PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL

UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO

UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO

CENTRO DE CIÊNCIAS HUMANAS E NATURAIS

PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL

GABRIELLA ALEIXO ROCHA

Rhodolith Bed Heterogeneity Expressed in Backscatter Data

PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL

UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO

ESPÍRITO SANTO

2019

GABRIELLA ALEIXO ROCHA

Rhodolith Bed Heterogeneity Expressed in Backscatter Data

Dissertação apresentada ao Programa de Pós Graduação em Oceanografia Ambiental da Universidade Federal do Espírito Santo, como requisito parcial para obtenção do título de Mestre em Oceanografia Ambiental.

Orientador: Prof. Dr. Alex Cardoso Bastos

Espírito Santo

2019

GABRIELLA ALEIXO ROCHA

Rhodolith Bed Heterogeneity Expressed in Backscatter Data

Dissertação apresentada ao Programa de Pós-Graduação em Oceanografia Ambiental da Universidade Federal do Espírito Santo, como requisito parcial para obtenção do título de Mestre em Oceanografia Ambiental.

COMISÃO EXAMINADORA

____

Prof. Dr. Alex Cardoso Bastos – Orientador

Universidade Federal do Espírito Santo/UFES

____

Profª. Drª. Helenice Vital – Examinadora Externa

Universidade Federal do Rio Grande do Norte

____

Prof. Dr. Arthur Ayres Neto – Examinador Externo

Universidade Federal de Fluminense

AGRADECIMENTOS

Primeiramente agradeço a Deus por sempre abrir portas certas, nas horas certas, e ter me proporcionado a oportunidade de ingressar e concluir mais essa etapa de vida.

Agradeço aos órgãos financiadores da minha pesquisa. A Capes e a Fapes pela concessão da bolsa de estudos.

Agradeço ao meu orientador, professor Alex Bastos, que depositou sua confiança em mim desde o primeiro contato via e-mail, ao aceitar ser meu orientador de mestrado. Agradeço por todas as oportunidades, aprendizados e ideias compartilhadas.

Agradeço aos professores da pós que contribuíram para que eu pudesse admirar e entender um pouco mais sobre o amplo mundo da oceanografia. Agradeço aos professores que compõem a banca por aceitarem avaliar meu trabalho e contribuir com ele.

Agradeço a Universidade Federal do Espírito Santo, ao Departamento de Oceanografia Ambiental e ao Laboratório de Oceanografia Geológica (LaboGeo) pelo espaço e estrutura concedidos.

Gratidão a todos meus amigos do LaboGeo. Tenho orgulho de ter feito parte de um grupo multidisciplinar e unido, que auxiliaram e acrescentaram muito nesse trabalho. Obrigada pelas discursões produtivas e pelos papos descontraídos no horário de almoço. Agradeço em especial àqueles que vinheram de outros Estados (ou da Austrália - Bel), que diante da distancia de amigos e familiares, se tornaram uma pequena família.

Agradeço a minha família, em especial a minha mãe, por entender todos os momentos de ausência e me apoiar nas minhas decisões. Agradeço ao Rodrigo, que nunca desistiu de nós dois e fez questão de estar ao meu lado sempre me dando força. Agradeço por sempre acreditarem tanto em mim.

Obrigada!

“Dentro de um processo

A vida se desencadeia

Dentro de estudos

Um mar de conhecimentos

Aprender o que é justo

Na injustiça das desigualdades

Encontrar amor nesse processo

Tão passageiro”

Por Dentro

Tatiana Aleixo

RESUMO

Esse estudo tem como objetivo mostrar o potencial de mosaicos de backscatter acústico, obtidos com Sistema de Sonar Multifeixe (SMF), para mapear a variação de cobertura de nódulos de alga calcária ao longo de fundos de rodolitos. Muitos estudos identificam acusticamente os fundos de rodolitos, no entanto, verificar quantitativamente a densidade de rodolitos no fundo marinho a partir do backscatter de SMF é uma nova abordagem.

Dados de alta resolução de SMF foram adquiridos em Abril de 2018 na área de proteção ambiental (APA) Costa das Algas, localizada na plataforma continental do Espírito Santo. Três áreas foram selecionadas baseadas em dados pretéritos, totalizando 73km² de aquisição. Os dados de SMF foram processados no software Caris Hips and Sips 9.1.7, gerando assim, três mosaicos georreferenciados de backscatter. Em junho de 2018, 80 estações foram selecionadas na área de estudos, onde foram coletados vídeos do fundo marinho. Esses vídeos foram analisados no software *Coral Point Count* com *Excell Extension*, fornecendo assim o tipo de substrato marinho e o percentual dos diferentes substratos em cada estação.

Os dados foram segmentados em classes baseadas na variação da intensidade do backscatter e nas informações de verdade de fundo. Como resultado final, identificamos três classes relacionadas aos fundos de rodolitos em diferentes densidades: Baixa cobertura de rodolitos (inferior a 25%), moderada cobertura de rodolitos (entre 25% e 35%) e alta cobertura de rodolitos (acima de 35%). Também foram identificadas classes associadas a sedimento não consolidados, bioconcreções e algas vermelhas do gênero *Peyssonnelia.*

A metodologia utilizada nesse trabalho é uma ferramenta eficaz para mapear habitats bentônicos e detalhar a distribuição de nódulos ao longo de um banco de rodolitos. Essa metodologia pode ser aplicada para melhorar a gestão espacial, monitorar e proteger ecossistemas marinhos vulneráveis.

Palavras-chaves: Habitats marinhos, backscatter, acústica, mapeamento de habitats, rodolitos

ABSTRACT

This study aims at showing the potential of acoustic backscatter mosaic obtained from Multibeam Sonar System (MBSS) to map the cover variation of calcareous algaes nodules along rhodolith beds. Many studies have previously acoustically identified rhodolith beds. However, to verify quantitatively the rhodolith density using MBSS backscatter is a new approach.

High-resolution MBSS data were acquired on April 2018, in the Marine Protection Area (MPA) Costas das Algas, located in the Espírito Santo continental shelf. Three areas were selected based on preterit data, totalizing 73km² of data acquisition. The MBSS data were processed on Caris Hips and Sips 9.1.7 software, and three georeferenced backscatter mosaics were created. On June 2018, 80 videos of the seafloor were collected in the areas. These videos were analyzed on the Coral Point Count with Excel Extension Software and used to provide the seafloor type and the percentage of different substrates in each station.

The data were segmented into classes based on backscatter intensity variation and ground truth information. As a final result, we identified three classes related to rhodolith in different density: low rhodolith coverage (inferior to 25% of rhodolith), moderate rhodolith coverage (between 25% and 35% of rhodolith), and high rhodolith coverage (greater than 35%). Classes associated with unconsolidated sediment, bioconcretions and red algae genus peyssonelias were also identified.

The methodology used in this work is an efficacious tool to map benthic habitats and to detail nodules distribution across a rhodolith bed. It can be used to improve spatial management of marine systems, to monitor and protect vulnerable marine ecosystems.

Key-words: Marine Habitats, backscatter, acoustic, habitat mapping, rhodoliths

Table

Figures

Summary

1. Introduction

Over the past decade, efforts have been made to map and better understand the seabed and its supporting habitats, as less than 10% of the seafloor is mapped at high resolution (Wright & Heyman 2008). Benthic habitat mapping along the Brazilian Continental Shelf (BCS) is becoming increasingly important as the region is currently under pressure from commercial activities including mining and oil extraction, overfishing and climate change (Martin et al. 2014; Horta et al. 2016). Benthic habitat mapping is therefore vital for sustainable resource management, and can then be used to better protect vulnerable marine ecosystems (Gougeon et al. 2017). Among the diverse benthic megahabitats in Brazil, rhodoliths stand out since the largest rhodolith bed in the world is located on the BCS (Foster 2001), which represents the most extensive marine megahabitat in Brazil (Amado-Filho *et al.*, 2007).

Rhodoliths are free calcareous algae, non-articulated, that form rhodolith beds when in high density. They play an important role in the marine environment as they provide substrate, shelter and habitat for benthic, demersal and pelagic marine fauna. Rhodoliths are also a significant contributor to the global quantity of calcium carbonate, since they form large CaCO3 deposits (Hetzinger et al. 2006; Amado-Filho & Pereira-Filho 2012). Amado-Filho et al (2017) show that extensive rhodolith banks are mapped along the east, northeast and northern BCS. Specific banks are also mapped in the Fernando de Noronha Archipelago, Arvoredo Island, Abrolhos Bank and Vitoria Trindade Seamounts. Moura et al. (2016) mapped rhodolith beds in the Amazon Shelf in depths ranging from 30m to 120m. Despite their common occurrence and dominance as an important benthic habitat, only a few published data accurately mapped the spatial extension of this habitat in Brazil (Amado-Filho & Pereira-Filho 2012; Amado et al. 2007). Moreover, rhodolith beds can show a degree of heterogeneity in their structure, for example, changes in nodules density and size, and even the occurrence of fixed fused nodules forming crusts (Amado-Filho et al. 2016).

In the last few decades, remote acoustic methods have been used to map the seafloor as they are able to indirectly access deep underwater areas. Multibeam

Sonar System (MBSS) is one of the main and most effective acoustic methods to indirectly investigate seafloor habitats (Gavrilov et al. 2005; Parnum et al. 2006; Hamilton & Parnum 2011) as it provides complete seabed high resolution bathymetry, and records acoustic geo-referenced backscatter data. Acoustic backscatter is widely used in seafloor substrate mapping (Collier & Brown 2005; Fonseca & Mayer 2007; Brown & Blondel 2009; Kloser et al. 2010; Hamilton & Parnum 2011b; Huang et al. 2013; Monteys et al. 2016) and marine habitat mapping (Parnum et al. 2006; Brown & Blondel 2009; Le Bas & Huvenne 2009; Kloser et al. 2010; Brown et al. 2011; Che Hasan et al. 2012; Gougeon et al. 2017). The relationship between acoustic backscatter and seafloor type helps to identify and characterize benthic habitats, as different marine habitats are related to different substrate and backscatter characteristics. The characterization of areas with contrasting backscatter intensity is typically based on ground truth information, such as underwater images and grabs samples.

MBSS backscatter has been showed to be an efficient tool in acoustic mapping of rhodolith beds. In studies of seafloor classification and habitat mapping, Parnum et al. (2006), Micallef et al. (2012) and Sañé et al. (2016) acoustically identify rhodolith beds associated to high backscatter intensity. Innangi et al. (2018) show the backscatter variation in rhodolith beds when associated with other seafloor types. They identify rhodoliths beds associated with maerl, bioclastic coarse sand and gravel (medium/low backscatter); dense *Lhytophyllum* (medium/low backscatter); and bioclastic and volcaniclastic sand (intermediate backscatter).

Amado et al. (2007) and Brasileiro et al. (2018) analyzed rhodolith beds in the southern region of Espírito Santo and observed variability related with depth. Lower nodules densities were observed in the deeper zones, and, in contrast, rhodoliths from deepest zones have the largest mean diameter when compared to shallowest ones. Brasileiro et al. (2018) also pointed that, in general, the nodules are spheroidal to subspheroidal, formed mainly by Lithothamnion and Mesophyllum coralline algae. Eleven species of coralline red algae (CCA) were reported on the rhodoliths surface of South Espírito Santo States. Amado et al. (2017) documented 33 CCA on rhodolith surface of the continental shelf, seamount and oceanic islands of Brazil. From aerial observations and scuba surveys**,** Steller & Foster (1995) pointed out the importance of rhodoliths habitats, since they increase local flora and fauna diversity, and suggest that discontinuous distribution in a rhodolith bank can be caused mainly by water motion and sedimentation rate.

These statements show that rhodolith habitats vary in terms of forming species, size, density and distribution of nodules along the continental shelf. Due to these variations, the objective of this study is to use backscatter data, not only to baseline rhodoliths areas but to map and identify the spatial heterogeneity in rhodolith beds. Backscatter mosaics calibrated with ground truth information were used to map the occurrence and spatial distribution of rhodoliths. Changes in the backscatter intensity were analyzed as a function of areas with different densities of rhodoliths. Methodologies to accurately map rhodoliths bed and their variations can be a key to help to manage, minimize negative impacts, and better understanding the development of this important marine benthic ecosystem.

2. Methodology

High-resolution MBSS data and seabed high resolution videos were collected on April 2018 and June 2018 respectively. The study area is located in the Marine Protection Area (MPA) Costas das Algas, in the Espírito Santo continental shelf, south-east Brazilian Shelf. Three areas inside the MPA were defined based on available regional data (Bastos et al., 2015). These areas were selected based on the morphology (presence of paleovalleys) and sedimentary cover (rhodoliths). They were named as area A (25km²), B (33km²) and C (15km²) (Figure 1).

The MPA Costa das Algas was created on June, 2010 with the goal of protecting the large diversity of marine macro-algae, calcareous and non-calcareous algae, non-geniculated and geniculated algae (IBAMA, 2006). The area is known for having a complex seafloor relief, and a transition from terrigenous mud and mixed sands in the inner shelf to carbonate gravel and rhodoliths beds to mid and outer shelf (Bastos et al., 2015). The extensive coverage of rhodolith beds in a complex morphology makes this area an unique environment for habitat studies.

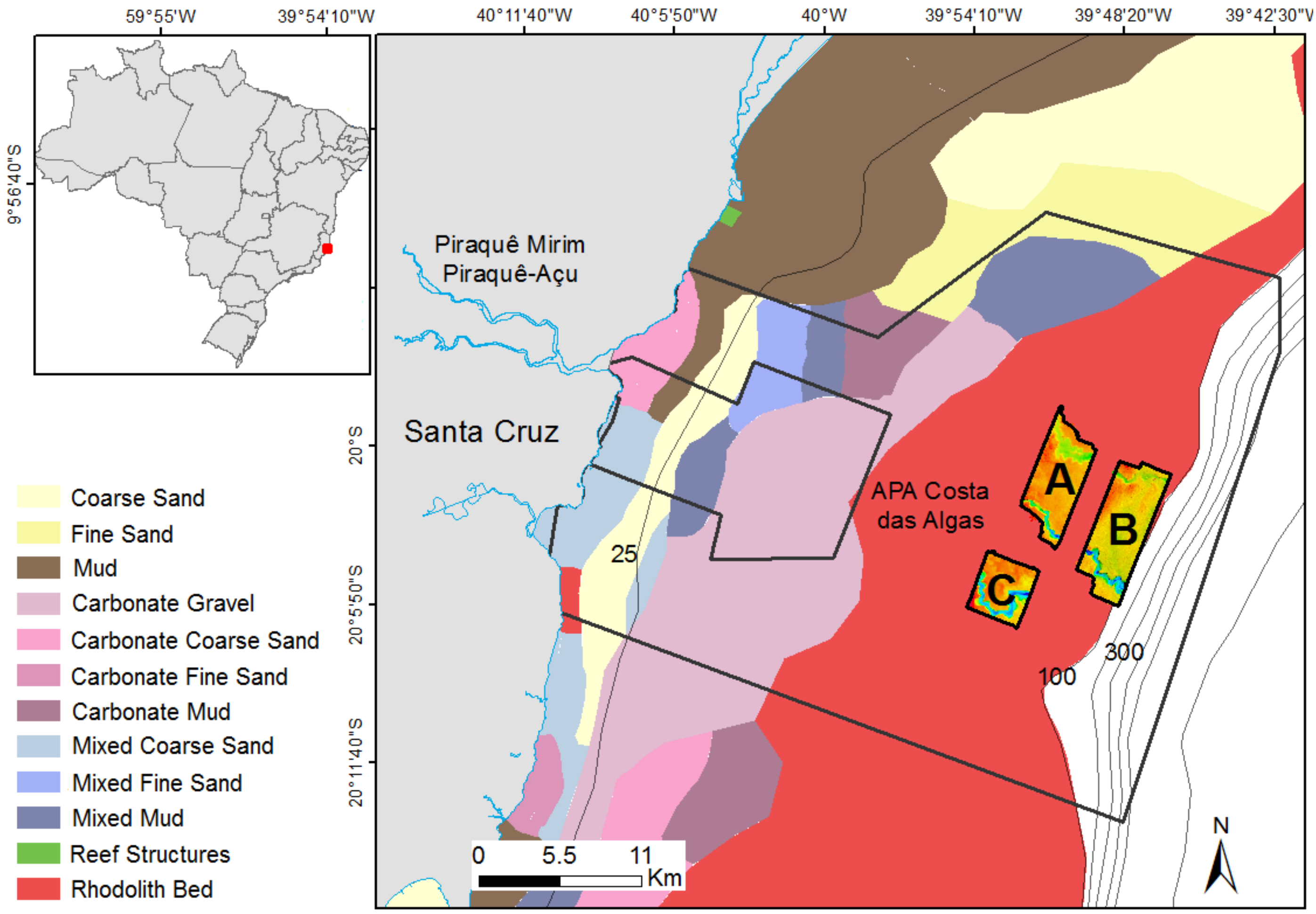


Figure 1 Location map of the research area highlighting area A, B and C. The sedimentary map adaptated from Vieira (2017) shows the rhodolith facies in the mid and outer continental shelf. Isobtahs are in meters.

2.1. Acoustic Data Acquisition and Processing

MBSS data were acquired using a hull mounted Reson 7101, operating at 240 kHz, integrated with a Teledyne TSS DMS-05 system for heave, pitch, roll and yaw corrections. The real time navigation and data storage were performed by the PDS 2000 software. A total of approximately 772 kilometers of MBSS data was collected. Sound velocity profiles (SVP) were collected using a Valeport Conductivity, Temperature and Depth (CTD) at regular intervals of three hours during the MBSS acquisition, and used to correct sound velocity variations in the water column.

Lines samples crossing the areas were taken to define specific acquisition parameters, in order to de keep constancy in the acquisition settings, as suggested by Lurton & Lamarach (2015) and Lamarach & Lurton (2018). Power, Maximum Ping Rate, Pulse Length and Gain were kept at the same value during the entire acquisition to produce consistent backscatter mosaics.

The data was processed in Caris Hips and Sips 9.1.7 software. The bathymetry data was calibrated and corrected with patch tests and tide corrections. A Combined Uncertainty and Bathymetric Estimator (CUBE) surface of 1 meter of horizontal resolution was created and all data considered spurious were removed using subset surfaces.

A backscatter processing algorithm implemented in Caris Hips and Sips, known as a Geocoder engineering, was used to generate backscatter mosaics. Automatic gain, angle variation correction, beam pattern, and a digital terrain model were applied to the data using the geocoder engineering, creating three georeferenced backscatter mosaics with 2 meters of horizontal resolution.

The backscatter mosaics were segmented using the Maximum Likelihood Classification (MLC), a supervised classification tool available in ArcMap 10.1 software. Six class signatures were previously defined based on backscatter variations (see 3.1) and on ground truth information (see 3.2). Using this supervised approach, the classes signatures were used by MLC to group the pixels of the mosaic into classes with higher probability of association. A final map with six classes was created.

2.2. Ground Truth Data Acquisition and Processing

Based on the backscatter mosaics, ground truth data were collected in 80 stations. The locations of the stations are showed in figure 2.

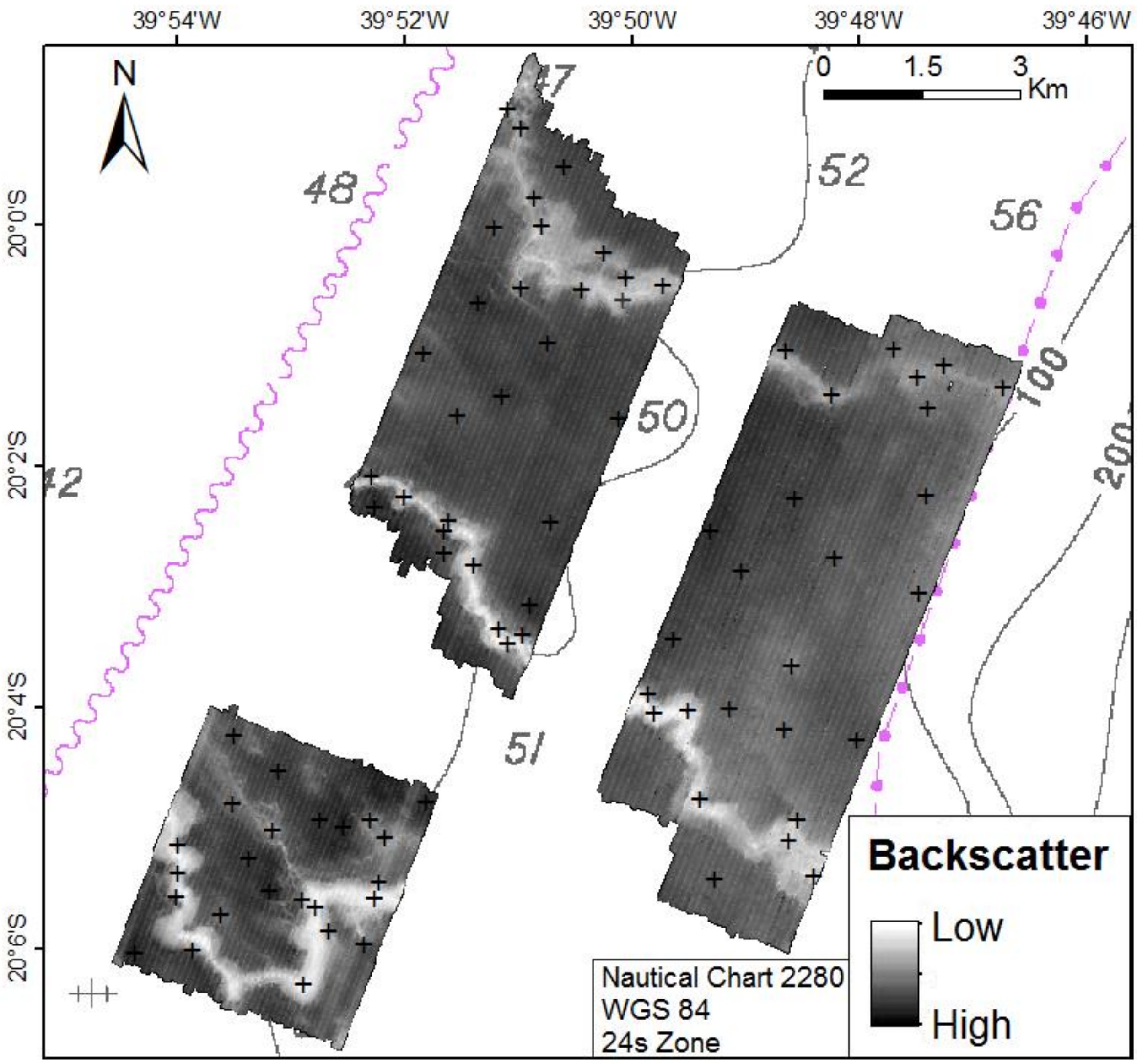


Figure 2 Backscatter mosaics of area A, B and C, and the ground truth stations plotted in it. The stations were determined based on visual backscatter variations.

A drop-camera system, in which consists of two cameras (GoPro Hero 4) and two flashlight attached in a metallic structure (Fig. 3), was used to acquire the data. The cameras were set to record videos all time during the descent and recovery. One camera was positioned looking down at the base of the structure, forming a square of 60x60cm. The second camera was attached to the side of the structure, looking forward in order to get a more panoramic view of the seabed. Three drops of two minutes of recording were carried out at each station.

Figure 3 Drop-camera system used to acquire ground truth data. Two GoPros and two flashlights are attached in the metallic structure to record videos of the seafloor

Seabed coverage analysis was conducted using two frame images of each record. The Coral Point Count with Excel Extensions (CPCe) software was used to quantify the benthic coverage. For each frame, 50 points were randomly distributed and visually described based on a dictionary created with the main seafloor types previously observed in the images, e.g. rhodolith, macroalgaes and unconsolidated sediment (Fig 4). The CPCe software statistically determines the percentage of substrates cover based on user description of the points (Kohler and Gill 2006). The percentage of each seafloor type was then determined for each frame, and a mean was calculated for each station.

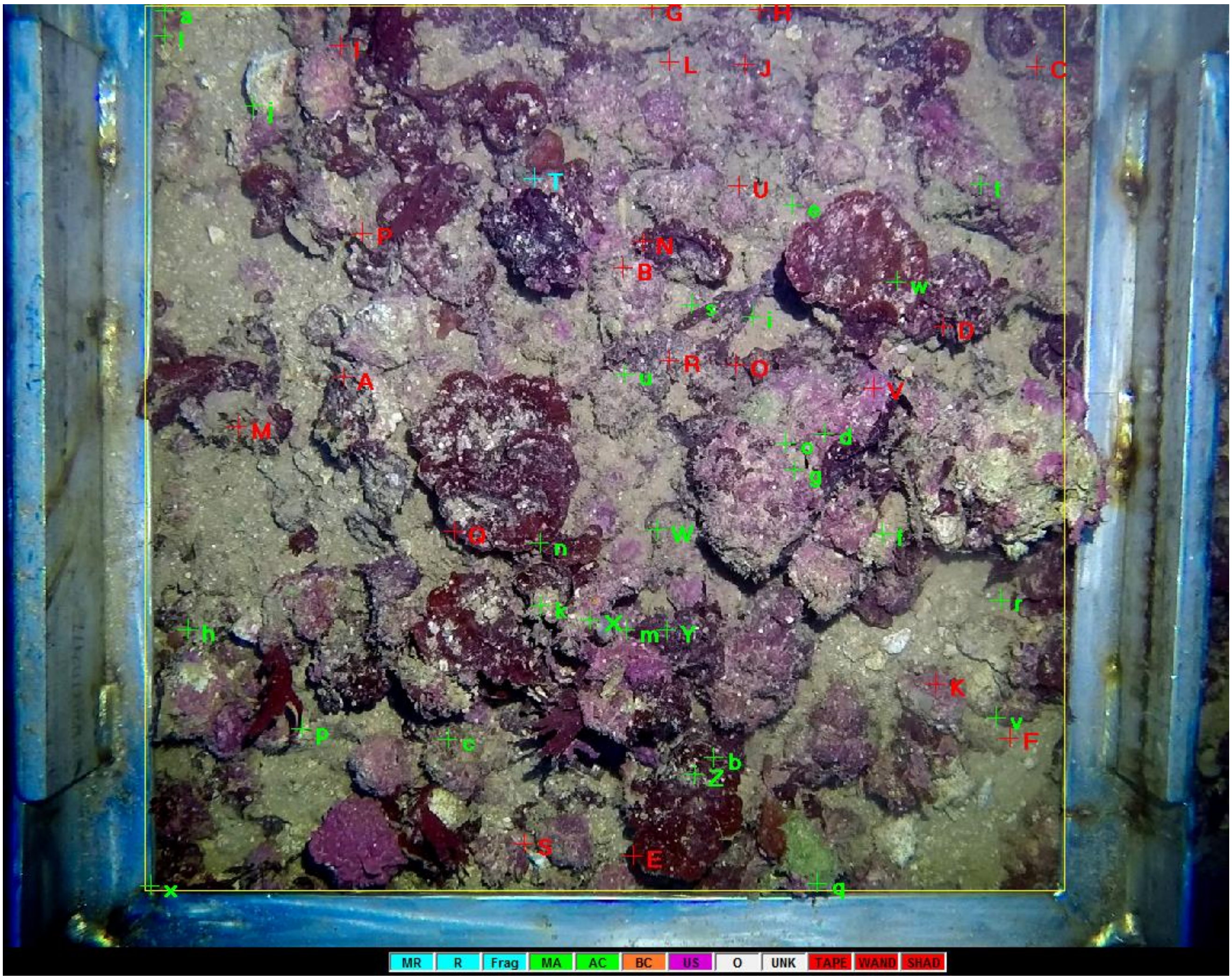


Figure 4 CPCe Screenshot showing the points randomly overlaid on the image frame. Each point is described by user and the percentage of points with different benthic descriptions is calculated.

3. Results

3.1. Bathymetry and Backscatter

The varied seafloor relief of the MPA Costa das Algas is well expressed in the bathymetry of the areas, varying from, approximately, 44m to 82m deep. This bathymetric variation is predominantly due to the presence of three paleo-channels, two located in areas A and B, and one in the south of area C (Fig 5).

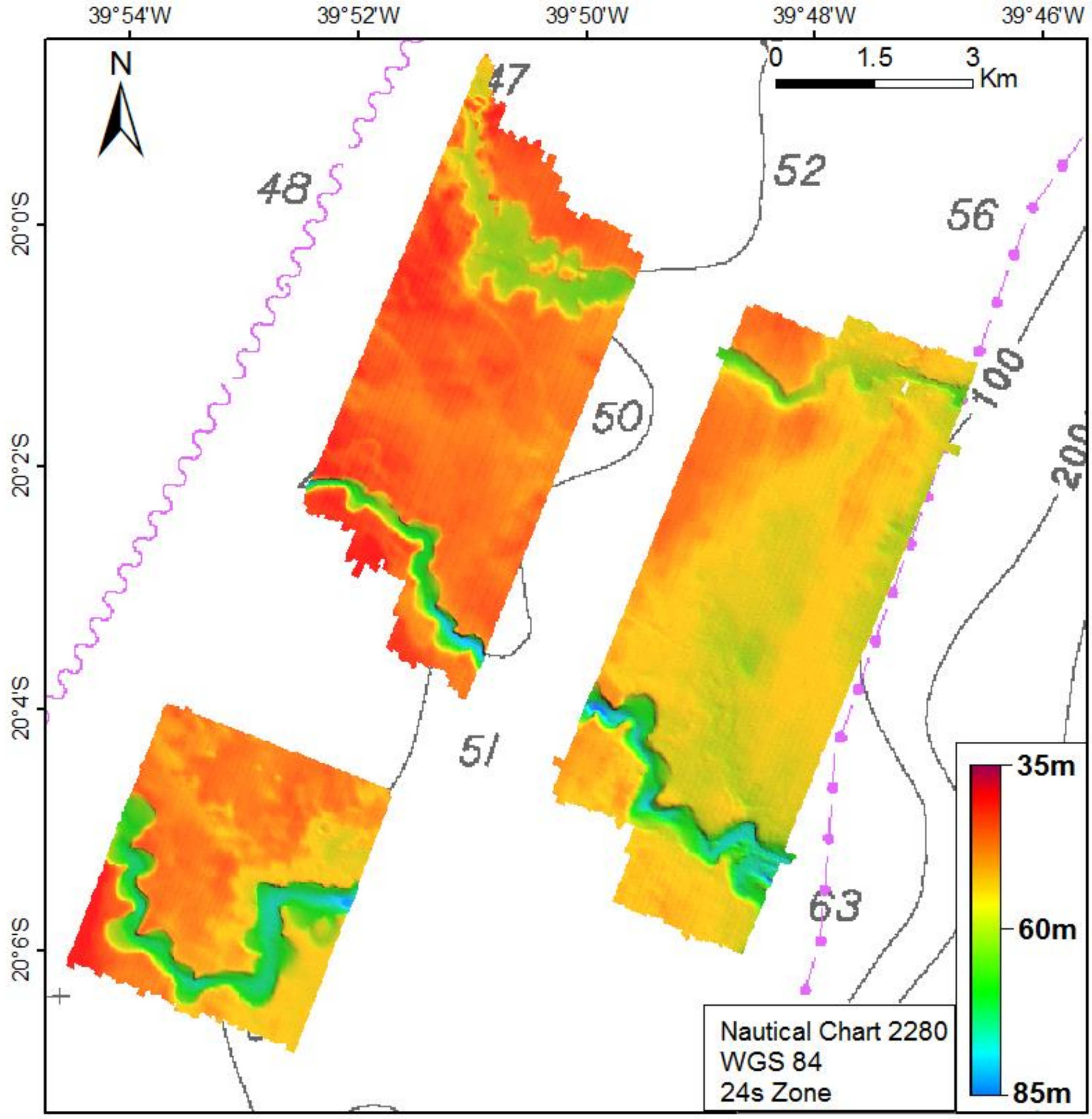
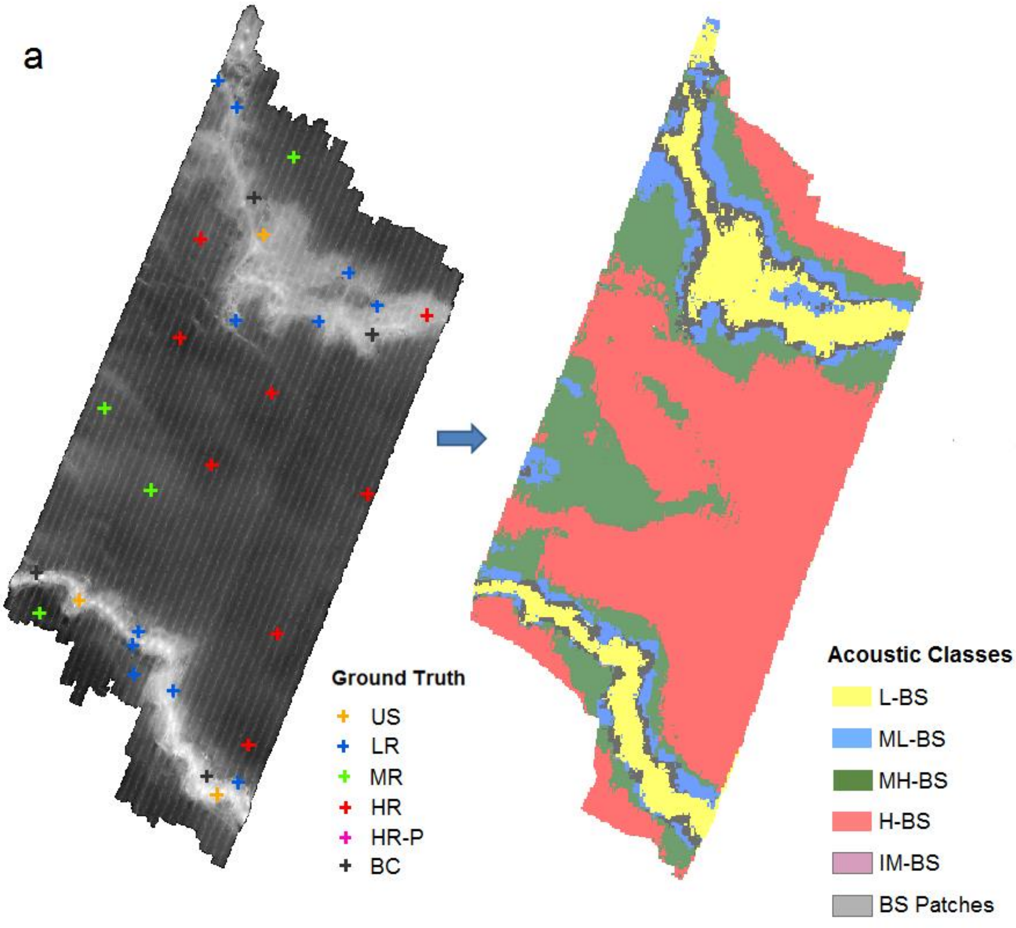


Figure 5 Bathymetric data of areas A, B and C. The bathymetric data were acquired using a Multibeam Sonar 7101 (see methodology).

The backscatter shows great substrate diversity. Six backscatter patterns related with ground truth information were observed in the mosaics and grouped with the MLC tool (Fig 6): Low Backscatter (L-BS), Moderate-Low Backscatter (ML-BS), Moderate-High Backscatter (MH-BS), High Backscatter (H-BS), Moderate-Inhomogeneous Backscatter (IM-BS), and elongated BS patches (BS Patches). The L-BS is concentrated in the deepest parts of the paleo-channels. In area B, there is a change in the north paleo-channel, which shows higher intensity when compared with the others, classified as ML-BS, with presence of BS Patches. The same pattern is observed close to the border of the other paleo-channels.

In area A, the flat area between the paleo-channels is described as H-BS intercalated with some MH-BS spots. Area B is marked by a high intensity in the northeast, followed by heterogeneous backscatter intensity. This area was classified as IM-BS. Area C has L-BS and ML-BS intensity located in the paleo-drainage, H-BS between the paleo-drainage and the paleo-channel, followed by MH-BS and ML-BS close to the paleo-channel.

The paleo-channel borders of the tree paleo-channels show BS patches with sector of L-BS and H-BS.



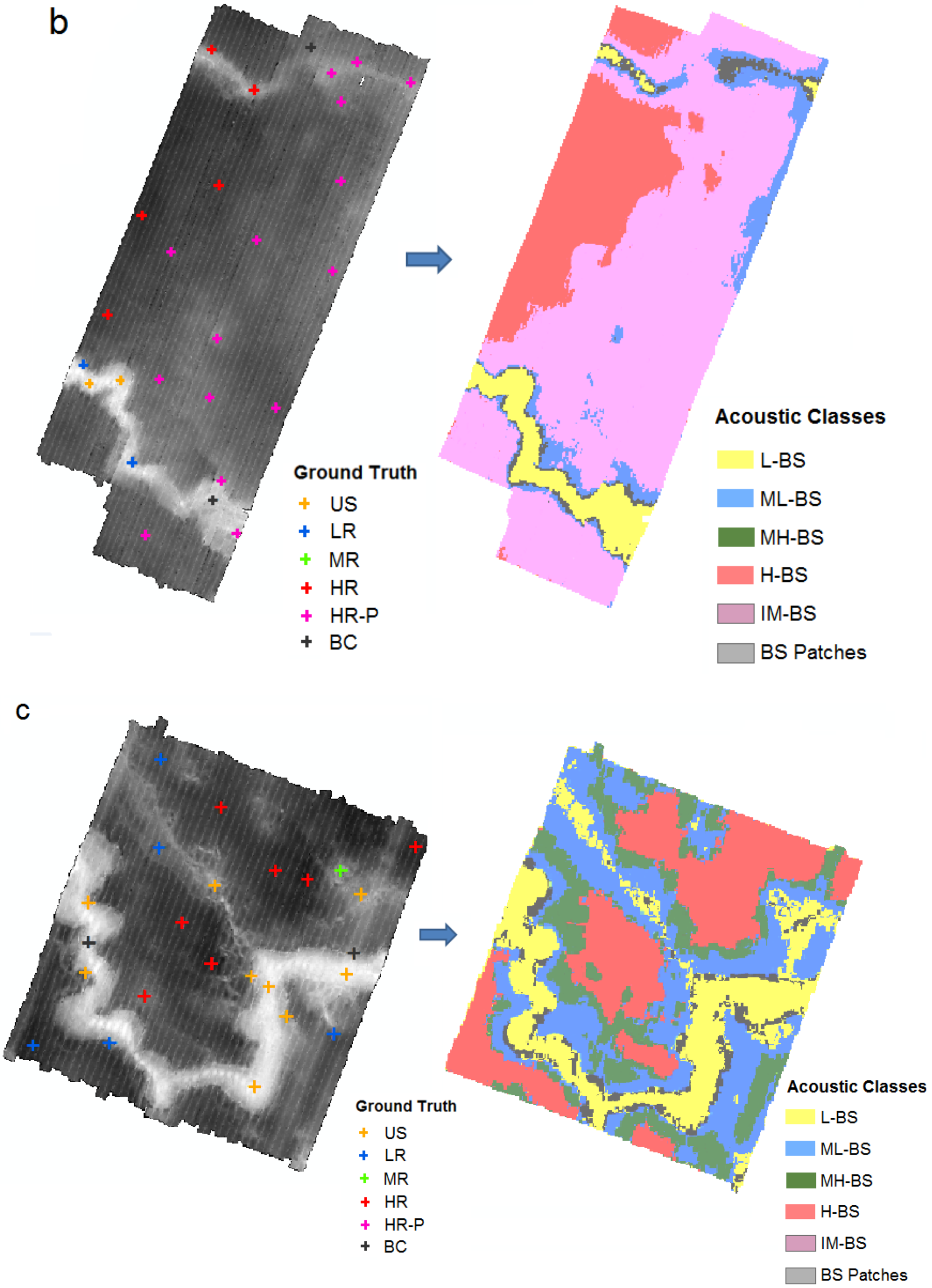


Figure 6 (a), (b) and (c) show the backscatter mosaics and the interpreted ground truth stations of area A, B and C respectively, followed by the acoustic segmented map of each area.

3.2. Ground Truth

The analyses of the ground truthing showed six main seafloor types: Unconsolidated Sediment (US), Low Rhodolith Coverage (LR), Moderate Rhodolith Coverage (MR), High Rhodolith Coverage (HR), Rhodolith beds with *Peyssonnelias* growing on the nodules (HR-P), and Bioconcretions (BC) (Table 1).

Rhodolith coverage ranges from 2% to 74% and were classified into three categories: LR, inferior to 25% of rhodoliths covering the area; MR, with coverage between 25% and 35%; and HR, greater than 35% of coverage. They predominate along the flat areas between the paleo-channels, showing these varying concentrations.

This classification were based and adapted from Matsuda & Iryu (2011). They analysed rhodolith coverage on the sea bottom and classified into high coverage (more than 40%) and low coverage (less than 30%). A gap between 30% and 40% were found in their data. An approximate value was found in our results and classified as moderate rhodolith coverage.

The paleo-channels of areas A and C are characterized by unconsolidated sediments, with no presence of rhodoliths. In Area B, unconsolidated sediments are predominant in the southern paleo-channel, while in the northern one, rhodoliths are observed and classified as LR and HR-P.

Bioconcretions occurred in the edge/margin of the paleo-channels, forming a rigid carbonate substrate. BC class was also observed within the southern paleo-channel of area B.

The HR-P was observed at depths above ~55m in Area B. This bed type is characterized by high rhodolith cover with epiphytes red algae of the *Peyssonnelia* genus. The percentage of *Peyssonnelias* covering the seafloor varies between 3.67% and 42.5%.

3.3. Seabed Habitat Mapping

Figure 7 shows a direct correlation between the backscatter intensity and rhodoliths coverage. Spearman correlation (ρ) was 0.7956 for area A and 0.7986 for area C (fig. 7a and 7c). Even with the correlation decreasing to 0.5893 in area B (fig. 7b), the result still shows direct correlation between relative backscatter intensity and rhodolith coverage for all areas. The significance level was over 99% for the three areas. Table 1 illustrates the associated backscatter class with the seabed type.

The stations with varied rhodolith coverage (2 to 74% of rhodolith cover) and no rhodolith (unconsolidated sediments) were grouped according to their respective acoustic class (Fig.8). The results showed that all station with no rhodoliths presence (US) are concentrated in the LB acoustic class, with the exception of one station in area B. ML-BS, MH-BS and HB are well correlated with LR, MR and HR, respectively, mainly in areas A and C. The Spearman correlation shows ρ = 0.92576 for area A, ρ = 0.91982 for area C, and ρ = 0.6580 for area B. The significance level was also over 99% for the three areas.

The main difference observed in Area B is the presence of *Peyssonnelias*, as shown in figures 7b and 8b by red dots. *Peyssonnelia* is a genus of non-calcified to calcified, crust-forming red crustose calcareous algae with smooth warty to lumpy thallus, of great ecological significance (Gabriel et al. 2015), which can be found as epiphytes in hard substrates (Ballantine and Ruiz, 2006). In stations with *Peyssonnelias*, backscatter shows heterogeneous patterns of moderate-low and moderate-high intensity, which difficult direct correlation with a specific acoustic class (Fig. 8b), decreasing the Spearman correlation rank. HR-P was then associated with the IM-BS. Stations with bioconcretions are located in the paleo-channel margins and were associated with the BS patches observed in the same region.

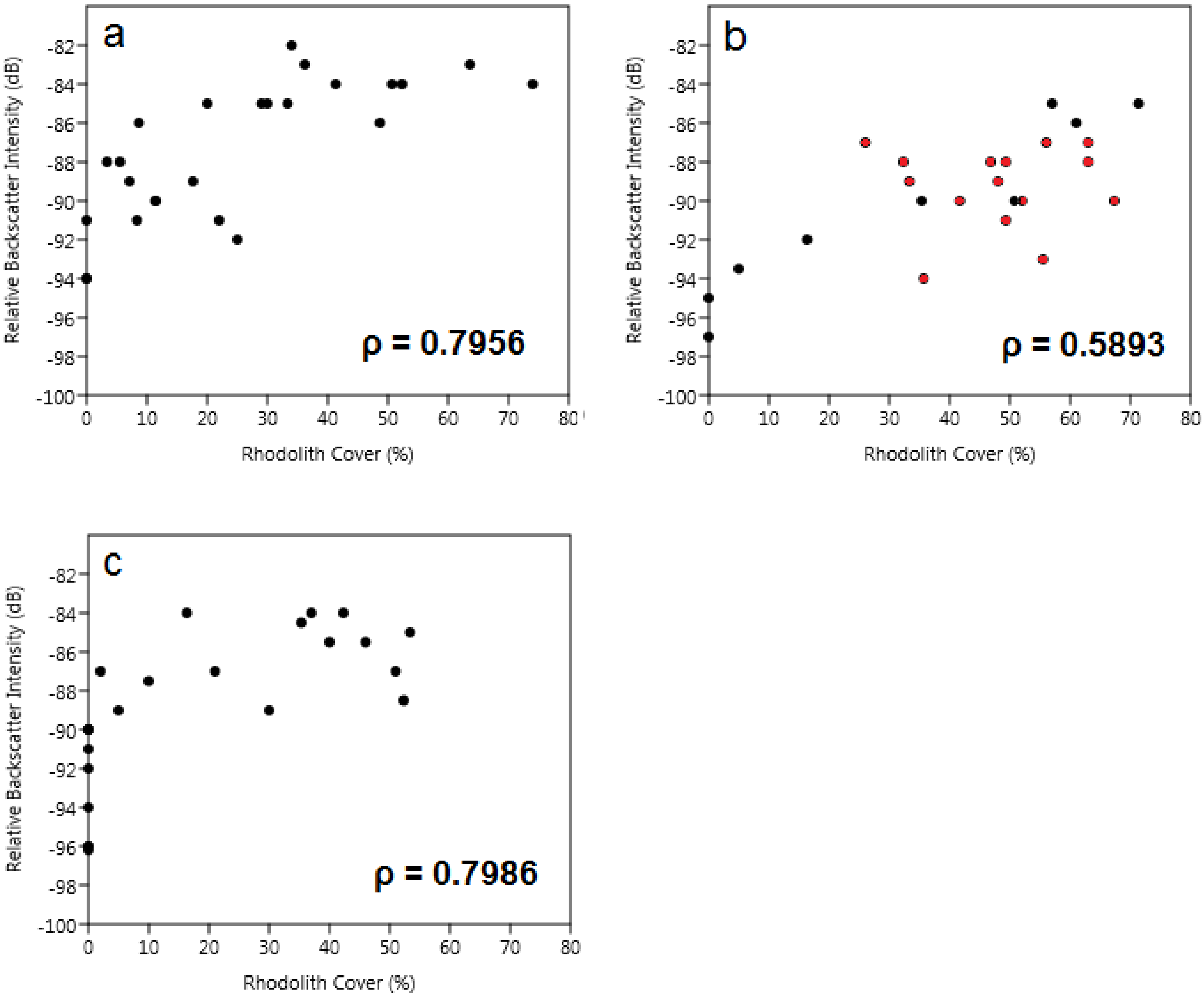


Figure 7 Graphs of Relative backscatter Intensity x Rhodolith Percentage Cover. 6a, 6b and 6c represent area A, B and C respectively. Spearman Statistic is indicated by ρ and show a high similar correlation in (a) and (c), which decrease in (b) but still show a significant correlation of ρ = 0.5893. Red dots in figure 7b indicate stations where Peyssonnelias were observed.

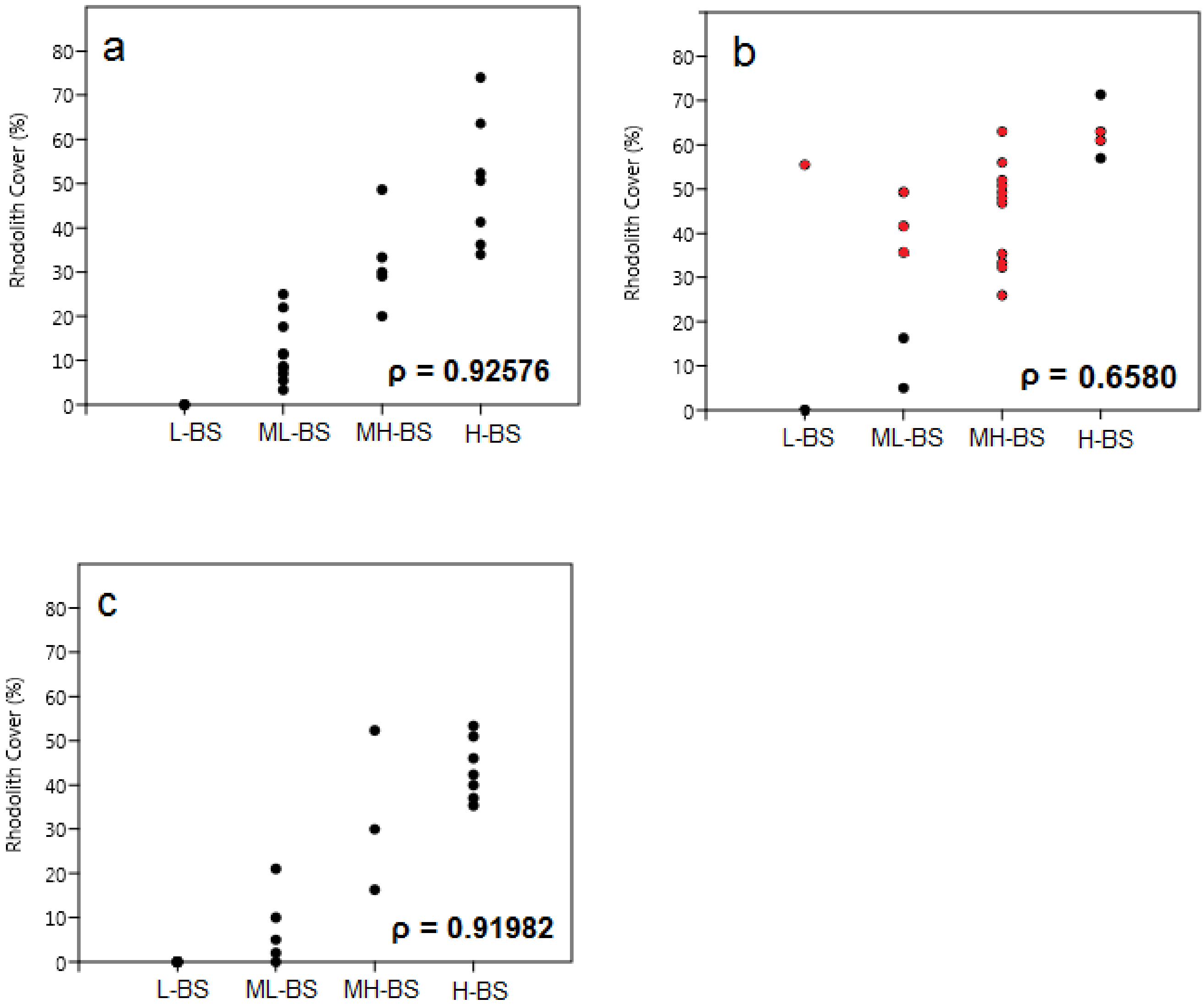


Figure 8 Graphs of Rhodoliths Percentage Cover x Acoustic Classes. 7a, 7b and 7c represent area A, B and C respectively. Spearman Statistic is indicated by ρ and shows very similar correlation in (a) and (c), and lowers (but still significant) correlation in (b). Red dots in figure 7b indicate stations where Peyssonnelias were observed.

Table 1 shows a summary of the acoustic classes observed and their classifications based on the types of seafloor described from the ground truth images.

Table 1 Description table of the acoustic classes and the related seafloor type.

Backscatter	Seafloor type	Images
Lower Backscatter Intensity (L-BS)	Unconsolidated Sediment – No presence of rhodoliths (US)	
Moderate- Low Backscatter Intensity (ML-BS)	Low Rhodoliths coverage - inferior to 25% (LR)	
Moderate- High Backscatter Intensity (MH – BS)	Moderate Rhodoliths coverage - between 25 and 35% (MR)	
High Backscatter Intensity (H-BS)	High rhodoliths coverage - greater than 35% of the seafloor are covered by rhodoliths nodules (HR)	
Moderate- Dishomogeneous Backscatter Intensity (IM – BS)	Rhodolith beds with Peyssonnelias covering the nodules (HR-P)	
Elongated BS patches	Bioconcretions located in the paleo-channel borders (BC)	

Following the correlation between backscatter intensity and rhodolith coverage, a seabed habitat map was produced (Fig. 9). Based on backscatter mosaics and ground truth information, areas with different categories of rhodolith coverage distribution were recognized, represented by LR, MR and HR. In addition, it was also possible to map US, BC, and HR-P seabed types over the study area.

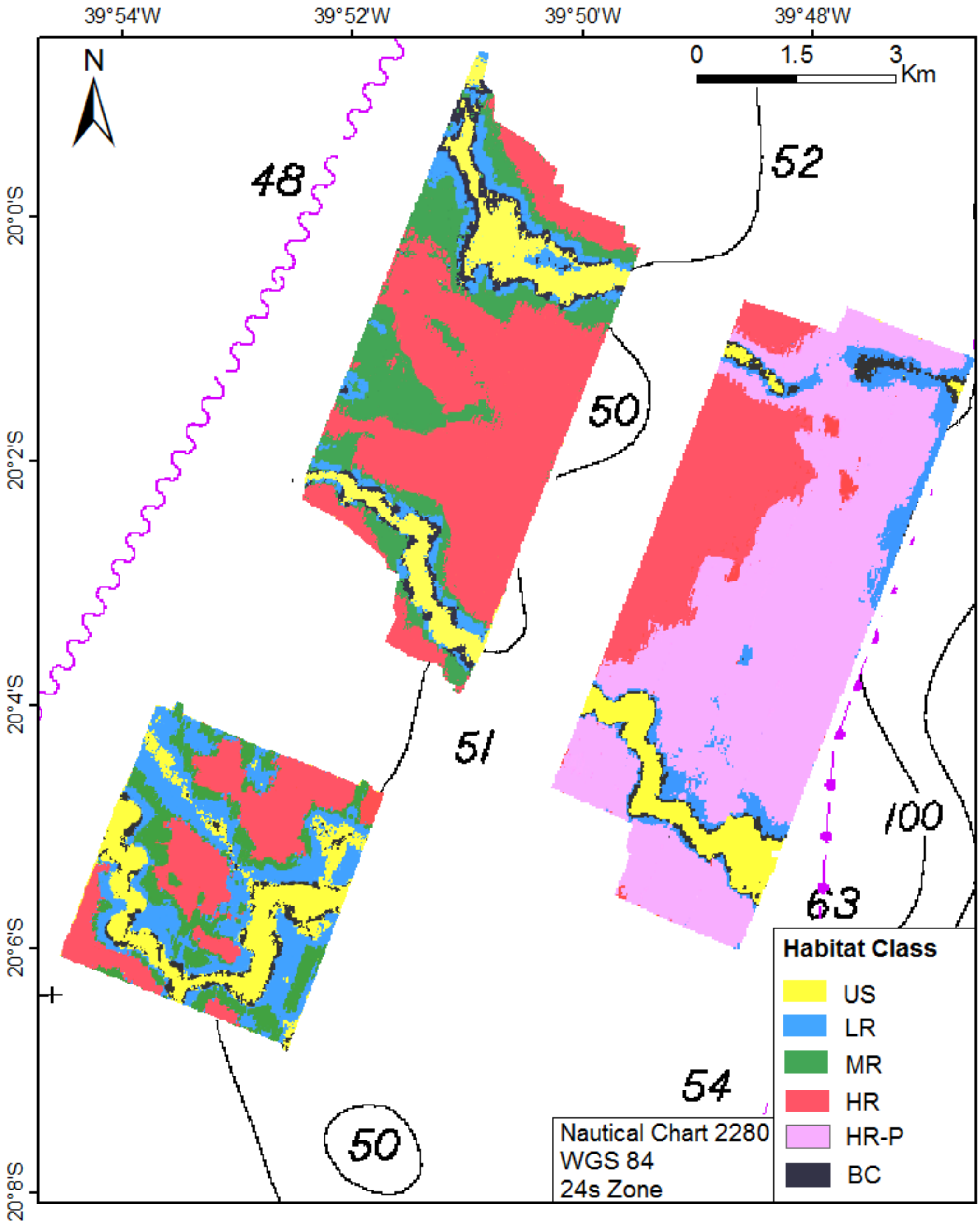


Figure 9 Final habitat map showing the six Habitat Classes observed in the areas: Unconsolidated Sediment (US), Low Rhodolith Coverage (LR), Moderate Rhodolith Coverage (MR), High Rhodolith Coverage (HR), Rhodolith beds with *Peyssonnelias* growing on the nodules (HR-P) and Bioconcretions (BC).

4. Discussion

4.1 Acoustically Mapping Rhodolith Beds

Cross-shelf changes in the structure of rhodolith beds have been described by several authors (Amado et al. 2007; Brasileiro et al. 2018; Steller & Foster 1995, Bahia et al., 2010; Pascelli et al., 2013, Horta et al., 2016). The variations are usually associated with the slope and width of the shelf, and water depth. Changes in nodule density, size, volume and morphology, result in a non-uniform distribution of rhodolith across the continental shelf. Here, we were successful in acoustically mapping this heterogeneity, when considering changes in nodule coverage and the occurrence of coralline concretion. A supervised segmentation tool (MLC) distinguished different backscatter patterns correlated to seabed images, defining six seabed types. These seabed types include five types related to the presence of crustose coralline algae showing variated rhodolith coverage (LR, MR and HR), BC, HR-P, and one typifying a general US (no rhodoliths).

In general, the acoustic response of rhodolith beds is associated with a high backscatter pattern (Parnum et al. 2006; Sañé et al. 2016; Micallef et al. 2012). However, when considering the heterogeneity along rhodolith beds, and the gradual changes between rhodoliths and surrounded habitats, we determined that the occurrence of rhodoliths can be associated with low, moderate and high backscatter response, i.e., the varying coverage of the carbonate nodules provided distinct acoustic responses. The results demonstrated that 35% of rhodolith coverage of the seabed is enough to provide a high backscatter signal.

Results have also pointed out that the presence of macroalgae on rhodoliths influences the acoustic signature. In area B, the correlation analysis showed that some stations with HR were associated with patters of ML-BS and MH-BS. This was a clear divergence with the results from areas A and C, which resulted in a lower Spearman correlation in area B. A more detailed analysis of the seabed images showed that, in areas deeper than ~55m in area B, rhodoliths were associated with epiphytes coralligenous macroalgae (*Peyssonnelias*) that attenuated the acoustic signal. Then, based in the ground truth, the moderate acoustic class in area B was associated to HR-P, and reclassified to IM-BS.

The figure 10 shows an example of HR (fig 10a), HR-P (Fig 10b), and the relationship between all stations with high rhodolith coverage (>35% of rhodolith coverage, including also the stations with *Peyssonnelias* growing on the carbonate nodules) and the Relative Backscatter Intensity (Fig 10c). Stations with *Peyssonnelia*s are represented in figure 10c by red dots. Most of the stations with *Peyssonnelias* are concentrated below -87.5dB, while most stations with no *Peyssonnelia*s are above -87.5dB (only one HR-P station is located above that value). Thus, the backscatter intensity, in this case, is controlled mainly by the macroalgae presence, and not by the rhodolith coverage.

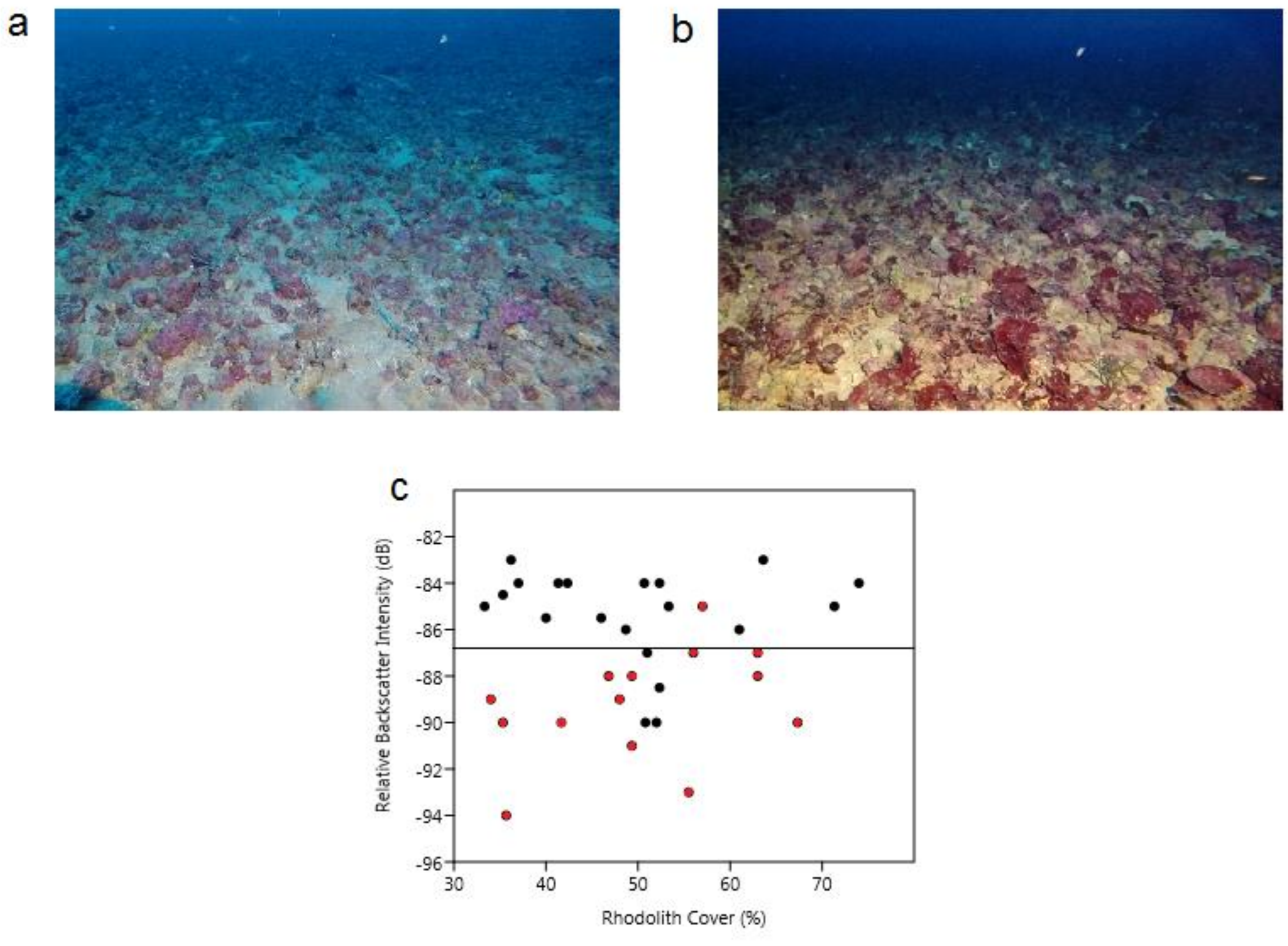


Figure 10 (a) Example of seafloor with HR coverage. (b) Example of seafloor with HR-P. Peyssonnelias are recognized by the dark red color. (c) The graph show the stations with high Rhodoliths Percentage Cover (>35%, including the stations with epiphytes *Peyssonnelias* in

the rhodolith nodules) x Relative Backscatter Intensity (dB). Red dots indicate stations where Peyssonnelias were observed. It is possible to notice that most all stations of HR-P are below 87.5dB, while most stations with no Peyssonnelias are above 87.5dB. It demonstrates the decrease in the backscatter intensity for areas covered by Peyssonnelias.

An example of macroalgae signal attenuation was described by Falco et al. (2010) and Micallef et al. (2012) for the presence of *Posidonia oceanica*. *Posidonia Oceanica* is a seagrass species that is endemic to the Mediterranean Sea. The authors associated the presence of *Posidonia oceanica* with moderate inhomogeneous backscatter. The backscatter intensity is a response of the canopy leaf of the *Posidonia* rather than the substrate on which it grows. We infer that the presence of *Peyssonnelias* lead to an acoustic signal attenuation. The backscatter intensity represents the interaction with the top of the *Peyssonnelia* instead of the percentage of rhodoliths nodules below. This could be related to the acoustic frequency, since high multibeam frequencies do not allow significant penetration of the signal (Micallef et al. 2012).

Another important result of the backscatter segmentation and the habitat classes definition is the recognition of coralline or carbonate concretions, described as BC. These concretions can be formed due to low seabed dynamics, below wave storm action, and far from terrestrial sediment stress (Locker et al. 2010). Encrustation processes led by coralline algae or even sponges can fuse together rhodoliths, forming a carbonate fixed pavement, bringing more complexity to the seabed, as it could be know described as a reef bed. Pereira-Filho et al. (2015) and Amado-Filho et al. (2016) described the occurrence and hypothesize the formation of these crust in Fernando de Noronha Island (NE Brazil) and Atol das Rocas (NE Brazil).

4.2 Rhodolith Beds Heterogeneity in MPA Costa da Algas

The seabed habitat map showed in Figure 9 defines the heterogeneity of the rhodolith beds in the Costa das Algas MPA. Although the study areas represent a small part of the shelf, they encompass a range in water depth from ~44 to 82m deep. So, it was possible to observe changes in rhodolith coverage across a depth gradient. The main driver of the coralligenous algae nodule covarege, in the researcher area, seems to be the morphology of the area. The seabed morphology is marked by the occurrence of paleo-channels separated by regular and irregular flat areas. The paleochannels are characterized by US and no presence of rhodoliths. The flat areas are dominated by HR. The habitat class HR-P dominates in areas deeper than 55m. LR and MR habitat classes are observed closest to the paleo-channel margins, and BC marks the channel edges.

Since rhodoliths are three-dimensional structures, they bring complexity to the seafloor, and are considered "bioengineers" that increase the biodiversity (Arango and Riosmena-Rodríguez 2004; Amado-Filho & Pereira-Filho 2012; Horta et al. 2016). They provide stable substrate for incrusting organisms such as bryozoans, sponges, corals, barnacles, and macro-algae (Villas-Boas et al. 2014; Riosmena-Rodríguez, 2017); shelter and habitat for the infauna and cryptofauna (Steller, et al. 2003); and food and substrate for the icthyofauna (Horta et al. 2016).

The MPA Costa das Algas was created to protecting the habitats and high biodiversity of the region, since the area is known for having a complex submarine relief, housing a large marine biodiversity (IBAMA, 2006). This high biodiversity of the MPA Costas das Algas may be associated to the large rhodolith bed in the mid and outer shelf, which forms heterogeneous habitats of high diversity, that extend along the BCS. Amado et al. (2007) pointed that the rich marine biodiversity in Espírito Santo State is directly associated to the large rhodolith beds located in the Espírito Santo Continental shelf, and defines the rhodolith beds as the most important benthic habitat in the BCS.

Rhodoliths are no renewable resources due to the low growth-rate of about 1 mm year^{-1} (Coletti et al. 2017), vulnerable to global changes (Horta et al. 2016), and are recognized as a potential habitat to bioprospection due to CaCO3 production and the elevated number of algae species and organisms associated (Amado-Filho & Pereira-Filho 2012). They are also threat by anthropogenic activities such as pollution, fishing, oil and mining exploration (Martin et al. 2014; Basso et al. 2017). Even the recent researches have been pointed the importance of rhodolith beds, actions to protect this habitat are still scarce in Brazil. Assessing the rhodolith beds distribution and extent is a key step to incentive public policies to conserve their biodiversity. This research emphasizes the rhodolith bed heterogeneity, and demonstrates an effective tool to detailed map this areas, which can help the management and conservation of existing MPA, and subsidize the creation of new MPAs in vulnerable areas.

4.3 MBSS Backscatter Application to Map Rhodolith beds

MBSS backscatter on its own is not sufficient to accurately infer the seafloor type, since backscatter is a function of diverse factors such as acoustic frequency, incident angle, sediment type, grain size, sediment volume, seabed slope and roughness (Le Bas & Huvenne 2009; Lurton and Lamarach 2015), and may result in ambiguous results. Ground truth is then fundamental to validate and characterize acoustic classes, and it was used to identify the seafloor type, classify the rhodolith coverage into categories, and distinguish similar acoustic classes, as the M-BS associated with MR and the IM-BS associated with HR-P.

One of the main advantages of using MBSS backscatter to benthic habitat mapping is the speed of the survey and its non-destructive methods. MBSS data is collect in a swath width that varies with depth, which makes possible to optimize the time of surveys and cover large areas in high resolution (Hasan et al. 2012). Since there is a lack of knowledge on the extension and distribution of rhodolith bed in BCS (Horta et al. 2016), this methodology can help to effectively fill those knowledge gaps through mapping of these areas.

Collecting backscatter with MBSS has also the advantage of acquiring bathymetric high resolution data together (Brown and Collier 2008). This makes it possible to correct morphology variations in the backscatter data, as seafloor slope can interfere in the return of the signal. Furthermore, bathymetric information helps in the interpretation of the data. Bathymetric derivatives, e.g. curvature, slope, rough, etc., are used in many researches to support habitat mapping (Micallef et al. 2012, Che Hasan et al. 2014; Calvert et al. 2014; Innangi et. al 2018). However, since the purpose of this research was to focus in the result of habitat mapping based in backscatter mosaic, only a visual comparison between the final habitat map with the bathymetric maps was done, which showed that the rhodolith beds are denser in the flatter sea bottom, conforming pointed by Matsuda et al. (2011).

Backscatter mosaic and ground truth data provide a suitable approach for fine-scale mapping of benthic habitats. The rhodolith bed heterogeneity expressed in backscatter can to help further researches to better understanding this important habitat and its high associated ecological diversity.

5. Conclusion

Rhodoliths bring a tree-dimensional habitat feature, which increases significantly the marine biodiversity. Thus, monitoring and mapping of rhodoliths bed is fundamental in order to protect and mitigate possible impacts on their development, and associated marine communities (Martin et al. 2014; Horta et al. 2016).

MBSS acoustic backscatter allowed us to produce high resolution maps of the seafloor to detail calcareous algae nodules distribution across a rhodoliths bed. We identify five types of seafloor related to the presence of crustose coralline algae, represented by three group of rhodoliths coverage (LR, MR and HR), BC and HR-P, and one with no presence of rhodoliths, typified as US. Despite inherent errors associated with vessel derivation during ground truth acquisition, we consider the approach used in this work to have been successful in map rhodolith bed heterogeneity.

The methodology used here is an efficacious tool to adequately map benthic habitats and understand the calcareous algae nodules distribution across a rhodolith bed. It can be used to improve spatial management of marine systems and define key areas for the implementation and monitoring of MPAs.

6. Reference

Amado-Filho, G.M. et al., 2016. Mesophotic ecosystems of the unique South Atlantic atoll are composed by rhodolith beds and scattered consolidated reefs. *Marine Biodiversity*, 46(4), pp.933–936.

Amado-Filho, G.M. & Pereira-Filho, G.H., 2012. Rhodolith beds in Brazil: A new potential habitat for marine bioprospection. *Brazilian Journal of Pharmacognosy*, 22(4), pp.782–788.

Amado, G.M. et al., 2007. Structure of rhodolith beds from 4 to 55 meters deep along the southern coast of Espirito Santo State, Brazil. *Ciencias Marinas*, 33(4), pp.399–410.

Ballantine, D. L., Ruiz H., 2006. Peyssonnelias Imbricata sp. nov. (Peyssonneliacea, Rhodophyta) from Puerto Rico, Caribbean Sea. Botanica Marina 49. pp 431-437.

Basso, D., Babbini, L., Ramos-Esplá, A. A., Salomidi, M. (2017). Mediterranean Rhodolith Beds. Rhodolith/Maërl Beds: A Global Perspective, Coastal Research Library 15, pp: 281-298.

Brasileiro, P.S. et al., 2018. Burial Rate Determines Holocene Rhodolith Development on the Brazilian Shelf. *Palaios*, 33, pp.464–477. Available at: http://dx.doi.org/10.2110/palo.2017.109.

Brown, C.J. et al., 2011. Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. *Estuarine, Coastal and Shelf Science*, 92(3), pp.502–520.

Brown, C.J. & Blondel, P., 2009. Developments in the application of multibeam sonar backscatter for seafloor habitat mapping. *Applied Acoustics*, 70(10), pp.1242–1247. Available at: http://dx.doi.org/10.1016/j.apacoust.2008.08.004.

Brown, C.J. & Collier, J.S., 2008. Mapping benthic habitat in regions of gradational substrata: An automated approach utilising geophysical, geological, and biological relationships. *Estuarine, Coastal and Shelf Science*, 78(1), pp.203–214.

Che Hasan, R., Ierodiaconou, D. & Laurenson, L., 2012. Combining angular response classification and backscatter imagery segmentation for benthic biological habitat mapping. *Estuarine, Coastal and Shelf Science*, 97, pp.1–9. Available at: http://dx.doi.org/10.1016/j.ecss.2011.10.004.

Coletti, G., Basso, D., Frixa, A. (2017) Economic Importance of Coralline Carbonates. Rhodolith/Maërl Beds: A Global Perspective, Coastal Research Library 15, pp: 87-101.

Collier, J.S. & Brown, C.J., 2005. Correlation of sidescan backscatter with grain size distribution of surficial seabed sediments. *Marine Geology*, 214(4), pp.431–449.

Falco, G. De et al., 2010. Relationships between multibeam backscatter , sediment grain size and Posidonia oceanica seagrass distribution. *Continental Shelf Research*, 30(18), pp.1941–1950. Available at: http://dx.doi.org/10.1016/j.csr.2010.09.006.

Fonseca, L. & Mayer, L., 2007. Remote estimation of surficial seafloor properties through the application Angular Range Analysis to multibeam sonar data. *Marine Geophysical Researches*.

Foster, M.S., 2001. Minireview Rhodoliths : Between Rocks and Soft Places 1. , 667, pp.659–667.

Gabriel, D. et al., 2015. The crustose red algal genus Peyssonnelia (Peyssonneliales , Rhodophyta) in the Azores : from five to one species. *Arquipelago - Life and Marine*, 32, pp.1–9.

Gavrilov, A.N., Siwabessy, P.J.W. & Parnum, I., 2005. Multibeam echo sounder backscatter analysis Cooperative Research Centre for Coastal Zone Estuary and Waterway Management. *Cooperative Research Centre for Coastal Zone Estuary and Waterway Management*, 03, p.32.

Gougeon, S. et al., 2017. Mapping and classifying the seabed of the West Greenland continental shelf. *Estuarine, Coastal and Shelf Science*.

Hamilton, L.J. & Parnum, I., 2011. Acoustic seabed segmentation from direct statistical clustering of entire multibeam sonar backscatter curves. *Continental Shelf Research*.

Hasan, R.C., Ierodiaconou, D. & Monk, J., 2012. Evaluation of Four Supervised Learning Methods for Benthic Habitat Mapping Using Backscatter from Multi-Beam Sonar. , pp.3427–3443.

Hetzinger, S. et al., 2006. Sedimentology and Acoustic Mapping of Modern Rhodolith Facies on a Non-Tropical Carbonate Shelf (Gulf of California, Mexico). *Journal of Sedimentary Research*, 76(4), pp.670–682. Available at: http://jsedres.sepmonline.org/cgi/doi/10.2110/jsr.2006.053.

Hinojosa-arango, G. & Riosmena-rodrıguez, R., 2004. Hinojosa-arango, Riosmena-Rodríguez, 2004. Influence of Rhodolith-Forming Species and Growth-Form on Associated Fauna of Rhodolith Beds in the Central-West Gulf of California , 25(2), pp.109–127.

Horta, P.A. et al., 2016. Rhodoliths in Brazil: Current knowledge and potential impacts of climate change. *Brazilian Journal of Oceanography*, 64(Special Issue 2), pp.117–136.

Huang, Z. et al., 2013. Predictive mapping of seabed cover types using angular response curves of multibeam backscatter data: Testing different feature analysis approaches. *Continental Shelf Research*.

Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renováveis - IBAMA. Relatório Final da Proposta de Criação das UC's APA Costa das Algas e REVIS de Santa Cruz. Vitória, 2006. Volumes I, II, III, IV e V. Anexos de 1 a 29.

Innangi, S. et al., 2018. Seabed mapping in the Pelagie Islands marine protected area (Sicily Channel, southern Mediterranean) using Remote Sensing Object Based Image Analysis (RSOBIA). *Marine Geophysical Research*, 0(0), p.0. Available at: http://dx.doi.org/10.1007/s11001-018-9371-6.

Kloser, R.J., Penrose, J.D. & Butler, A.J., 2010. Multi-beam backscatter measurements used to infer seabed habitats. *Continental Shelf Research*.

Kohler, K.E. & Gill, S.M., 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology $. , 32, pp.1259–1269.

Lamarach, G. & Lurton, X., 2018. Recommendations for improved and coherent acquisition and processing of backscatter data from seafloor-mapping sonars. *Marine Geophysical Research*, 39(1–2), pp.5–22.

Le Bas, T.P. & Huvenne, V.A.I., 2009. Acquisition and processing of backscatter data for habitat mapping - Comparison of multibeam and sidescan systems. *Applied Acoustics*, 70(10), pp.1248–1257. Available at: http://dx.doi.org/10.1016/j.apacoust.2008.07.010.

Locker, D. S., Armstrong, R. A., Battista, T. A., Rooney, J. J., Sherman, C., Zawada, D. G., 2010. Geomorphology of mesophotic Coral Ecosystems: Current Perspectives on Morphology, Distribution, and Mapping Strategies. Coral Reefs 29, pp: 329-345.

Lurton, X. and Lamarach, G. 2015. Backscatter mesurments by seafloor-mapping sonar Guidelines and Recommendations. *Studies in Computational Intelligence*, (May), p.200p. Available at: http://geohab.org/wp?content/uploads/2014/05/BSWG?REPORT?MAY2015.pdf%255CnCover.

Mair, E., Parnum, I. & Schut, T., 2012. Using multibeam echo-sounder backscatter to characterise the seafloor of Davis Harbour, Antarctica: preliminary results. *Australian Acoustical Society*, pp.21–23.

Martin, C.S. et al., 2014. Coralligenous and maërl habitats: Predictive modelling to identify their spatial distributions across the mediterranean sea. *Scientific Reports*, 4, pp.1–9.

Matsuda, S., Iryu, Y. & I-, H.I., 2011. Rhodoliths from deep fore-reef to shelf areas around Okinawa-jima , Ryukyu Islands , Japan. *Marine Geology*, 282(3–4), pp.215–230. Available at: http://dx.doi.org/10.1016/j.margeo.2011.02.013.

Micallef, A. et al., 2012. A multi-method approach for benthic habitat mapping of shallow coastal areas with high-resolution multibeam data. *Continental Shelf Research*.

Monteys, X. et al., 2016. The use of multibeam backscatter angular response for marine sediment characterisation by comparison with shallow electromagnetic conductivity. *Applied Acoustics*.

Moura, R.L. et al., 2016. An extensive reef system at the Amazon River mouth - Supplementary Material. *Science Advances*, 2(4), pp.e1501252–e1501252. Available at: http://advances.sciencemag.org/content/2/4/e1501252.abstract.

Parnum, I.M. et al., 2006. Analysis of High-Frequency Multibeam Backscatter Statistics From Different Seafloor Habitats. *Eighth European Conference on Underwater Acoustics, 8th ECUA*, p.6.

Pereira-Filho, G.H. et al., 2015. Sponges and fish facilitate succession from rhodolith beds to reefs. Bulletim Marine Science 91 pp.45-46.

Riosmena-Rodrígues, R., 2017. Natural History of Rhodolith/Maerl Beds: Their Role in Near-Shore Biodiversity and Management. Rhodolith/Maërl Beds: A Global Perspective, Coastal Research Library 15, pp: 2-26.

Sañé, E. et al., 2016. Environmental factors controlling the distribution of rhodoliths: An integrated study based on seafloor sampling, ROV and side scan sonar data, offshore the W-Pontine Archipelago. *Continental Shelf Research*, 129(September), pp.10–22. Available at: http://dx.doi.org/10.1016/j.csr.2016.09.003.

Steller, D.L. & Foster, M.S., 1995. Environmental factors influencing distribution and morphology of rhodoliths in Bahía Concepción, B.C.S., México. *Journal of Experimental Marine Biology and Ecology*.

Steller. D.L., Riosmena-Rodríguez. R, Foster M. S., Roberts C.A., 2014. Rhodolith Bed Diversity in the Gulf of California: the Importance of Rhodolith Structure and Consequences of Disturbance.Aquatic Conservation: Marine and Freshwater Ecosystems. Vol 13, Issue S1.

Villas-Boas, A.B., Riosmena-Rodriguez, R. & de Oliveira Figueiredo, M.A., 2014. Community structure of rhodolith-forming beds on the central Brazilian continental shelf. *Helgoland Marine Research*, 68(1), pp.27–35.

Wright, D.J. & Heyman, W.D., 2008. Geomorphometric patterns of Nassau grouper (Epinephelus striatus) spawning aggregation sites in the Cayman Islands. *Marine Geodesy*, 31(4), pp.231–245.