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Rhodolith beds in Brazil: a new potential habitat for marine bioprospection

Gilberto M. Amado-Filho,^{*1} Guilherme H. Pereira-Filho²

¹Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Brazil,

²Departamento de Botânica, Universidade Federal Rural do Rio de Janeiro, Brazil.

Abstract: Rhodoliths are the free-living forms of a number of nongeniculate coralline algae. Rhodolith beds are a common feature of subtidal environments and have been recognized as important carbonate producers and paleoenvironmental indicators, as well as recognized as habitat-forming species. The rhodolith structure provides a hard three-dimensional substrate serving as microhabitat for a wide range of biodiversity, including commercially importance species. The largest known latitudinal occurrence range of rhodolith beds is on the Brazilian coastal shelf from 2°N to 25°S. Despite their importance for the Brazilian benthic communities, only in the last decade sampling efforts allowed a more comprehensive understanding of the beds' distribution, their structure and associated communities, as well as data concerning the influence of environmental factors on rhodolith bed structure and dynamics. In this work, we review the available information on the biodiversity associated with the recently described Brazilian rhodolith beds of the continental shelf and oceanic islands, focusing on the associated organisms with potential for bioprospection research.

Introduction

Rhodolith (maërl) beds, communities dominated by free living, calcareous, non-geniculate coralline algae, are a common feature of subtidal environments worldwide. Rhodoliths are the free-living forms of a number of nongeniculate coralline algal genera of the Corallinales and Sporolithales and have been recognized as foundation species (Amado-Filho et al., 2007; Foster et al., 2007; Steller et al., 2007). Well preserved as fossils, they have long been recognized as important carbonate producers and paleoenvironmental indicators (Foster et al., *in press*). Rhodoliths often occur at high concentrations over large areas, forming rhodolith beds that are among the "Big Four" benthic communities dominated by marine macrophytes, ranking with kelp forests, seagrass meadows and coralline reefs (Foster 2001; Foster et al., *in press*).

Living rhodolith commonly occur on sediment, often of biogenic origin. The structure of the rhodolith has a large effect on the associated organisms, causing an increase in diversity over that of a purely soft benthic habitat (Steller & Foster, 1995). The rhodolith structure provides a hard, three-dimensional substrate, serving as a microhabitat for a wide diversity of invertebrates, associated algae and fishes, many of whom are of significant commercial importance (Foster et al., 1997; Steller et al., 2003; Littler & Littler, 2008). Thus,

rhodoliths are widely recognized as habitat-forming species (e.g., Amado-Filho et al., 2007; Foster et al., 2007; Steller et al., 2007).

Foster (2001) pointed out that current reports indicate that rhodolith beds are especially abundant in the Mediterranean, Gulf of California, the Atlantic coasts of Norway, Ireland, Scotland, northeastern Canada, and the eastern Caribbean, as well as the coasts of southern Japan and western Australia. However, the largest known latitudinal occurrence of rhodolith beds is on the Brazilian continental shelf from 2°N to 25°S, covering an extension of 4.000 km from Pará down to Rio de Janeiro states (Kempf, 1970; Milliman, 1977) with a small bed occurring on the southern coast off Arvoredo Island (Gherardi, 2004). In the 1970's, many studies of rhodoliths in Brazil derived from investigations of the sedimentary character of the Brazilian shelf, together with the prospects for commercial exploitation (Kempf, 1970; Mabessone et al., 1972; Milliman & Amaral, 1974; Milliman, 1977; Vicalvi & Milliman, 1977). These studies estimated that the rhodolith beds represent a storage of calcium carbonate (CaCO₃) of 2x10¹¹ tons.

Calcium carbonate production by marine organisms is an essential process in the global budget of CO₃²⁻ (Milliman, 1993; Vecsei, 2004) and this process is largely determined by variations in the pH of seawater (Doney et al., 2009). Ocean acidification is a predictable consequence of rising atmospheric carbon dioxide (CO₂)

levels. The levels of atmospheric CO₂ have increased around 40% in the past 250 years (Solomon et al., 2007) and a third of the anthropogenic carbon added to the atmosphere has been tempered by oceanic uptake (Sabine & Feely, 2007), representing a decrease in pH of approximately 0.1 units, from pH 8.21 to pH 8.10 (Royal Society, 2005). According to the Intergovernmental Panel on Climate Change (IPCC), the projected end-of-century concentration of atmospheric CO₂ is 800 ppmv, representing more than twice the current value (Doney et al., 2009). If the atmospheric concentrations reaches this value, a further decrease of 0.3-0.4 pH units of seawater could be expected (Orr et al., 2005), reducing the structural integrity of carbonate-based structures (Doney et al., 2009). Changes in carbonate dissolution represent losses of habitat and, consequently, losses of biodiversity.

The Earth's biodiversity is richer and more varied nowadays than ever before. Around 15,000 to 20,000 new species have been described and, even for relatively well-known areas such as the United States of America, the rate of discovery suggests that only a third of the species of organisms have been discovered so far (Dirzo & Raven, 2003). Some of the new discoveries are of evident economic importance, such as a species of maize, *Zea diploperennis*, from western Mexico that was discovered only 32 years ago (Iltis et al., 1979). Despite the high expected values of the Earth's diversity, the consequences of the major extinction episode of the Phanerozoic Era can be recognized in current days (May et al., 1995). Habitat loss due to anthropogenic causes is at present a principal driver of extinction (Dirzo & Raven, 2003).

For coralline reefs, the most profound impacts caused by anthropogenic causes occur at depths shallower than 20 m, while reefs in the mesophotic zone (deeper than 30 m) have been reported to be free from the majority of these impacts (Bak et al., 2005; Lesser et al., 2009; Kahng et al., 2010). For many decades, the mesophotic zone was understudied because of technological limitations and the excessive costs of accessing these areas (Hinderstein et al., 2010). A few new phyla and classes of eukaryotic organisms are being found each decade. Most of them are from marine habitats (Dirzo & Raven, 2003), probably because marine ecosystems have been more neglected for decades than terrestrial ones. Current advances in technical diving methods and instrumentation, such as mixed gas diving, remotely operated vehicles (ROV), rebreathers and autonomous underwater vehicles (AUV), together with image analysis techniques, are facilitating the sampling of the mesophotic zone (Hinderstein et al., 2010). The mesophotic coralline reefs consist mainly of species of corals, sponge and algae (Bak et al., 2005; Kahng et al., 2010). We present here a review of the largest coralline reefs of Brazil: the rhodolith beds. In addition,

we highlight their importance to marine biodiversity and their potential for harboring many species of importance to bioprospection.

Rhodolith beds in Brazil

Until the second half of the 1990's, the principal interest in rhodolith studies was the sedimentary character of the Brazilian shelf and the potential of the rhodolith beds for commercial exploitation of carbonates (Kempf et al., 1970; Mabessone et al., 1972; Milliman & Amaral, 1974; Milliman, 1977; Vicalvi & Milliman, 1977). In the mid-90's, several studies approached the rhodolith beds from a biological point of view, providing consistent information on rhodolith bed structure and mapping a limited area of the northeastern Brazilian coast (e.g., Testa, 1997; Testa & Bosence, 1999; Testa et al., 1997).

Only in the last decade extensive sampling efforts allowed a more comprehensive understanding of the rhodolith bed distribution along the Brazilian coast, of their structure and associated communities and of the influence of environmental factors on rhodolith bed habitats. These recent studies have reported several important new finds related to marine algae: one new species (*Lithophyllum depressum*) (Villas-Boas et al., 2009), three new occurrences for the Atlantic Ocean (*Scinaia aborealis*, *Sporolithon ptychoides*, *Hydrolithon rupestris*) (Amado Filho et al., 2010; Bahia et al., 2011; Pereira-Filho et al., 2012), two new occurrences for the western Atlantic Ocean (*Mesophyllum engelhartii*, *Reticulocaulis mucosissimus*) (Amado Filho et al., 2010; Guimarães & Amado Filho, 2009), five new occurrences for the Southwestern Atlantic Ocean (*Acrosymphyton caribaicum*, *Dudresnaya crassa*, *Naccaria corymbosa*, *Platoma* sp. and *Predaea feldmannii*) (Guimarães & Amado Filho, 2008) and four new occurrences for the Brazilian coast (*Dasya ramosissima*, *Halymenia elongate*, *Udotea abbottiorum*, *Lithothamnion muelleri*) (Riul et al., 2009; Amado Filho et al., 2010).

At present, the fauna associated with rhodoliths seems to be the greatest gap in our knowledge. Santos et al. (2011) described a new species of Polychaeta associated with rhodolith beds (*Sabellaria corallinea*) and reported, for the first time, the occurrence of *Sabellaria pectinata* in the western Atlantic Ocean. The diversity of other groups such as Sponges, Echinoderms and Tunicates that can be found associated with rhodoliths still remains unknown. Because large areas of the Brazilian shelf are covered by rhodolith beds (Foster et al., *in press*), an increase in the number of new occurrences is expected as more areas are better sampled for the associated fauna. Recent advances in mixed-gas diving techniques (Figure 1A), complemented by ROV observations and high-resolution, multibeam, bathymetric mapping systems, have allowed us to determine extent, structure and

dynamics of rhodolith beds much better. These tools are now being used to investigate extensive areas of the mesophotic zone of the continental shelf (e.g., the Abrolhos Bank) (Amado Filho et al., 2012), the tops of seamounts (Vitoria-Trindade Ridge) (Pereira-Filho et al., 2012) and around oceanic islands (e.g., Trindade Island and Fernando de Noronha Island) (Pereira-Filho et al., 2011).

Rhodoliths and bioprospection

In the last forty years, drug discovery efforts have changed their focus from terrestrial plants and microorganisms to marine environments, where invertebrates (e.g. Sponges, Corals and Tunicates) and benthic algae have been the subject of screening programs (Tabares et al., 2011). Marine benthic algae contain minerals, polysaccharides, amino acid derivatives, carotenoids and phenolic compounds that are often of economic interest. Extracts obtained from different species have shown important pharmacological effects *in vivo*, including hypolipidemic (Ara et al., 2002), antioxidant (Yuan & Walsh, 2006), immunological (Saker et al., 2004), antitumoral (Lee & Sung, 2003), antiviral (Rinehart et al., 1983) and antibacterial activities (Lima-Filho et al., 2002).

The number of algal species associated with rhodolith beds in Brazil varies between 56 and 190 species and their amount varies from 1.88 g.m⁻² to 225.8 g.m⁻² (Riul et al., 2009; Amado Filho et al., 2010; Bahia et al., 2010). The biomass of the algae associated with rhodolith beds is influenced by the season, depth, latitudinal gradient and distance from the continent (Bahia et al., 2010). *Amansia multifida*, *Bryothamnion seaforthii*, *Halymenia floridana*, and *Plocamium brasiliense*, as well as brown algae members of the family Dictyotaceae (e.g., *Lobophora variegata*, *Styopodium zonale*, *Dictyopteris jolyana* (Figure 1B), *Dictyopteris plagiogramma*, *Dictyopteris jamaicensis*, and *Dictyota mertensii*), have been reported as the dominant species associated with rhodolith beds in Brazil (Riul et al., 2009; Amado Filho et al., 2010; Bahia et al., 2010).

Lima-Filho et al. (2002) found that extracts of *A. multifida* showed activity against enteric Gram-negative bacteria. In addition, Neves et al. (2007) reported that *A. multifida* was the source of a lectin with antinociceptive properties. Teixeira et al. (2007) found that lectins extracted from *B. seaforthii* that inhibited the adherence of streptococci to teeth could play an important role in preventing caries in the early stages. Ferreira et al. (2010) reported a high reduction in the infectivity of the virus HSV-1 in the presence of a crude extract of *P. brasiliense*. Dictyotaceae are well known to be a rich source of sesquiterpenes with a great range of bioactivities: antifungal, antitumoral, antibiotic, anti-

inflammatory, insecticidal, anti-bacterial and others (see Paula et al., 2011).

One of the most interesting features of the Brazilian rhodolith beds in the mesophotic zone, recently investigated using technical diving (Figure 1C), are the associated populations of the endemic deep-water kelp *Laminaria abyssalis* (Figures 1D and E) (Marins et al., 2012). Besides the known importance of *Laminaria* in the food industry and for alginate extraction, polysaccharides from *Laminaria japonica* have been observed to have antithrombotic potential (Xie et al., 2011). Species of *Laminaria* may also be an important biomass for biofuels (Adams et al., 2011). *Laminaria abyssalis* occurs on the continental shelf at latitudes of 19°-23°S and depths of 45-120 m, where the bottom can be completely covered by rhodoliths (Amado Filho et al., 2007). Kelp populations are closely associated with the rhodoliths, the *L. abyssalis* holdfasts being attached to one or more rhodoliths (Figures 1D and E). Graham et al. (2007) suggested that such deep-water kelp refugia are potential hotspots for tropical marine diversity and productivity. This suggestion has been confirmed in the Brazilian deep-water rhodolith-kelp beds, where endemic species of different taxonomic groups have been found in this area.

In rhodolith beds where the rhodoliths are dense and large enough to decrease their rate of turnover, sponges often seem to be associated with them (Pereira-Filho et al., 2012). Sponges are often associated with a large amount of a phylogenetically diverse microbial composition, which can account for around half of the animal's biomass (Taylor et al., 2007). The Order Actinomycetes (Phylum Actinobacteria) has been identified in sponges and are of particular interest due to their unmatched capacity to produce novel and bioactive secondary metabolites with anticancer and antitumoral activities (Fenical et al., 2009; Kwon et al., 2006; Tabares et al., 2011).

More than 50 secondary metabolites have been isolated from Tunicates and many of them are bioactive peptides (Vo et al., 2011). Eudistomins and didemnins, isolated from Tunicates, displayed high antiviral activity against Herpes simplex viruses (Rinehart et al., 1983). Other groups of invertebrates with expected potential for bioprospection such as Echinoderms, Mollusks and Bryozoa (Vo et al., 2011) are also associated with rhodolith beds. However, except for Polychaeta (Santos et al., 2011; Berlandi et al., 2012), there are no published data on invertebrates associated with Brazilian rhodolith beds.

Conclusion

Given the large areas covered by rhodolith beds in the Brazilian Exclusive Economic Zone (EEZ)

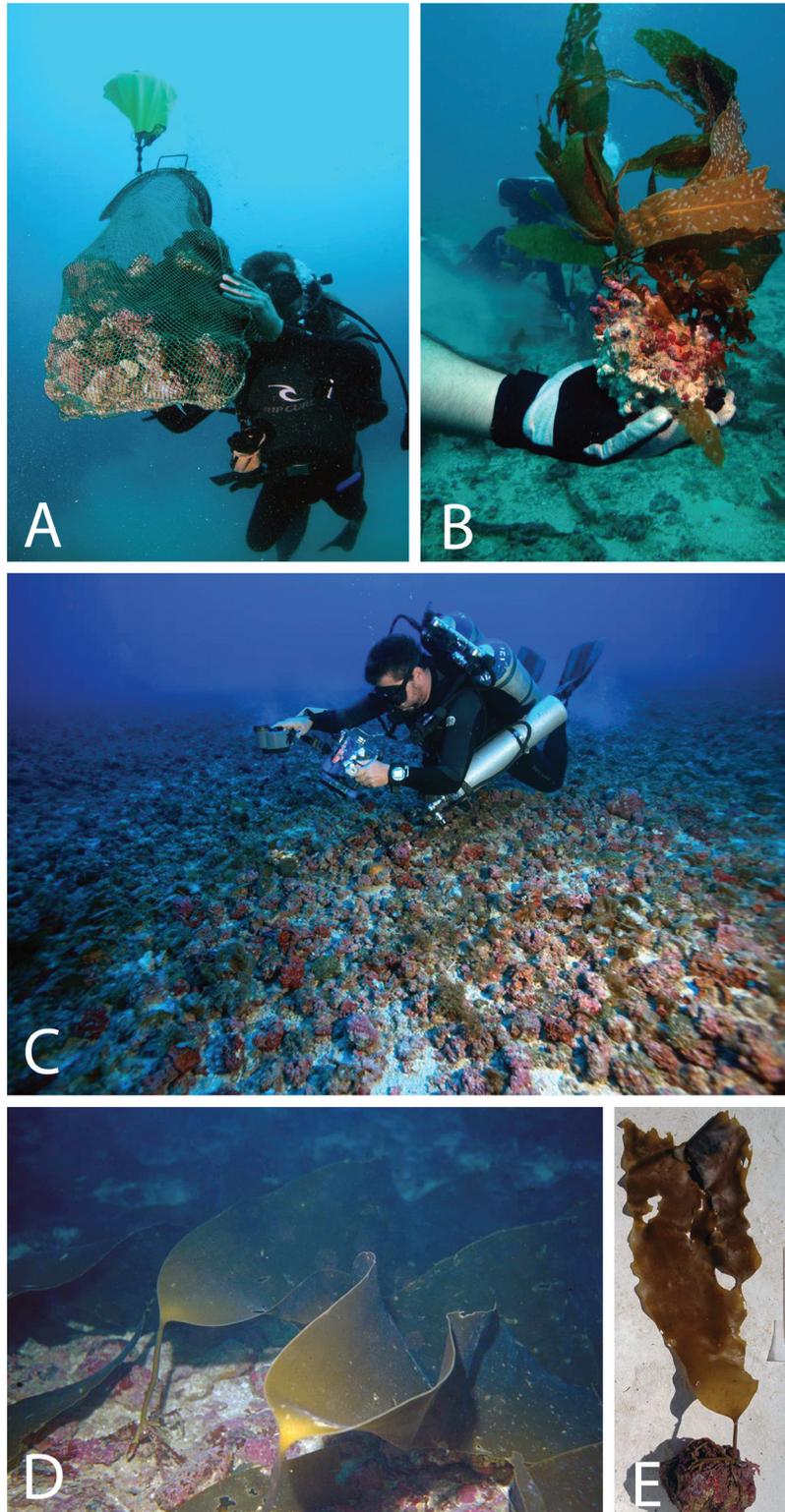


Figure 1. Brazilian rhodolith beds and their associated communities. A-Diver preparing to lift to the surface rhodolith samples collected on the south of the Abrolhos Bank. (Photo RL Moura). B-A typical sample collected from the north region of the Abrolhos Bank, showing the association between rhodoliths and *Dictyopteris jolyana* (Photo RL Moura). C-Technical diving equipment being used to take video images at 60 m on Fernando de Noronha Archipelago (Photo: Z. Matheus). D-Natural habitat of *Laminaria abyssalis* in the south of Espírito Santo State and the clear association between kelp and the rhodolith (Photo GM Amado Filho). E-*L. abyssalis* attached to a rhodolith, showing holdfast, stipe and blade (Photo GM Amado Filho).

(Amado-Filho et al., 2007; Riul et al., 2009; Amado Filho et al., 2010; Pereira-Filho et al., 2012; Amado Filho et al., 2012), their vulnerability to global changes (Feely et al., 2004; Doney et al., 2009) and the high diversity of organisms with recognized potential for bioprospection associated with them, research programs and public policies to conserve their biodiversity and to maintain the sovereignty of these areas are urgently needed.

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***Correspondence**

Gilberto M. Amado-Filho
Instituto de Pesquisas Jardim Botânico do Rio de Janeiro,
Rua Pacheco Leão, 915, 22460-30 Rio de Janeiro-RJ, Brazil
gfilho@jbrj.gov.br
Tel. +55 21 32042150