Bottom type mapping of the Abrolhos Coral Reef Bank using high resolution WorldView-2 satellite imagery

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Abstract. In this work we present a bottom type mapping produced from high spatial resolution remote sensing data for the Marine National Park in the Abrolhos Coral Reef Bank (ACRB). Imagery of the WorldView2 (WV02) orbital sensor, concomitant with field observations, was used. The imagery was passed through routines of geometric and atmospheric correction, and ws also corrected for sunglint and water column interference. Due to limitations in water column corrections, bottom reflectance was used only at 478 nm. The resulting map had an accuracy of 88.2% with a Kappa index of 0.8 was considered satisfactory for the four thematic classes used: Reef, Sand, Macroalgae, and Inter-reef areas. The isolated reefs, locally known as *chapeirões,* covered an area of approximately 22 km^2 that corresponds to 12.4% of the total area. *Chapeirões* were distributed in almost all the studied area, formed by patches with different sizes and concentration of reefs. Macroalgae constituted the most abundant benthic functional type in the scene and concentrated around the Archipelago and inter-reef areas. Further work regarding a more extensive *in situ* data collection to conclusively describe the benthic communities and their spectral behavior, as well as water column constituents and bathymetric surveys are recommended to improve satellite mapping of the bottoms types in the ACRB. More ground control points are still required for a more robust validation of the bottom type map.

Palavras-chave: ocean-color remote sensing, bottom reflectance, water column correction, chapeirões, sensoriamento remoto da cor do oceano, reflectância de fundo, correção da coluna de água.

1. Introduction

Remote sensing represents an efficient and complementary tool for field studies. As for terrestrial areas, in reef ecosystems it provides data acquisition with the best cost-benefit relation, because it allows synoptic monitoring in extensive areas, including places with difficult access (Mumby et al., 1999). Mapping of reefs offers important information for the management of these ecosystems, both to examine reef structure and resource inventory and also for the estimation of ecological functions (Yamano, 2013).

The Abrolhos Coral Reef Bank (ACRB), Brazil, extends 60 km, along the coastal zone and is considered the largest and richest coral reef area in the South Atlantic Ocean. The biologic relevance of this area boosted the creation of the first Marine National Park in Brazil in part of the ACRB, besides being an environmental protected area and a marine extractive reserve. In spite of the elapsed time since the first application of remote sensing in coral reefs in the 1970's, only a few works have used this type of data to map submerged benthic substrates in the ACRB (e.g. Moreira, 2008). These works were focused in coastal reefs, but no mapping of the bottom substrate has yet been done inside the Marine National Park. The aim of the present work was to produce a bottom type map in the Marine National Park of the ACRB, using a WorldView-2 (WV02) high resolution satellite image.

2. Materials and Methods

2.1. Study area

The coral reefs encompasses the area between coordinates 17°54'9.38"/18°3'22.71"S and 38°35'43.25"/38°45'38.17"W, located at approximately 60 km from the Brazilian Eastern coast (Figure 1). It corresponds to a portion of the Marine National Park in the ACRB. The type of growth in structures called “chapeirões” characterizes the geomorphology of the reefs in the area. Such structures are vertical columns and their shapes are similar to mushrooms with circular or elongated tops, whose diameters vary between 20 to 300 m (Leão, 1999). The area also includes the Abrolhos Archipelago, which is composed of small islands.

Mainly cnidarians and seaweeds dominate the benthic community in ACRB. Comparing with other coral reefs worldwide, the cnidarian fauna of ACRB is characterized by low diversity, high degree of endemism and absence of branching scleractinian. Sedimentation rates in the ACRB are relatively higher than in other reef areas (Segal-Ramos, 2003) and this is responsible for its biologic characteristics (Leão, 1999). The algae populations constitute one of the most abundant elements in the ACRB, and are found throughout the entire reef ecosystem.

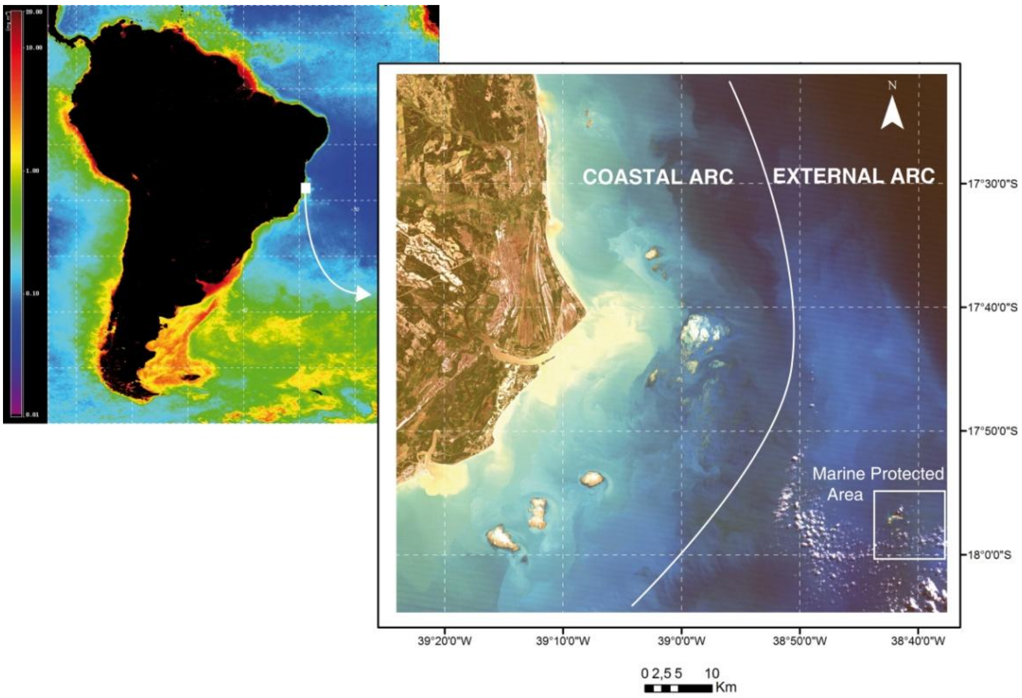

Figure 1. Landsat TM-5 image (RGB) of the ACRB(right). Inside this, the white square shows the area encompassed by the WV02 image. Location of the ACRB in South America, indicated in a MODIS-Aqua Chlorophyll image (left).

2.2. Remote sensing data and pre-processing steps

The WV02 image was acquired on 02/14/2012 at 10:06 local time, concomitantly with a field campaign. The WV02 sensor collects radiance in 5 spectral bands in the visible and 3 in the Near Infrared (NIR) region with a nominal spatial resolution of 2 m.

The pre-processing steps consisted of:

(i) Image geo-referencing through the numeric model Rational Function using PCI Geomatica 2013 software;

(ii) Atmospheric correction using the ATCOR2 package assuming a flat terrain, maritime aerosol type and tropical condition. Visibility and adjacency effects were set as 43 and 0.18 km, respectively;

(iii) Sunglint correction following the method proposed by Hedley et al. (2005);

(iv) Water column correction to obtain the bottom reflectance using the Maritorena et al.'s algorithm (1994) (Equation 1).

$$\frac{R(0^-)-R_\infty(0^-)}{e^{-2K_d z}} + R_\infty(0^-) = \rho_{b\ retrieved} \tag{1}$$

where $R(0^-)$ and $R_\infty(0^-)$ correspond to below-water reflectance of shallow and deep waters, respectively. K_d is the diffuse attenuation coefficient and z is the depth. $R_\infty(0^-)$ was obtained from the average between samples of pixels extracted from the image in deep-water areas. The K_d used for each band, was obtained from *in situ* data measured during field campaigns in the austral summer of 2012 and 2013. Bathymetric information for all pixels in the WV-02 image was derived from remote sensing data using the algorithm proposed by Stumpf et al. (2003). This algorithm can be applied over non-homogeneous bottom types since the reflectance ratio in two wavelengths compensates for variations in the bottom reflectance. The algorithm was adapted to the study area (Equation 2) using water reflectance at 478 and 546 nm ($\rho_{w,478}$ and $\rho_{w,546}$, respectively) and *in situ* bathymetric data at 135 points distributed over the WV02 scene.

$$z = 56.279\frac{ln(500\rho_{w,478})}{ln(500\rho_{w,546})} + 59.9808 \tag{2}$$

Pixels were masked out when retrieved-bathymetry >12 m or when the water column correction algorithm retrieved values lower than 0 or higher than 1.

2.3. Bottom type mapping

After applying the water column correction to the WV02 image, the band at 478 nm showed the higher number of valid pixels (67.8%) in comparison to the other bands. Following this, the classification scheme used to produce the bottom type map of the ACRB was applied to this band. Even though spectral information was lost using only one band, the adopted criterion was to prioritize the spatial extension of the bottom type map able to be produced with the quantity of classes discriminated with the 478 nm band.

Four classes were considered based on image interpretation and field work. The classes were: (i) Sand: sand areas and sometimes also including sparse algae or seagrass; (ii) Macroalgae: dominated by different types of algae (brown, red or green) and, in some cases, also included exposed sand or rocks in low proportion; (iii) Reefs: different benthic communities located above the *chapeirões*, with a mixture of coral, macroalgae, sponge, calcareous algae and Zoanthids, in different percentages; and (iv) Inter-reef areas: located around the *chapeirões* and included Sand, Sediments, Macroalgae, Algal Turf and Rhodoliths, in different proportions.

The mapping was performed using an Object-Based Image Analysis (OBIA) approach with eCognition software. An image segmentation process was developed in several steps. First, a multi-resolution segmentation was made to separate sand from inter-reef areas, empirically defining an upper threshold for reflectance values between 0.16 - 0.19 for different subsets of the scene with variable size. The Scale Parameter, which determines the size of individual segments, varied between 50 and 100. Then, a multi-resolution segmentation was made to identify small reefs, defining a lower threshold for reflectance values between 0.18-0.15. Here the Scale Parameter varied between 10 and 50. In every subset, the higher threshold value used to identify sand segments was always higher than the lower threshold value used to identify reef areas.

The classification process was performed using objects that were assigned manually to different classes according to their reflectance values and sizes. Sand areas presented the highest reflectance values, and macroalgae, the lowest. Threshold values were defined according to the behavior of each feature in different subsets of the image. Maximum reflectance values in inter-reef areas were found in the center of the scene, coincident with the shallowest area in the bathymetric map. In some occasions, a threshold in the object size was also delimited (50 to 300 pixels for reef areas, p. ex.).

In situ taxonomic information of the benthic communities collected at 34 sites was used for the map validation. These locations were sampled during two surveys in February/2012 and March/2013. The accuracy assessment of the bottom type map was obtained through a standard confusion matrix (Congalton; Green, 1999). Accuracy of the user, producer and Kappa index were also calculated.

3. Results and Discussion

One of the main challenges for the submarine bottom type mapping presented in this work was the water column correction procedure. Unsuccessful retrievals of bottom reflectance in several WV02 bands relied in the lack of adequate input data. The main reasons accounting for this underperformance were mostly the uncertainties associated with and bathymetry derived from the Stumpf et al.'s algorithm (RMSE 2.1 m).

Figure 2 depicts the bottom type map produced from the WV02 scene. The inter-reef class was the most abundant, totalizing 129 km^2 that corresponds to 73.1% of the total mapped area, followed by reefs, sand and macroalgae classes (Table 1). It does not mean that macroalgaes were restricted only to 4.4 % of the area, but that they were the dominant group in these areas. In fact, macroalgaes were also present in the other three classes of bottom type and this group is probably the most representative in all substrates of the ACRB. Inter-reefs areas are relevant from the ecologic point of view since rhodolith beds are located in these areas (Amado-Filho et al., 2012). Inter-reefs areas, sand patches and reefs were the main features found in the study area and matches with findings showed by Amado-Filho et al. (2012).

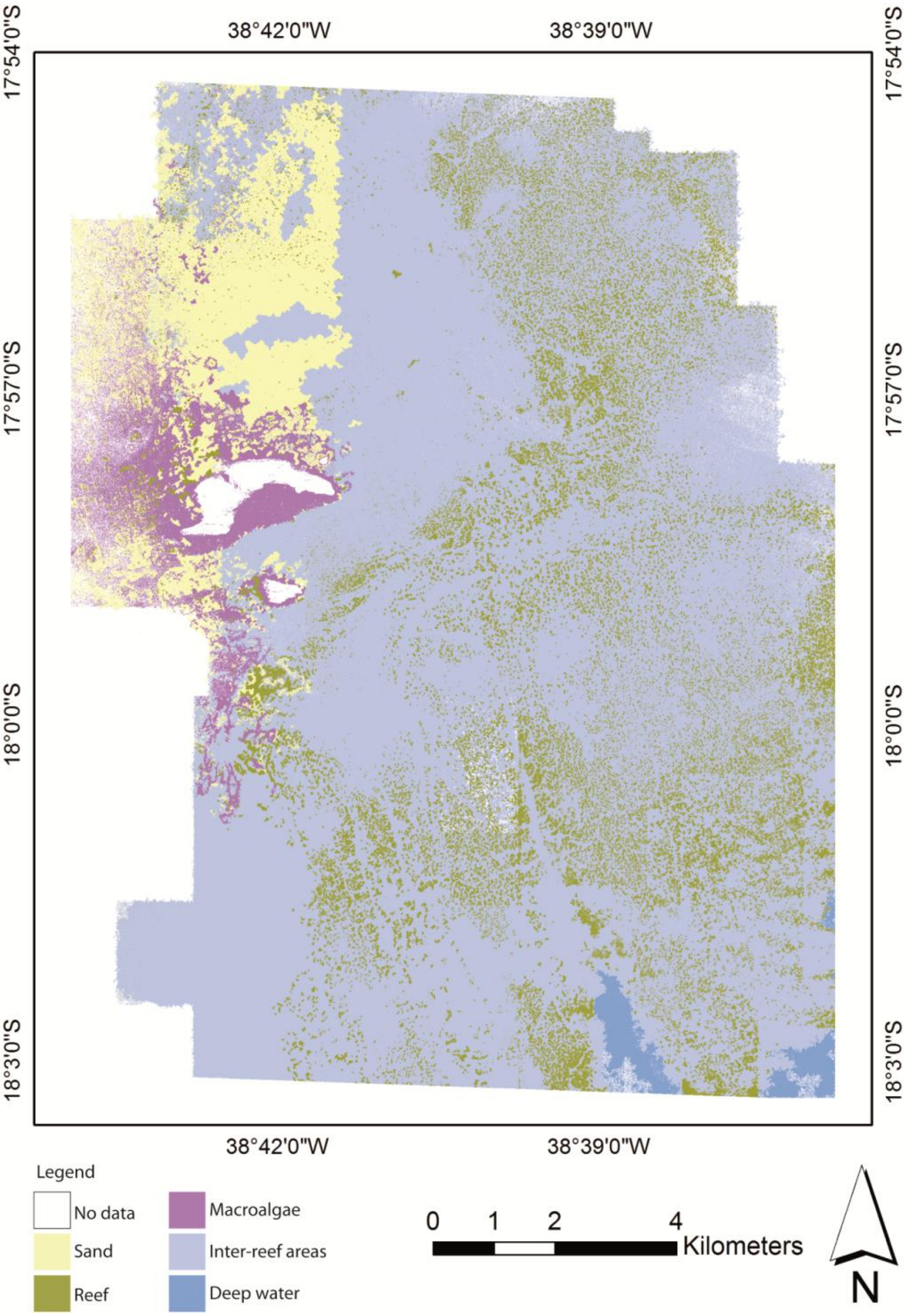

Figure 2. Bottom type map of the ACRB produced from the WV02 image collected in February/2012. The "No data" class includes also land areas.

Table 1. Area and percentage of occupation of each class of bottom type

	Reef	Inter-reef areas	Macroalgae	Sand	Deep water
Area (km^2)	21.9	129.6	7.8	15.8	2.1
Area (percentage)	12.4	73.1	4.4	8.9	1.2

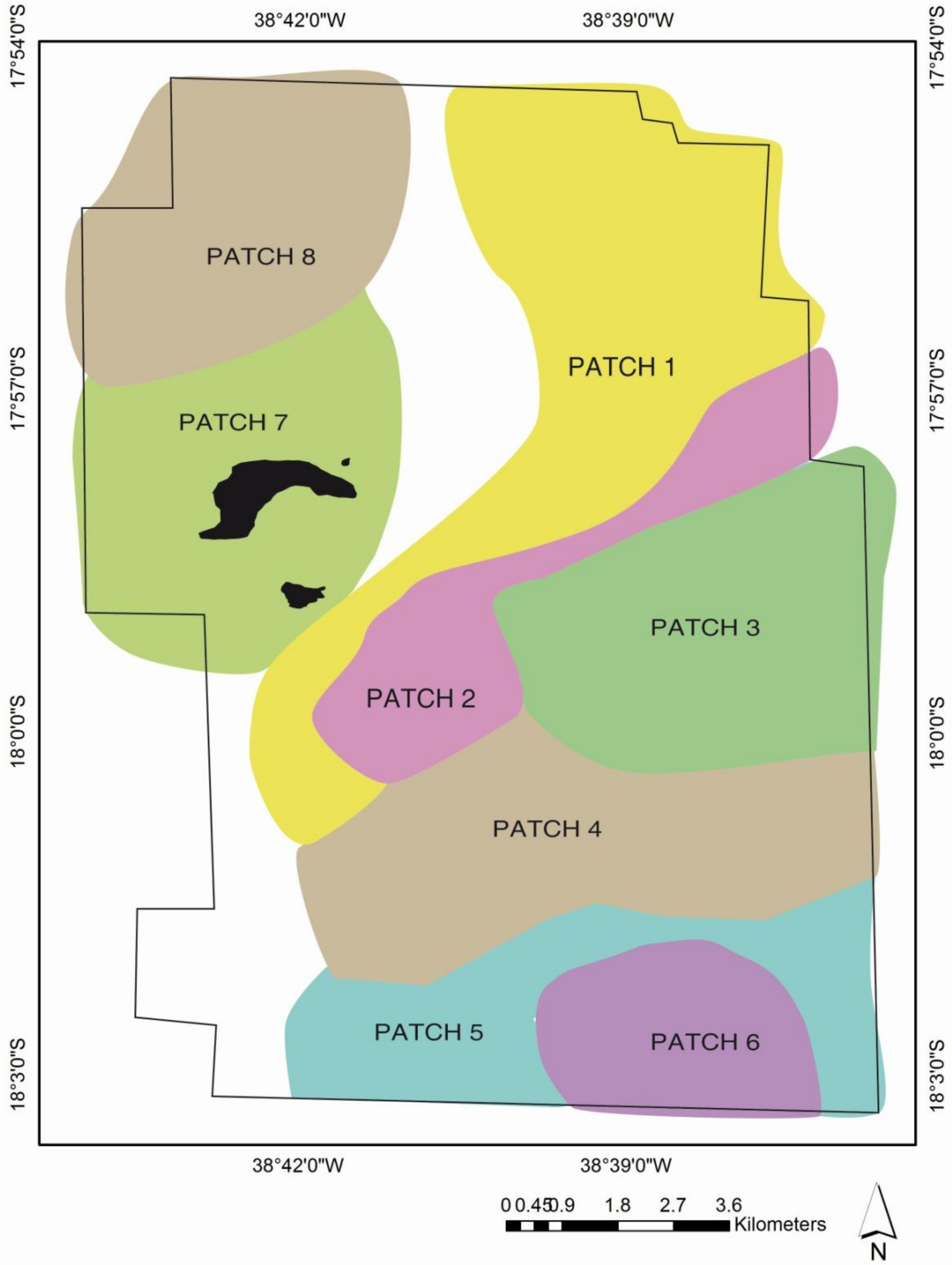

Figure 3. Patches with different patterns of spatial distribution of coral reefs in the ACRB.

This work shows the first map produced for the Marine National Park of ACRB, where the distribution of the reefs and the quantification of the area occupied by them are shown. The isolated reefs were spatially distributed in patches with different abundance among them. To facilitate the identification of these interspersed patches, Figure 3 shows their location according to a visual inspection. From the Archipelago towards the east, a broad area with high concentration of reefs disposed in shape of an arc can be observed (Patch 1). Inside this arc, reefs were larger compared to other parts of the map and several of them were so close to each other that they seemed to be merged. Southwestward to this arc there was a narrow channel with scarce *chapeirões* that encircles Patch 1 (Patch 2). Patch 3 located south of Patch 2, was characterized by small spaced reefs, followed by another area where *chapeirões* were once again very frequent (Patch 4). Some thin cracks with a NW-SE direction were also present in Patch 4. Another area with scarce reefs was Patch 5, and in the southeast portion, Patch 6 with a lot of reefs was identified. From the islands to the northern sector, an area with large reefs scarcely distributed and inter-spaced with macroalgae and sand was identified as Patch 7. In the northeast portion of the map, small reefs were homogeneously distributed in low frequency (Patch 8).

The accuracy achieved for the bottom type map was relatively high, with an overall accuracy of 88.2 % and a Kappa index of 0.8 (Table 2). The main confusions were between reef and inter-reef areas and between macroalgae with reef or sand. In the North of the islands, near the center of the map, a disruption in the sand class was observed. This abrupt delimitation of the class does not seem a natural feature, but an artifact of the imagery. A vertical stripe was coincident with the delimitation of the sand class, thus, a radiometric problem could probably be responsible for this discontinuity. During our two field works, this wide area of sand, northern to the Archipelago, was not visited and there are no records of the bottom type, both for training or validation. This area was classified as sand according to the higher reflectance values compared with the neighbor areas and similar reflectance values found in specific features visited near the islands. Other areas with interesting features that were mapped in the northwest of the scene, could not be validated in this work due to the lack of field work information. A greater number of validation points, better distributed in the entire scene is required for a more robust validation. The spectral ravel of benthic communities in the ACRB, the quantity of points used for validation and the availability of only one spectral band after the water column correction, were responsible for the simplicity in the definition of only 4 classes of bottom type. It is expected that a more exhaustive inspection in the field will provide not only a more robust accuracy assessment, but also the accomplishment of a more detailed map, with a higher number of classes.

Table 2. Confusion matrix for the classified WV02 image. The overall accuracy and Kappa index are also provided

		Real Substrate					
		Reef	Sand	Inter-reef	Macroalgae	Row Totals	Producer accuracy
Assigned class	Reef	14	0	1	0	15	93.3%
	Sand	0	1	0	0	1	100.0%
	Inter-reef	0	0	2	0	2	100.0%
	Macroalgae	2	1	0	13	16	81.3%
	Column Totals	16	2	3	13	34	
	User accuracy	87.5%	50.0%	66.7%	100.0%		
	Overall accuracy:	88.2%					
	Kappa index:	0.8					

4. Concluding remarks

The bottom characteristics of the Marine Protected Park within the ACRB, was inspected for the first time using a high spatial resolution remote sensing image Due to the spectral confusion of the benthic communities and the low performance of the water column correction applied to the image, a reduced number of thematic classes was chosen for the bottom type mapping. The isolated reefs covered an area of ~22 km^2 that corresponded to 12.4% of the total area. *Chapeirões* were distributed in almost all the studied area, formed by patches of different bottom types, covering different areas. Macroalgae was the most abundant functional type, and was concentrated around the Archipelago and in inter-reef areas. A greater number of ground points are needed for a more robust map validation and should be collected in further works, covering all the area imaged by the WV02 sensor at the ACRB. Building a comprehensive *in situ* data base covering the ACRB, further works may improve benthic type mapping using high resolution imagery for ecosystem functioning studies, to monitoring environmental changes and for management strategies of the Marine Park.

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