Short communication

Seasonal and depth-driven changes in rhodolith bed structure and associated macroalgae off Arvoredo island (southeastern Brazil)

Cecília Pascelli [a,*], Pablo Riul [b], Rafael Riosmena-Rodríguez [c], Fernando Scherner [a], Marcos Nunes [d], Jason M. Hall-Spencer [e], Eurico Cabral de Oliveira [a], Paulo Horta [a]

[a] Departamento de Botânica, CCB, Universidade Federal de Santa Catarina, 88010-970 Florianópolis, SC, Brazil
[b] Departamento de Engenharia e Meio Ambiente, CCAE, Universidade Federal da Paraíba, 58297-000 Rio Tinto, PB, Brazil
[c] Departamento de Biologia Marina, Universidad Autonoma de Baja California Sur, CP. 23080 La Paz, B. C. S., Mexico
[d] Departamento de Botânica, IB, Universidade Federal da Bahia, 40170-115 Salvador, BA, Brazil
[e] Marine Biology and Ecology Research Centre, Plymouth University, Plymouth PL4 8AA, UK

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ABSTRACT

Rhodoliths are formed by coralline red algae and can form heterogeneous substrata with high biodiversity. Here we describe a rhodolith bed at the southern limit of the known distribution of this habitat in the western Atlantic. We characterized rhodolith and macroalgal assemblages at 5, 10 and 15 m depth during summer and winter. Lithothamnion crispatum was dominant amongst the six rhodolith-forming species present. Most rhodoliths were spheroidal in shape indicating high mobility due to water movement. Rhodolith density decreased with increasing depth and during winter. Turf-forming seaweeds accounted for 60% of the biomass growing on rhodoliths. Macroalgae increased abundance and richness in the summer, but was similar between 5 and 15 m depth. They were less abundant and diverse than that recorded in rhodolith beds further north in Brazil. Both, season and depth, affected the structure of the macroalgae assemblages. We conclude that Lithothamniom is the most representative genus of Brazilian rhodolith beds. Summer is responsible for increasing the diversity and richness of macroalgae, as well as increasing rhodolith density.

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1. Introduction

Rhodoliths are of conservation interest as they provide long-lived, complex coralline algal habitat for diverse communities (Foster, 2001). Rhodoliths are non-renewable resources and particularly interesting for conservation (Barbera et al., 2003; Blake and Maggs, 2003). In Brazil, rhodolith beds cover extensive areas of the continental shelf and also occur on seamounts and oceanic islands (Amado-Filho et al., 2007; Riul et al., 2009; Bahia et al., 2010; Amado-Filho et al., 2012a,b; Pereira-Filho et al., 2012). Brazilian rhodolith beds are dredged intensively (Riul et al., 2008) and a lack of information on their ecological role has hindered conservation and management strategies. Rhodolith dredging is causing on-going environmental problems in the NE Atlantic and is now banned in the UK (Grall and Hall-Spencer, 2003; Hall-Spencer, 2005). It has been assumed that rhodolith beds have a continuous distribution along the Brazilian shelf (Kempf, 1970), but there are considerable gaps in their known distribution from 23° to 27°S (Horta, 2002) and very little information is available on the southernmost beds (Gherardi, 2004; Rocha et al., 2006; Metri and Rocha, 2008; Scherner et al., 2010).

Here we describe a rhodolith bed and associated macroalgal assemblage at the southernmost known limit of this habitat in the western Atlantic. We assess the influence of season and depth on (i) rhodolith density, (ii) rhodolith volume, (iii) number of species and biomass of associated macroalgae and (iv) the structure of associated assemblages.

2. Material and methods

The Marine Biological Reserve of Arvoredo (Rebio Arvoredo) is a 176 km² "no take" marine protected area. In summer this reserve is influenced by warm coastal waters (22 °C), in winter the influence of Prata River and the Falklands current decrease water temperatures to 17 °C (Piola et al., 2005). The seabed has a mixture of calcareous sediment, biodetritus and calcareous nodules, covering an area of approximately 1000 m² (Gherardi, 2004). Samples were collected at Rancho Norte (27°17'S 48°22'W) in February (summer) and August (winter) 2008 at 5, 10 and 15 m depth by SCUBA diving. At each depth, nine samples (quadrats 25 × 25 cm) were distributed haphazardly and all specimens inside the quadrats were collected.

* Corresponding author. Tel.: +55 4899121002; fax: +55 4833042375.
E-mail address: cecilia_pascelli@yahoo.com.br (C. Pascelli).

Table 1
Mean (±SE) rhodolith density (0.0625 m^2) at the Arvoredo island (southeastern Brazil).

Species	Summer			Winter		
	5 m	10 m	15 m	5 m	10 m	15 m
Hydrolithon sp.	0.56 (±0.44)	2.11 (±0.42)	1.00 (±0.44)	0.78 (±0.46)	1.78 (±0.43)	–
Lithophyllum rugosum	1.67 (±0.55)	1.89 (±0.56)	1.33 (±0.65)	0.22 (±0.15)	3.00 (±1.29)	0.22 (±0.15)
L. stictaeforme	5.89 (±1.51)	5.33 (±1.50)	2.11 (±0.65)	4.89 (±1.70)	4.22 (±0.70)	0.89 (±0.26)
L. margarettae	1.00 (±0.37)	0.11 (±0.11)	–	0.67 (±0.29)	–	–
Lithothamniom crispatum	24.11 (±2.17)	4.44 (±0.96)	6.78 (±1.14)	26.67 (±3.39)	11.89 (±2.21)	5.11 (±0.89)
Mesophyllum erubescens	3.00 (±1.08)	14.67 (±2.03)	–	2.78 (±1.41)	3.67 (±1.71)	0.11 (±0.11)

Rhodolith identification followed Woelkerling (1988), Horta (2002) and Basso et al. (2011). When rhodoliths were formed by more than one species only the dominant (highest cover) was identified. Shorter (S), intermediate (I) and longer (L) axes of each rhodolith were measured using a caliper (±0.1 mm). Rhodolith volumes (volume of water displaced by the rhodolith) were measured in a graduated beaker. Epiphytes were removed from rhodoliths, identified, and weighed with a balance (0.01 g precision) after drying at 60° C for 48 h. Species with weights below 0.01 g were considered as presenting 0.001 g

We used the degree of sphericity to describe variations in rhodolith shape, this method uses the relationships rhodolith axes to classify them as discoidal (D), ellipsoidal (E) or spheroidal (S) (Bosence and Pedley, 1982). After assessing homogeneity of variances using Cochran's Test we performed a Two-Way Analysis of Variance to test differences on rhodolith density and volume (square root transformed), and number of species and biomass of associated macroalgae (log transformed) between the seasons and depths. Whenever significant differences were found, the Newman–Keuls test was applied. To describe the spatial distribution of samples we employed non-metric Multi Dimensional Scaling nMDS (Clarke and Warwick, 1994). Permutational Multivariate Analysis of Variance (PERMANOVA) was used to test for simultaneous responses of species biomass to seasons and depths (Anderson, 2001; McArdle and Anderson, 2001). Similarity matrices used in MDS and PERMANOVA were calculated with the Bray–Curtis index and abundance values were transformed (square root). PERMANOVA was made on unrestricted permutation raw data using 999 random permutations. To describe the variations in rhodolith shape we used the TRIPLOT spreadsheet (Graham and Midgley, 2000). Analyses of Variance were performed in General ANOVA Designs package (GAD – Sandrini-Neto and Camargo, 2012) under the R language and environment for statistical computing (R CORE TEAM, 2012). nMDS and PERMANOVA were performed in PRIMER 6 + PERMANOVA (PRIMER-E Ltd., Plymouth Marine Laboratory, Plymouth, United Kingdom).

3. Results

Six rhodolith-forming species were found; *Lithothamnion crispatum* Hauck dominated the assemblage (Table 1). More than 75% of the rhodoliths in both seasons and all depths were spherical in shape (Table 2: Fig. S1). Significant differences were observed when comparing the mean density and volume of rhodoliths between seasons and depths (Table S1). Density of rhodoliths (mean ± SE) was higher in the summer (25 ± 2 individuals per sample) than winter (22 ± 3) and different between all depths, decreasing from 36 ± 2 individuals per sample at 5 m to 27 ± 2 and 9 ± 1 at 10 and 15 m respectively. Volume was also higher in summer (0.55 ± 0.06 l per sample) than winter (0.42 ± 0.05). Rhodolith volumes were similar at 5 and 10 m (0.72 ± 0.03 and 0.63 ± 0.04 l per sample) but lower at 15 m (0.11 ± 0.02).

A total of 44 macroalgal infrageneric taxa was recorded (Table S2). *Cladophora vagabunda*, *Anotrichium tenue*, *Ceramium luetselburgii* and *Erythrotrichia carnea* were found at all depths sampled and in both seasons. Regarding the biomass the algal turf (composed mostly of *Gelidium crinale*, *Bryopsis pennata* and *C. vagabunda*) was the most abundant morpho-functional unit accounting for 61% of the total biomass, followed by *P. simulans* and *Hypnea spinella* with 18% and 9% respectively. Significant differences were observed when comparing the mean number of species and biomass of macroalgae associated to rhodoliths between seasons but not between depths (Table S3). Mean number of species and biomass of macroalgae were significantly higher in summer (10 ± 1 species and 0.09 ± 0.01 g per sample) when compared to the winter (4 ± 1 species and 0.01 ± 0.01 g per sample).

The MDS based on macroalgae biomass suggested differences in assemblages from 5, 10 and 15 m and between summer and winter (Fig. 1). When comparing seasons PERMANOVA indicated that assemblages differed between summer and winter. Comparison among depths indicated that macroalgal assemblages at 5 and 10 m depths were similar and both differed from 15 m (Table S4). Additionally, PERMANOVA demonstrated that assemblages at all
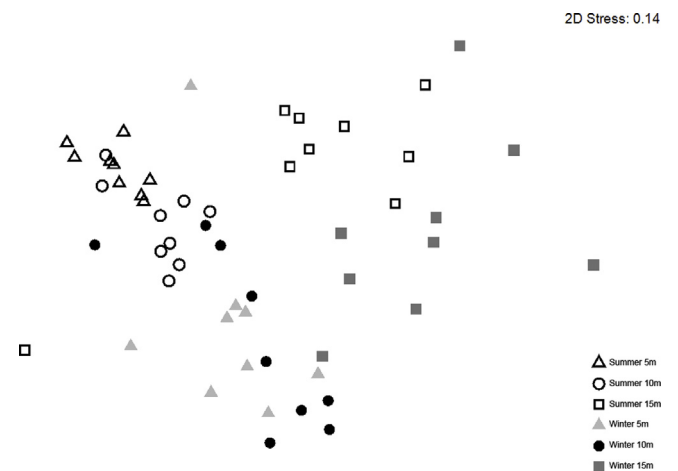
Table 2
Rhodolith shape and number of individuals at Arvoredo island (southeastern Brazil).

Shape	Summer			Winter		
	5 m	10 m	15 m	5 m	10 m	15 m
Discoidal	4.9%	5.5%	3%	1.9%	0.9%	5.3%
Ellipsoidal	6.1%	15.7%	9.9%	9.6%	10%	14%
Spheroidal	89%	78.8%	87.1%	88.6%	89.1%	80.7%
N	326	255	101	324	221	57

Fig. 1. Multivariate distribution (nMDS) of samples of macroalgae associated with rhodolith beds at two seasons and three depths at Arvoredo island (southeastern Brazil).

depths were different during the summer. During the winter the assemblages at 5 and 10 m were similar but different from those at 15 m (Table S4).

4. Discussion

Here we have described the structure of a rhodolith bed and its associated macroalgae at the currently known southern limit of distribution of this habitat in western Atlantic. *Lithothamnion* appears to be the most important genus of rhodolith-forming species in the SW Atlantic since *L. crispatum* is dominant at the southern limit of this habitat and also dominates the largest rhodolith deposit in the world, off eastern Brazil (Amado-Filho et al., 2012b) with *Lithothamnion* sp. dominant off NE Brazil (Riul et al., 2009). We found that most of the rhodoliths off SW Brazil were spheroidal, as is the case off E Brazil (Amado-Filho et al., 2007; Bahia et al., 2010), reflecting high seabed mobility since rhodolith shape changes from discoidal to spheroidal as water movement increases (Prager and Ginsburg, 1989).

We found that winter storms spreading rhodoliths apart and reducing their volume by fragmentation or due to the burial of larger and heavier specimens. Reduction in rhodolith density and/or volume with an increase in depth was also observed in other studies (Steller and Foster, 1995; Riul et al., 2009; Amado-Filho et al., 2010; Bahia et al., 2010). Increasing depth is followed by a reduction in temperature, irradiance and increased sedimentation. These factors lead to physiological limitations affecting rhodolith growth (Wilson et al., 2004). We also observed a reduction in number of species and biomass of associated macroalgae during the winter which is likely to be due to lower irradiance and temperatures, as observed on other rhodolith beds (Steller and Foster, 1995; Amado-Filho et al., 2007, 2010). This seasonality could be also related to increased water movement (Hinojosa-Arango et al., 2009) promoting sediment suspension and causing epiphytes to be scraped off as the rhodoliths are moved. As expected from studies in northeastern Brazil (Riul et al., 2009; Bahia et al., 2010) we found seasonal and depth-driven changes in the structure of the assemblages of macroalgae associated with rhodoliths. We believe these differences reflect synergistic effects of herbivory, irradiance and hydrodynamics, promoting differences in species abundance and composition (Breitburg, 1985; Scherner et al., 2010).

The Arvoredo bed had a relatively low number of species and biomass of associated macroalgae compared with another Brazilian rhodolith beds reflecting the biogeographic trend of decreasing species richness with increasing latitude in the warm temperate SW Atlantic (Horta et al., 2001). Nevertheless, the no-take reserve status of Rebio Arvoredo makes this environment particularly interesting for ecological comparisons with other rhodolith beds worldwide. We believe further work should focus on manipulative experiments regarding effects of movement on rhodolith shape and growth rates and also broader scales investigations on connectivity between these ecosystems, including population structure of rhodolith-forming species to assess the factors shaping rhodolith distribution.

Acknowledgements

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.aquabot.2013.05.009.

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