et al. 2018). Besides, this community (microorganisms and rhodoliths) is essential for the maintenance of marine ecosystems, due to the importance of calcium carbonate substrate in the life cycle of many macroalgae (Fredericq et al. 2019).

In general, the ecosystem services provided by rhodoliths may differentiate depending on the geographic region. In the tropical region, these algae provide a calcified substrate for other organisms (Gherardi & Bosence 1999). Furthermore, can play a physical, stabilizing role that permits coral settlement and establishment of coral reefs over geologic timescales (Tierney & Johnson 2012). As for other ecosystem services associated with the rhodoliths beds, water filtration and pH regulation in waters and sediments, as well as additives for animal food (raw material production) are among the described ones (Birkett et al. 1998, UK Marine SACS Project 2019).

CLIMATE CHANGE AND ANTHROPOGENIC IMPACTS

Ocean acidification, global warming and associated consequences, such as changes in carbon chemistry and sea level rise, ultimately contribute to promote the reduction of marine biodiversity, including the calcareous organisms (e.g. coral reefs, rhodoliths/maërl beds), promoting changes in the functioning of the marine ecosystem (Millero 2007, IPCC 2014, Horta et al. 2016). The mechanism of carbonate sequestration (absorption and storage of atmospheric CO_2) by these algae may be equivalent to the coral reefs in extent and productivity (Amado-Filho et al. 2012a), so that rhodoliths have been considered as ‘algae reefs’ (Erickson-Davis 2014). However, ocean acidification through the increase of the $p\text{CO}_2$ levels may negatively affect the calcification of the rhodoliths, due to the high solubility of their calcite and magnesium structures (Martin & Hall-Spencer 2017), the phenomenon known as ‘coralline algae bleaching’ that causes the depletion of photosynthetic pigments and may lead to necrosis (Martone et al. 2010). On the other hand, dissolved inorganic carbon may benefit the increase of foliose algae (‘fleshy algae’), in detriment of the calcareous algae (Fredericq et al. 2014, Martin & Hall-Spencer 2017).

In addition, besides affecting the calcification rates of the coralline algae, the levels of alkalinity, dissolved inorganic carbon and oxygen, may affect respiration and photosynthesis rates (Martin & Hall-Spencer 2017), whose effects may be aggravated by temperature increase, as documented, for e.g. for *Porolithon onkodes* (Heydrich) Foslie 1909 from Australia (Anthony et al. 2008), and *Lithophyllum cabiochae* (Boudouresque & Verlaque) Athanasiadis 1999 from Mediterranean Sea (France) (Martin & Gattuso 2009).

Still, the effects of the climate drivers may be highly species-specific. Some species have the capacity to maintain high internal pH to precipitate CaCO₃, despite the decrease in environmental pH, for e.g. *Bossiella orbigniana* (Decaisne) P.C.Silva 1957, *Neogoniolithon* sp., *Lithothamnion glaciale* and *Lithophyllum cabiochae* (Ries et al. 2009, Hurd et al. 2011, Cornwall et al. 2013). However, as a side effect, these species would be more prone to pathogens (Martin et al. 2013). Furthermore, these negative impacts may lead to the decrease in photosynthetic activity, compromising the metabolism of the algae, eventually leading to the death of rhodoliths and the fauna associated (Horta et al. 2015).

Besides the climate impacts, rhodolith beds have low resilience and, therefore, they are extremely vulnerable to anthropogenic activities, such as dredging/trawling, coastal chemical pollution, aquaculture, petroleum exploration/drilling activities, overexploitation, tourism activities, and indirect effects of invasive species (Hall-Spencer & Bamber 2007, Peña & Bárbara 2008). A summary of these anthropogenic activities and potential impacts in the rhodolith beds is summarized in Table 2.

Table 2. Main anthropogenic activities affecting rhodoliths beds, with examples of impacts.

Drivers	Examples of consequences/impacts	References
Dredging/trawling	Production of a plume of fine sediment, amplifying the impact on the remaining organisms; Physical perturbation in the algae and fauna associated	(Riul et al. 2008)
Coastal chemical pollution	Affects the carbon cycle and the carbonate sequestration by the algae	(Martin & Hall-Spencer 2017)
Aquaculture	Changes in the associated fauna, decrease of their complexity and biodiversity, due to deposition of fine sediments with high organic matter content	(Peña 2010, Peña et al. 2014a)
Petroleum exploration/drilling activities	Disturbs photosynthesis due to sediment suspension; Induces burial of the algae	(Figueiredo et al. 2012, Amado-Filho et al. 2017)
Overexploitation – rhodolith as raw material	Declines rhodoliths and associated fauna	(Amado-Filho et al. 2017)
Tourism activities	Trampling of the sediment beds with rhodolith; Changes in the associated fauna, due to increased and seasonal organic pollution	(Costa et al. 2019)
Indirect effects of invasive species	Excrements produced by invasive molluscs (e.g. <i>Crepidula fornicata</i>) cover the spaces between the stalks of the rhodoliths	(Grall & Hall-Spencer 2003, Hernandez-Kantun et al. 2017)

CONSERVATION OF RHODOLITH BEDS AND PROTECTION SCHEMES

Despite the importance of rhodoliths as a unique biotope in the world, they are consistently threatened due to climate change and anthropogenic pressures (as mentioned above). Also, efforts towards their protection are limited, and there is an overall lack of a clear perception of the functioning of these structures as an ecosystem (Riosmena-Rodríguez 2017). However, some conservation and protection initiatives are becoming more spread worldwide, to avoid the extinction of such unique and important habitats. Examples of such protection schemes are the habitats directive within ‘Natura 2000’ from the European Commission, i.e. Directive nº 92/43/CEE, category 1170: reefs (Republic Diary Portugal 2017, Riosmena-Rodríguez 2017, European Commission 2019). The goal of the habitat directive is to ensure the maintenance of its conservation status, as well as its expansion (Republic Diary Portugal 2017), and the species rhodolith-forming alga *L. corallioides* and *P. calcareum* are among the priority

habitats (Council of the European Union 1992). Natura 2000 branches over all the 28 countries of the European Union, with jurisdiction in both land and sea (European Commission 2019). In Europe, there is also the ‘Biomaërl’ programme that began in 1996 in Spain, France, Malta and United Kingdom, with the main aims to inventor and monitor biodiversity associated to the maërl beds from the NE Atlantic and Mediterranean, as well as to assess their main anthropogenic impacts (BIOMAERL Team 1999).

In Eastern Pacific, few Marine Protected Areas have considered rhodolith-forming algae as relevant habitats for conservation, e.g. in Mexico (Riosmena-Rodríguez et al. 2010) and isolated actions in Costa Rica and Panama (Robinson et al. 2017).

In Asia, there are some Global Geoparks from the UNESCO that include rhodolith banks, e.g. Jeju Island in Korea (Jeju Island Geopark) and the Shimabara Peninsula in Kyushu, Japan (Unzen Volcanic Geopark) (Global Geoparks Network 2019), and some local parks in Japan (Ministry of the Environment of Japan 2010).

In Brazil, there is marine monitoring network known as ‘ReBentos’ (“*Rede de Monitoramento de Habitats Bentônicos Costeiros*”), aiming to implement an integrated network of studies on benthic habitats along the Brazilian coastline, including vegetated submerged sea bottoms, beaches, rocky shores, mangroves, marshes, rhodolith benches, coral reefs, and estuaries, all integrated with actions of environmental education (Turra & Denadai 2015). ReBentos is connected to the ‘Coastal Zones Subnet from CLIMATE Network’ (Brazilian Ministry of Science, Technology, Innovation and Communications) and to the National Institute of Science and Technology for Climatic Changes (“*Instituto Nacional de Ciência e Tecnologia para Mudanças Climáticas*”, INCT-MC). The aim of this organization is to provide scientific bases for detecting effects of regional and global environmental changes in the mentioned benthic habitats, including rhodolith beds, and this way to be an important tool to implement efficient environmental management policies. This organisation has thus began a historical data collection of the marine biodiversity along the Brazilian coastline (Turra & Denadai 2015). However, the studies are in progress, with no results published so far.

Also, in the context of conservation, environmental education can represent an important tool to raise local awareness from the people who are enjoying these marine communities (McKinley & Fletcher 2012), including the rhodolith beds and associated

biota (Rodolitos 2015). In this way, to protect the coastal zones could benefit the tourist sector, for avoiding visitor's degradation in those areas.

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CHAPTER III

TAXONOMIC STUDY OF THE MARINE INVERTEBRATES ASSOCIATED WITH RHODOLITHS/MAËRL BEDS (CORALLINALES) FROM THE COAST OF PARAÍBA STATE, NORTHEAST BRAZIL



TAXONOMIC STUDY OF THE MARINE INVERTEBRATES ASSOCIATED WITH RHODOLITHS/MAËRL BEDS (CORALLINALES) FROM THE COAST OF PARAÍBA STATE, NORTHEAST BRAZIL

Abstract. This study presents an identification guide/key, with the diagnostic features and distribution patterns worldwide and local (including new records) of the marine invertebrate fauna associated with rhodolith beds, from three beaches of the State of Paraíba, in Northeast Brazil, namely Miramar, Seixas and Maceió beaches. Rhodolith/maërl are non-geniculated red corallineous algae (Corallinales, Rhodophyta) that form extensive banks at sea-bottom in all oceans of the world, mainly in the tropical region. A total of 60 species were identified, belonging to six phyla (Platyhelminthes, Annelida, Sipuncula, Mollusca, Arthropoda, and Echinodermata) existing in the rhodolith beds of the beaches, being 53 new records. The annelids (Class Polychaeta) were the most representative taxa in Miramar and Seixas beaches, while molluscs were mostly found in Maceió Beach. This work proposes to contribute to the knowledge of marine invertebrates in Northeast Brazil, providing support for future environmental studies.

Keywords: Diversity; New Records; Distribution; Calcareous Red Algae; Tropical beaches

INTRODUCTION

Marine invertebrates are a group of animals characterized by the absence of a backbone, living in the oceanic zone around the world, from the intertidal region to high depths. The fauna is represented by many taxa, from poriferans (sea sponges) to cephalochordates (lancelets), with a great variety of morphological characteristics, types of behaviour, feeding habits, participating in all levels of food webs, being essential for the maintenance of homeorhesis and equilibrium in the oceans.

The red non-articulated calcareous algae, known as rhodoliths or maërl (European name), are reported in all oceans, from the intertidal zone to depths of 270 m, and these habitat-like structures are considered as hotspot of biodiversity, harbouring many groups of invertebrates, mainly juveniles (Schnerer et al. 2010), e.g. polychaetes, crustaceans, molluscs, sipunculids, echinoderms (Prata et al. 2017). The Brazilian coast, in particular the Northeast region may represent the zone with the highest abundance of rhodoliths worldwide, due to the large deposits of calcium carbonate (Amado-Filho et al. 2012).

The present study aimed to describe, by diagnostic characteristics, the marine invertebrates associated with rhodoliths of three beaches from the State of Paraíba, Northeast Brazil, with the inclusion of new records.

MATERIAL AND METHODS

Study area

The Brazilian coast zone extends for 8,500 km and has a width of 12 nautical miles outwards from the coast (MMA 2020). Paraíba is one of the states of the Northeast region, having a coastline that extends for 140 km (Lima & Heckendorff 1985), from the estuary of the Guajú River (in the north) up to the estuary of the Goiana River (in the south) (Neves et al. 2006).

The campaigns were carried out in the year 2018, at the coastal region of the State of Paraíba, Northeast Brazil, at Miramar (municipality of Cabedelo), Seixas (João Pessoa) and Maceió (Pitimbu) beaches (Fig. 1), considering two depths in each beach, 1.5 and 4m deep.

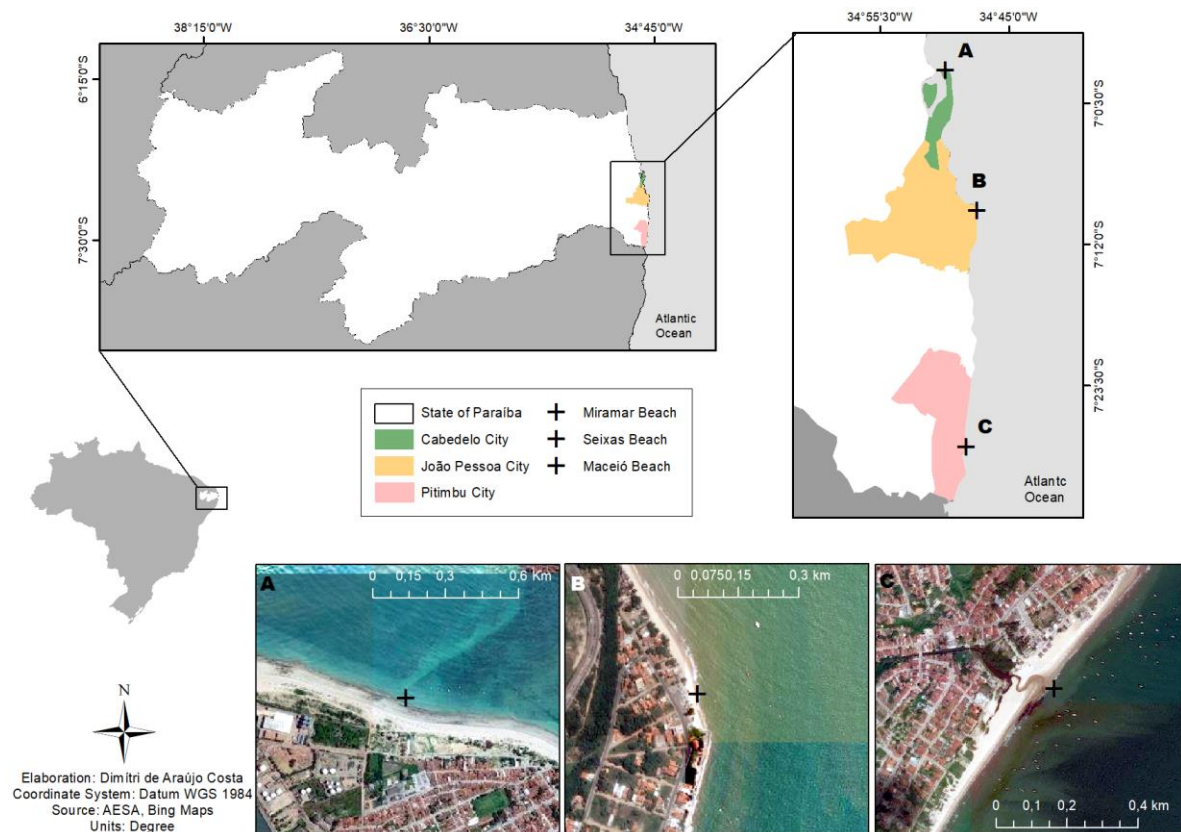


Figure 1. Location of the sampling regions and beaches in the State of Paraíba coast, Northeast Brazilian. **A.** Miramar Beach; **B.** Seixas Beach; **C.** Maceió Beach.

Methodological approach

The samples' habitats are constituted of rhodoliths, i.e., red calcareous non-articulated algae from Order Corallinales. The biological material was sorted at the “Laboratório de Invertebrados Paulo Young” of the “Universidade Federal da Paraíba (UFPB-Campus I, Brazil)”. The invertebrates were removed, fixed in 4% formaldehyde (for 24 hours), stored in 70% alcohol and identified to the lowest taxonomic resolution possible. The species were photographed with a Canon 6d digital camera–length 100mm macro L, or a Leica MZ12.5 stereomicroscope.

The taxonomic groups were organised according to the World Register of Marine Species (WoRMS Editorial Board 2020), with additional information for polychaetes (Rouse & Fauchald 1997). Records in the State of Paraíba was performed according this study, and available data in previous studies.

All specimens were deposited in the “Coleção Zoológica Aquário Paraíba”, municipality of João Pessoa, Northeast Brazil. The collection of invertebrates was authorized by the “Sistema de Autorização e Informação em Biodiversidade” (SISBIO), “Instituto Chico Mendes de Conservação da Biodiversidade” (ICMBio), request n° 63971, report n° 25753 (Supplementary material 1), Ministry of Environment, from the Federal Republic of Brazil.

RESULTS

A total of 60 species were found along of the Miramar (municipality of Cabedelo), Seixas (João Pessoa), and Maceió (Pitimbu) beaches. From these, 53 species were considered as new records in the beaches. Next, a key of the invertebrate fauna found in the rhodolith habitat from the Northeast region will be presented, based on the identified species.

Key of the invertebrate fauna associated with rhodolith beds along the coast from the Paraíba State, Northeast Brazil:

1.1) Body flatworm-like .. **Platyhelminthes**-*Enchiridium* cf. *evelinae* (Fig. 2, page 102)



1.2) Body segmented cylindrical, with parapodia, chaetae **2-Annelida** (page 102)



1.3) Body cylindrical, with anterior distinct end ('introvert').... **3-Sipuncula** (page 137)



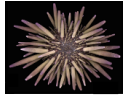
1.4) Body with one or more shells..... **4-Mollusca** (page 141)



1.5) Body with articulated exoskeleton**5-Arthropoda** (page 148)



1.6) Body with calcareous endoskeleton**6-Echinodermata** (page 157)



2) Polychaeta

2.1) Prostomium with a prominent protuberance ('caruncle') *Eurythoe complanata*
(Fig. 3, page 102)

2.2) Prostomium with five segmented antennae, peristomium with two segmented cirri,
branchiae pectinate (1 to 8 filaments).....*Eunice biannulata*
(Fig. 4, page 104)

2.3) Prostomium with five smooth antennae, peristomium with two smooth cirri,
branchiae absent*Eunice wasinensis*
(Fig. 5, page 105)

2.4) Prostomium with three smooth antennae, peristomial cirri and branchiae absent
.....*Lysidice ninetta*
(Fig. 6, page 106)

2.5) Prostomium with one smooth antenna, peristomial cirri and branchiae absent
.....*Lysidice unicornis*
(Fig. 7, page 107)

2.6) Prostomium with five smooth antennae, peristomial cirri absent, ramified branchiae
(1 to 3 filaments), dark subacicular bidentate hooks*Marphysa angelensis*
(Fig. 8, page 108)

2.7) Prostomium with five smooth antennae, peristomial cirri absent, ramified branchiae
(1 to 4 filaments), dark subacicular unidentate hooks*Marphysa regalis*
(Fig. 9, page 109)

2.8) Prostomium with five smooth antennae, peristomial cirri absent, branchiae with
single filaments, dark subacicular unidentate hooks*Marphysa stylobranchiata*
(Fig. 10, page 110)

2.9) Prostomium with five smooth antennae, peristomium with two smooth cirri,
Branchiae with single filaments, subacicular hooks absent*Palola brasiliensis*
(Fig. 11, page 111)

- 2.10)** Prostomium with three antennae, jaws prionognath-type with maxillary parts like scissors with blades*Lysarete brasiliensis*
(Fig. 12, page 112)
- 2.11)** Prostomium without antennae, jaws prionognath-type with maxillary parts like scissors with blades*Arabella iricolor*
(Fig. 13, page 113)
- 2.12)** Prostomium with five segmented basally antennae, jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers), peristomium with two cirri, branchiae pectinate (1-5 filaments).....*Kinbergonuphis nonatoi*
(Fig. 14, page 114)
- 2.13)** Prostomium with two antennae, eight pairs of anterior modified cirri, parapodia sesquiramous-type (notopodial region reduced to cirri and no chaetae)*Hesione splendida*
(Fig. 15, page 115)
- 2.14)** Prostomium with three antennae, six pairs of modified cirri, parapodia biramous-type (notopodial and neuropodial lobes with cirri and chaetae)*Oxydromus pugettensis*
(Fig. 16, page 117)
- 2.15)** Prostomium with two antennae, proboscis with conical paragnaths in areas II to IV, and VI (areas I and V, VII and VIII no cirri or chaetae)..... *Ceratonereis singularis*
(Fig. 17, page 118)
- 2.16)** Prostomium with two antennae, proboscis with conical paragnaths in areas I to IV, and VI to VIII (area V no cirri or chaetae)*Nereis riisei*
(Fig. 18, page 119)
- 2.17)** Prostomium with two antennae, proboscis with paragnaths in all areas*Pseudonereis gallapagensis*
(Fig. 19, page 120)
- 2.18)** Prostomium with four antennae, four pairs of modified anterior cirri, parapodia carry dorsal enlarged foliaceous cirri*Phyllodoce schmardaei*
(Fig. 20, page 121)
- 2.19)** Prostomium with three antennae, dorsum covered by 12 pairs of elytra from anterior to posterior end.....*Lepidonotus* cf. *squamatus*
(Fig. 21, page 122)

- 2.20)** Prostomium with three antennae, digestive tract: pharynx with tooth; a distinct and prominent muscular region of the anterior part (“proventricle”).....*Syllis guidae* (Fig. 22, page 123)
- 2.21)** Prostomium conical-shaped without antennae, parapodial cirri absent, capillaries chaetae start from chaetiger one*Neopseudocapitella brasiliensis* (Fig. 23, page 124)
- 2.22)** Prostomium with prominent cephalic margin, palps carry lateral notches and eight nuchal cirri, chaetigers 1-3 carry a distinct external spine, chaetiger 4 with a robust anterior collar, anal plate with 28 cirri*Euclymene coronata* (Fig. 24, page 125)
- 2.23)** Prostomium T-shaped, with few eyespots grouped in two ‘comma groups’ forming Y-shaped, proboscis enlarged sac-like*Naineris setosa* (Fig. 25, page 125)
- 2.24)** Body divided into four regions: operculum (with merged lobes in shallow mid ventral indentation), parathorax, abdomen, and cauda.....*Phragmatopoma caudata* (Fig. 26, page 127)
- 2.25)** Body with dark spots on surface, anterior radiolar crown united at the base by short membrane, 46 pairs of radioles with stylodes, thoracic unciniger (‘tori’) carry avicular uncini*Branchiomma nigromaculatum* (Fig. 27, page 128)
- 2.26)** Anterior end with branchial lobes supported by stalk, each lobe carries 12 radioles (with about 20 eyespots), collar divided at two regions lobe-like, thoracic unciniger with avicular uncini*Hypsicomus capensis* (Fig. 28, page 129)
- 2.27)** Prostomium pointed without eyes, 3-4 tentacular filaments in anterior segments, branchiae start from chaetiger 3, with sigmoid hooks.....*Cirratulus africanus* (Fig. 29, page 130)
- 2.28)** Prostomium rounded, without eyes, anterior chaetigers carry numerous tentacular cirri, branchiae start from chaetiger 1, with sigmoid hooks *Cirriformia capensis* (Fig. 30, page 131)
- 2.29)** Prostomium bluntly without eyes, peristomium with two segmentations, two groups of five tentacular filaments, branchiae start from chaetiger, parapodia with acicular spines (slightly sigmoid, with truncated tips)*Timarete punctata* (Fig. 31, page 132)

2.30) Body covered by papillae, chaetigers 1-3 covered by thin layer of sand on the dorsal surface, anterior region prolonged by a translucent membranous tube chaetae three first iridescent, forming a cephalic cage.....*Pherusa scutigera*

(Fig. 32, page 133)

2.31) Prostomium carry tentacular lobe horseshoe-shaped with numerous grooved tentacles, eyespots arranged in two or three rows on the posterior margin of the tentacular lobe, segment 6 with three pairs branchiae with spiral filaments*Terebella plagiostoma*

(Fig. 33, page 134)

2.32) Prostomium with delineated dorsal and ventral lips, two pairs of branchiae in anterior end, about 16 ventral pads followed by a narrow streak of glandular tissue in a ventral groove along the abdomen*Terebella pterochaeta*

(Fig. 34, page 135)

2.33) Proboscis spoon-shaped with brown streaks, head with two ventral golden chaetae, body with outer layer of integument in posterior half of trunk separated from inner layers but still attached to trunk*Echiurus echiurus*

(Fig. 35, page 136)

3) Sipuncula

3.1) Body with anal shield covered with dark chalky points, margin caudal shield with irregular ridges, anterior end known as “introvert” similar in size to body, with rows of double-pointed hooks anteriorly*Aspidosiphon* cf. (*Paraspidosiphon*) *steenstrupii*

(Fig. 36, page 137)

3.2) Body marbled with brown flecks and bands, anterior end known as “introvert” longer than the body, carrying numerous rows of hooks, hooks with a distinct streak (triangle and internal clear steak not divided)*Phascolosoma* cf. (*Phascolosoma*) *nigrescens*

(Fig. 37, page 138)

3.3) Body with longitudinal muscle bands (LMBs) and the nephridiopores open between LMBs 4 to 8, the LMBs do not subdivide in the glans region, spindle muscle weakly developed*Sipunculus* cf. (*Sipunculus*) *phalloides*

(Fig. 38, page 140)

4) Mollusca

4.1) With two trigonal valves (shells), left hinge with the usual V-shaped cardinal tooth *Mulinia cleryana*

(Fig. 39, page 141)

4.2) With two subtriangular valves, laterally inflated; external, opisdotelic and parvincular ligaments; heterodont hinge with two cardinal teeth *Phlyctiderma cf. semiasperum*

(Fig. 40, page 142)

4.3) With two dark-brown valves, fan-shaped shell with fine divercating radial ribs, interior umbones has purple-brown blotches with 1-4 dysodont hinge teeth *Brachidontes exustus*

(Fig. 41, page 143)

4.4) With a smooth and shiny symmetrical shell dark brown to black, sculpture of fine concentric semi-circular rings, with two muscle scars, pallial line was seen as a curved line towards the adductor scar *Mytella charruana*

(Fig. 42, page 144)

4.5) Shell oval-shaped (right valve slightly operculum-shaped, left one fixed in substrate, more larger than right valve), adductor muscle postero-dorsal located, occupying 1/5 of total size of animal, palps with margin superior free *Crassostrea brasiliiana*

(Fig. 43, page 145)

4.6) Gastropod with oval shaped shell, slightly spiral convex sculptures with axial ventricular ribs, ending towards the base, oblique, denticulated opening on the inner surface of the outer lip, straight columella, anal notch present *Parvanachis obesa*

(Fig. 44, page 146)

4.7) With many plates on surface, tegument with many white spots mainly on apical region, girdle white with transverse orange bands *Acanthochitona cf. terezae*

(Fig. 45, page 147)

5) Crustacea

5.1) Head lateral cephalic lobes apically truncate, antenna 1 flagellum with about 19 articles; accessory flagellum with two articles *Grandidierella cf. bonnieroides*

(Fig. 46, page 148)

- 5.2)** Head with lateral cephalic lobe truncated, antero-ventral margin with notch; antenna 1 longer than antenna 2, peduncular article 1 shorter than article 2, flagellum with 12 articles, mandible incisor asymmetrical*Elasmopus cf. rapax*
(Fig. 47, page 149)
- 5.3)** Head with lateral cephalic lobe truncated, antero-ventral corner with slender chaeta, antenna 1 peduncular article 1 shorter than article 2, with 3 prominent chaetae along posterior margin.....*Dulichella appendiculata*
(Fig. 48, page 150)
- 5.4)** Peduncular eyes with well-developed cornea, subcircular carapace adorned with fine granules, orbital margin longer than half the maximum width of the carapace and trimmed with fine bristles.....*Cyclodorippe cf. longifrons*
(Fig. 49, page 151)
- 5.5)** Carapace is broader than long, rostrum incised by a narrow notch, orbit is armed with one spine below, one at the outer angle and three above*Mithraculus forceps*
(Fig. 50, page 152)
- 5.6)** Shield longer than broad, rostrum obtuse with lateral projections, ocular peduncles slender and shorter than shield width, with corneae dilated.....*Pagurus criniticornis*
(Fig. 51, page 153)
- 5.7)** Long and straight rostrum, beyond the scaphocerit, upper margin with 10 to 14 teeth, first two placed on the carapace behind the orbit and third placed well above this limit, lower margin with five teeth*Leander cf. paulensis*
(Fig. 52, page 153)
- 5.8)** Carapace about a third wider than it is long, convex; dorsal surface covered with green granules, stronger in front and on the edges, smaller behind; several well-marked granular lines, arranged horizontally*Garthiope spinipes*
(Fig. 53, page 154)
- 5.9)** Isopod with body ventrally folded rostral process that just overlaps the anterior point of the frontal lamina, the frontal lamina always pentagonal, dorsal surfaces are smooth with brown or black chromatophores*Cirolana cf. parva*
(Fig. 54, page 155)
- 5.10)** Stomatopod with two eyes with subglobular cornea, carapace with marked gastric sulcus, raptorial leg with dilated dactyl at the base, slightly distally crenulated, and protruded with distally serrated inner margin.....*Neogonodactylus cf. torus*
(Fig. 55, page 156)

6) Echinodermata

6.1) Sea urchin with elongate oval test with two rows of large tubercles along the ambulacra and interambulacra; spines long and slender, thickened at the base, and sharply pointed at the tips..... *Echinometra lucunter*

(Fig. 56, page 157)

6.2) Sea cucumber with body cylindrical, tegument thin with some papillae or warts formed by agglomeration of ossicles, mouth and anus terminal, color light pink to translucent, body wall with wheels with six holes *Chiridota rotifera*

(Fig. 57, page 159)

6.3) Disk circular to pentagonal with invaginations in inter-radial areas, disk covered by small and imbricated scales, ventral side of the disk covered by smaller scales, five elongated arms about seven to ten times the diameter of the disk

..... *Amphipholis januarii*

(Fig. 58, page 160)

6.4) Disk rounded covered by medium size scales (similar to ventral surface ones), radial shields slightly long than wider, separated by a thin scale up to the distal region of the shields, five arms five times the disk diameter..... *Amphipholis squamata*

(Fig. 59, page 161)

6.5) Disk rounded with indentations in the radial region, disk covered by small scales, radial shields joined at half of length and separated by three scales on the proximal edge, oral shield diamond-shaped, five arms 6-8 times the disk diameter

..... *Microphiopholis gracillima*

(Fig. 60, page 162)

6.6.) Disk rounded to pentagonal covered by medium size scales in the centre and in the interradial surface, radial shield large and triangular, occupying more than half the disk, six arms, about five times the diameter of the disk, tapering distally

..... *Ophiactis savignyi*

(Fig. 61, page 163)

Diagnostic features and distribution of identified species:

Phylum Platyhelminthes Minot, 1876

Order Polycladida Lang, 1884

Family Prosthiosomidae Lang, 1884

***Enchiridium cf. evelinae* Marcus, 1949** (Fig. 2)



Figure 2. *Enchiridium cf. evelinae* Marcus, 1949. Photo: Costa, D.A.

Diagnosis (Bahia et al. 2014): Flatworm of free-living, long and narrow body; dorsal region cream with brown dots, more densely disposed at the median line; margin with orange dots; pharynx reaches 1/3 of the body length; seminal and prostatic vesicles highly muscularized; penis papilla and male atrium long.

Global distribution: Brazilian coast (Rio Grande do Norte, Alagoas, Rio de Janeiro, São Paulo states) (Bahia et al. 2015, Tyler et al. 2019).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Phylum Annelida Grube, 1850

Class Polychaeta Grube, 1850

Subclass Errantia Audouin & H Milne Edwards, 1832

Order Amphinomida Fauchald, 1977

Family Amphinomidae Lamarck, 1818

***Eurythoe complanata* (Pallas, 1766)** (Fig. 3)

Synonyms: *Amphinome complanata* (Pallas, 1766); *Amphinome jamaicensis* Schmarda, 1861; *Amphinome macrotricha* Schmarda, 1861; *Aphrodita complanata* Pallas, 1766; *Blenda armata* Kinberg, 1867; *Eurythoe albosetosa* Kinberg, 1857; *Eurythoe alcyonaria* Gravier, 1902; *Eurythoe assimilis* McIntosh, 1925; *Eurythoe capensis* Kinberg, 1857; *Eurythoe corallina* Kinberg, 1857; *Eurythoe ehlersi* Kinberg, 1867; *Eurythoe havaica* Kinberg, 1867; *Eurythoe indica* Kinberg, 1867; *Eurythoe kamehameha* Kinberg, 1857; *Eurythoe pacifica* Kinberg, 1857; *Eurythoe pacifica*

levukaensis McIntosh, 1885; *Lycaretus neocephalicus* Kinberg, 1867; *Pleione alcyonea* Lamarck, 1818.



Figure 3. *Eurythoe complanata* (Pallas, 1766). Photo: Prata, J.

Diagnosis (Barroso & Paiva 2007, Arias et al. 2013): This species carries a prostomium with four eyes (trapezoidally arranged), three smooth antennae, two cirriform palps, and a fleshy dorsal protuberance known as caruncle, extending to third chaetiger. Branchiae ramified from chaetiger 2. Each parapodium with two slender/digitiform cirri (dorsal and ventral, similar in size); notopodia (dorsal) with following kinds of chaetae: furcate, smooth, serrated, and a slender blade with a small spur; neuropodia (ventral) with furcate chaetae.

Global distribution: Caribbean Sea to Brazilian coast (Ceará, Rio Grande do Norte, Pernambuco, Alagoas, Bahia, Espírito Santo, Rio de Janeiro, São Paulo states); Iberian Peninsula to Red Sea; Azores Archipelago; East Africa; Pacific Ocean (Oceania to South America, and Hawaii) (Amaral et al. 2013, Read & Fauchald 2019i).

Distribution in Paraíba coast: Barra de Camaratuba Beach, Mamanguape River, Cabo Branco Beach (De Assis et al. 2012), Seixas Beach (Costa et al. 2017), and Miramar Beach (**New record**, this study).

Order Eunicida Fauchald, 1977

Family Eunicidae Berthold, 1827

Eunice biannulata Moore, 1904 (Fig. 4)



Figure 4. *Eunice biannulata* Moore, 1904. Photo: Prata, J.

Diagnosis (Fauchald 1992, Paxton 2009): Prostomium with a median sulcus deep, with four eyes (arranged in a curved line), and five segmented antennae. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomium with two segmented cirri. Branchiae pectinate (1 to 8 filaments) from chaetiger 3. Parapodia with notopodial medially inflated cirri, with articulations (anterior and median ones) or without articulations (posterior ones), larger than ventral ones; neuropodia carry anterior inflated basally cirri and posterior ones digitiform, pre and post-chaetal lobes, limbate, pectinate and falcigers chaetae, yellow aciculae paired, and yellow subacicular bidentate hooks.

Global distribution: Pacific coast from United States of America, Brazilian coast (Rio Grande do Norte, Alagoas, Sergipe, Bahia and Paraná states) (Nonato & Luna 1970, Amaral et al. 2013, Read & Fauchald 2019g).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), and Miramar Beach (**New record**, this study).

***Eunice wasinensis* Fauchald, 1992 (Fig. 5)**

Synonyms: *Eunice (Nigidion) gracilis* (Crossland, 1904); *Nigidion gracilis* Crossland, 1904.



Figure 5. *Eunice wasinensis* Fauchald, 1992. Photo: Freitas, P.

Diagnosis (Fauchald 1992, Paxton 2009): Prostomium with a median sulcus deep, with four eyes (arranged in a curved line), and five smooth antennae. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomium with two smooth cirri. Branchiae absent. Notopodia with filiform cirri, larger than ventral ones. Neuropodia with rounded acicular lobes (in anterior segments), conical (median ones) and pointed; thick and tapering ventral cirri (anterior segments), inflated (median ones) and short tubercular (posterior ones); pre and post-chaetal lobes; pectinates and falcigers chaetae, besides dark aciculae single, and dark subacicular bidentate hooks.

Global distribution: East Africa, Northeast Brazilian (Bahia state) (Amaral et al. 2013, Read & Fauchald 2019h).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Miramar Beach (**New record**, this study).

***Lysidice ninetta* Audouin & H Milne Edwards, 1833** (Fig. 6)

Synonyms: *Lysidice brevicornis* Kinberg, 1865; *Lysidice bilobata* Verrill, 1900; *Lysidice brachycera* Schmarda, 1861; *Lysidice mahagoni* Claparède, 1864; *Lysidice margaritacea* Claparède, 1868; *Nereis olympia* Blainville, 1825; *Nereis valentina* Blainville, 1825.

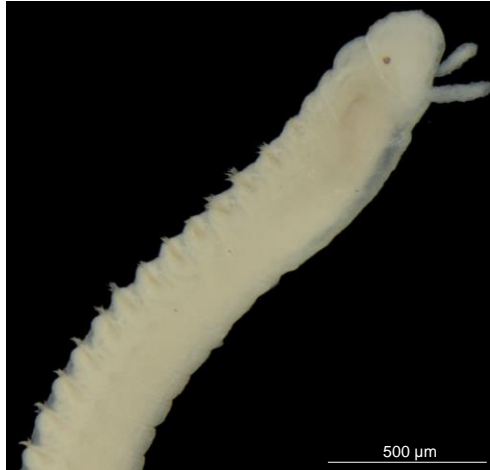


Figure 6. *Lysidice ninetta* Audouin & H Milne Edwards, 1833. Photo: Prata, J.

Diagnosis (Nonato & Luna 1970, Uebelacker & Johnson 1984, Salazar-Vallejo & Carrera-Parra 1997, Paxton 2009): Prostomium rounded without sulcus, with two eyes, and three smooth antennae. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomial cirri and branchiae absent. Notopodia carry digitiform cirri. Neuropodia carry conical cirri smaller than dorsal ones; with limbate, pectinates and falcigers chaetae; dark aciculae single, and dark subacicular bidentate hooks.

Global distribution: Gulf of Mexico to Caribbean Sea, North Atlantic Ocean (Ireland to Mediterranean Sea), Brazilian coast (Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia (including Abrolhos Archipelago), Rio de Janeiro, São Paulo and states), Red Sea, East Australia to New Zealand (Amaral et al. 2013, Read & Fauchald 2019o).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

***Lysidice unicornis* (Grube, 1840) (Fig. 7)**

Synonyms: *Lumbriconereis unicornis* Grube, 1840; *Nematonereis grubei* Quatrefages, 1866; *Nematonereis unicornis* Schmarda, 1861; *Nematonereis unicornis* (Grube, 1840).



Figure 7. *Lysidice unicornis* (Grube, 1840). Photo: Prata, J.

Diagnosis (Salazar-Vallejo & Carrera-Parra 1997, Paxton 2009): Prostomium rounded without sulcus, with two eyes, and only one smooth antenna. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomial cirri and branchiae absent. Notopodia with digitiform cirri, larger than ventral cirri. Neuropodia with globular cirri; with limbate, pectinates and falcigers chaetae; yellow aciculae single, and yellow subacicular bidentate hooks.

Global distribution: Atlantic Ocean (North to South), South-Southeast Brazilian (São Paulo and Paraná states), Mediterranean Sea, Red Sea, Madagascar, and New Zealand (Amaral et al. 2013, Read & Fauchald 2019p).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Cabo Branco Beach (De Assis et al. 2012), Miramar Beach (**New record**, this study).

***Marphysa angelensis* Fauchald, 1970** (Fig. 8)



Figure 8. *Marphysa angelensis* Fauchald, 1970. Photo: Prata, J.

Diagnosis (Fauchald 1970, Salazar-Vallejo & Carrera-Parra 1997, Paxton 2009): Prostomium with a short anterior incision, with two eyes, and five smooth antennae. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomial cirri absent. Ramified branchiae (1 to 3 filaments) from chaetiger 9. Anterior notopodial cirri enlarged, and posterior ones digitiform, both types longer than ventral ones. Neuropodia with anterior cirri globular, posterior ones conical; limbate, pectinates, falcigers and spinigers chaetae; 1-3 dark aciculae by chaetiger, and dark subacicular bidentate hooks.

Global distribution: Gulf of California, Gulf of Mexico, Southeast Brazilian (São Paulo state) (Amaral et al. 2013, Read & Fauchald 2019q).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

***Marphysa regalis* Verrill, 1900 (Fig. 9)**



Figure 9. *Marphysa regalis* Verrill, 1900. Photo: Prata, J.

Diagnosis (Salazar-Vallejo & Carrera-Parra 1997, Paxton 2009, Molina-Acevedo & Carrera-Parra 2017): Prostomium divided in two lobes, with two eyes, and five smooth antennae (with brown perpendicular bands). Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomial cirri absent. Ramified branchiae (1 to 4 filaments) from chaetiger 19. Notopodial cirri (longer than neuropodial ones) enlarged in anterior chaetigers, digitiform in posterior chaetigers. Neuropodia carry anterior acicular lobe rounded, posterior ones triangular; anterior globular basally cirri larger than posterior ones; pre and post-chaetal lobes; limbate, pectinates and falcigers chaetae; 1-3 dark aciculae by chaetiger, and dark subacicular unidentate hooks.

Global distribution: Gulf of Mexico to Caribbean Sea, Islands of Bermuda, Brazilian coast (Pernambuco, Alagoas, Bahia, Espírito Santo and Rio de Janeiro states) (Amaral et al. 2013, Read & Fauchald 2019r).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Cabedelo pier (De Assis et al. 2012), Miramar Beach (**New record**, this study).

***Marphysa stylobranchiata* Moore, 1909** (Fig. 10)



Figure 10. *Marphysa stylobranchiata* Moore, 1909. Photo: Prata, J.

Diagnosis (Nonato & Luna 1970, Knox & Green 1972, Paxton 2009): Prostomium with a short anterior incision, with two eyes, and five smooth antennae. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomial cirri absent. Branchiae with only one filament from chaetiger 20. Anterior dorsal cirri longer than posterior ones. Neuropodia with cirri smaller than dorsal ones; falcigers chaetae; 1-5 dark aciculae, and dark subacicular unidentate hooks.

Global distribution: Pacific coast (Monterey Bay), Brazilian coast (Alagoas, Bahia and Rio de Janeiro states) (Amaral et al. 2013, Read & Fauchald 2019s).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Miramar and Maceió beaches (**New records**, this study).

***Palola brasiliensis* Zanol, Paiva & Attolini, 2000** (Fig. 11)



Figure 11. *Palola brasiliensis* Zanol, Paiva & Attolini, 2000. Photo: Prata, J.

Synonyms: *Palolo brasiliensis* Zanol, Paiva & Attolini, 2000.

Diagnosis (Zanol et al. 2000, Paxton 2009): Prostomium with a short anterior incision, two eyes, and five smooth antennae. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomium with two smooth cirri. Branchiae with single filaments starting on chaetiger 58. Notopodial cirri digitate, anterior longer than other ones. Neuropodia carry anterior cirri digitiform, median ones inflated, and posterior ones short and tapering; with limbate and falcigers, and dark acicula single. Subacicular hooks absent.

Global distribution: Brazilian coast (Bahia, Espírito Santo and Rio de Janeiro states) (Amaral et al. 2013, Read & Fauchald 2019x).

Distribution in Paraíba coast: Seixas Beach (De Assis et al. 2012, Costa et al. 2017).

Family Lumbrineridae Schmarda, 1861

***Lysarete brasiliensis* Kinberg, 1865** (Fig. 12)

Synonyms: *Oenone brevimaxillata* Treadwell, 1931.

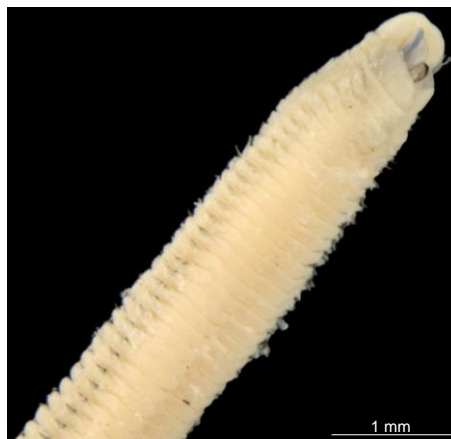


Figure 12. *Lysarete brasiliensis* Kinberg, 1865. Photo: Prata, J.

Diagnosis (Camargo & Lana 1995, Clemo & Dorgan 2017): Prostomium with four eyes, three antennae, and two lips palps. Jaws prionognath-type with maxillary parts like scissors with blades (“carriers”). Notopodia carry anterior cirri rounded smaller than posterior shaped-foliate ones; and dark acicula single. Neuropodia carry pre and post-chaetal lobes; limbate chaetae, and five aciculae.

Global distribution: Atlantic Ocean (North to South), Gulf of Mexico, Brazilian coast (São Paulo, Rio de Janeiro, Paraná and Rio Grande do Sul states), Mexican Pacific coast (Amaral et al. 2013, Read & Fauchald 2019n).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Remarks: The species was recorded for Seixas Beach as *Lysarete raquelae* Carrera-Parra, 2001 (Costa et al. 2017), but now it is revised and replaced to *Lysarete brasiliensis*.

Family Oeononidae Kinberg, 1865

***Arabella iricolor* (Montagu, 1804)** (Fig. 13)

Synonyms: *Arabella* (*Arabella*) *iricolor* (Montagu, 1804); *Arabella lagunae* Chamberlin, 1919; *Arabella maculosa* Verrill, 1900; *Arabella multidentata* (Ehlers, 1887); *Arabella setosa* Treadwell, 1921; *Aracoda moebiana* Grube, 1878; *Aracoda multidentata* Ehlers, 1887; *Drilonereis pinnata* Treadwell, 1921; *Lumbriconereis longissima* Grube, 1857; *Lumbriconereis opalina* Verrill, 1873; *Lumbriconereis quadristriata* Grube, 1840; *Lumbriconereis splendida* Leidy, 1855; *Lumbrinereis st-hilaryi* Delle Chiaje, 1841; *Lumbrinereis tricolor* Johnston, 1865; *Lumbrineris dubia* Quatrefages, 1866; *Lumbrineris gigantea* Quatrefages, 1866; *Maclovia gigantea* (Quatrefages, 1866); *Maclovia iricolor* (Montagu, 1804); *Maclovia iricolor capensis* Willey, 1904; *Nereis iricolor* Montagu, 1804; *Nereis tricolor* Leach in Johnston, 1865; *Notocirrus margaritaceus* Quatrefages, 1866; *Notocirrus tricolor* (Johnston, 1865); *Oenone maculata* Milne Edwards, 1836.



Figure 13. *Arabella iricolor* (Montagu, 1804). Photo: Prata, J.

Diagnosis (Day 1967a, Uebelacker & Johnson 1984, Paxton 2009): Prostomium with four eyes, without appendages. Jaws prionognath-type with maxillary parts like scissors with blades (“carriers”). Anterior notopodial cirri longer than posterior ones. Neuropodia carry pre and post-chaetal lobes; serrated winged capillaries, and yellow acicula.

Global distribution: Cosmopolitan (Read & Fauchald 2019a).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Family Onuphidae Kinberg, 1865

***Kinbergonuphis nonatoi* Lana, 1991** (Fig. 14)

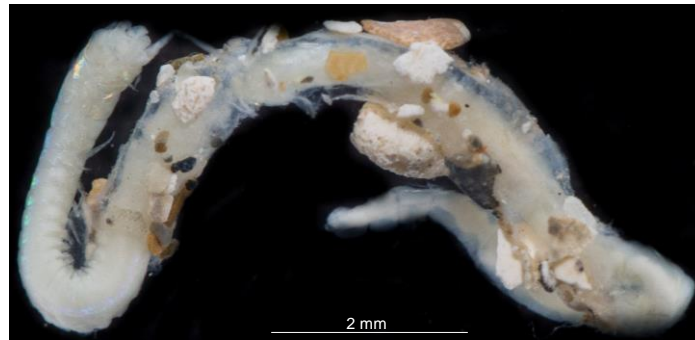


Figure 14. *Kinbergonuphis nonatoi* Lana, 1991. Photo: Freitas, P.

Diagnosis (Lana 1991): Prostomium with five segmented basally antennae, and four eyespots. Jaws eulabidognath-type (asymmetrical, posterior parts dentate to forceps-like, short carriers). Peristomium with two cirri. Branchiae pectinate (1-5 filaments) from chaetiger 7-8. Anterior dorsal cirri longer than posterior ones. Neuropodia carry pre and post-chaetal lobes; limbate and pectinate chaetae, pseudocompound tridentate hooks (1-5 chaetigers), bidentate subacicular hooks (median and posterior chaetigers), and three aciculae.

Global distribution: Brazilian coast (Rio de Janeiro, São Paulo, Paraná and Santa Catarina states) (Amaral et al. 2013, Read & Fauchald 2019l).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Order Phyllodocida Dales, 1962

Family Hesionidae Grube, 1850

***Hesione splendida* Lamarck, 1818** (Fig. 15)

Synonyms: *Fallacia pantherina* (Risso, 1826); *Hesione ceylonica* Grube, 1874; *Hesione ehlersi* Gravier, 1900; *Hesione festiva* Savigny in Lamarck, 1818; *Hesione pacifica* McIntosh, 1885; *Hesione pantherina* Risso, 1826; *Hesione savignyi* Costa, 1841; *Hesione sicula* Delle Chiaje, 1830; *Hesione steenstrupi* Quatrefages, 1886; *Nereis splendida* (Lamarck, 1818).



Figure 15. *Hesione splendida* Lamarck, 1818. Photo: Prata, J.

Diagnosis (Fonte: (Imajima 2003, Costa et al. 2008, Costa & Christoffersen 2016)): Prostomium with four eyes, two papilla-like antennae, facial tubercle, nuchal organs, and an incision in posterior end. Anterior proboscis ring smooth, carrying two black points in medium-lateral region and a tubercle in the median-posterior region. First segments with eight pairs of modified cirri (“tentacular cirri”). Parapodia sesquiramous-type (notopodial region reduced to cirri and no chaetae); neuropodia with falcigers and dark aciculae.

Global distribution: Red Sea, Mediterranean Sea, Greece, Italy, Atlantic coast of France to Senegal, Cape Verde Archipelago, Brazilian coast (Ceará, Rio Grande do Norte, Paraíba, Pernambuco and Alagoas states), Caribbean Sea, Jamaica, Puerto Rico, Gulf of Mexico, Florida (USA), Pacific Ocean, Japan, tropical Indo-West Pacific, Samoa, Tonga, Sri Lanka (Costa et al. 2008, De Assis et al. 2012, Amaral et al. 2013, Costa & Christoffersen 2016, Read & Fauchald 2019j).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

***Oxydromus pugettensis* (Johnson, 1901)** (Fig. 16)

Synonyms: *Ophiodromus pugettensis* (Johnson, 1901); *Podarke pugettensis* Johnson, 1901.



Figure 16. *Oxydromus pugettensis* (Johnson, 1901). Photo: Prata, J.

Diagnosis (Uchida 2004): Prostomium with four eyes, three antennae, facial tubercle, nuchal organs, two palps, and an incision in posterior end. Anterior proboscis ring ciliated. First segments with six pairs of modified cirri (“tentacular cirri”). Parapodia biramous-type (notopodial and neuropodial lobes with cirri and chaetae), with capillaries, falcigers chaetae, and aciculae transparent.

Global distribution: Northeast Ocean Pacific, Washington (USA), Brazilian coast (Paraíba, Rio de Janeiro and São Paulo states) (De Assis et al. 2012, Villalobos-Guerrero & Harris 2012, Amaral et al. 2013, Read & Fauchald 2019w).

Distribution in Paraíba coast: Cabedelo, Conde municipalities (De Assis et al. 2012), Seixas Beach (Costa et al. 2017).

Family Nereididae Blainville, 1818

***Ceratonereis singularis* Treadwell, 1929** (Fig. 17)



Figure 17. *Ceratonereis singularis* Treadwell, 1929. Photo: Prata, J.

Diagnosis (Perkins 1980, Santos & Lana 2003): Prostomium with four eyes, two antennae (as long as prostomial width), and two palps (size similar to antennae). Proboscis with conical paragnaths (areas I and V, VII and VIII no ones, area II with 9-15 long oval group ones, area III with 6-10 group triangular ones, area IV with 10-16 oval group ones, and area VI with cushion-like lobe), and jaws with 5-6 teeth. Four pairs of modified anterior cirri (“tentacular cirri”). Parapodia with notopodial and neuropodial lobes (with pre and post-chaetal lobes) of same size, falcigers and spinigers chaetae, and dark aciculae.

Global distribution: Northeast Pacific Ocean (Baja California), Caribbean Sea, Brazilian coast (Maranhão, Paraíba and Alagoas states) (Amaral et al. 2013, Read & Fauchald 2019c).

Distribution in Paraíba coast: Penha Beach (De Assis et al. 2012), Seixas Beach (Costa et al. 2017) and Miramar Beach (**New record**, this study).

***Nereis riisei* Grube, 1857** (Fig. 18)

Synonyms: *Heteronereis fasciata* Schmarda, 1861; *Nereis ambiguus* Treadwell, 1937; *Nereis bicruciata* Augener, 1906; *Nereis decora* Treadwell, 1932; *Nereis glandulata* Hoagland, 1919; *Nereis lata* Hansen, 1882.



Figure 18. *Nereis riisei* Grube, 1857. Photo: Prata, J.

Diagnosis (Uebelacker & Johnson 1984, Santos & Lana 2003, Amaral et al. 2005): Prostomium with four eyes, two antennae, and two palps. Proboscis with conical paragnaths (area I with one structure, area II 10 ones, area III with 18-20 ones, area IV with 26-30 ones, area V no ones, area VI with six ones, area VII and VIII with five ones), and serrated jaws. Four pairs of modified anterior cirri (“tentacular cirri”). Parapodia with notopodial and neuropodial lobes (with pre and post-chaetal lobes) of same size, falcigers and spinigers chaetae, and dark aciculae.

Global distribution: Gulf of Mexico, Caribbean Sea, Brazilian coast (Pará to Santa Catarina states) (Read & Fauchald 2019v).

Distribution in Paraíba coast: Lucena Beach (De Assis et al. 2012), Seixas Beach (Costa et al. 2017), Maceió Beach (**New record**, this study).

***Pseudonereis gallapagensis* Kinberg, 1865** (Fig. 19)

Synonyms: *Neanthes variegata* Kinberg, 1866; *Pseudonereis formosa* Kinberg, 1865.

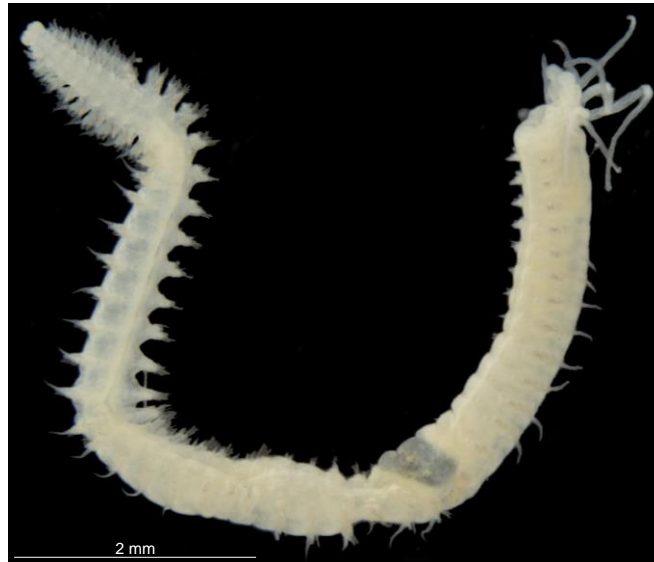


Figure 19. *Pseudonereis gallapagensis* Kinberg, 1865. Photo: Prata, J.

Diagnosis (Dueñas-Ramírez & Quiros-Rodríguez 2012): Prostomium with four eyes, two antennae, and two palps. Proboscis with paragnaths (area I with two conical ones, area II with three rows of pectinate bars, area III with four pectinate bars, area IV with five pectinate bars, area V with one conical paragnath, area VI with transverse ones, and areas VII and VIII with a single row conical ones), and serrated jaws. Four pairs of modified anterior cirri (“tentacular cirri”). Parapodia with notopodial and neuropodial lobes (with pre and post-chaetal lobes) of same size, falcigers and spinigers chaetae, and dark aciculae.

Global distribution: Pacific Ocean: Galápagos Islands, Hawaii, Baja California to Chile; Brazilian coast (Rio Grande do Norte, Paraíba, Pernambuco, São Paulo and Paraná states); Cape of Good Hope, Madagascar, Red Sea (Read & Fauchald 2019ab).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Miramar Beach (**New record**, this study).

Phyllodocidae Örsted, 1843

Phyllodoce schmardaei Day, 1963 (Fig. 20)

Synonym: *Phyllodoce macrophthalma* Schmarda, 1861.



Figure 20. *Phyllodoce schmardaei* Day, 1963. Photo: Prata, J.

Diagnosis (Day 1967a): Body green. Prostomium with two eyes, four antennae, nuchal organs, and a small posterior-median papilla. Proboscis divided at two parts, proximal one with soft papillae, distal one papillated with six divisions. Four pairs of modified anterior cirri (“tentacular cirri”). Parapodia carry dorsal enlarged foliaceous cirri, and neuropodial lobe with spinigers chaetae.

Global distribution: South Africa, English Channel, Mediterranean Sea (Read & Fauchald 2019aa).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Family Polynoidae Kinberg, 1856

***Lepidonotus* cf. *squamatus* (Linnaeus, 1758)** (Fig. 21)

Synonyms: *Aphrodita armadillo* Bosc, 1802; *Aphrodita longirostra* Bruguière, 1789; *Aphrodita pedunculata* Pennant, 1777; *Aphrodita punctata* Müller, 1771; *Aphrodita squamata* Linnaeus, 1758; *Lepidonote armadillo* (Bosc, 1802) sensu Leidy, 1855; *Lepidonote punctata* Örsted, 1843; *Lepidonotus granularis* Leach in Johnston, 1865; *Lepidonotus verrucosus* Leach in Johnston, 1865; *Polinoe scutellata* Risso, 1826; *Polynoe dasypus* Quatrefages, 1866; *Polynoe inflatae* Castelnau, 1842; *Polynoe punctata* Castelnau, 1842; *Polynoe squamata* Savigny in Lamarck, 1818.

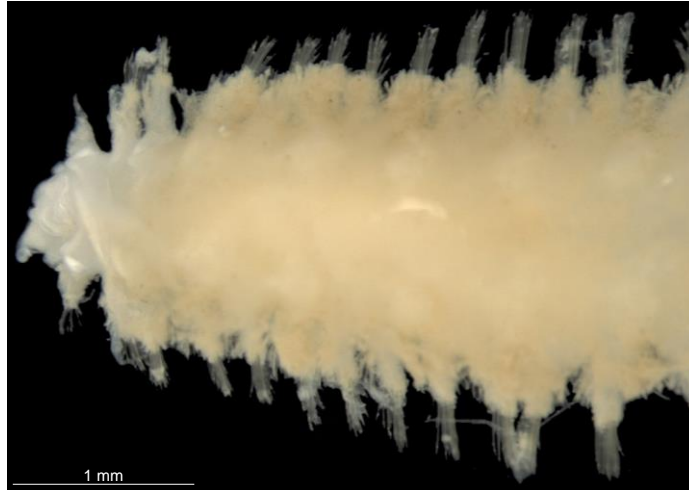


Figure 21. *Lepidonotus* cf. *squamatus* (Linnaeus, 1758). Photo: Prata, J.

Diagnosis (Imajima & Hartman 1964): Prostomium with four eyes, three antennae, and two palps. Dorsum covered by 12 pairs of elytra from anterior to posterior end, with papillae on the surface, and marginally fringed. Notopodial region carries cirri and capillaries chaetae; neuropodial lobes enlarged with falcate chaetae.

Global distribution: North Atlantic Ocean to Greenland; Mediterranean Sea (Read & Fauchald 2019m).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Family Syllidae Grube, 1850

***Syllis guidae* Nogueira & Yunda-Guarin, 2008 (Fig. 22)**



Figure 22. *Syllis guidae* Nogueira & Yunda-Guarin, 2008. Photo: Prata, J.

Diagnosis (Nogueira & Yunda-Guarin 2008): Prostomium with four eyes, three antennae, two palps, and nuchal organs. All antennae e cirri moniliform-like (similar to pearl necklace). Two pairs of modified anterior cirri (“tentacular cirri”). Digestive tract: pharynx with tooth; a distinct and prominent muscular region of the anterior part (“proventricle”). Parapodia carry falcigers and simple chaetae, one or two aciculae per parapodium.

Global distribution: Northeast Brazil (State of Ceará) (Amaral et al. 2013, Read & Fauchald 2019ac).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Miramar Beach (**New record**, this study).

Subclass Sedentaria Lamarck, 1818

Order Capitellida Fauchald, 1977

Family Capitellidae Grube, 1862

Neopseudocapitella brasiliensis Rullier & Amoureux, 1979 (Fig. 23)



Figure 23. *Neopseudocapitella brasiliensis* Rullier & Amoureux, 1979. Photo: Prata, J.

Diagnosis (Rullier & Amoureux 1979, Amaral 1980): Prostomium conical-shaped with two eyespots, and nuchal organs, without antennae. Proboscis enlarged and voluminous. Parapodial cirri absent. Capillaries chaetae start from chaetiger one, hooks from chaetiger 12.

Global distribution: Brazilian coast (Sergipe and Bahia states), Iberian Peninsula, Mediterranean Sea (Amaral et al. 2013, Read & Fauchald 2019u).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Family Maldanidae Malmgren, 1867

***Euclymene coronata* Verrill, 1900** (Fig. 24)



Figure 24. *Euclymene coronata* Verrill, 1900. Photo: Silva, F.A.

Diagnosis (Jiménez-Cueto & Salazar-Vallejo 1997): Prostomium with prominent cephalic margin, nuchal organs, without eyes; palps carry lateral notches and eight nuchal cirri. Chaetigers 1-3 carry a distinct external spine, chaetiger 4 with a robust anterior collar. Parapodia carry notochaetae bilimbate-type, with chitinous zone ‘toothed plate’-shaped known as ‘uncini. Anal plate with 28 cirri.

Global distribution: Mexico, Caribbean Sea, Bermuda, Brazilian coast (State of São Paulo) (Amaral et al. 2013, Read & Fauchald 2019f).

Distribution in Paraíba coast: Seixas Beach (De Assis et al. 2012).

Order Orbiniida Fauchald, 1977

Family Orbiniidae Hartman, 1942

***Naineris setosa* (Verrill, 1900)** (Fig. 25)

Synonyms: *Anthostoma latacapitata* Treadwell, 1901; *Aricia setosa* Verrill, 1900.



Figure 25. *Naineris setosa* (Verrill, 1900). Photo: Prata, J.

Diagnosis (Khedhri et al. 2014): Prostomium T-shaped, with few eyespots grouped in two ‘comma groups’ forming Y-shaped. Eversible pharynx (proboscis) enlarged sac-like. Branchiae from chaetiger 6, basally broader and tapering to pointed end. Paired sensorial organs from chaetiger 8 in upper zone of branchiae. Dorsal crests in dorsum, mainly in abdominal region. Parapodia with neuropodial lobes shorter than notopodial ones; notopodia carry capillaries and furcate chaetae (last ones only in abdomen region); neuropodia with capillaries and uncini (last one in posterior segments).

Global distribution: Eastern Pacific: Mexico to Costa Rica; Atlantic Ocean: Gulf of Mexico, Caribbean Sea, Bermuda, Brazilian coast (Rio de Janeiro, São Paulo, Paraná states) (Amaral et al. 2013, Read & Fauchald 2019t).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Order Sabellida Fauchald, 1977

Family Sabellariidae Johnston, 1865

***Phragmatopoma caudata* Krøyer in Mörch, 1863** (Fig. 26)

Synonyms: *Centrocorone spinifera* Treadwell, 1939; *Hermella caudata* (Mörch, 1863); *Phragmatopoma lapidosa* Kinberg, 1866.

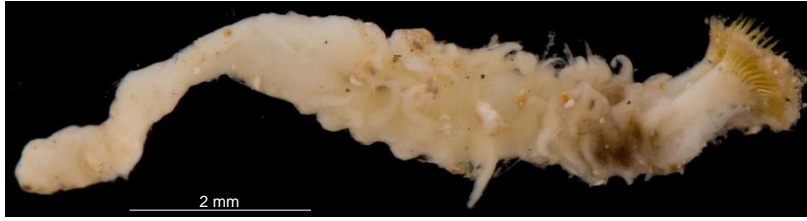


Figure 26. *Phragmatopoma caudata* Krøyer in Mörch, 1863. Photo: Freitas, P.

Diagnosis (Capa et al. 2012): Anterior end with an operculum longer than wide, with merged lobes in shallow mid ventral indentation. Distal disc flat and perpendicular to longitudinal axis, with opercular papillae around it. Outer paleae arranged in curved line. Inner operculum paleae like as two concentric rows, with paleae geniculate carrying convex blades. Pectinate tentacular filaments arranged in series of rows. Palps similar in length to operculum. Neuropodia of chaetiger 1 carry one conical cirri. Chaetiger 2 carry four triangular-shaped lobes. Thorax with branchiae. Three parathoracic segments, with lanceolate and capillaries chaetae.

Global distribution: Gulf of Mexico, West Indies, Brazilian coast (Northeast to State of Santa Catarina), north of the South China Sea (Pratas Islands) (Amaral et al. 2013, Read & Fauchald 2019z).

Distribution in Paraíba coast: Infralittoral region from Cabedelo municipality (after coral reefs zones known as “Areia Vermelha” and “Barretas”), Bessa Beach (De Assis et al. 2012), Seixas Beach (Costa et al. 2017), Maceió Beach (**New record**, this study).

Family Sabellidae Latreille, 1825

***Branchiomma nigromaculatum* (Baird, 1865)** (Fig. 27)

Synonyms: *Bispira nigromaculata* (Baird, 1865); *Dasychone argus chefinae* McIntosh, 1925; *Dasychone loandensis* Treadwell, 1943; *Dasychone nigromaculata* (Baird, 1865); *Dasychone ponce* Treadwell, 1901; *Sabella crispa* Krøyer, 1856; *Sabella lynceus* Krøyer, 1856; *Sabella nigromaculata* Baird, 1865.



Figure 27. *Branchiomma nigromaculatum* (Baird, 1865). Photo: Prata, J.

Diagnosis (Tovar-Hernández & Knight-Jones 2006): Body with dark spots on the dorsal and ventral surfaces; interramal dark spots. Radiolar crown united at the base by short web or membrane. 46 pairs of radioles, with stylodes and dark brown bands alternating with bands of white and orange; 5-6 ventralmost radioles on each side without stylodes, arising from inrolled parts of crown basis; rachis with segmented appearance. Thoracic unciniger ('tori') carry avicular uncini. Presence of collar chaetae like as compact fascicles.

Global distribution: Gulf of Mexico, West Indies, Brazilian coast (Pernambuco to São Paulo states), Angola (Luanda), East Africa (Amaral et al. 2013, Read & Fauchald 2019b).

Distribution in Paraíba coast: Cabo Branco Beach (De Assis et al. 2012), Seixas Beach (Costa et al. 2017).

***Hypsicomus capensis* Day, 1961 (Fig. 28)**



Figure 28. *Hysicomus capensis* Day, 1961. Photo: Freitas, P.

Diagnosis (Day 1967b): Anterior end with branchial lobes supported by stalk; each lobe carries 12 radioles. These ones with about 20 eyespots. Collar divided at two regions lobe-like. Collar chaetae are capillaries arranged in a line. Chaetigers 2-8 carry notochaetae capillaries and paleae with rounded blades ending in pointed tips; and neurochaetae like as row of pick-axe chaetae with transparent tapered blades and a row of avicular uncini. Abdominal notochaetae are avicular uncini similar to the thoracic ones and the neurochaetae are capillaries.

Global distribution: South Africa (Read & Fauchald 2019k).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Order Terebellida Rouse & Fauchald, 1997

Family Cirratulidae Ryckholt, 1851

Cirratulus africanus Gravier, 1906 (Fig. 29)



Figure 29. *Cirratulus africanus* Gravier, 1906. Photo: Prata, J.

Diagnosis (Day 1967b): Prostomium pointed, without eyes. 3-4 tentacular filaments in anterior segments. Branchiae from chaetiger 3 to beginning of the posterior end, arising close above the notochaetae. Parapodia with capillary chaetae in notopodial and neuropodial lobes. There are also chaetae similar to intermediate between capillaries and acicular hooks, and normal sigmoid hooks about the middle of the body.

Global distribution: Brazilian coast (Bahia, Rio de Janeiro and São Paulo states), Mozambique, Red Sea (Amaral et al. 2013, Read & Fauchald 2019d).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

***Cirriformia capensis* (Schmarda, 1861)** (Fig. 30)

Synonyms: *Cirratulus australis* Stimpson, 1856; *Cirratulus capensis* Schmarda, 1861.



Figure 30. *Cirriformia capensis* (Schmarda, 1861). Photo: Prata, J.

Diagnosis (Day 1967b): Anterior end of prostomium rounded, without eyes. Anterior chaetigers carry numerous tentacular cirri. Branchiae from chaetiger 1 to the posterior end. Robust single filaments and in the middle of the body they arise further above the notochaetae. Parapodia with capillary chaetae in notopodial and neuropodial lobes. Sigmoid hooks appear about chaetiger 12.

Global distribution: Gulf of Mexico, South Africa (Read & Fauchald 2019e).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Miramar Beach (**New record**, this study).

***Timarete punctata* (Grube, 1859)** (Fig. 31)

Synonyms: *Audouinia punctata* (Grube), 1858; *Cirratulus multicirratus* Treadwell, 1936; *Cirratulus niger* Hartman, 1939; *Cirratulus nigromaculatus* Treadwell, 1901; *Cirrhatus nigromaculatus* Grube, 1869; *Cirrhatus punctatus* Grube, 1859; *Cirriformia punctata* (Grube, 1859).



Figure 31. *Timarete punctata* (Grube, 1859). Photo: Prata, J.

Diagnosis (Çinar 2007): Robust prostomium bluntly pointed in anterior end, without eyes. Peristomium with two segmentations. Tentacular filaments from chaetigers 3 and 4, forming two evident groups, each with five filaments. Branchiae from chaetiger 1 to posterior segments. Parapodia with capillary chaetae in notopodial and neuropodial lobes. Acicular spines (slightly sigmoid, with truncated tips) from notochaetae 8 and neurochaetae 6; pale brown.

Global distribution: Mexico, Gulf of Mexico, West Indies, Brazilian coast (Northeast to Southeast) (Amaral et al. 2013, Read & Fauchald 2019af).

Distribution in Paraíba coast: Mataraca, Baía da Traição, Rio Tinto, João Pessoa, Conde municipalities (De Assis et al. 2012, Costa et al. 2017), Miramar Beach (**New record**, this study).

Family Flabelligeridae De Saint-Joseph, 1894

***Pherusa scutigera* (Ehlers, 1887)** (Fig. 32)

Synonym: *Stylarioides scutiger* Ehlers, 1887.



Figure 32. *Pherusa scutiger* (Ehlers, 1887). Photo: Prata, J.

Diagnosis (Nonato & Luna 1970): Body covered by papillae. Chaetigers 1-3 covered by thin layer of sand on the dorsal surface. Anterior region prolonged by a translucent membranous tube. Chaetae three first iridescent, forming a cephalic cage. A waistline marks the transition between the anterior segments and the posterior ones. Chaetigers 1-5 with capillaries chaetae; following segments with ventral aciculae chaetae.

Global distribution: Caribbean Sea, Brazilian coast (Sergipe, Rio de Janeiro, São Paulo and Rio Grande do Sul states) (Amaral et al. 2013, Read & Fauchald 2019y).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Family Terebellidae Johnston, 1846

***Terebella plagiostoma* Schmarda, 1861** (Fig. 33)

Synonyms: *Neottis rugosa* Ehlers, 1897; *Terebella heterobranchia* Schmarda, 1861; *Thelepus plagiostoma* (Schmarda, 1861); *Thelepus rugosus* (Ehlers, 1897); *Thelepus setosus africana* Day, 1951.



Figure 33. *Terebella plagiostoma* Schmarda, 1861. Photo: Prata, J.

Diagnosis (Rozbaczylo et al. 2006): Prostomium carry tentacular lobe horseshoe-shaped with numerous grooved tentacles; eyespots arranged in two or three rows on the posterior margin of the tentacular lobe. Segment 6 with three pairs branchiae with spiral filaments. Notochaetae capillaries-like arranged in two rows. Uncini from chaetiger 3; uncinigers ('tori') from segment 2.

Global distribution: Brazilian coast (State of Rio de Janeiro) (Amaral et al. 2013, Read & Fauchald 2019ad).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017), Miramar Beach (**New record**, this study).

***Terebella pterochaeta* Schmarda, 1861** (Fig. 34)

Synonyms: *Heteroterebella pterochaeta* (Schmarda, 1861); *Schmardanella pterochaeta* (Schmarda, 1861).



Figure 34. *Terebella pterochaeta* Schmarda, 1861. Photo: Freitas, P.

Diagnosis (Day 1967b): Prostomium with delineated dorsal and ventral lips. Two pairs of branchiae in anterior end. About 16 ventral pads followed by a narrow streak of glandular tissue in a ventral groove along the abdomen. Uncini on ventral tori originate from ventral ridges on the abdomen, with 3-4 teeth. Notochaetae: anterior ones with winged shafts and denticulate tips which become proportionately larger on posterior segments until they form most of the blade.

Global distribution: Caribbean Sea, Colombia, Brazilian coast (State of São Paulo), South Africa, Mozambique, Red Sea (Amaral et al. 2013, Read & Fauchald 2019ae).

Distribution in Paraíba coast: Seixas Beach (Costa et al. 2017).

Subclass Echiura Newby, 1940

Order Echiuroidea Bock, 1942

Family Echiuridae Quatrefages, 1847

***Echiurus echiurus* (Pallas, 1766)** (Fig. 35)

Synonyms: *Bonellia fabricii* Diesing, 1851; *Echiurus chrysacanthophorus* (Couthouy, 1838); *Echiurus forcipatus* (Fabricius, 1780); *Echiurus gaertnerii* Quatrefages, 1847; *Echiurus luetkenii* Diesing, 1859; *Echiurus pallasii* (Guérin-Méneville, 1831); *Echiurus vulgaris* (Savigny, 1822); *Lumbricus echiurus* Pallas, 1766; *Thalassema (Echiurus) pallasii* Guérin-Méneville, 1831; *Thalassema echiura* (Pallas, 1766); *Thalassema vulgaris* Savigny, 1822.

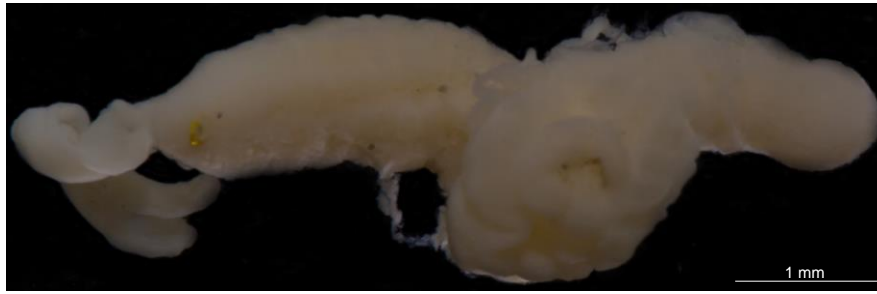


Figure 35. *Echiurus echiurus* (Pallas, 1766). Photo: Freitas, P.

Diagnosis (Biseswar 1997): Proboscis spoon-shaped with brown streaks. Head with two ventral golden chaetae. Body with outer layer of integument in posterior half of trunk separated from inner layers but still attached to trunk. Conical papillae, projecting from surface of integument, arranged in concentric rings around trunk. With the unaided eye, papillae appear as spherical, transparent spots. Rows of larger papillae alternate with three or four rows of uniform smaller papillae. Two rows of anal chaetae around posterior end.

Global distribution: West and East from North Atlantic Ocean, Arctic Ocean, New Zealand (WoRMS 2019c).

Distribution in Paraíba coast: Seixas and Maceió beaches (**New records**, this study).

Phylum Sipuncula Stephen, 1965

Class Phascolosomatidea

Order Aspidosiphonida

Family Aspidosiphonidae Quatrefages, 1865

***Aspidosiphon* cf. (*Paraspidosiphon*) *steenstrupii* Diesing, 1859** (Fig. 36)

Synonyms: *Aspidosiphon* (*Paraspidosiphon*) *makoensis* Satô, 1939; *Aspidosiphon* (*Paraspidosiphon*) *ochrus* Cutler & Cutler, 1979; *Aspidosiphon* (*Paraspidosiphon*) *steenstrupi* Diesing, 1859; *Aspidosiphon* (*Paraspidosiphon*) *steenstrupii steenstrupii* Diesing, 1859; *Aspidosiphon* (*Paraspidosiphon*) *trinidensis* Cordero & Mello-Leitão, 1952; *Aspidosiphon exostomum* Johnson, 1965; *Aspidosiphon fuscus* Sluiter, 1881; *Aspidosiphon makoensis* Satô, 1939; *Aspidosiphon ochrus* Cutler & Cutler, 1979; *Aspidosiphon semperi* ten Broeke, 1925; *Aspidosiphon speculator* Selenka, 1885; *Aspidosiphon steenstrupii* Diesing, 1859; *Aspidosiphon steenstrupii* var. *fasciatus* Augener, 1903; *Aspidosiphon trinidensis* Cordero & Mello-Leitão, 1952; *Paraspidosiphon* (*Aspidosiphon*) *steenstrupi* (Diesing, 1859); *Paraspidosiphon*

exostomus (Johnson, 1965); *Paraspidosiphon makoensis* (Satô, 1939); *Paraspidosiphon semperi* (ten Broeke, 1925); *Paraspidosiphon speculator* (Selenka, 1885); *Paraspidosiphon steenstrupi* (Diesing, 1859); *Paraspidosiphon steenstrupii* (Diesing, 1859); *Paraspidosiphon steenstrupii fasciatus* (Augener, 1903); *Paraspidosiphon steenstrupii steenstrupii* (Diesing, 1859); *Paraspidosiphon trinidadensis* (Cordero & Mello-Leitão, 1952).



Figure 36. *Aspidosiphon* cf. (*Paraspidosiphon*) *steenstrupii* Diesing, 1859. Photo: Freitas, P.

Diagnosis (Hylleberg 1994): Body semi-transparent in the middle region, darker anteriorly and posteriorly. Anal shield covered with dark chalky points. Margin caudal shield with irregular ridges. Anterior end known as “introvert” similar in size to body; with rows of double-pointed hooks anteriorly; spines posteriorly. Longitudinal musculature in separate bands.

Global distribution: Gulf of Mexico, Central Atlantic Ocean (Saiz-Salinas 2019a).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Order Phascolosomatida

Family Phascolosomatidae Stephen & Edmonds, 1972

***Phascolosoma* cf. (*Phascolosoma*) *nigrescens* (Keferstein, 1865)** (Fig. 37)

Synonyms: *Phascolosoma* (*Antillesoma*) *horsti* (ten Broeke, 1925); *Phascolosoma* (*Antillesoma*) *minutum* (ten Broeke, 1925); *Phascolosoma* (*Phascolosoma*) *diaphanes* (Sluiter, 1886); *Phascolosoma* (*Phascolosoma*) *evisceratum* (Lanchester, 1905); *Phascolosoma* (*Phascolosoma*) *extortum* (Sluiter, 1902); *Phascolosoma* (*Phascolosoma*) *lacteum* (Sluiter, 1886); *Phascolosoma* (*Phascolosoma*) *puntarenae* Grube, 1858; *Phascolosoma* (*Phascolosoma*) *spengeli* (Sluiter, 1886); *Phascolosoma*

(*Phascolosoma*) *varians* Keferstein, 1865; *Phascolosoma* (*Satonus*) *duplicigranulatum* (Sluiter, 1886); *Phascolosoma hainanicum* Chen, 1963; *Phascolosoma nigrescens* Keferstein, 1865; *Phascolosoma planispinosum* Baird, 1868; *Phascolosoma plicatum* (Quatrefages, 1865); *Phascolosoma puntarena* Grube, 1858; *Phascolosoma puntarenae* Grube, 1858; *Phascolosoma uncatum* Chen, 1963; *Phascolosoma varians* Keferstein, 1865; *Phascolosomum puntarenae* Grube, 1858; *Phymosoma diaphanes* Sluiter, 1886; *Phymosoma duplicigranulatum* Sluiter, 1886; *Phymosoma lacteum* Sluiter, 1886; *Phymosoma nigrescens* (Keferstein, 1865); *Phymosoma spengeli* Sluiter, 1886; *Phymosoma varians* (Keferstein, 1865); *Physcosoma agassizii* var. *puntarenae* (Grube, 1858); *Physcosoma duplicigranulatum* (Sluiter, 1886); *Physcosoma evisceratum* Lanchester, 1905; *Physcosoma extortum* Sluiter, 1902; *Physcosoma horsti* ten Broeke, 1925; *Physcosoma lacteum* (Sluiter, 1886); *Physcosoma minutum* ten Broeke, 1925; *Physcosoma nigrescens* (Keferstein, 1865); *Physcosoma spengeli* (Sluiter, 1886); *Physcosoma varians* (Keferstein, 1865); *Sipunculus* (*Phymosomum*) *nigrescens* (Keferstein, 1865); *Sipunculus* (*Phymosomum*) *plicatus* Quatrefages, 1865; *Sipunculus* (*Phymosomum*) *puntarenae* (Grube, 1858); *Sipunculus* (*Phymosomum*) *varians* (Keferstein, 1865).



Figure 37. *Phascolosoma* cf. (*Phascolosoma*) *nigrescens* (Keferstein, 1865). Photo: Costa, D.A.

Diagnosis (Hylleberg 1994): Body marbled with brown flecks and bands. Anterior end known as “introvert” longer than the body, carrying numerous rows of hooks, and the dorsal side crossed by brownish bands intermingled with lighter ones. Hooks with a

distinct streak (triangle and internal clear steak not divided), prominent swelling of proximal crescent. Above 20 tentacles.

Global distribution (Saiz-Salinas 2019b): Circumtropical.

Distribution in Paraíba coast: Miramar and Seixas beaches (**New records**, this study).

Order Golfingiida

Family Sipunculidae Rafinesque, 1814

***Sipunculus* cf. (*Sipunculus*) *phalloides* Pallas, 1774** (Fig. 38)

Synonyms: *Lumbricus phalloides* Pallas, 1774; *Sipunculus galapagensis* Fisher, 1947; *Sipunculus multisulcatus* Fischer, 1912; *Sipunculus phalloides* (Pallas, 1774).



Figure 38. *Sipunculus* cf. (*Sipunculus*) *phalloides* Pallas, 1774. Photo: Freitas, P.

Diagnosis (Cutler & Cutler 1985): Sipunculid with longitudinal muscle bands (LMBs) and the nephridiopores open between LMBs 4 and 5, 5 and 6, 6 and 7 or 7 and 8. The nephridia are less than 25% of trunk length and unattached. They open 5-10% of the trunk length anterior to the anus. The ventral retractors originate on LMB 1 or 2 and extend over 2-6 bands while the dorsals start on LMB 12-16 and spread over 2-6 bands. The LMBs do not subdivide in the glans region. Spindle muscle weakly developed.

Global distribution: Central Atlantic Ocean (Saiz-Salinas 2019c).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Phylum Mollusca Linnaeus, 1758

Class Bivalvia Linnaeus, 1758

Subclass Heterodonta Neumayr, 1884

Order Venerida Gray, 1854

Family Mactridae Lamarck, 1809

***Mulinia cleryana* (d'Orbigny, 1846)** (Fig. 39)

Synonyms: *Gnathodon cantrainei* G. B. Sowerby II, 1873; *Mactra carinulata* Reeve, 1854; *Mactra cleryana* d'Orbigny, 1846; *Mactra guadelupensis* Récluz, 1852; *Mulinia branneri* Dall, 1901; *Mulinia portoricensis* Shuttleworth, 1856.



Figure 39. *Mulinia cleryana* (d'Orbigny, 1846). Photo: Freitas, P.

Diagnosis (Signorelli 2019): Shells trigonal, inflated, umbos placed about half shell length, inflated and prosogyrate; external surface smooth; postero-dorsal area defined by a distinct keel-like carina; anterior and posterior ends low and well defined; ventral margin sinuous; right hinge with two anterior and two posterior lateral teeth, being the ventral more elongated, two divergent and unfused cardinal teeth; left hinge with the usual V-shaped cardinal tooth, flanked by an accessory lamella, one anterior and one posterior lateral tooth complete the hinge; anterior adductor muscle scars semielliptical, posterior oval; pallial sinus low and V-shaped.

Global distribution: Gulf of Mexico to all the Brazilian coast (Gernet et al. 2018, MolluscaBase 2019d, Signorelli 2019).

Distribution in Paraíba coast: Paraíba River estuary (Lima et al. 2017), Miramar, Seixas and Maceió beaches (**New records**, this study).

Family Veneridae Rafinesque, 1815

Phlyctiderma cf. semiasperum (Philippi, 1836) (Fig. 40)

Synonyms: *Diplodonta (Phlyctiderma) semiaspera* Philippi, 1836; *Diplodonta platensis* Dall, 1899; *Diplodonta semiaspera* Philippi, 1836; *Entodesma platensis* (Dall, 1899); *Lucina granulosa* C. B. Adams, 1845; *Lucina semireticulata* d'Orbigny, 1846; *Phlyctiderma platensis* (Dall, 1899); *Taras semiaspera* (Philippi, 1836).



Figure 40. *Phlyctiderma* cf. *semiasperum* (Philippi, 1836). Photo: Freitas, P.

Diagnosis (Romera 2012): Subtriangular valves, later pointed, white in color; covered by thin and translucent periostracum. Sideways inflated. External, opisthotelic and parvincular ligaments. Tall and wide. Externally ornamented by small pustules. Internally white in color. Similar muscle impressions. Whole pallial line without sinus. Heterodont hinge, with two cardinal teeth. Long and narrow nymph.

Global distribution: Gulf of Mexico (MolluscaBase 2019g).

Distribution in Paraíba coast: Maceió Beach (**New record**, this study).

Subclass Pteriomorpha Beurlen, 1944

Order Mytilida Férussac, 1822

Family Mytilidae Rafinesque, 1815

***Brachidontes exustus* (Linnaeus, 1758)** (Fig. 41)

Synonyms: *Brachidontes exustus* var. *rosaceus* Nowell-Usticke, 1969; *Modiola magellanica* Reeve, 1857; *Mytilus biceps* Menke, 1848; *Mytilus domingensis* Lamarck, 1819; *Mytilus exustus* Linnaeus, 1758; *Mytilus lavalleanus* d'Orbigny, 1853.



Figure 41. *Brachidontes exustus* (Linnaeus, 1758). Photo: Freitas, P.

Diagnosis (Smithsonian Marine Station at Fort Pierce 2019): Shell dark-brown color. Fan-shaped shell with fine divercating radial ribs. The ribbed surface of the shell is most evident at the outer edges. Umbones situated in the anterior end. The interior has purple-brown blotches with one to four small purplish dysodont hinge teeth.

Global distribution: Gulf of Mexico, Celtic Sea (MolluscaBase 2019b).

Distribution in Paraíba coast: Paraíba River estuary (Lima et al. 2017), Seixas Beach (**New record**, this study).

***Mytella charruana* (d'Orbigny, 1842)** (Fig. 42)

Synonyms: *Modiola strigata* Reeve, 1857; *Modiolus arciformis* Dall, 1909; *Mytella falcata* (d'Orbigny, 1846); *Mytilus charruanus* d'Orbigny, 1842; *Mytilus falcatus* d'Orbigny, 1846; *Mytilus mundahuensis* Duarte, 1926; *Mytilus sinuatus* Reeve, 1857; *Mytilus strigatus* Hanley, 1843; *Volsella reevei* Angas, 1867.



Figure 42. *Mytella charruana* (d'Orbigny, 1842). Photo: Freitas, P.

Diagnosis (Mediodia et al. 2017): With a smooth and shiny symmetrical shell and has predominantly dark brown to black colour with wavy dark pattern. Sculpture of fine concentric semi-circular rings. It has two similar shaped valves joined by a hinge without teeth at the anterior portion. It has two muscle scars, the large posterior adductor muscle scar and the greatly reduced anterior adductor muscle. The byssal and pedal retractor muscle scar is located below the adductor muscle forming a thick straight line moving towards the middle portion of the shell. The pallial line was seen as a curved line towards the adductor scar.

Global distribution: United States (MolluscaBase 2019e).

Distribution in Paraíba coast: Paraíba River estuary (Lima et al. 2017), Maceió Beach (**New record**, this study).

Subclass Pteriomorpha Beurlen, 1944

Order Ostreida Férussac, 1822

Family Ostreidae Rafinesque, 1815

***Crassostrea brasiliana* (Lamarck, 1819)** (Fig. 43)

Synonyms: *Crassostrea brasiliensis*; *Crassostrea paraibanensis* Singarajah, 1980;

Ostrea brasiliana Lamarck, 1819.

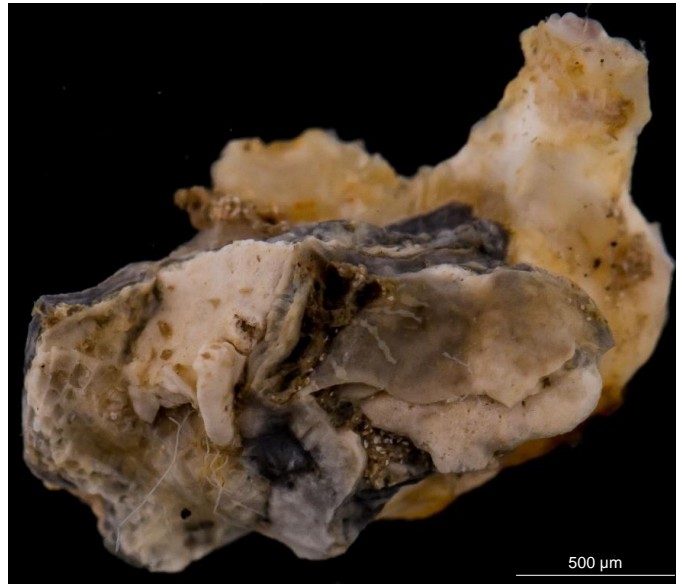


Figure 43. *Crassostrea brasiliana* (Lamarck, 1819). Photo: Freitas, P.

Diagnosis (Amaral & Simone 2014): Shell shape cupped or oval; right valve slightly operculum-shaped; left valve, fixed in substrate, more larger than right valve. Muscle impression is purple and adductor muscle, oval central in posterior region. Adductor muscle postero-dorsal located, occupying 1/5 of total size of animal; hood present and fully filled by palps and gonads; colour of mantle edge brown. Accessory heart of three branches of similar length, starting from common centre. Palps with margin superior free.

Global distribution: Brazilian coast (Rio Grande do Norte, Paraíba, Alagoas, Espírito Santo, Rio de Janeiro, São Paulo, Paraná, Santa Catarina states) (Amaral & Simone 2014, Gernet et al. 2018, MolluscaBase 2019c).

Distribution in Paraíba coast: Paraíba River estuary (Lima et al. 2017), Seixas and Maceió beaches (**New records**, this study).

Class Gastropoda Cuvier, 1795

Subclass Caenogastropoda Cox, 1960

Order Neogastropoda Wenz, 1938

Family Columbellidae Swainson, 1840

***Parvanachis obesa* (C. B. Adams, 1845)** (Fig. 44)

Synonyms: *Anachis obesa* (Adams, 1845); *Anachis radwini* Altena, 1975; *Buccinum concinnum* C. B. Adams, 1845; *Buccinum obesum* C. B. Adams, 1845; *Columbella*

costulata C. B. Adams, 1850; *Columbella crassilabris* Reeve, 1859; *Columbella decipiens* C. B. Adams, 1850; *Columbella ornata* Ravenel, 1859.



Figure 44. *Parvanachis obesa* (C. B. Adams, 1845). Photo: Freitas, P.

Diagnosis (Muniz 2015): Gastropod with oval shaped shell, slightly spiral convex sculptures with axial ventricular ribs, ending towards the base. Spiral sculpture found between axial ribs over basal area of shell. Oblique, denticulated opening on the inner surface of the outer lip, straight columella, anal notch present.

Global distribution: East Pacific Ocean: Mexico to Colombia, North West Atlantic Ocean (MolluscaBase 2019f).

Distribution in Paraíba coast: Paraíba River estuary (Lima et al. 2017), Seixas Beach (**New record**, this study).

Class Polyplacophora Gray, 1821

Subclass Neoloricata Berghenayn, 1955

Order Chitonida Thiele, 1909

Family Acanthochitonidae Pilsbry, 1893

***Acanthochitona* cf. *terezae* Guerra Júnior, 1983 (Fig. 45)**

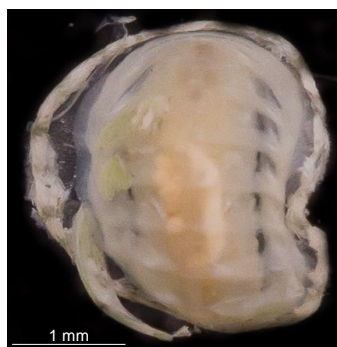


Figure 45. *Acanthochitona* cf. *terezae* Guerra Júnior, 1983. Photo: Freitas, P.

Diagnosis (Jardim et al. 2017): Mollusc with many plates on surface. Tegument with many white spots mainly on apical region. Girdle white with transverse orange bands. Intermediate valves trapezoidal to oblong in outline, subcarinate, weakly beaked. Pustules on latero-pleural area round to oval, randomly arranged; each pustule convex, bearing 4–7 pores on superior to median surface. Tail valve with prominent, submedian mucro; postmucronal area concave. Dorsal side of girdle covered with minute elongated spicules; spicule height about 8–9 times as long as wide, sculptured by longitudinal parallel fissures. Sutural tufts with elongated spicules and sculptured by longitudinal fissures.

Global distribution: Brazilian coast: States of Pernambuco (Fernando de Noronha Archipelago), Bahia, Espírito Santo (Trindade islands, MD55 station) (Jardim et al. 2017, MolluscaBase 2019a).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Phylum Arthropoda von Siebold, 1848

Subphylum Crustacea Brünnich, 1772

Class Malacostraca Latreille, 1802

Subclass Eumalacostraca Grobben, 1892

Order Amphipoda Latreille, 1816

Family Aoridae Stebbing, 1899

***Grandidierella cf. bonnieroides* Stephensen, 1947** (Fig. 46)



Figure 46. *Grandidierella cf. bonnieroides* Stephensen, 1947. Photo: Freitas, P.

Diagnosis (Lo Brutto et al. 2016): Head lateral cephalic lobes apically truncate. Antenna 1 flagellum with about 19 articles; accessory flagellum with one long and one distal rudimentary article. Antenna 2 with few long setae. Lower lip with fine setae only. Mandible, palp article 3 subequal to 2, posterior margin substraight, chaetae distal.

Pereonites 1–3 with apically acute sternal spines. Gnathopod 1 enlarged in males only; coxa unproduced antero-distally.

Global distribution: Mexico, Gulf of Mexico, Colombia, West Indies, Brazilian coast (Maranhão, Pernambuco, Alagoas, São Paulo states), African continent, Indian Ocean, Australia (Serejo & Siqueira 2018, Horton et al. 2019c).

Distribution in Paraíba coast: Miramar Beach (**New record**, this study).

Family Maeridae Krapp-Schickel, 2008

Elasmopus cf. rapax Costa, 1853 (Fig. 47)



Figure 47. *Elasmopus cf. rapax* Costa, 1853. Photo: Freitas, P.

Diagnosis (Hughes & Lowry 2010): Head with two eyes; lateral cephalic lobe enlarged, truncated, antero-ventral margin with notch. Antenna 1 longer than antenna 2; peduncular article 1 shorter than article 2, with 1 robust seta on posterior margin; article 2 longer than article 3; accessory flagellum with 3 articles; flagellum with 16 articles. Antenna 2 peduncular article 2 cone gland not reaching to end of peduncular article 3; article 4 subequal to article 5; flagellum with 12 articles. Mandible incisor asymmetrical.

Global distribution: Mexico, Atlantic Ocean (West and Northeast coast), Mediterranean Sea, Red Sea, Tropical Indo-Pacific (Serejo & Siqueira 2018, Horton et al. 2019b).

Distribution in Paraíba coast: Seixas and Maceió beaches (**New records**, this study).

Family Melitidae Bousfield, 1973

Dulichella appendiculata (Say, 1818) (Fig. 48)



Figure 48. *Dulichiella cf. appendiculata* (Say, 1818). Photo: Costa, D.A.

Diagnosis (Lowry & Springthorpe 2007): Head with two eyes; lateral cephalic lobe enlarged, truncated, antero-ventral corner with slender chaeta. Antenna 1 peduncular article 1 shorter than article 2, with 3 prominent chaetae along posterior margin. Antenna 2 peduncular article 2 cone gland reaching at least to end of peduncular article 3; article 4 slightly longer than article 5. Mandibular palp article 1 about as long as broad, inner margin article 1 not produced distally; article 2 slightly longer than article 3.

Global distribution: United States, Mexico, Gulf of Mexico, Caribbean Sea, Cuba, Costa Rica, Venezuela, South Africa, Mozambique (Serejo & Siqueira 2018, Horton et al. 2019a).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Order Decapoda Latreille, 1802

Family Cyclodorippidae Ortmann, 1892

Cyclodorippe cf. longifrons O. Campos Junior & Schmidt de Melo, 1999 (Fig. 49)



Figure 49. *Cyclodorippe* cf. *longifrons* Campos Junior & Schmidt de Melo, 1999. Photo: Silva, F.A.

Diagnosis (Campos Junior & De Melo 1999): Peduncular eyes with very reduced mobility, well-developed cornea. Subcircular carapace, adorned with fine granules. Orbital margin longer than half the maximum width of the carapace and trimmed with fine bristles. Rounded front edge with bristles, with the entire front region heavily excavated. Advanced front in relation to the orbital-external angles of the carapace. Narrow and excavated orbit, undeveloped antennular sumps.

Global distribution: Brazilian coast (State of São Paulo) (Melo et al. 2003, WoRMS 2019b).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Family Mithracidae MacLeay, 1838

***Mithraculus forceps* A. Milne-Edwards, 1875** (Fig. 50)

Synonyms: *Mithraculus hirsutipes* Kingsley, 1879; *Mithraculus ochraceus* Gomez, 1933.



Figure 50. *Mithraculus forceps* A. Milne-Edwards, 1875. Photo: Freitas, P.

Diagnosis (Wagner 1990): The carapace is broader than long, rather flat. Branchial sulci on its surface are not or very weakly broken by transverse grooves. Rostrum is little advanced, incised by a narrow notch. The basal antennal segment has two spines, of which the second, situated on the antero-external angle, is five times as large as the first. In small individuals two acute tips can be observed distally on the second spine. The antennae are 0.2 times as long as the carapace. The orbit is armed with one spine below (not counting the basal antennal spines), one at the outer angle and three above.

Global distribution: Gulf of Mexico to Brazilian coast (Fernando de Noronha Archipelago and Rocas Atol, Maranhão to Santa Catarina states) (Alves et al. 2012, WoRMS 2019f).

Distribution in Paraíba coast: Miramar and Seixas beaches (**New records**, this study).

Family Paguridae Latreille, 1802

***Pagurus criniticornis* (Dana, 1852)** (Fig. 51)

Synonyms: *Bernhardus criniticornis* Dana, 1852; *Eupagurus criniticornis* (Dana, 1852).



Figure 51. *Pagurus criniticornis* (Dana, 1852). Photo: Freitas, P.

Diagnosis (Nucci & De Melo 2007): Shield slightly longer than broad. Rostrum obtuse, slightly overreaching lateral projections. Ocular peduncles slender and shorter than shield width, with corneae slightly dilated. Ocular acicles with anterior margins rounded, with 1 strong submarginal spine; occasionally accessory marginal spinule on mesial margin. Antennular peduncles overreaching corneae; antennal peduncles usually not reaching distal margins of corneae; flagella long, usually overreaching right cheliped.

Global distribution: Gulf of Mexico to Argentina (Lemaitre & McLaughlin 2019).

Distribution in Paraíba coast: Maceió Beach (**New record**, this study).

Family Palaemonidae Rafinesque, 1815

***Leander cf. paulensis* Ortmann, 1897** (Fig. 52)

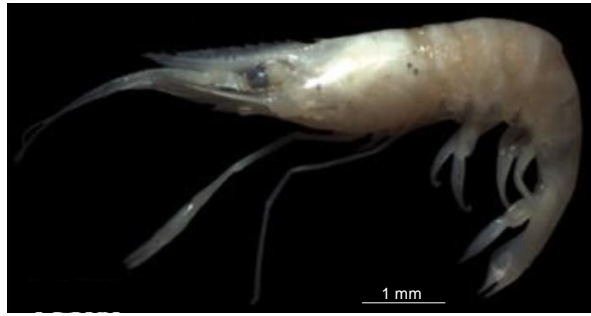


Figure 52. *Leander* cf. *paulensis* Ortmann, 1897. Photo: Figueiredo, B.M.B.

Diagnosis (Machado et al. 2010): Shrimp with long and straight rostrum, beyond the scaphocerit, upper margin with 10 to 14 teeth, first two placed on the carapace behind the orbit and third placed well above this limit, lower margin with five teeth. Small antero-lateral spine, reaching the middle of the second segment of the antennular peduncle. Larger scaphocerit in the proximal region, with strong distal tooth that extends beyond the anterior margin of the lamella. Jaw with biarticulated palp.

Global distribution: Florida, Gulf of Mexico, Brazilian coast (Maranhão, Ceará, Paraíba, Pernambuco, Bahia, São Paulo, Santa Catarina states) (Ramos-Porto 1985, Machado et al. 2010, WoRMS 2019e).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Family Xanthidae MacLeay, 1838

***Garthiope spinipes* (A. Milne-Edwards, 1880)** (Fig. 53)

Synonyms: *Micropanope spinipes* A. Milne-Edwards, 1880; *Pilumnus andrewsii* Rathbun, 1898.



Figure 53. *Garthiope spinipes* (A. Milne-Edwards, 1880). Photo: Freitas, P.

Diagnosis: Carapace about a third wider than it is long, convex. Dorsal surface covered with green granules, stronger in front and on the edges, smaller behind; several well-marked granular lines, arranged horizontally at the front of certain areas of the dorsal surface and emphasized by a row of long silks; regions poorly indicated but nevertheless delimited and expanded in the previous half.

Global distribution: Florida, Gulf of Mexico, Antilles, Venezuela, Brazilian coast (Maranhão, Rio Grande do Norte, Paraíba, Pernambuco, Espírito Santo, São Paulo states) (Alves et al. 2012, WoRMS 2019d).

Distribution in Paraíba coast: Seixas Beach (**New record**, this study).

Order Isopoda Latreille, 1817

Family Cirolanidae Dana, 1852

Cirolana cf. parva Hansen, 1890 (Fig. 54)



Figure 54. *Cirolana cf. parva* Hansen, 1890. Photo: Freitas, P.

Diagnosis (Sidabalok & Bruce 2017): Body ventrally folded rostral process that just overlaps the anterior point of the frontal lamina, the frontal lamina always pentagonal, dorsal surfaces are smooth with brown or black chromatophores, lateral margins of pleonites 3 and 4 are posteriorly produced, the pleotelson is mostly linguiform, the uropodal rami have bifid apices, and the lateral margin of the uropodal exopod has a continuous row of slender plumose setae interspersed with short, acute robust setae.

Global distribution: Tropical Atlantic Ocean: Gulf of Mexico, West Indies, Brazilian coast (Amapá to Espírito Santo states), Northwest Africa; Red Sea (Paiva & Souza-Filho 2014, Boyko et al. 2019).

Distribution in Paraíba coast: Miramar Beach (**New record**, this study).

Order Stomatopoda Latreille, 1817

Family Gonodactylidae Giesbrecht, 1910

Neogonodactylus cf. torus (Manning, 1969) (Fig. 55)

Synonym: *Gonodactylus torus* Manning, 1969.



Figure 55. *Neogonodactylus cf. torus* (Manning, 1969). Photo: Freitas, P.

Diagnosis (Albuquerque 2010): Two eyes with subglobular cornea. Carapace with slightly marked gastric sulcus. Raptorial leg with dilated dactyl at the base, slightly distally crenulated, and protruded with distally serrated inner margin. Body rent dorsally. Thoracic and flat abdominal somites. Telson of *Oerstedii*-type, with intermediate marginal teeth distinct and intermediate denticles located anteriorly to the end of the intermediate tooth.

Global distribution: Southeast from United States of America to Brazilian coast (Maranhão to Bahia states) (Silva 2011, WoRMS 2019g).

Distribution in Paraíba coast: Miramar, Seixas and Maceió beaches (**New records**, this study).

Phylum Echinodermata Bruguière, 1791 [ex Klein, 1734]

Class Echinoidea Leske, 1778

Subclass Euechinoidea Bronn, 1860

Order Camarodonta Jackson, 1912

Family Echinometridae Gray, 1855

Echinometra lucunter (Linnaeus, 1758) (Fig. 56)

Synonyms: *Cidaris fenestrata* Leske, 1778; *Cidaris lucunter* (Linnaeus, 1758); *Cidaris subangularis* Leske, 1778; *Echinometra acufera* (de Blainville, 1825); *Echinometra lobatus* (Blainville, 1825); *Echinometra michelini* Desor in L. Agassiz & Desor, 1846; *Echinometra nigrina* Girard, 1850; *Echinometra subangularis* (Leske, 1778); *Echinus acufer* de Blainville, 1825; *Echinus lobatus* Blainville, 1825; *Echinus lucunter* Linnaeus, 1758; *Echinus maugéi* Blainville, 1825; *Ellipsechinus lobatus* (Blainville, 1825); *Ellipsechinus lukunter* (Linnaeus, 1758); *Ellipsechinus subangularis* (A. Agassiz, 1872-74); *Heliocidaris castelnaudi* Hupé, 1857; *Heliocidaris mexicana* L. Agassiz in L. Agassiz & Desor, 1846; *Toxocidaris mexicana* (L. Agassiz in L. Agassiz & Desor, 1846).

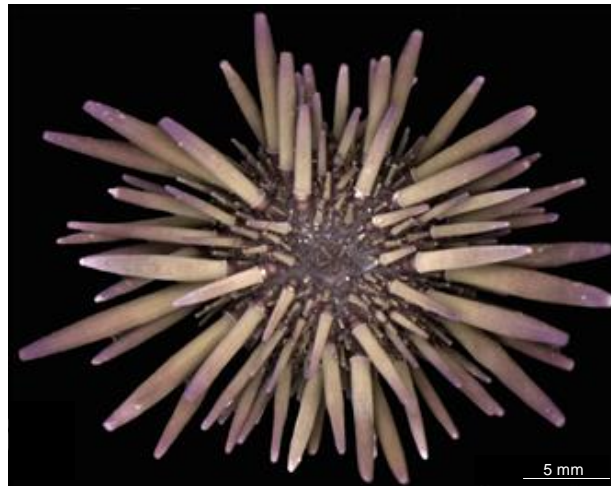


Figure 56. *Echinometra lucunter* (Linnaeus, 1758). Photo: Prata, J.

Diagnosis (Miller et al. 1995, Prata et al. 2017): Elongate oval test with two rows of large tubercles along the ambulacra and interambulacra, pairs of pores arranged in arcs of six, and a large peristome. Spines long and slender, thickened at the base, and sharply pointed at the tips. On aboral side, primary and secondary spines dark olive green, with greenish violet to purple tips. In general, the color is blackish.

Global distribution: Tropical Eastern Pacific Ocean: Mexico to Colombia; Tropical Western Atlantic Ocean: Gulf of Mexico to Venezuela, Northeast to Southeast Brazilian (Ceará, Paraíba to Santa Catarina states) (Prata et al. 2017, Kroh & Mooi 2019).

Distribution in Paraíba coast: Cabo Branco Beach (Gondim et al. 2008), Seixas Beach (Prata et al. 2017), Miramar Beach (**New record**, this study).

Class Holothuroidea Blainville, 1834

Order Apodida Brandt, 1835

Family Chiridotidae Östergren, 1898

***Chiridota rotifera* (Pourtalès, 1851)** (Fig. 57)

Synonym: *Synapta rotifera* Portalès, 1851.



Figure 57. *Chiridota rotifera* (Pourtalès, 1851). Photo: Freitas, P.

Diagnosis (Prata et al. 2017): Body cylindrical, elongated. Tegument thin, with some papillae or warts formed by agglomeration of ossicles. Mouth and anus terminal. Color light pink to translucent. Body wall with wheels with six holes. Small, straight to curved (C-shaped) rods in radial zones. Tentacles with rods similar to those of body.

Global distribution: Tropical Eastern Pacific Ocean: Mexico, Panamá coast; Tropical Western Atlantic Ocean: Gulf of Mexico to Venezuela, Brazilian coast (Ceará, Paraíba to Alagoas, Bahia, Rio de Janeiro states) (Prata et al. 2017, WoRMS 2019a).

Distribution in Paraíba coast: Cabo Branco Beach (Gondim et al. 2008), Seixas Beach (Prata et al. 2017), Miramar Beach (**New record**, this study).

Class Ophiuroidea Gray, 1840

Subclass Myphiuroidea Matsumoto, 1915

Order Amphilepidida O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017

Family Amphiuridae Ljungman, 1867

***Amphipholis januarii* Ljungman, 1866** (Fig. 58)

Synonym: *Amphipholis pachybactra* H.L. Clark, 1918.

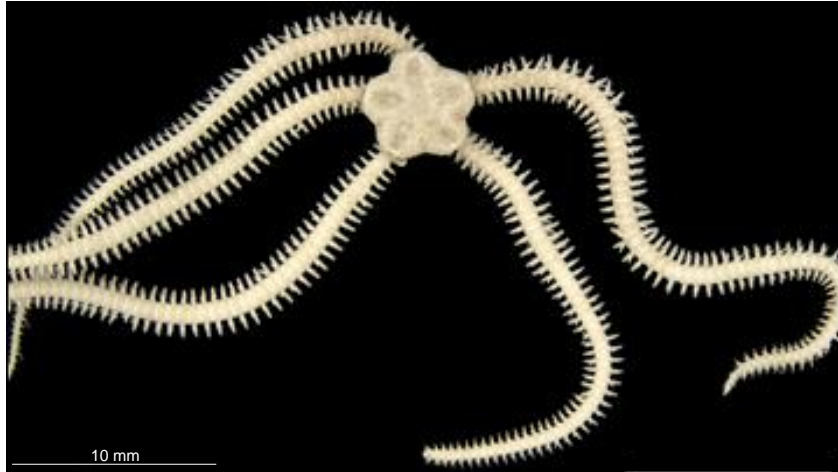


Figure 58. *Amphipholis januarii* Ljungman, 1866. Photo: Prata, J.

Diagnosis (Prata et al. 2017): Disk circular to pentagonal, with reentrances in inter-radial areas. Disk covered by small and imbricated scales. Radial shields narrow, longer than wide, usually separated by one or two scales, the internal more elongated. Ventral side of the disk covered by smaller scales, imbricated. Bursal slit long, near the first arm plate. Oral shield diamond-shaped, adoral shield triangular. Two oral papillae in each side of jaw, the distal triangular and robust, a pair of elongated and robust infradental papillae. Five elongated arms, about seven to ten times the diameter of the disk.

Global distribution: Southeast from United States of America (South Carolina, Florida, Texas), Gulf of Mexico, Antilles, Caribbean Sea, Brazilian coast (Pará, Ceará, Paraíba, Alagoas, Bahia, Rio de Janeiro, São Paulo states) (Prata et al. 2017, Stöhr et al. 2019a).

Distribution in Paraíba coast: Cabo Branco Beach (Gondim et al. 2008), Seixas Beach (Prata et al. 2017), Miramar Beach (**New record**, this study).

***Amphipholis squamata* (Delle Chiaje, 1828)** (Fig. 59)

Synonyms: *Amphioplus squamata* (Delle Chiaje, 1828); *Amphipholis appressa* Ljungman, 1872; *Amphipholis australiana* H.L. Clark, 1909; *Amphipholis elegans* (Farquhar, 1897); *Amphipholis japonica* Matsumoto, 1915; *Amphipholis kinbergi* Ljungman, 1872; *Amphipholis lineata* Ljungman, 1872; *Amphipholis minor* (Döderlein, 1910); *Amphipholis patagonica* Ljungman, 1872; *Amphipholis squamata tenuispina* (Ljungman, 1865); *Amphipholis tenera* (Lütken, 1856); *Amphipholis tenuispina* (Ljungman, 1865); *Amphipholis tissieri* Reys, 1961; *Amphiura elegans* (Leach, 1815); *Amphiura neglecta* Forbes, 1843; *Amphiura parva* Hutton, 1878; *Amphiura squamata* (Delle Chiaje, 1828); *Amphiura tenera* Lütken, 1856; *Amphiura tenuispina* Ljungman,

1865; *Asteria squamata* Delle Chiaje, 1828; *Asterias noctiluca* Viviani, 1805; *Asterias squamata* Delle Chiaje, 1828; *Axiognathus squamata* (Delle Chiaje, 1829); *Ophiactis minor* Döderlein, 1910; *Ophiolepis tenuis* Ayres, 1852; *Ophiura elegans* Leach, 1815.



Figure 59. *Amphipholis squamata* (Delle Chiaje, 1828). Photo: Prata, J.

Diagnosis (Prata et al. 2017): Disk rounded, covered by medium size scales, with circular to semicircular imbricated scales. Radial shields slightly long than wider, separated by a thin scale up to the distal region of the shields. Ventral surface of the disk covered by scales similar to dorsal scales. Bursal slits narrow, near the first plate of the arms. Diamond-shaped oral shield, adoral shields longer than wide, touching the proximal edge. Two oral papillae in each side of jaw, the more distal bigger and trapezoidal, other rounded and smaller. A pair of elongated infradental papillae. Five arms, about five times the disk diameter.

Global distribution: Cosmopolitan; in Brazilian coast the species was reported to Pará, Maranhão, Ceará, Paraíba, Alagoas, Bahia, Rio de Janeiro, São Paulo states (Prata et al. 2017, Stöhr et al. 2019b).

Distribution in Paraíba coast: Cabo Branco Beach (Gondim et al. 2008), Seixas Beach (Prata et al. 2017), Miramar Beach (**New record**, this study).

***Microphiopholis gracillima* (Stimpson, 1854)** (Fig. 60)

Synonyms: *Amphipholis gracillima* (Stimpson, 1854); *Micropholis gracillima* (Stimpson, 1854); *Ophiolepis gracillima* Stimpson, 1854.

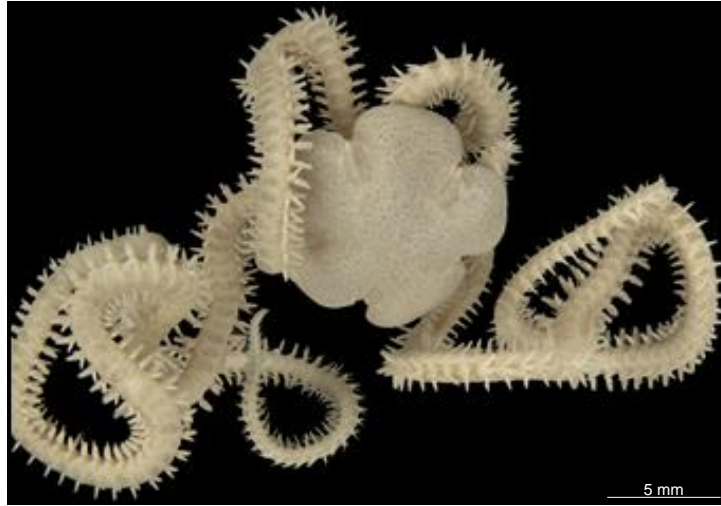


Figure 60. *Microphiopholis gracillima* (Stimpson, 1854). Photo: Prata, J.

Diagnosis (Prata et al. 2017): Disk rounded with indentations in the radial region. Disk covered by numerous small and imbricated scales. Radial shields narrow and elongated, joined at half of length, and then separated by three scales on the proximal edge. Ventral surface of disk covered by small and imbricated scales. Bursal slit large, near the first to fourth ventral arm plate. Oral shield diamond-shaped. Adoral shield elongated and slightly wide distally. Jaws with three oral papillae, the more distal rectangular, bigger than proximal papilla. Arms long, about six to eight times the diameter of the disk.

Global distribution: South Carolina, Florida, Gulf of Mexico, Antilles, Caribbean Sea, Brazilian coast (Paraíba, Bahia, Rio de Janeiro states) (Prata et al. 2017, Stöhr et al. 2019c).

Distribution in Paraíba coast: Seixas Beach (Prata et al. 2017), Miramar Beach (**New record**, this study).

Family Ophiactidae Matsumoto, 1915

***Ophiactis savignyi* (Müller & Troschel, 1842)** (Fig. 61)

Synonyms: *Ophiactis brocki* de Loriol, 1893; *Ophiactis conferta* Koehler, 1905; *Ophiactis incisa* v. Martens, 1870; *Ophiactis krebsii* Lütken, 1856; *Ophiactis maculosa* von Martens, 1870; *Ophiactis reinhardti* Lütken, 1859; *Ophiactis reinhardtii* Lütken, 1859; *Ophiactis savignyi* var. *lutea* H.L. Clark, 1938; *Ophiactis sexradia* (Grube, 1857); *Ophiactis versicolor* H.L. Clark, 1939; *Ophiactis virescens* Lütken, 1856; *Ophiolepis savignyi* Müller & Troschel, 1842; *Ophiolepis sexradia* Grube, 1857.

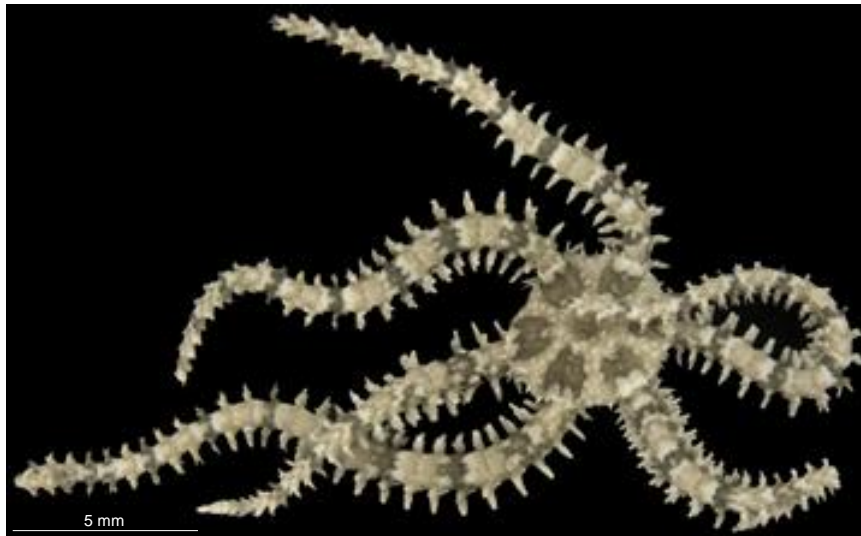


Figure 61. *Ophiactis savignyi* (Müller & Troschel, 1842). Photo: Prata, J.

Diagnosis (Prata et al. 2017): Disk rounded to pentagonal, covered by medium size scales, imbricated, more numerous in the centre and in the interradial surface. Small rough-tipped spines scattered over the disk, more numerous at the edges. Radial shield large and triangular, occupying more than half the disk. They are united distally and separated by two scales proximally, the most internal more elongated. Ventral surface of the disk covered by small and imbricated scales. Bursal slits large. Oral shield sub-diamond shaped. Adoral shield longer than wide, more wide distally, separated proximally. Two oral papillae flattened and robust, similar in size. An apical papillae large and triangular. Six arms, about five times the diameter of the disk, tapering distally.

Global distribution: Indo-West and Eastern Pacific Ocean, Atlantic Ocean: South Carolina to Brazilian coast (Amapá to Maranhão, Ceará, Paraíba to Alagoas, Bahia, Rio de Janeiro, São Paulo states) (Prata et al. 2017, Stöhr et al. 2019d).

Distribution in Paraíba coast: Cabo Branco Beach (Gondim et al. 2008), Seixas Beach (Prata et al. 2017), Miramar Beach (**New record**, this study).

DISCUSSION

The first descriptive works involving systematics analysis from the rhodoliths of coast of the Paraíba State, have been suggesting new records for the region, including new occurrences to the Western Atlantic Ocean, and even new endemic species, e.g. *Sabellaria corallinea* Dos Santos, Riul, Brasil & Christoffersen, 2011 (Dos Santos et al. 2011, Read & Fauchald 2020). With this study, the taxonomy of the invertebrate fauna

associated to rhodoliths from State of Paraíba is now complemented in relation to previous studies. Indeed, a total of 48 species were identified in Seixas Beach, mostly composed by polychaetes, 24 in Miramar and 11 in Maceió. From these, 18 were new records for the Seixas, and all identified species for Miramar and Maceió beaches were new occurrences. The results for the Seixas Beach were in agreement with previous studies, which have identified 49 species of polychaetes for this beach, with 10 new occurrences from the South Atlantic Ocean, and 23 from the Paraíba coast (Costa et al. 2017). Furthermore, a new eunicid species named *Leodice calcaricola* Bergamo, Carrerette, Zanol & Nogueira, 2018 was described for João Pessoa, Conde and Pitimbu municipalities (Bergamo et al. 2018). Regarding echinoderms, 12 species were reported for Seixas Beach (João Pessoa) (Prata et al. 2017), including the six species of the present study. So, an important diversity has been found associated to the rhodolith beds from the coast of the State of Paraíba, with Polychaeta species being most representative, particularly in the Miramar and Seixas beaches.

Despite their importance, rhodolith habitats are still poorly studied, particularly in relation to the direct anthropogenic impacts to which they are subjected (e.g. super-exploitation, oil exploration, pollution, tourism, trawl fishing (Riul et al. 2008)), as well as to more indirect ones, such as those related to the climate crisis (e.g. global warming and ocean acidification (Horta et al. 2016, Riosmena-Rodríguez 2017)). These events modify the physical-chemical parameters of the water, which may compromise the rhodolith banks, and hence, the associated biota (Horta et al. 2015), affecting survival and levels of calcification and photosynthesis, causing the bleaching phenomenon (Martin & Gattuso 2009, Martin et al. 2013). Therefore, the conservation of these algae (and habitats) is critical, because this action may guarantee the habitat conservation of a large diversity of marine fauna (OSPAR Commission 2010, Costa et al. 2019).

Overall, this study may be regard as baseline information on the rhodolith associated communities from this tropical region and highlights the importance of knowing and understanding their diversity levels, with the ultimate aim to promote conservation of this important biogenic habitat. Furthermore, this study is included in the fourteenth objective of the ‘Sustainable Development Goals’ (SDGs 2020).

CONCLUSIONS

The beaches from the coast of the State of Paraíba had a total 60 species of invertebrates from different main taxa, associated with rhodolith beds. The species of Polychaeta

were the most representative in Miramar and Seixas beaches, while molluscs were found mainly at Maceió Beach. This knowledge about the local fauna diversity may be regarded as baseline information for a variety of purposes, to know and understand local diversity levels associated to this less known habitat in the regions as well as to promote environmental education actions, with the objective of making local residents and beach goers aware of the conservation of local coastal environments.

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Supplementary material 1. Authorization for the collection of invertebrates, provided by the Brazilian Ministry of the Environment.



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Dados da solicitação

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CHAPTER IV

IMPORTANCE OF RHODOLITHS AS BIOHABITATS FOR BENTHIC COMMUNITIES IN IMPACTED ENVIRONMENTS



IMPORTANCE OF RHODOLITHS AS BIOHABITATS FOR BENTHIC COMMUNITIES IN IMPACTED ENVIRONMENTS

Abstract. Rhodolith beds (non-geniculated aggregates of coralline red algae) are extremely common and abundant in the Brazilian coast, especially in the Northeastern region. These algae are usually considered biodiversity hotspots for marine invertebrates. Nonetheless, ecological characterization studies are still scarce in the region. This study evaluated the rhodoliths and invertebrates associated at three beaches in Northeastern Brazil, with different levels of environmental impacts, Seixas, Miramar and Maceió. The highest densities of rhodoliths, as well as, the diversity and density of invertebrates, were registered in Seixas Beach, despite the higher touristic pressure. This result was associated with the high availability of calcium carbonate in nearby locations. On the opposite, higher mortality of rhodoliths and lower diversity and density of invertebrates were recorded in the most polluted beach, Maceió, which had high concentrations of thermotolerant coliforms (>1000 units/100mL). In respect to the functional composition of the invertebrate community, a similar variation trend was found for the less polluted beaches, with polychaete and echinoderm dominance, with these taxa being mostly biodiffusers, slow free movement and predators. These traits appear advantageous for the interaction rhodolith-habitat and invertebrate, due to the food and structural protection provided by the rhodoliths, but also due to oxygenation and remobilization of the sediment by the resident fauna. The most polluted beach showed distinct characteristics marked by the absence of the taxa and traits described for the other beaches, with the dominance of bivalves, mostly suspension feeders with limited movement. This result can be associated with a higher suspended material more common in organic polluted environments.

Keywords: Coralline red algae; Biodiversity; Environmental drivers; Traits; Northeast Brazil.

INTRODUCTION

Rhodoliths (or ‘maërls’) are non-geniculated aggregates of coralline red algae, with a high content of calcium carbonate (Foster et al. 2007), forming extensive beds on the bottom of the oceans (Foster 2001, Riosmena-Rodríguez 2017). Due to its three-dimensional poliformism, these algal structures represent an important habitat, harbouring a wide variety of marine invertebrates, such as polychaetes, echinoderms, crustaceans and molluscs (Hinojosa-Arango & Riosmena-Rodríguez 2004, Prata et al. 2017, Perry & Tyler-Walters 2018), as well as, some fish species (Gagnon et al. 2012). Herbivores use the algae produced by the rhodoliths directly, while predator species (carnivores) feed on other animals present in these algae and detritivores and

decomposers assure the recycling of the dead matter. Thus, rhodoliths are essential in the energy and matter flux and this way also for the maintenance marine biodiversity, being frequently considered biodiversity hotspots (Peña et al. 2014, Costa et al. 2019).

Despite this importance, rhodolith are still poorly studied, particularly relative to the direct anthropogenic impacts they are subjected to (e.g. super-exploitation, oil exploration, coastal pollution, trawl fishing (Riul et al. 2008)), as well as, to more indirect ones, such as those related to the climate crisis (e.g. global warming and ocean acidification (Horta et al. 2016, Riosmena-Rodríguez 2017)), and abiotic factors, such as temperature, hydrodynamism, luminosity, sedimentation, salinity and water quality. These may affect the survival, calcification and photosynthesis, causing bleaching phenomena (Martin & Gattuso 2009, Martin et al. 2013). The conservation of these algae is emergent, because it may guarantee the habitat of a large diversity of the marine fauna (OSPAR Commission 2010, Costa et al. 2019), including endemic species associated with rhodolith (e.g. *Sabellaria corallinea* Dos Santos, Riul, Brasil & Christoffersen, 2011 (Santos et al. 2011)).

In this way, monitoring rhodolith beds and their associated communities is essential in environmental impact assessment and conservation, providing essential information for management programs (Amaral et al. 2006). So, it becomes important to characterize this complex micro-ecosystems, from the algae and associated fauna and how this may be affected for the local environment (Costa et al. 2019). Yet, these sorts of studies, particularly those considering both the rhodoliths characterization, its fauna from different perspectives (taxonomic and functional) and potential environmental constraints are still scarce on the tropical regions, such as in Brazil.

The Brazilian coast is considered as the area with the largest number of rhodolith beds in the world, mainly in the Abrolhos archipelago, in the Northeast region (Amado-Filho et al. 2012). The State of Paraíba, located in the same region, has a large amount of rhodoliths in its coastal region, with some studies on the invertebrates associated with this biohabitat, mainly concentrated in the municipalities of João Pessoa (Batista 2004, Riul et al. 2008, Santos et al. 2011, Costa 2016, Costa et al. 2017, 2019, Prata et al. 2017) and Cabedelo (Riul 2007, Riul et al. 2009). The importance of continuing these studies, aiming at future monitoring programs of these calcareous algae beds, is evident.

The beaches of Miramar (municipality of Cabedelo), Seixas (João Pessoa, capital from the Paraíba State) and Maceió (Pitimbu) are located in the Paraíba state. These beaches have different touristic and pollution pressures. Maceió Beach receives a

large contribution of organic pollution from non-treated domestic effluents near the ‘Maceió River’ (Coutinho 2017), due to low adequate basic sanitation. Seixas Beach has the highest tourist pressure, being one of the main beaches visited in the region (Costa et al. 2019). Data from 2018, indicate that the city of João Pessoa (where the beach locates) received 1,259,310 guests in its hotel network (G1 Paraíba 2019). On the other hand, Miramar beach seems to be one of the most preserved of the three, given the lower tourist pressure and less evidence of organic pollution. Yet, the beach has a port in the nearby region (Barbosa et al. 2018). These differences in anthropogenic pressures presumably affect the rhodoliths and their associated fauna. This has motivated the present study, to evaluate and characterize the rhodoliths' (e.g. abundance, morphology and growth form) and invertebrates associated (abundance and composition, including a functional perspective) from the three beaches in Northeastern Brazil, with different levels of anthropogenic impacts.

MATERIAL AND METHODS

Study area

Sampling was carried out during the wet season of 2018, at the three beaches from the Paraíba State coast in Northeastern Brazil: Miramar Beach in Cabedelo, Seixas Beach in João Pessoa and Maceió Beach in Pitimbu (Fig. 1).

The municipality of Cabedelo is located at North coast of the Paraíba State, with 29.763 km² of territorial area and approximately 68,000 of the estimated population (IBGE Cidades-Cabedelo 2019). Cabedelo is the unique port city in this state (Barbosa et al. 2018). The Miramar Beach locates in the vicinity of the port and the mouth of the Paraíba River estuary.

The municipality of João Pessoa is the capital of the Paraíba State, located at South of Cabedelo city, with 211.286 km² of territorial area, and approximately 809,000 of the estimated population (IBGE Cidades-João Pessoa 2020). Seixas Beach is the most Eastern Point of the “Americas”. It is highly touristic and exposed to the turbulence by ‘catamarans’, which are small vessels used to transport tourists, and to the diving activities in the region in recent years, mainly at the 4.0m depth (Costa et al. 2019), affecting rhodolith beds through trampling, anchoring boats, disposal of organic waste by the tourist.

Finally, the municipality of Pitimbu is the last city from Paraíba State, with 137.243 km² of territorial area, and approximately 19,000 of the estimated population

(IBGE Cidades-Pitimbu 2020). The Maceió Beach is subjected to several pollution sources, particularly from the anthropogenic sewage waters from the Maceió river, in particular in the “Riacho Engenho Velho” area (Coutinho 2017). Furthermore, only 17% of the population has adequate sanitary sewage (IBGE Cidades-Pitimbu 2020).

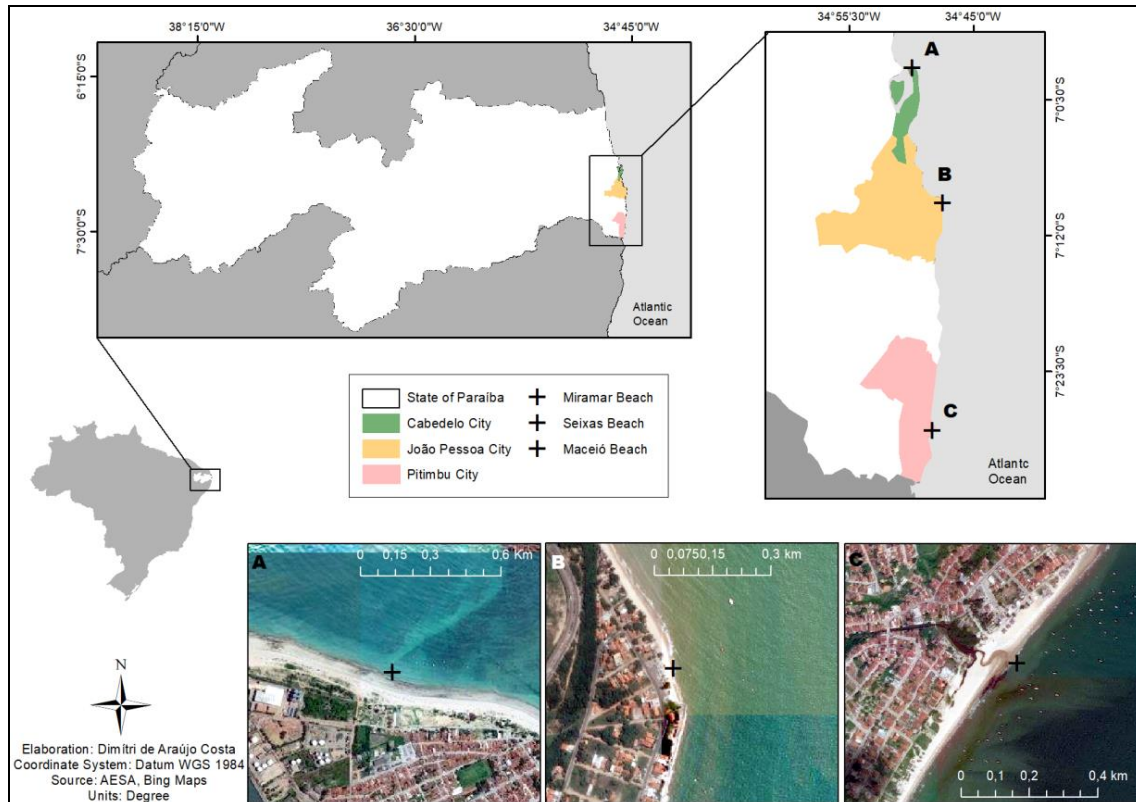


Figure 1. Study area in the Paraíba State coast, Northeast Brazilian, with the indication of the sampling points and respective municipality: A) Miramar Beach in Cabedelo, B) Seixas Beach in João Pessoa, C) Maceió Beach in Pitimbu.

Sampling procedure

The sample procedure design for the rhodoliths and associated invertebrate communities followed the quadrant methodology, adapted from (Underwood & Chapman 2013). At each beach, a 100 m² quadrant was selected at a shallow depth (1.5m) and other at a deeper depth (4.0m), with 20 meters distance apart, from which 5 replicates were chosen with 225cm² (0.225m²) area each. The replicates were chosen at each of the quadrant edge and in the centre point (sampling scheme at Supplementary material 1). All the rhodoliths present in each replicate were collected and taken to the laboratory.

Besides, at each sampling location, water temperature (°C), dissolved oxygen (mg/L), salinity (ppm) and pH were measured *in situ* from a bottom water sample. This water sample was taken to the laboratory to evaluate thermotolerant coliforms content

(colony-forming unit in 100mL of water sample, procedure detailed at Supplementary material 2). Transparency (cm) was measured *in situ* with a Secchi disk, while the atmospheric temperature (°C) was measured with a digital weather thermometer. A sediment sample was taken at each sampling location to evaluate sediment grain size (*phi*), organic material content (g) and carbonate content (g) in the laboratory (procedure detailed in Supplementary material 2). The grain size was determined after sieving the grained material through successive smaller sieves (2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, and 0.063mm). The mean grain size was determined with the aid of the GRADISTAT 8.0 (Blott & Pye 2001) using the logarithmic Folk and Ward method, with the determination of the percentage of the different sediment fractions. All values were converted in ϕ -scale ($-\log_2$ mm). Precipitation (mm) was obtained from “Agência Executiva de Gestão das Águas do Estado da Paraíba” website (AESA 2020) (Supplementary material 2).

In the laboratory, the biological material was sorted at the “Laboratório de Invertebrados Paulo Young” of the “Universidade Federal da Paraíba (UFPB-Campus I)”. The rhodoliths were counted and classified according to their type of morphology following the description of (Sañé et al. 2016), i.e., boxwork, unattached branches or pralines (Basso 1998, 2012). The praline-type was further also classified according to the growth form, i.e., encrusting-warty, lumpy or fruticose (Woelkerling et al. 1993). Then, the rhodoliths were placed in plastic trays and were broken using a grinder, to remove the associated fauna. The invertebrates were removed, fixed in 4% formaldehyde (for 24 hours), and stored in 70% alcohol until identified the lowest taxonomic resolution possible, counted and weighed (wet weight).

Traits analysis

The invertebrate communities were also analysed with biological trait analysis. The traits considered were the maximum body size, sediment reworking type, mobility, feeding strategy and fecundity (Table 1) using information from online datasets, such as the Biological Traits Information Catalogue (MarLIN 2006), World Register of Marine Species (WoRMS Editorial Board 2020), SeaLifeBase (Palomares & Pauly 2020), “Données d'Observations pour la Reconnaissance et l'Identification de la faune et la flore Subaquatiques” (DORIS 2020) and related articles (Queirós et al. 2013, Jumars et al. 2015). The full classification of the species is available in Supplementary material 3.

Table 1. Traits adopted, categories, description and ecological relevance.

Traits	Categories	Description and ecological relevance
Maximum Body Size	<1cm	Measured as maximum length.
	1-3 cm	Size defines and correlates with other life-history traits and mediates structuring interactions.
	4-10 cm	
	11-20 cm	
>20 cm		
Sediment Reworking Type	Biodiffusor	Defined as:
	Conveyor	Biodiffusor: Organisms whose activities result in a constant and random local sediment biomixing over short distances;
	Epifauna	Conveyor: Organisms that transport sediment during feeding and defecation activities. They may be upward conveyors or downward conveyors;
	Regenerator	Epifauna: Organisms whose activities occur predominantly above the sediment-water interface.
	Surficial modifier	Regenerator: Organisms that excavate holes, maintain these continuously in sediment, and transferring sediment at depth to the surface.
		Surficial modifier: Organisms that live in the uppermost layers of the sediment (typically up to 2 cm), with low impact on sediment particles reworking, except for the sediment-water interface.
		The sediment Reworking reflects the bioturbation potential of the species and its impact on sediment transport and resource dynamics.
Mobility	Fixed/sedentary	Defined as the propensity to move through the sedimentary matrix (Queirós et al. 2013).
	Free movement	
	Limited movement	The mobility relates to resource dynamics (nutrients, sediment and space) and changes in their availability, capture and use, influencing the biogenic mixing depth.
	Slow free movement	
Feeding Strategy	Deposit	Combination integrating information of the feeding method and potential trophic group: Deposit: Organisms that are mostly/strictly detritivores, feeding only on fragmented particulate organic matter from the sediment, including surface (in the sediment surface) and sub-surface (within the sediment). Grazer: Organisms that primarily scrape the substrate surface to either consume the film of microorganisms (diatoms, bacteria, ciliates) or directly the vegetal substrate. Occasionally may feed on POM (Particulate Organic Matter) within the sediment depending on the environmental condition. Interface: Those that switch readily from surface deposit feeding and suspension feeding, therefore feeding between the water column and underlying sediment. Predators/Scavenger: Organisms that feed on another animals (macrophages), killing them for food (predators) or feeding on its dead material (scavengers). The feeding on live or dead animal material is not exclusive of the group, as the diet may include a mix of plant and animal material (omnivores). Suspension: Organisms that feed on particulate organic matter suspended in the water column, catching food from water by actively sweeping and pumping, or filter held into flowing water, or collecting the 'rain' of detritus on sticky apparatus other than a filter. The feeding strategy reflects the trophic structure, distribution of resources and how organisms adapt to the habitat.
	Grazer	
	Interface	
	Predators/Scavenger	
	Suspension	
Fecundity	≤100	Measured as the number of possible eggs/embryos released. Fecundity reflects the recoverability potential of the species and associated larval dispersal potential.
	101-1,000	
	1,001-10,000	
	10,001-1 million	
	>1 million	

Data analysis

Environmental variables were analysed with a PCA (Principal Components Analysis) to clarify the differences between beaches and the sampling depth. Prior to the analysis, the need for data transformation among the physical-chemical parameters was checked using a Draftsman plot. All variables were then normalized, and the correlation between variables was checked with the Draftsman plot to remove the collinear environmental variables.

Abundance data of rhodolith and associated invertebrates were converted into density. These data were then analysed for differences between beaches and depths, considering a 2-way crossed experimental design (Anderson et al. 2008) for the factors ‘beach’ with 3 levels (Miramar, Seixas, Maceiό), and ‘depth’ with 2 levels (shallow and deep). The data were examined with a PERMANOVA (Permutational Analysis of Variance) considering, first the density of rhodoliths and then the invertebrate communities. Prior to analysis, the invertebrate data were square-root transformed, to scale down the score of the high-density species, and converted into a similarity matrix using a zero-adjusted Bray-Curtis dissimilarity matrix (Clarke et al. 2014). All these analyses were done using PRIMER+ PERMANOVA software (Clarke et al. 2014).

The invertebrate communities were further analysed with the Community Weighted Means (CWM) for the considered traits in Table 1, using FD library implemented in R software (version 3.6.2) (The R Foundation 2020). The CWM allows to identify shifts in the traits identity within communities and clarifies which traits might be exerting a dominant effect on the ecosystem processes (Ricotta & Moretti 2011).

Finally, the relationships between the rhodoliths’ associated invertebrate communities and the environmental variables were explored through canonical analysis (Smilauer & Lepš 2014). The same environmental variables of PCA were used, with the inclusion of rhodoliths density to determine whether the number of rhodoliths exerted an influence on the invertebrate communities. All environmental variables were initially checked for collinearity, as detailed above. Initially, a detrended correspondence analysis (DCA) was used to evaluate the type of model response for the canonical analysis. As a unimodal response was detected, a canonical correspondence analysis (CCA) was performed. The significance of the non-collinear environmental variables was evaluated using the forward selection procedure (Monte-Carlo permutation tests).

These analyses were performed with the library *vegan* implemented in R software (version 3.6.2).

RESULTS

Environmental characterization

The variation of the physical-chemical parameters among beaches and depths is available in Table 2. The full range values were then plotted in a PCA, to clarify differences among sites. Prior to the PCA analysis, the need for data transformation and collinearity among the physical-chemical parameters was checked. Based on this analysis, precipitation and organic matter were square-root transformed, and then all data were normalized. From the initial 11 variables, 8 were selected for the PCA (organic matter, transparency, and salinity were considered as collinear, > 0.97 of correlation in the draftsman plot).

The PCA test showed that the first two principal components explain 82.6% of the variation in the data, with PCA1 explaining 58.7% and PCA2 23.9%. The 3 beaches were separated in a plot based on the differences of the environmental parameters (Fig. 2). In addition, Seixas beach showed differences regarding depth, while for the other beaches this difference exists but is not as pronounced. Along x-axis (PCA1), the Seixas shallow zone was distinguished by higher carbonate content, pH, dissolved oxygen, lower mean grain size (i.e. coarser sands, (Gray & Elliott 2009)) and precipitation than in the other beaches and in the deep zone (Fig. 2, Table 2). Indeed, the highest carbonate content was observed in the shallow depth, 1/3 higher than in the deep area and the other beaches, as well as higher dissolved oxygen and pH (Table 2).

In opposition, the other beaches were characterized by higher mean grain size (Fig. 2), that corresponded to fine sands (Gray & Elliott 2009). The thermotolerant coliforms were clearly associated with the Maceió beach (Fig. 2), which also had the lowest salinity values (Table 2). This beach had also the lowest transparency compared to the other beaches (± 40 cm for Maceió compared to $\pm 60-70$ cm for Seixas and Miramar, Table 2). At Maceió beach, thermotolerant coliforms reached 1045 ± 6.4 colony-forming units per 100mL, while in the other ones these values dropped to less than 595 ± 6.1 for Seixas Beach and 397 ± 8.8 for Miramar Beach (Table 2). Miramar showed a trend for higher water temperature compared to the other locations (Table 2).

Table 2. Average and standard deviation of the environmental parameters measured at Miramar, Seixas and Maceió beaches (Northeast Brazilian), per depth.

Sample	Atmospheric temp. (°C)	Water sample temp. (°C)	Transparency of water (cm)	Dissolved oxygen (mg/L)	Salinity (ppm)	pH	Thermot. coliforms (CFU/100mL)	Precipitation (mm)	Organic material (g)	Carbonate content (g)	Logarithmic mean grain size (phi)
Miramar Shallow	31.0 ± 0	30.6 ± 0.2	64.6 ± 0.2	7.6 ± 0	36.8 ± 0.1	7.8 ± 0	405.8 ± 0.5	2.6 ± 0	4.53 ± 0	52.2 ± 0	2.2 ± 0
Miramar Deep	31.0 ± 0	28.6 ± 0	69.4 ± 0.2	7.2 ± 0	36.1 ± 0	7.4 ± 0	389.2 ± 0.5	2.6 ± 0	5.0 ± 0	48.1 ± 0	2.2 ± 0
Seixas Shallow	32.5 ± 0	30.3 ± 0.1	59.2 ± 0.6	8.5 ± 0.1	35.0 ± 0.1	8.2 ± 0	600.8 ± 0.9	25.4 ± 0	1.7 ± 0	80.4 ± 0	0.4 ± 0
Seixas Deep	32.5 ± 0	28.6 ± 0	66.0 ± 0.3	7.7 ± 0	34.9 ± 0	7.5 ± 0	589.6 ± 0.5	25.4 ± 0	5.0 ± 0	53.5 ± 0	0.9 ± 0
Maceió Shallow	26.0 ± 0	28.0 ± 0.1	40.1 ± 0.1	7.9 ± 0	33.3 ± 0.1	7.9 ± 0	1039.8 ± 0.9	6.2 ± 0	3.9 ± 0	52.5 ± 0	2.3 ± 0
Maceió Deep	26.0 ± 0	26.8 ± 0	43.0 ± 0	7.5 ± 0	32.6 ± 0	7.7 ± 0	1051.6 ± 0.5	6.2 ± 0	4.9 ± 0	49.0 ± 0	2.3 ± 0

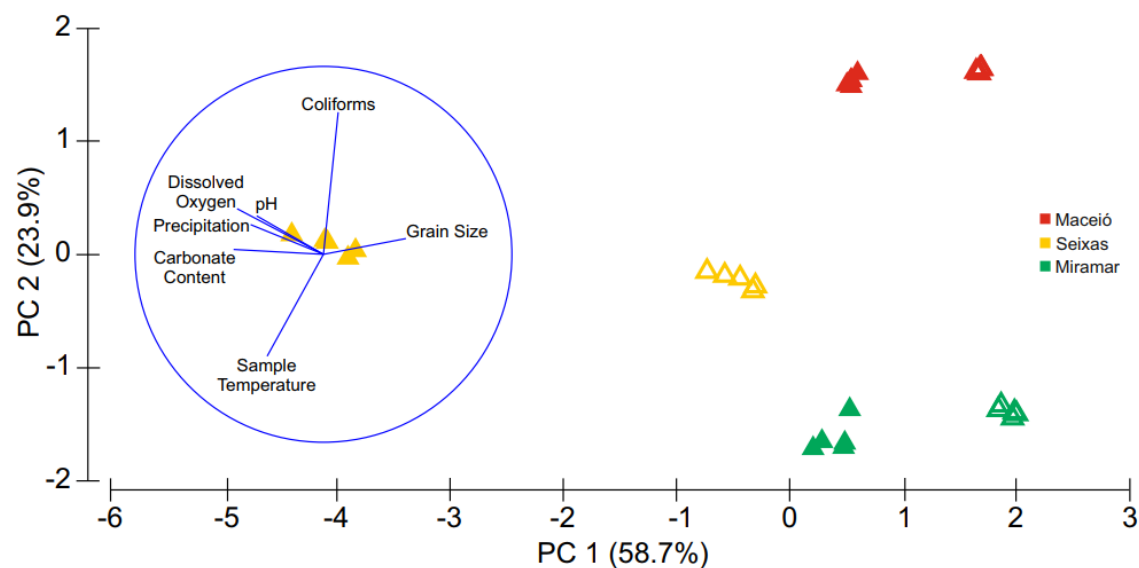


Figure 2. Principal Component Analysis (PCA) ordination plot of the samples from each beach (Miramar, Seixas, Maceió) and depth (shallow-1.5m, full bar; deep-4.0m, open bar), regarding the non-collinear environmental variables.

Rhodoliths

A total of 144 rhodoliths were collected in the three beaches during the sampling campaigns. When converted into density levels, these represented a value between 100 to 400 individuals per m², depending on the beach and depth.

In general, the highest density was observed in Seixas Beach, which was significantly different compared the other beaches (p-perm < 0.05; Supplementary material 4A), particularly at the shallow depth (Fig. 3). Still, Maceió could also attain a similar high density, > 300 indiv./m², also in the shallow depth. Miramar was the beach with the least density of rhodoliths, with values similar in both depths (Fig. 3). For these values, the percentage of dead rhodoliths for each depth and beach was counted. Dead rhodoliths were considered those totally white ('bleaching phenomenon') and had no invertebrates within their structure. Maceió beach obtained the highest density of dead ones (80%), followed by Miramar (23%) and Seixas (15%).

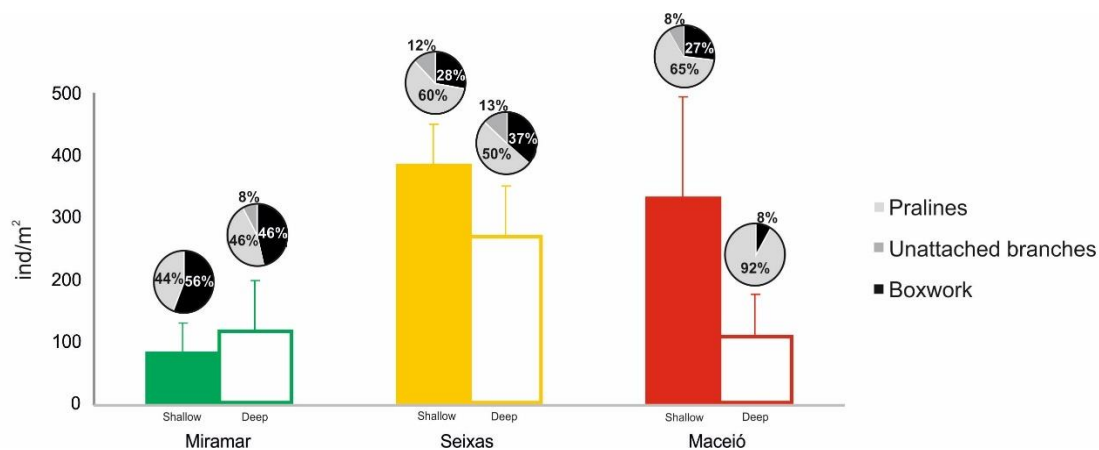


Figure 3. Rhodoliths' density at the three beaches (Miramar-green, Seixas-yellow, Maceió-red), considering the two depths-shallow (1.5m depth, full bar) and deep (4.0m depth, open bar). The percentage of each the 3 morphology of the rhodoliths (Pralines, Unattached branches, Boxwork) was superimposed as a circular graph.

Regarding the type of morphology, the pralines-type was dominant in the beaches of Seixas and Maceió, while in Miramar the boxwork had a higher expression (Beach: p-perm = 0.003, Fig. 3, Supplementary material 4B). There were no differences in depth (p-perm > 0.05). For the pralines-type, the growth-form 'lumpy' was predominant on all beaches (70% in Miramar, 56% in Seixas, and 77% in Maceió). Rhodoliths 'encrusting-warty' growth-form were not found at Maceió Beach.

Rhodoliths' associated invertebrate communities

A total of 60 species were identified in this study (full species list in Supplementary material 5). The highest species richness was found at Seixas Beach, mainly at shallow depth, reaching a maximum peak of 20 species (Fig. 4a). Miramar obtained intermediate values of specific richness, which were higher at deep depth and similar to the values observed at the same depth in Seixas (about 8 species, Fig. 4a). When considering the abundance, by Simpson's index, Maceió obtained similar values in relation to Miramar, mainly at shallow depth (Fig. 4b).

Regarding the total density of the communities, similar to the species richness and Simpson diversity, the highest density was observed in Seixas, followed by Miramar and the lowest density of invertebrates in Maceió (Fig. 4c). Regarding the taxonomic groups, Polychaeta was the most representative group in all beaches, except for the shallow depth at Maceió, where there was a predominance of molluscs (Fig. 4d). On the other hand, Seixas was the only one that presented all 6 taxa collected, especially in the shallow area (Fig. 4d).

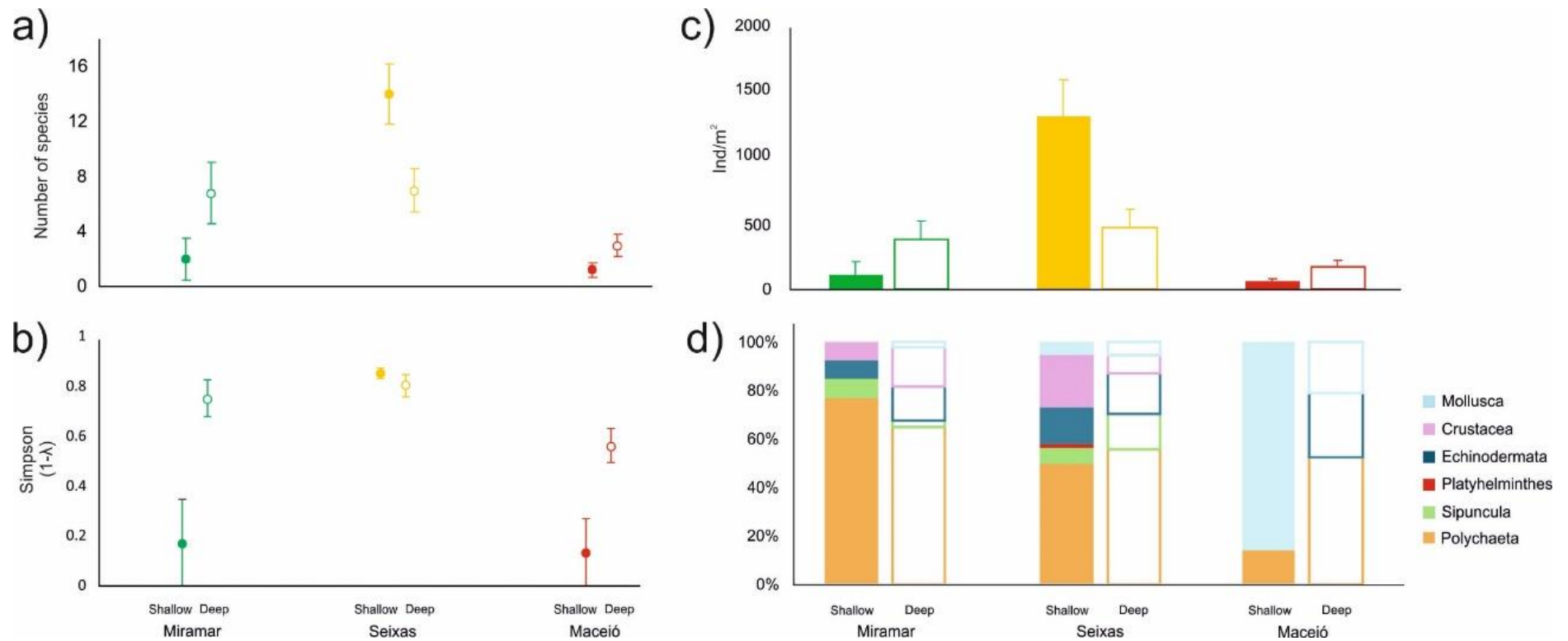


Figure 4. Characterization of the invertebrate communities regarding a) species richness; b) index of diversity Simpson; c) total density of the community per beach and depths (shallow and deep); and d) composition of the main taxonomic groups collected at the three beaches.

Significant differences were observed in the composition and structure of the communities, as evidenced by the significant BeachxDepth interaction (p-perm = 0.009, Supplementary material 4C). The pairwise tests indicated significant differences among 3 beaches for both depths (p-perm < 0.05), with the exception of Miramar and Maceió beaches at shallow depth (p-perm = 0.248). This result was also evidenced by the total density of invertebrates, which was higher in Seixas and varying within similar values for the other beaches (Fig. 4c). Considering the differences by depth in each beach, there were only significant differences in Seixas (p-perm = 0.009).

The above differences were expressed in the analyses of the species with the highest density in the three beaches. The polychaete *Marphysa regalis* was the most abundant species in Miramar, in both depths (Table 3). In Seixas, the echinoderm species *Amphipholis januarii* obtained greater abundance both in shallow and deep zones, yet Polychaeta species were also among the most abundant (Table 3). Regarding the differences per depth, apart from the common *A. januarii*, all the other most abundant species were different, e.g. *Eunice biannulata* and *Elasmopus* cf. *rapax* more abundant at the shallow, while *Lysidice ninetta* and the *Sipunculus* cf. (*Sipunculus*) *phalloides* occurred more expressively at the deep depth (Table 3). In Maceió, the bivalve *Mulinia cleryana* at the shallow, and the polychaete *Phragmatopoma caudata* at the deep depth were the most abundant, yet other common species were also abundant in both depths.

Functional approach

According to the CWM for each trait, a similar tendency of variation was observed for the Miramar and Seixas beaches (Fig. 5). In general, for these beaches the dominant traits were the maximum size varying from 4 to 20cm, being mainly biodiffusors organisms, slow free movement, predators, with high fecundity. In Seixas, deposit feeders were also representative in terms of density, as well as, individuals with lower fecundity (< 100 eggs, Fig. 5). In Maceió, the maximum potential size of individuals was similar to other beaches, however, for the other traits, the tendency of variation was clearly different: organisms mainly surficial modifiers and epifauna, with limited movement, suspension feeders, with fecundity above 10,001 and 1 million of eggs/embryos (Fig. 5). It should be noted that the density associated with traits in Maceió was lower than in other beaches, and the dominant categories observed in this beach were also observed in other beaches (Fig. 5).

Table 3. Average density and standard error of the top 5 most abundant species (whenever 5 species were present) on each beach (Miramar, Seixas and Maceió) by depth (shallow-1.5m, deep-4.0m).

Beach	Depth	Most abundant species	Average density (indiv. / m²)
Miramar	Shallow	<i>Marphysa regalis</i>	26.7 ± 17.8
		<i>Eunice biannulata</i>	17.8 ± 17.8
		<i>Terebella plagiostoma</i>	17.8 ± 17.8
	Deep	<i>M. regalis</i>	62.2 ± 33.3
		<i>E. biannulata</i>	35.6 ± 16.6
		<i>Eurythoe complanata</i>	35.6 ± 25.9
<i>Eunice wasinensis</i>		26.7 ± 17.8	
		<i>Lysidice unicornis</i>	26.7 ± 10.9
Seixas	Shallow	<i>Amphipholis januarii</i>	186.7 ± 85.9
		<i>E. biannulata</i>	186.7 ± 51.4
		<i>Elasmopus cf. rapax</i>	177.8 ± 126.5
		<i>Aspidosiphon cf. (Paraspidosiphon) steenstrupii</i>	88.9 ± 34.4
		<i>Naineris setosa</i>	88.9 ± 46.6
	Deep	<i>A. januarii</i>	62.2 ± 22.7
		<i>Lysidice ninetta</i>	62.2 ± 30.1
		<i>Sipunculus cf. (Sipunculus) phalloides</i>	53.3 ± 16.6
		<i>E. wasinensis</i>	44.4 ± 24.3
		<i>Palola brasiliensis</i>	44.4 ± 28.1
Maceió	Shallow	<i>Mulinia cleryana</i>	26.7 ± 17.8
		<i>Crassostrea brasiliiana</i>	17.8 ± 10.9
		<i>Marphysa stylobranchiata</i>	8.9 ± 8.9
		<i>Mytella charruana</i>	8.9 ± 8.9
	Deep	<i>Phragmatopoma caudata</i>	53.3 ± 43.1
		<i>C. brasiliiana</i>	26.7 ± 10.9
		<i>Pagurus criniticornis</i>	26.7 ± 10.9
		<i>Echiurus echiurus</i>	17.8 ± 10.9

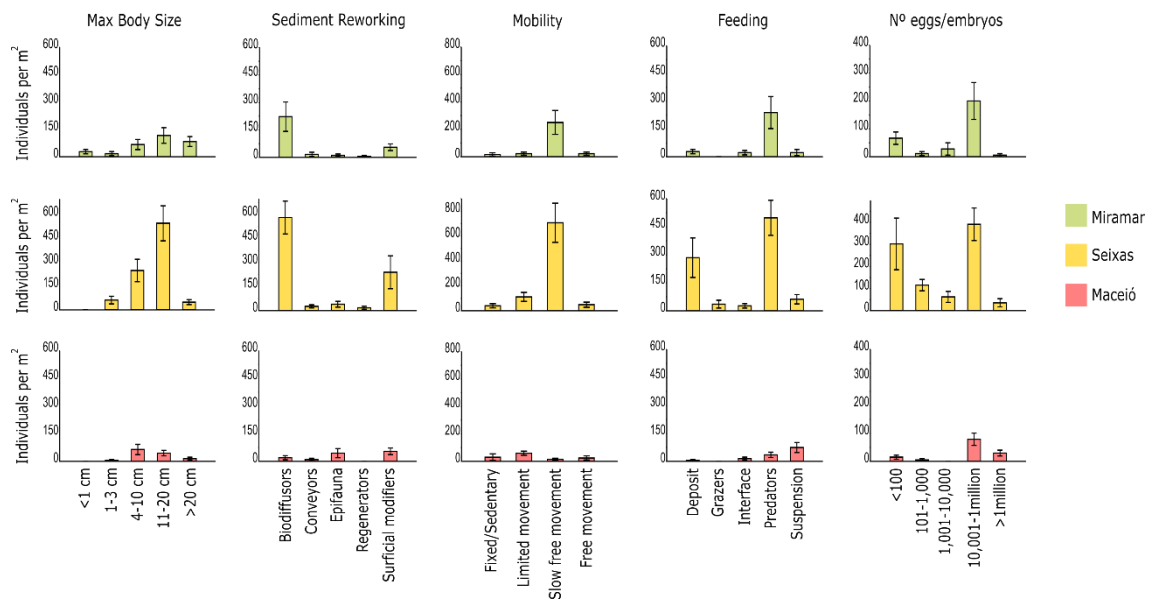


Figure 5. Average density and standard error associated with the Community Weighted Mean trait' categories of marine invertebrate communities per beach, Miramar, Seixas and Maceió.

Biological and environmental data

The model of canonical correspondence analysis (CCA) showed a clear distinction among the 3 beaches, and for the depths within the Seixas beach (Fig. 6). However, this model explained only 30% of the total variability observed. The significant environmental parameters explained 67.7% of the 30% variability observed and were: coliforms, mean grain size, rhodolith density and carbonate content (Fig. 6). The coliforms associated with the communities from Maceió, where some species, e.g. *Nereis riisei*, were distinguished (Fig. 6). This beach tends to have finer sediments (higher mean ϕ corresponds to finer sands), but this result was even more evident for the communities from Miramar, which grain size was a distinctive characteristic.

Seixas Beach was distinguished by its carbonate content, which is substantially higher than in the other beaches, as well as the higher number of rhodoliths, having also many more species associated with this beach compared to the others.

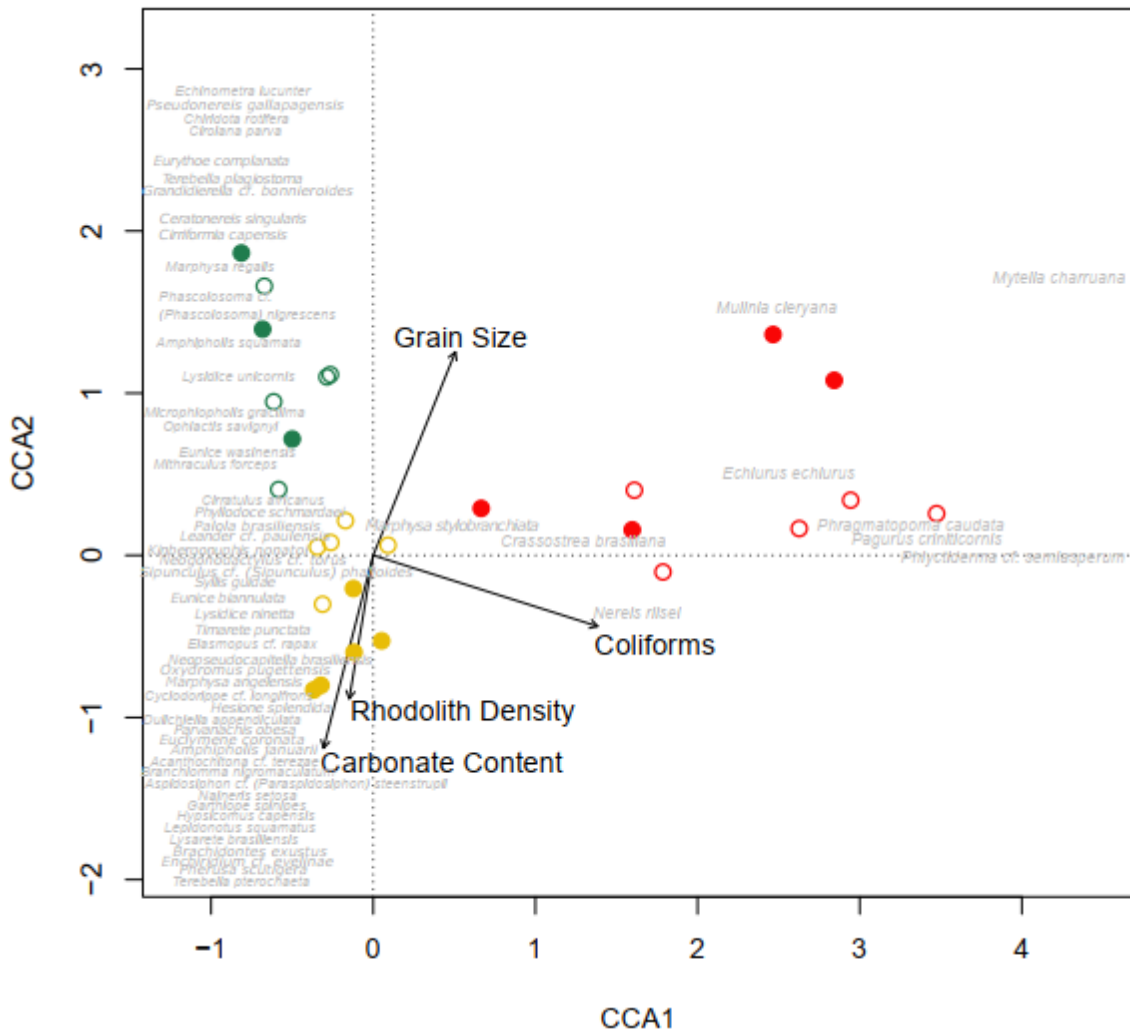


Figure 6. Canonical correspondence analysis (CCA) ordination tri-plot relating the invertebrate benthic communities to the significant environmental variables, for each beach (Miramar-green, Seixas-yellow, Maceió-red) and depth (shallow: full symbols; deep: open symbols). The significant environmental variables selected after Monte Carlo permutation tests; length of the arrow is proportional to relative significance.

DISCUSSION

The Brazilian Exclusive Economic Zone has a high diversity of invertebrates. Part of the diversity is due to the high abundance of rhodolith beds (Lavrado 2006), which harbours a great variety of marine fauna in comparison of other habitats (Nelson 2009). Despite the importance and abundance of the rhodolith beds in the Northeast region, these are still poorly studied (Horta et al. 2016), which has motivated our study.

In the present study, the three beaches studied along the coast of the State of Paraíba were different from the environmental point of view and these differences appeared to condition the existing biological communities, both regarding the biogenic rhodolith-habitat and the associated invertebrate communities. In general, Seixas Beach

distinguished from the others by the highest concentration of calcium carbonate, a component available due to the cliffs of the “Barreira do Cabo Branco” (Pereira 2017). This cliff is considered a “living” one, due to constant erosive action of the sea, wind, intensified after the construction of a science station (Pereira 2017), which provides carbonate sources for the adjacent to the coastal area. On this beach, differences in the characterization between the two depths were also found, expressed mainly in the higher mean grain size associated with higher depth. Seixas Beach is also a tourist beach, with a greater anthropic pressure mainly associated with higher depth (Melo et al. 2006, 2014), due to traffic and anchoring of vessels known as ‘catamarans’ largely used to transport tourists, and due to the diving activities in the region traffic (Costa et al. 2019).

Regarding the other beaches, the main differences were the finer sands, and in Maceió the high values of thermotolerant coliforms, in the order of 1045 CF/100mL. According to Brazilian legislation, values above 1000 CF/100mL of thermotolerant coliforms are considered unfit for bathing (CONAMA 2000), so Maceió has the most polluted environment from the studied beaches. This result is due to the direct contamination of domestic organic waste from the Maceió River (Barbosa et al. 2017), mainly due to the low level of sanitation in the city (17%) (IBGE Cidades-Pitumbu 2020), as also inferred by the generally lower salinity in this beach. At Miramar Beach, the lowest value of thermotolerant coliforms was recorded, indicating lower organic/faecal pollution at this site. Nevertheless, this beach is located in an area next to the commercial port (Ferreira et al. 2017), and may receive chemical contamination, which has not been assessed in this study.

The environmental characterization of the different beaches, based on the evaluated environmental parameters, appeared to influence our results regarding the density of the rhodolith-habitat. In general, the highest density was registered at Seixas, followed by Maceió and finally, Miramar. The average values recorded for these beaches ranged from 100 to 400 rhodoliths/m², which is in the order of magnitude recorded for other tropical beaches at the depths considered (e.g. 207 ± 67 rhodoliths/m² in the coastal zone of the Salvador municipality (Bahia et al. 2010); 211 ± 20 rhodoliths/m² in Abrolhos zone (Amado-Filho & Pereira-Filho 2012)). Most the rhodoliths found were of the ‘praline’ form-type, with the predominance of the ‘lumpy’ growth-type. The predominance of lumpy growth types occurs mainly in shallow waters

(Halfar et al. 2012), i.e., 1.0 to 5.0m depth since these forms are more resistant to wave energy (Foster et al. 1997), which seems to be the present scenario.

The highest density of rhodoliths in Seixas Beach was probably associated with the higher concentration and availability of calcium carbonate in this region, since this is an essential element for the growth of the algae that make up the rhodoliths (Riosmena-Rodríguez et al. 2017). Concerning to the other beaches, according to the organic pollution, we would have expected a higher density of rhodoliths in Miramar, but on this beach, the density was lower than in Maceió. However, most of the rhodoliths found in Maceió were dead (89% in the shallow zone, 50% in the deep zone), which may be associated with the high concentration of coliforms found in the beach.

With regard to the associated invertebrate communities with the rhodoliths, the results for the three beaches were consistent with the observed amount of live rhodoliths: the highest diversity and density was observed for Seixas, followed by Miramar and finally Maceió. In general, the values of diversity recorded on the beaches (between 11 and 48 species, Simpson' index close to 0.8 and the total density of communities varied similarly to the values recorded in other studies of the region (Batista 2004, Riul 2007, Costa 2016, Prata et al. 2017, Costa et al. 2019). Nevertheless, the composition and structure of the communities varied among the beaches, which may be associated to the density of the rhodoliths and calcium carbonate concentrations, but also with the concentration of coliforms and granulometry. On the beaches of Seixas and Miramar, the dominant group were the Polychaeta. In Seixas beach, the diversity of polychaetes was higher than in Miramar, having as dominant species *Eunice biannulata* and *Lysidice ninetta*. The echinoderm species *Amphipholis januarii*, was also abundant in Seixas Beach, in both depths, which has already been reported in a previous study (Prata et al. 2017). At Miramar, the most abundant species were the polychaetes *Marphysa regalis* and *Eunice biannulata*.

Maceió was characterized by a greater predominance of the Mollusca group, highlighting the bivalves *Mulinia cleryana* and *Crassostrea brasiliiana*. In fact, the composition of the community, as well as, the lowest density observed on Maceió beach may be related to organic pollution (Foster 2001), assessed by the higher content of coliforms, which can determine the death of rhodoliths, as well as, their associated biota (Grall & Hall-Spencer 2003). Excessive organic pollution can lead to hypoxia of the aquatic environment (Renault 2015) and excessive sedimentation, compromising the rhodolith and fauna. On the other hand, the increase in particulate organic matter in the

water column may favour more tolerant species to organic pollutants, such as some bivalves that feed on this organic matter, such as oysters and cockles (from the same group in this study) (Leal et al. 2008, El-Sorogy et al. 2019). Although the particulate matter was not assessed in this study, the lower values of transparency in Maceió indicate a higher probability of suspended matter, which may have benefited this group of species.

The differences observed in the composition and structure of the invertebrate communities at the 3 beaches also manifested in their functional organisation, with the Seixas and Miramar beaches being more similar to each other, as opposed to Maceió. This result, based on the functional approach, also highlights that despite the lower density of rhodoliths in Miramar beach, this beach is able to maintain the functional abilities found in more stable community, as in the Seixas beach.

Regarding functional composition, all beaches showed a dominance of individuals with the potential to grow to a maximum of 11 to 20 cm. This result mirrors the maximum possible size for the species, which in some cases was evaluated with information from the genus or family, given the lack of information in the literature for the species in this study. Indeed, these sizes were rarely achieved. However, the role of rhodoliths as nursery areas, for invertebrates and some vertebrates, is widely known (Kamenos et al. 2004a b, Riosmena-Rodríguez et al. 2017, Prata et al. 2017), which could contribute to this outcome as far as size is concerned. Once individuals begin to grow, they can leave the rhodolith-like habitat. In relation to other traits, and as mentioned above, Miramar and Seixas beaches were more similar and characterized mainly by the occurrence of slow free movement biodiffusors, and predators with high fecundity, which may corroborate with the conditions of the habitat itself. The expressive occurrence of slow free movement biodiffusors may be related to the three-dimensionality of the rhodolith-habitat, with several irregular shapes (Sciberras et al. 2009, Basso et al. 2016). This type of biogenic architecture probably benefits the slow movement in the rhodolith structure, as well as those organisms whose activities result in the constant and random sediment biomixing (over a short distances, i.e., biodiffusors, (Kristensen et al. 2012)) inside and within the rhodolith. This strategy seems suitable to deal both with limited space inside the rhodolith, as well as promoting oxygenation and sediment and other particles transportation (Michaud et al. 2005, Kristensen et al. 2012) in and outside the rhodolith, that might be used for feeding or other purposes. This bioturbation dynamics may also be relevant for the rhodoliths

vitality, as it might be important to maintain the rhodolith in an unburied state (Foster 2001) and to maintaining the oxygen levels. In Seixas Beach, the deposit feeders were also expressive in terms of abundance, as well as individuals with lower fecundity (< 100 eggs). This means that there may be other functional strategies in the habitat.

In Maceió, the trend of variation of the remaining traits was clearly distinct, similar to the taxonomic differences found, where bivalves were dominant. This result may be associated with environmental constraints related to organic pollution (Rodil et al. 2019), from higher turbidity, organic pollutants, and others. The dominant categories were mainly surficial modifiers and/or epifauna, with limited movement, suspension feeders, and fecundity above 10,001 and 1 million of eggs/embryos, which may be associated with the higher suspended matter as discussed above. These categories were also found on other beaches and in some cases with similar densities, but not as dominant. That is, the main difference between beaches was the absence, or low expression, of free movement biodiffusers, a phenomenon that may be associated both with local disturbance and with adjacent areas providing source populations (Hinojosa-Arango et al. 2009). From a management point of view, this result evidences the importance of considering a functional perspective and highlighting the deprovision of some functional properties of the community in the most impacted beach.

Further studies will be needed for a better understanding of the natural dynamics and causality among rhodoliths-habitat, associated community and environmental constraints (e.g. local hydrodynamics). Despite this, the present study highlighted considerable differences both in the structural and particular in functional composition of the beaches studied, underlining the importance of adequate monitoring for a better understanding of these complex habitats and their conservation.

CONCLUSIONS

This was the first comparative study to characterize rhodolith beds and associated invertebrate fauna, considering three tropical beaches exposed to different impacts. The highest density of rhodoliths, as well as, the diversity and density of fauna was found on the beach with highest calcium carbonate source in the region, Seixas Beach. On the other hand, the beach with signs of high domestic pollution - Maceió, presented the highest density of dead rhodoliths and lower diversity and density of associated invertebrate communities. In general, the invertebrate communities in the less polluted beaches were dominated by Polychaeta, followed by Echinodermata. These individuals

were mainly biodiffusors, slow free movement, predators and high fecundity. These traits seem to be advantageous for a three-dimensional environment such as rhodoliths, contributing to a positive interaction: from habitat, food and structural protection to fauna conveyed by the rhodolith, as well as oxygenation and sediment remobilization by the resident fauna. The invertebrate community of the most polluted beach revealed distinct characteristics, being dominated mainly by bivalves, which were suspension feeders, with limited movement, and loss of some functions found in the other two beaches. These may be associated with environments with a greater amount of suspended material, from an organic pollution environment.

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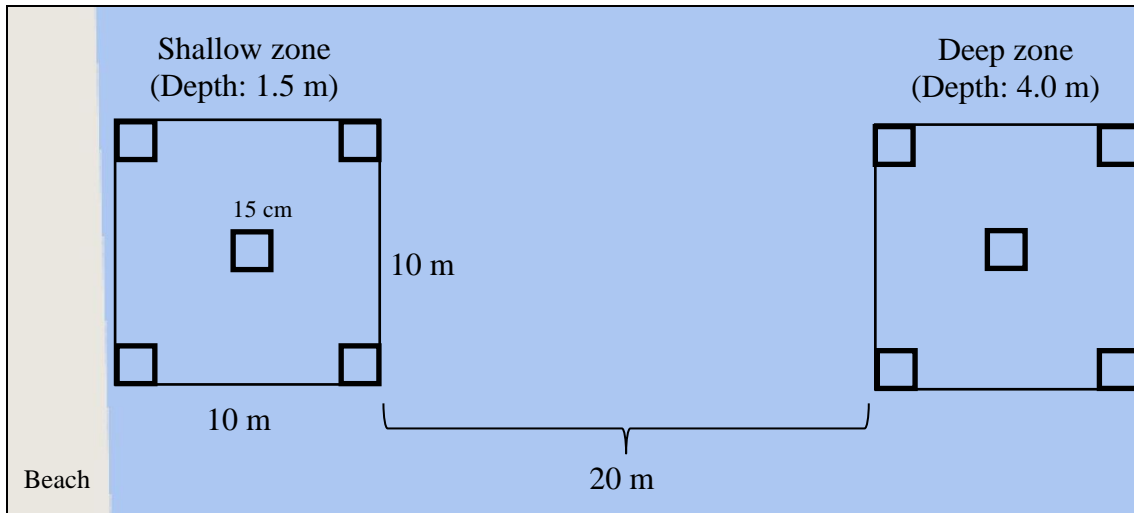
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Supplementary material 1. Schematic representation of the methodology for collecting rhodoliths, at the three beaches in this study, considering the shallow (1.5 m) and deep (4.0 m) depth zones.



Supplementary material 2. Variables tested, including the technique of sampling and analysis.

Variables	Methodology
Atmospheric Temperature (°C)	Measured at 1.5m above ground, using a digital weather thermometer.
Water sample Temperature (°C)	Measured from a bottom water sample, using a digital water thermometer.
Transparency of water (cm)	Measured with a Secchi disk.
Dissolved oxygen (mg/L)	Measured from a bottom water sample, using a digital oximeter.
Salinity (ppm)	Measured from a bottom water sample, using a digital salinometer
pH	Measured from a bottom water sample, using a digital Ph meter.
Thermotolerant coliforms	Thermotolerant coliforms (or faecal coliforms) represent the bacterial group (e.g. <i>Escherichia coli</i>) that survive in endothermic animal faeces and reproduce (in less than 24 hours) at temperatures above 40°C. Quantified from the bottom water sample collected, using 100mL of the sample, filtered through a membrane filter which retains the bacteria found in the sample. The filters are then transferred to an absorbent pad saturated with a dish containing M-Endo agar and incubated for another 21 + 1h at 35°C ± 0.5°C. Sheen colonies are then counted under magnification in a petri dish. Method available at “Standard Methods for the Examination of Water and Wastewater”, from American Public Health Association (APHA 2020).
Precipitation (mm)	The average precipitation in the month was used, available at Brazilian governmental site “Agência Executiva de Águas do Estado da Paraíba” (AESA 2020).
Organic material (g)	The sediment was collected in the area under the rhodoliths of the sample. In the laboratory, 20g of each sediment sample was dried in an oven at 100°C, for 24h to eliminate the water present in the residues. Then, manual maceration in mortar was performed to ensure the homogeneity of the sample. After maceration, 5g of each sample were weighed and placed on a previously weighted crucible. Subsequently, these samples were placed in the muffle furnace (EDG 1800 - 3PS) and incinerated at a temperature of 500°C, for a period of 5 hours, with a landing time of 2h. The organic matter content was determined as the loss of mass of the incinerated residue, considering the material lost by burning in the temperature range of 100°C to 500°C.
Carbonate content (g)	The sample sediments obtained from the organic matter quantification (incinerated at 500°C) were placed at a furnace combustion muffle type (high temperature furnace, EDG 1800 - 3PS) and incinerated at 900°C for 5h and remained in the furnace at this temperature for 2h (step time) to complete the calcination. After all elimination of CaCO ₃ , the remaining material was weighed and the CaCO ₃ concentration calculated by weight difference.
Grain size	Sediment samples were air dried for 48h; then, combusted (12h, 100°C) and 100g of this material was sieved thorough a set of successively smaller sieves (analytical sieve shakers) - 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, and 0.063mm. The results were logarithmically transformed into <i>phi</i> (ϕ) values, using the expression $\phi = -\log_2 d$, where <i>d</i> is the grain diameter in millimetres. Classification, ϕ [-1 to 0]: very coarse sands; ϕ [0 to 1]: coarse sands; ϕ [1 to 2]: median sands; ϕ [2 to 3]: fine sands (Gray & Elliott 2009).

Supplementary material 3. Biological traits evaluated for all the invertebrate species collected at Miramar, Seixas and Maceió beaches, Northeast Brazilian.

Species	Max Body Size	Sediment Reworking	Mobility	Feeding	Fecundity (n° eggs/embryos)
<i>Enchiridium cf. evelinae</i>	4-10 cm	Surficial modifier	Limited movement	Predator	10,001-1 million
<i>Arabella iricolor</i>	>20 cm	Biodiffusor	Slow free movement	Predator	≤100
<i>Branchiomma nigromaculatum</i>	4-10 cm	Surficial modifier	Fixed/sedentary	Suspension	101-1,000
<i>Ceratonereis singularis</i>	>20 cm	Biodiffusor	Free movement	Predator	10,001-1 million
<i>Cirratulus africanus</i>	11-20 cm	Surficial modifier	Limited movement	Deposit	10,001-1 million
<i>Cirriformia capensis</i>	>20 cm	Surficial modifier	Limited movement	Deposit	10,001-1 million
<i>Echiurus echiurus</i>	4-10 cm	Conveyor	Limited movement	Interface	≤100
<i>Euclymene coronata</i>	11-20 cm	Conveyor	Fixed/sedentary	Deposit	≤100
<i>Eunice biannulata</i>	11-20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Eunice wasinensis</i>	11-20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Eurythoe complanata</i>	4-10 cm	Biodiffusor	Slow free movement	Predator	1,001-10,000
<i>Hesione splendida</i>	4-10 cm	Epifauna	Slow free movement	Predator	10,001-1 million
<i>Hypsicomus capensis</i>	4-10 cm	Surficial modifier	Fixed/sedentary	Suspension	101-1,000
<i>Kinbergonuphis nonatoi</i>	4-10 cm	Surficial modifier	Slow free movement	Deposit	≤100

<i>Lepidonotus squamatus</i>	4-10 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Lysarete brasiliensis</i>	>20 cm	Biodiffusor	Slow free movement	Grazer	101-1,000
<i>Lysidice ninetta</i>	11-20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Lysidice unicornis</i>	11-20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Marphysa angelensis</i>	>20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Marphysa regalis</i>	>20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Marphysa stylobranchiata</i>	>20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Naineris setosa</i>	11-20 cm	Biodiffusor	Slow free movement	Deposit	1,001-10,000
<i>Neopseudocapitella brasiliensis</i>	4-10 cm	Conveyor	Limited movement	Deposit	101-1,000
<i>Nereis riisei</i>	>20 cm	Biodiffusor	Free movement	Predator	10,001-1 million
<i>Oxydromus pugettensis</i>	4-10 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Palola brasiliensis</i>	11-20 cm	Biodiffusor	Slow free movement	Predator	10,001-1 million
<i>Pherusa scutigera</i>	11-20 cm	Conveyor	Limited movement	Predator	101-1,000
<i>Phragmatopoma caudata</i>	4-10 cm	Epifauna	Fixed/sedentary	Suspension	10,001-1 million
<i>Phyllodoce schmardaei</i>	>20 cm	Biodiffusor	Slow free movement	Predator	1,001-10,000
<i>Pseudonereis gallapagensis</i>	>20 cm	Biodiffusor	Free movement	Predator	10,001-1 million

<i>Syllis guidae</i>	4-10 cm	Surficial modifier	Slow free movement	Predator	≤100
<i>Terebella plagiostoma</i>	11-20 cm	Conveyor	Fixed/sedentary	Interface	10,001-1 million
<i>Terebella pterochaeta</i>	11-20 cm	Conveyor	Fixed/sedentary	Interface	10,001-1 million
<i>Timarete punctata</i>	11-20 cm	Surficial modifier	Limited movement	Deposit	10,001-1 million
<i>Aspidosiphon</i> cf. (<i>Paraspidosiphon</i>) <i>steenstrupii</i>	11-20 cm	Biodiffusor	Slow free movement	Deposit	101-1,000
<i>Phascolosoma</i> cf. (<i>Phascolosoma</i>) <i>granulatum</i>	11-20 cm	Biodiffusor	Slow free movement	Deposit	101-1,000
<i>Sipunculus</i> cf. (<i>Sipunculus</i>) <i>phalloides</i>	11-20 cm	Biodiffusor	Slow free movement	Deposit	101-1,000
<i>Acanthochitona</i> cf. <i>terezae</i>	4-10 cm	Epifauna	Limited movement	Grazer	1,001-10,000
<i>Brachidontes exustus</i>	4-10 cm	Epifauna	Fixed/sedentary	Interface	>1 million
<i>Crassostrea brasiliana</i>	11-20 cm	Surficial modifier	Limited movement	Suspension	>1 million
<i>Mulinia cleryana</i>	4-10 cm	Surficial modifier	Limited movement	Suspension	10,001-1 million
<i>Mytella charruana</i>	4-10 cm	Surficial modifier	Limited movement	Interface	>1 million
<i>Parvanachis obesa</i>	4-10 cm	Surficial modifier	Free movement	Predator	10,001-1 million
<i>Phlyctiderma</i> cf. <i>semiasperum</i>	4-10 cm	Surficial modifier	Limited movement	Suspension	101-1,000
<i>Cirolana</i> cf. <i>parva</i>	<1 cm	Surficial modifier	Slow free movement	Predator	≤100
<i>Cyclodorippe</i> cf. <i>longifrons</i>	1-3 cm	Regenerator	Free movement	Grazer	≤100

<i>Dulichieilla cf. appendiculata</i>	1-3 cm	Epifauna	Slow free movement	Grazer	≤100
<i>Elasmopus cf. rapax</i>	11-20 cm	Surficial modifier	Slow free movement	Deposit	≤100
<i>Garthiope spinipes</i>	1-3 cm	Regenerator	Free movement	Predator	10,001-1 million
<i>Grandidierella cf. bonnieroides</i>	<1 cm	Epifauna	Slow free movement	Suspension	≤100
<i>Leander cf. paulensis</i>	1-3 cm	Epifauna	Free movement	Predator	1,001-10,000
<i>Mithraculus forceps</i>	1-3 cm	Regenerator	Slow free movement	Predator	10,001-1 million
<i>Neogonodactylus cf. torus</i>	1-3 cm	Biodiffusor	Free movement	Predator	10,001-1 million
<i>Pagurus criniticornis</i>	11-20 cm	Epifauna	Free movement	Predator	10,001-1 million
<i>Amphipholis januarii</i>	4-10 cm	Biodiffusor	Slow free movement	Predator	≤100
<i>Amphipholis squamata</i>	11-20 cm	Biodiffusor	Slow free movement	Predator	≤100
<i>Chiridota rotifera</i>	4-10 cm	Surficial modifier	Slow free movement	Deposit	1,001-10,000
<i>Echinometra lucunter</i>	4-10 cm	Biodiffusor	Slow free movement	Predator	>1 million
<i>Microphiopholis gracillima</i>	4-10 cm	Biodiffusor	Slow free movement	Interface	≤100
<i>Ophiactis savignyi</i>	4-10 cm	Surficial modifier	Limited movement	Suspension	≤100

Supplementary material 4A. Results of PERMANOVA for the total density (individuals per m²) of rhodoliths, testing the factors Beach (Miramar, Seixas and Maceió) and Depth (shallow-1.5 and deep-4.0m), with indication of the main test and pairwise testes for the significant term.

Main test Terms	df	Sum of Squares	Mean Square	Pseudo-F/t	P(perm)
Beach	2	12893.000	6446.700	9.457	0.002
Depth	1	1935.100	1935.100	2.839	0.067
BeachxDepth	2	3489.200	1744.600	2.559	0.068
Residual	24	16361.000	681.690		
Total	29	34678.000			
Pair-wise test			Pair-wise test		
<i>For the Beaches</i>					
Miramar, Seixas				4.811	0.001
Miramar, Maceió				1.774	0.081
Seixas, Maceió				2.511	0.010

Supplementary material 4B. Results of PERMANOVA considering the density associated for each morphology of rhodolith (Pralines, Unattached branches, Boxwork), testing the factors Beach (Miramar, Seixas and Maceió) and Depth (shallow-1.5 and deep-4.0m), with indication of the main test and pairwise testes for the significant term.

Main test Terms	df	Sum of Squares	Mean Square	Pseudo-F/t	P(perm)
Beach	2	11117.000	5558.500	4.531	0.003
Depth	1	2108.400	2108.400	1.718	0.172
BeachxDepth	2	4198.800	2099.400	1.711	0.148
Residual	24	29445.000	1226.900		
Total	29	46869.000			
Pair-wise test					
<i>For the Beaches</i>					
Miramar, Seixas				2.643	0.004
Miramar, Maceió				1.633	0.074
Seixas, Maceió				1.973	0.027

Supplementary material 4C. 2-way PERMANOVA results testing the invertebrate communities' composition and structure (considering indiv./m²), for the factors Beach (Miramar, Seixas and Maceiό) and Depth (shallow-1.5 and deep-4.0m), with indication of the main test and pairwise testes for the significant terms.

Main test Terms	df	Sum of Squares	Mean Square	Pseudo-F/t	P(perm)
Beach	2	23335.0	11667.0	3.306	0.001
Depth	1	7026.2	7026.2	1.991	0.006
BeachxDepth	2	11928.0	5964.0	1.690	0.009
Residual	24	84704.0	3529.3		
Total	29	1.270 x 10 ⁶			
Pair-wise test					
<i>For the Shallow depth</i>					
Miramar, Seixas				1.676	0.007
Miramar, Maceiό				1.147	0.248
Seixas, Maceiό				1.775	0.011
<i>For the Deep depth</i>					
Miramar, Seixas				1.437	0.031
Miramar, Maceiό				1.610	0.018
Seixas, Maceiό				1.859	0.008
<i>Between the Shallow and Deep depths</i>					
Miramar				1.124	0.283
Seixas				1.737	0.009
Maceiό				1.224	0.151

Supplementary material 5. List of species occurrence of all marine invertebrates collected in Miramar, Seixas and Maceió beaches (x = presence).

Main Taxa	Species	Miramar	Seixas	Maceió
Platyhelminthes	<i>Enchiridium</i> cf. <i>evelinae</i> Marcus, 1949		X	
Polychaeta	<i>Arabella iricolor</i> (Montagu, 1804)		X	
	<i>Branchiomma nigromaculatum</i> (Baird, 1865)		X	
	<i>Ceratonereis singularis</i> Treadwell, 1929	X		
	<i>Cirratulus africanus</i> Gravier, 1906		X	
	<i>Cirriformia capensis</i> (Schmarda, 1861)	X		
	<i>Echiurus echiurus</i> (Pallas, 1766)		X	X
	<i>Euclymene coronata</i> Verrill, 1900		X	
	<i>Eunice biannulata</i> Moore, 1904	X	X	
	<i>Eunice wasinensis</i> Fauchald, 1992	X	X	
	<i>Eurythoe complanata</i> (Pallas, 1766)	X		
	<i>Hesione splendida</i> Lamarck, 1818		X	
	<i>Hypsicomus capensis</i> Day, 1961		X	
	<i>Kinbergonuphis nonatoi</i> Lana, 1991		X	
	<i>Lepidonotus squamatus</i> (Linnaeus, 1758)		X	
	<i>Lysarete brasiliensis</i> Kinberg, 1865		X	
	<i>Lysidice ninetta</i> Audouin & H Milne Edwards, 1833		X	
	<i>Lysidice unicornis</i> (Grube, 1840)	X	X	
	<i>Marphysa angelensis</i> Fauchald, 1970		X	
	<i>Marphysa regalis</i> Verrill, 1900	X	X	
	<i>Marphysa stylobranchiata</i> Moore, 1909	X	X	X
	<i>Naineris setosa</i> (Verrill, 1900)		X	
	<i>Neopseudocapitella brasiliensis</i> Rullier & Amoureux, 1979		X	
	<i>Nereis riisei</i> Grube, 1857		X	X
	<i>Oxydromus pugettensis</i> (Johnson, 1901)		X	
	<i>Palola brasiliensis</i> Zanol, Paiva & Attolini, 2000		X	
	<i>Pherusa scutigera</i> (Ehlers, 1887)		X	
	<i>Phragmatopoma caudata</i> Krøyer in Mörch, 1863		X	X
	<i>Phyllodoce schmardaei</i> Day, 1963		X	
	<i>Pseudonereis gallapagensis</i> Kinberg, 1865	X		
	<i>Syllis guidae</i> Nogueira & Yunda-Guarin, 2008	X	X	
	<i>Terebella plagiostoma</i> Schmarda, 1861	X		
	<i>Terebella pterochaeta</i> Schmarda, 1861		X	
	<i>Timarete punctata</i> (Grube, 1859)	X	X	
Sipuncula	<i>Aspidosiphon</i> cf. (<i>Paraspidosiphon</i>) <i>steenstrupii</i> Diesing, 1859		X	
	<i>Phascolosoma</i> cf. (<i>Phascolosoma</i>) <i>granulatum</i> Leuckart, 1828	X	X	
	<i>Sipunculus</i> cf. (<i>Sipunculus</i>) <i>phalloides</i> Pallas, 1774		X	
Mollusca	<i>Acanthochitona</i> cf. <i>terezae</i> Guerra Júnior, 1983		X	
	<i>Brachidontes exustus</i> (Linnaeus, 1758)		X	
	<i>Crassostrea brasiliiana</i> (Lamarck, 1819)		X	X
	<i>Mulinia cleryana</i> (d'Orbigny, 1846)	X	X	X
	<i>Mytella charruana</i> (d'Orbigny, 1842)			X
	<i>Parvanachis obesa</i> (C. B. Adams, 1845)		X	
	<i>Phlyctiderma</i> cf. <i>semiasperum</i> (Philippi, 1836)			X
Crustacea	<i>Cirolana</i> cf. <i>parva</i> Hansen, 1890	X		

	<i>Cyclodorippe</i> cf. <i>longifrons</i> O. Campos Junior & Schmidt de Melo, 1999			X
	<i>Dulichchiella</i> cf. <i>appendiculata</i> (Say, 1818)			X
	<i>Elasmopus</i> cf. <i>rapax</i> Costa, 1853			X X
	<i>Garthiope</i> <i>spinipes</i> (A. Milne-Edwards, 1880)			X
	<i>Grandidierella</i> cf. <i>bonnieroides</i> Stephensen, 1947	X		
	<i>Leander</i> cf. <i>paulensis</i> Ortman, 1897			X
	<i>Mithraculus</i> <i>forceps</i> A. Milne-Edwards, 1875	X	X	
	<i>Neogonodactylus</i> cf. <i>torus</i> (Manning, 1969)	X	X	X
	<i>Pagurus</i> <i>criniticornis</i> (Dana, 1852)			X
Echinodermata	<i>Amphipholis</i> <i>januarii</i> Ljungman, 1866	X	X	
	<i>Amphipholis</i> <i>squamata</i> (Delle Chiaje, 1828)	X	X	
	<i>Chiridota</i> <i>rotifera</i> (Pourtalès, 1851)	X		
	<i>Echinometra</i> <i>lucunter</i> (Linnaeus, 1758)	X		
	<i>Microphiopholis</i> <i>gracillima</i> (Stimpson, 1854)	X	X	
	<i>Ophiactis</i> <i>savignyi</i> (Müller & Troschel, 1842)	X	X	

GENERAL CONCLUSIONS

Environmental Education and citizenship

In the face of the challenges for preserving marine ecosystems, together with the intensification of the anthropogenic impacts in recent decades, it is essential to seek efficient means to raise awareness. Among the methodologies often used to achieve this goal, practices in Environmental Education (EE) are useful tools, especially in the educational field. The traditional teaching method (formal education) can be adapted with non-formal education practices to encourage students to learn, in a more motivating way, the contents taught in the classroom. Even topics that are difficult to understand can become accessible to youngsters, such as concepts of ecology, zoology, general biology, among others. EE in youngsters, in the long run, promotes raising citizens with critical conservation awareness. Young people with knowledge and commitment to the environment provide a valuable force that can influence a paradigm shift towards the environmental issues (from conservation, climate change, among others).

In this study, the integrated EE activities have promoted the students from public elementary schools in the Northeast Brazilian, to better assimilation of the knowledge taught in the classroom (i.e. ecology, environment and its importance, biological concepts, zoology, among others). In fact, the learning acquired with the integrated teaching method, combining formal and non-formal education, was considered effective as all students considerably improved their answers after the sequential programme of practical activities. In the long term, this type of integrated practices can help students to better understand their environment and raise awareness for protection. In this sense, we also found that students from the town school had an increased motivation towards learning, despite more limited resources than in the capital school, and the rare opportunities of attaining more dynamic classes during their school years. This result was mainly due to the greater contact with coastal environments by the students, given that many of the families in that region depend on marine resources (e.g. fishing). Thus, in the end, both schools obtained similar results regarding learning the concepts transmitted along with this project. So, as for the first hypothesis tested, we were able to confirm that the integrated learning methodology was efficient for the knowledge acquisition by the students of both schools. This highlights the importance of using local biological resources to foster playful activities, as it is something that students will be able to recognize more easily in their daily lives. The teacher can promote and

support the activities of youngsters more effectively, seeking ways to improve understanding according to the potential of each region in which they live (De Vreede et al. 2014). However, this work has also highlighted some of the knowledge gaps regarding local marine ecosystems. For example, rhodolith beds are extremely abundant in the Northeast region and very important from the point of view of ecosystem services. Despite this coastal habitat is widespread in the Paraíba beaches, it is still poorly known in this region, particularly when taking into account its local distribution, abundance, and associated invertebrate communities.

Rhodoliths and associated fauna

Rhodoliths are non-articulated red coralline algae, which contribute to essential ecosystem services, from the maintenance of the oceanic pH, assimilation of dissolved carbon, a nursery for several invertebrates and fish that use them as habitat, food, and refuge, among others. The rhodoliths live in symbiosis with microorganisms, forming a holobiont environment (Hester et al. 2016), promoting ecological and chemical processes that allow the establishment and maintenance of marine biodiversity, being considered as biodiversity hotspots (Fredericq et al. 2019). There are approximately 600 species of rhodolith-forming algae (belonging to the Corallinales Order) (Horta et al. 2016, Guiry & Guiry 2020), distributed according to geographical region. At the local level, the occurrence and distribution of rhodolith beds may be influenced by environmental variables such as hydrodynamism, availability of calcium carbonate, salinity, temperature, among other factors. However, they are also extremely vulnerable to climate change and anthropogenic impacts. These characteristics summary from the literature review held in chapter II allowed to corroborate hypothesis 2, demonstrating the importance of rhodoliths for the maintenance of marine life, as well as contributing to the balance of different ecosystem functions.

Due to their ecological and functional importance, it is essential to protect rhodolith beds. Initiatives such as the European Union's Natura 2000, 'Marine Protected Areas' in the Eastern Pacific, UNESCO's 'Global Geoparks' in Asia, and the network for monitoring coastal benthic habitats ('ReBentos') in Brazil (the latter without published results), are examples of initiatives and directives for the preservation of rhodoliths and their associated biota. These actions are still timely and incipient, and more robust actions are needed to reach all the world's oceans more efficiently. In fact, the rhodolith/maërl from the Northeast Brazilian coast are among the most abundant in

the world (Amado-Filho et al. 2012), however, still poorly studied and known with regard to several aspects: from local distribution, associated fauna, and their environmental driver.

In the present study, considering three beaches from Northeast Brazil, 60 species of invertebrates from different groups were identified, i.e. Platyhelminthes, Annelida, Sipuncula, Mollusca, Crustacea, and Echinodermata. Of these, 53 were new records for the beaches considered, with the possibility of some being new species and/or endemic in rhodoliths (which has to be confirmed with molecular analysis), as previously found for the endemic species *Sabellaria corallinea* Dos Santos, Riul, Brazil & Christoffersen, 2011 (Dos Santos et al. 2011, Read & Fauchald 2020). This result proved the accuracy of hypothesis 3, that indeed the rhodoliths/maërl beds from the Northeast Brazilian coastal area encompass several new records and undescribed marine invertebrate species. The sort of descriptions done in chapter III is important also to promote the sort of EE activities as those proposed in chapter I. As part of the activities, students had to identify the invertebrates associated to the rhodolith in the beaches, and with a species list and simplified key, such as the one provided for this invertebrate fauna, the task becomes easier to implement.

Moving forward with the study and towards a more ecological approach, the beaches were studied regarding the characterization of the rhodolith habitat and associated invertebrate communities, according to the potential local environmental constraints. We found that the three beaches in the Northeast of Brazil were very distinct, with different levels of impact due to organic pollution by thermotolerant coliforms. This conditioned the density of the rhodolith beds (morphology and type of growth), as well as their survival (alive and dead) and the associated communities. Maceió Beach, located in the municipality of Pitimbu, was considered the most polluted due to a large concentration of coliforms that made it unsuitable for bathing in accordance with current Brazilian legislation. This contamination occurs mainly due to domestic organic waste dumped into the 'Maceió River' by local residents. Corroborating with this fact, this beach presented the highest density of dead rhodoliths, as well as the lowest diversity and density of marine invertebrates associated with these algae.

Other environmental variables may also determine the occurrence and distribution of the rhodoliths, such as the availability of calcium carbonate present in marine water. This occurred in Seixas Beach, which has the carbonate cliffs of the

“Barreira do Cabo Branco” and as such, the highest concentration of this compound amongst the studied beaches. This beach, with intermediate levels of coliforms, presented the highest density of rhodoliths, in the order of 400ind/m², as well as the highest associated invertebrate fauna diversity and density. Miramar Beach, with lower organic contamination, but also the lower concentration of calcium carbonate, essential for algae formation, did not reach such high values as in Seixas Beach.

In general, biological communities of the least polluted beaches were dominated by the Polychaeta and Echinodermata group, whose functional analysis revealed similar ways of using the habitat, namely with biodiffusors, slow free movement, predators and high fecundity individuals. These functional characteristics appear to be advantageous for a three-dimensional environment such as rhodoliths, but may also contribute to oxygenation and remobilization of the sediment, essential to maintaining the vitality of the rhodoliths themselves. The invertebrate community in the most polluted beach, i.e. Maceió, had very distinct characteristics, being dominated mainly by bivalves, with limited movement and suspension feeders, which may benefit from a greater amount of suspended material due to organic contamination. Thus, it was also possible to verify hypothesis 4, that rhodoliths/maërl and associated fauna are ecologically interlinked and affected by anthropogenic environmental drivers.

Final remarks

Knowing the environment in which one lives, understanding the consequences that can affect it, and conveying their importance to society is essential to promote awareness and consciousness changes in the long term. Working inside the school and taking students outside it, in practical classes involving environmental education, encourages them to acquire the perception to protect and conserve the ecosystems that often serve as entertainment, as well as, for the livelihood of families who use these environments.

For the educator, it is essential to use the potential of the region, e.g. rhodoliths and their associated fauna, as an object of study for students. This way, the youngsters can communicate the knowledge learned and spread the ideals of preservation and sustainable coexistence with coastal ecosystems. This study has also highlighted the knowledge gaps regarding the rhodolith habitat in the Northeast region from Brazil, and how its vitality is essential for the maintenance of local biodiversity and the associated ecosystem services. This was a first approach, where it was possible to obtain a checklist of reference species associated with rhodolith beds, as well as, to contribute to

the understanding of the phenomena/variables that may condition their existence and vitality. Further studies are needed to assess whether some of the identified species are new and endemic, as well as, to assess confirm some of the trends highlighted in this study, as the casualties between environmental factors and the functional components associated with the rhodolith beds.

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