Benthic habitat mapping at Recife de Fora, Brazil: Imagery and GIS

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Abstract. The coast of the State of Bahia, in Brazil hosts the largest and richest reef systems of the South Atlantic. A mapping effort was conducted to produce detailed bathymetry, high-(spectral, spatial and digital)-resolution imagery, and benthic habitat classification. Scuba-based ecological census was conducted at sixty sites for ground-truthing. Observations logged included substrate type, species or functional groups of Cnidaria (Anthozoa and Hidrozoa Classes), and functional groups of flora. A visual estimate of coverage areas was provided in a semi-quantitative hierarchy. High-definition videography and photography, as well as sediment and foraminifera sampling were also carried out. RGB triplets highlight WorldView 2's Coastal Blue Band capable of penetrating the water column. The Quick Bird scene was used for comparison and in decorrelation stretch. Heads-up, on-screen photo-interpretation over select RGB triplets generated polygons in the GIS. The processing took into consideration the geomorphology, interpreted from a bathymetry dataset and its derivatives (selected isobaths, hillshade, classified slope), as well as a generalized Inverse Distance Weighed model of the predominant bottom type compiled from the scuba-based videography-and-field-book database stored in the GIS. The resulting classification scheme used three basic attributes to describe each mapped polygon. Coral cover is generally low in the shallower water and increases with water depth. The offshore geology is predominantly composed of smooth compact sediment. Still, coral or accreted carbonate reef totally obscure the underlying geology.

Key words: WorldView 2, GIS, Habitat Mapping, Coral Reef.

Introduction

Coral reefs are an essential part of the earth's ecosystem, the most biologically diverse in the marine realm. They are economically important, providing people around the globe with food, medicines, jobs, coastal storm protection, recreational opportunities, etc. The world's reefs are sensitive indicators of the health of marine environments, and many reefs have been severely damaged over the past few decades. The causes of damage include habitat destruction, land-based pollution, sedimentation, overfishing, vessel groundings, coastal development, disease, and climate change.

Brazil's coasts have the only coral reefs in the South Atlantic, and these reefs are in relatively good conditions. Southern Bahia is the home of the largest and richest reef systems of Brazil (Fig. 1). Coral Vivo ("Living Coral") is a research and educational project that concentrates actions on Parque Municipal Marinho do Recife de Fora (hereinafter referred to as Recife de Fora, Outer Reef, or the Park), a 20 km² patch reef area that lies 5 km offshore from Porto Seguro, a major tourist destination. Recife de Fora has great diversity in corals, including at least three coral species endemic to the South Atlantic. As a marine protected area since 1997, Recife de Fora provides a visitation program permitting up to 400 visitors per day. A key aspect in its conservation management is mapping its coral reef system and benthic habitat, which is the main focus of the work presented in this paper.

Material and Methods

Bathymetry

While a previously available nautical chart is sufficient for navigation (Electronic Nautical Chart "Baías Cabrália e Porto Seguro", # 120501, DHN 2007, Fig. 1), a more detailed bathymetry dataset is necessary for geomorphological interpretation.

To develop a desired bathymetry model for Recife de Fora, in June 2007, a 13-day sea-going survey was conducted along 109 parallel east-west 4 km-long lines, totaling ~440 km, spaced every 50 m. The reefs, which are exposed at low tides, were surveyed using a two-beam echo sounder (50-200 kHz) coupled to a DGPS aboard a small 6-m boat over the reef during high tides. The sounder was set to average readings

every 10 m. Tide-corrected 10 m average water depths were recorded along with coordinates, totaling 41,266 data points. The average positional error was 8.7 m, or 15.0 m at 95% confidence level.
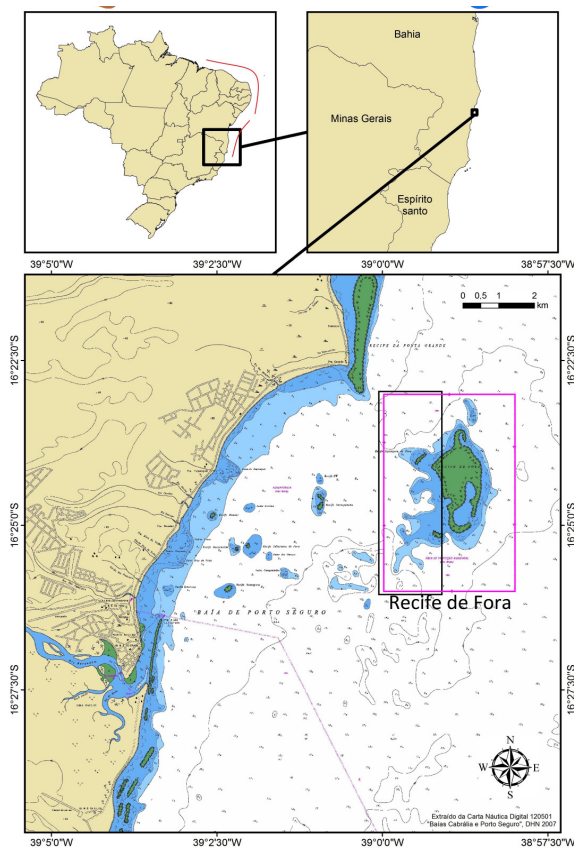

Figure 1: Location maps of Brazil (upper-left, coral reef occurrence marked by the red lines), the State of Bahia (upper-right), and an excerpt from the Electronic Nautical Chart "Baías Cabrália e Porto Seguro". # 120501 (DHN 2007). The boundary of the protected "Parque Municipal Marinho do Recife de Fora" and the study area are marked by the magenta and black boxes, respectively.

Bathymetry interpolation was conducted based on a Multiquadratic Radial Basis Function, with a 4x1 N-S anisotropy factor achieving the best model, from which aspect and slope maps were derived (Seoane et al. 2010a).

Mapping the physiography of the Park area was the first step in understanding the reef system, resulting in the production of a Physical Atlas at the 1:15.000 scale for the Secretary of the Environment of the city of Porto Seguro and for project use (Seoane et al. 2008a).

GIS Database
An early-afternoon Quick Bird image of the Park area at high tide (~1.5 m, average for the area and similar to the tidal conditions during the bathymetry survey described earlier), obtained for August 18th, 2006, was next integrated into the growing GIS database. Integrated with bathymetry and annotated for historical names of the places within the reef, with the help of local fishermen, a poster was produced for the population and state and local tourist agencies (Seoane et al. 2008b). Data are stored in projected UTM coordinates, Zone 24S, using the WGS-84 datum.

Field Effort
The GIS was then used to determine an array of diving sites, arranged in a regular grid of stations spaced 400 m apart over the area, with additional stations placed every 400 m along the reef edges (calculated as areas of high declivity from the bathymetry), thus encircling the reefs (Seoane et al. 2010b). The first array was aimed to acquire regularly-spaced information from field survey and the second to highlight diversity.

For each of a total of 234 stations in the Park area, scuba diving has been used for ecological census of the reef along a 20 m x 3 m transect, which is annotated on a spreadsheet that considers the functional groups within the reef community. To date, 144 of the 234 stations have been surveyed. The first observation pertains to the substrate type (loose sediment, coral reef, seagrass, macroalgae, etc.). Next, species or functional groups are surveyed, pertaining to Cnidaria including species from the Anthozoa Class (Octocorallia and Hexacorallia subclasses) and the Hidrozoa Class (Milleporidae Family), and functional groups of flora. A visual estimate of coverage areas is provided in a semi-quantitative hierarchy (rare-sparse, common, 1-5%, 5-25%, 25-50%, and over 50% of the coverage area). High-definition videography and photography, as well as collection of sediment (analyzed for grain-size and DRX mineralogy, Seoane et al. 2010b) and foraminifera (FI, Amphistegina distribution, health assessment) are also carried out. In order to minimize the temporal bias, station sampling is carried out randomly in clusters of three.

Digital Image Processing
The WorldView 2 scene was acquired for the early-afternoon of December 23rd, 2009, at a lower tide condition (~1.0 m, or a half-meter lower than the high tide condition of the Quick Bird image described earlier). WorldView 2 RGB triplets (a combination of any three given bands in the display monitor or printer) containing the new WorldView 2 "Coastal Blue" band, were used in this work. The "Coastal Blue" band is capable of penetrating the water column, and was assigned to the Blue channel of the triplet.

Table 1 highlights the sensor's bands. RGB 321, 421, and 531 were tested.

A very simple shift of 20.0 m west by 1.0 m north was carried out to dovetail the out-of-the-box WorldView 2 mosaic to the previously described database. The intersection among the WorldView 2 and Quick Bird scenes and the detailed bathymetry defined a study area (Fig. 1) of 9.5 km^2, within the Park, including 60 dive-sites for ground-truthing.

The RGB 321 (Red, Green, Blue) triplet of Quick Bird scene discussed previously is used for comparison with select WorldView 2 triplets and for decorrelation stretch.

Band Name	Center Wavelength (nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)
Panchromatic*	625	450	800
1 (Coastal Blue)	425	400	450
2 (Blue)	480	450	510
3 (Green)	545	510	580
4 (Yellow)	605	585	625
5 (Red)	660	630	690
6 (Red Edge)*	725	705	745
7 (NIR 1)*	835	770	895
8 (NIR 2)*	950	860	1040

*: not used in this work.

Table 1: WorldView 2 Spectral Band Edges and Center Wavelengths (Digital Globe, 2011).

Photo-interpretation
Heads-up, on-screen direct 1:2,500 - 1:5,000 scale photo-interpretation over a back-and-forth shifting of selected RGB triplets generates polygons in the GIS. This is accomplished by: (A) turning the desired layer on (e.g. raster image RGB 321), (B) photo-interpreting the desired feature, by drawing a polygon representing it on the appropriate theme, (C) turning the layer off, (D) turning another layer on (e.g. raster image RGB531), (E) checking the photo-interpretation against the new data, and adjusting the polygon drawn in (B) as necessary, (F) turning on the next layer of data to be used, and (G) repeating the process until a satisfactory interpretation is reached.

These take into consideration the geomorphology, interpreted from the bathymetry and its derivatives (selected isobaths, hillshade illuminated at N45W/45[o,] classified slope, see Seoane et al. 2008a), as well as a generalized Inverse Distance Weighed model of the predominant bottom type compiled from the scuba-based videography-and-field-book database stored in the GIS (Fig. 2).

Results

Benthic Habitat Classification
Polygons were classified based on photo-interpretation of the alternating GIS layers aided by the ground-truth data (field observations, field survey spreadsheets, high definition videography and photography). Classification followed a scheme modified from Mumby and Harborne (1999) and Gibbs and Cochran (2009), although no additional digitizing extension was employed. We adapted the scheme with input from coral reef scientists, managers, and local experts, as proposed by the aforementioned authors.
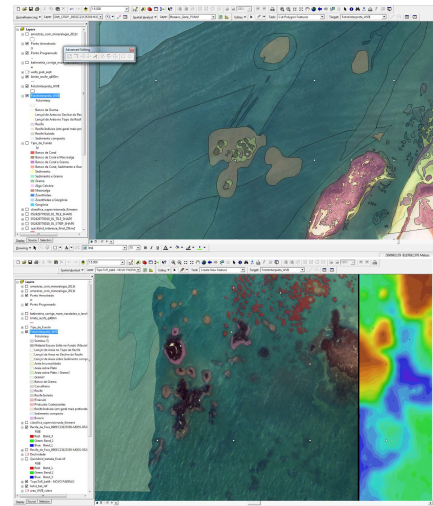

Figure 2: Compilation and classification of benthic habitat polygons. WorldView 2 RGB 321 as the background in the top panel, with bathymetry highlighted on the right part of the bottom panel.

Modifications to the classification scheme improved the characterization of the local benthic habitats. The resulting classification scheme used three basic attributes to describe each mapped polygon: (A) major structure of the substrate; (B) dominant structure (a subset of the major structure); and (C) major biologic cover found on the substrate.

The hierarchal scheme allows users to expand or collapse the level of thematic detail as necessary. Structure combined with the overlying biologic cover comprises the "habitat," and each polygon was coded with a 3-digit identifier (ABC) that reflected the combination of the individual habitat components (Table 2). If a polygon included two or more substrate or coverage types, the polygon was identified with the dominant one.

Five hundred and forty six (546) polygons cover the 9.5 km^2 study area. Minimum mapped area was 10 m^2, while maximum was 2,038,265 m^2 (mean: 18,940 m^2, standard deviation: 139,200 m^2).

A	Major Structure	B	Dominant Structure
1	Unconsolidated Sediment	1	Mud
		2	Compact Sediment
		3	Sand Waves over Compact Sediment
		4	Sand over Lower Reef Slope
		5	Sand over Upper Reef Slope
		6	Sand over Reef Plateau
		7	Sand over Reef Top
		8	Sand Patch
2	Reef	1	Deep, Undifferentiated Reef
		2	Individual Patch Reef – Cabeço (*M.Cavernosa*)
		3	Coalescent Patch Reef – Cabeços (*M.Cavernosa*)
		4	Reef Ruble
		5	Isolated Aggregate Reef – Pinnacle
		6	Main Aggregate Reef
		7	Dark Reef Top
3	Other	1	Shadow / Unknown
		2	Burrow / Hole / Pockmark
		C	**Major Biologic Cover**
		0	Unknown
		1	Uncolonized
		2	Macroalgae
		3	Seagrass & Macroalgae
		4	Coralline Algae
		5	Coral & Octocoral
		6	Gorgonia
		7	Zooanthidean

Table 2: List of individual habitat components in the classification scheme. Numbers represent a 3-digit identifier (ABC).

Discussion

Coral cover is generally low in shallower water and increases with water depth in the study area. The offshore geology is predominantly composed of smooth compact sediment. Still, coral or accreted carbonate reef totally obscure the underlying geology.

The unique aspect of this study is the integration of truly high resolution (spectral, spatial and digital) remotely-sensed and ground-truth data sets to map coral reef habitat. The additional Coastal Blue Band greatly enhances visual interpretation. The well-established technique of photo-interpretation, along with old-fashioned, carefully kept field-diving spreadsheets, modern high definition video- and photography, and high-tech, low-cost bathymetry surveys, all within the GIS provide a powerful mapping tool.

Even though computer-based classification should detect the same reef features, and it might be argued that it could lead to a more objective classification of reef features, most reef mapping projects require subsequent contextual editing by the user, thus diminishing the time gains. The extra detail available from the new satellite bands could make a strong case for using computer-based classification, and should also be tested. Nevertheless, as shown here, a high-resolution digital image is also amenable to photo-interpretation, by carefully constructing selected RGB triplets. The method does require considerable interpreter experience, but so does computer-based classification. By using photo-interpretation, researchers and managers familiar with coral habitats can give their contribution and feedback to mapping, without being necessarily advanced remote-sensor enthusiasts.

The habitat maps and associated data can be used as a stand-alone product or in a GIS to yield useful baseline information to scientists, managers and the general public. The final Benthic Habitat is presented in A0 PDF format, and can be printed in its native size at the scale of 1:5,000 (Fig. 3).

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High-Resolution Satellite Imagery and GIS Aid Benthic Habitat Mapping at Recife de Fora, Bahia, Brazil

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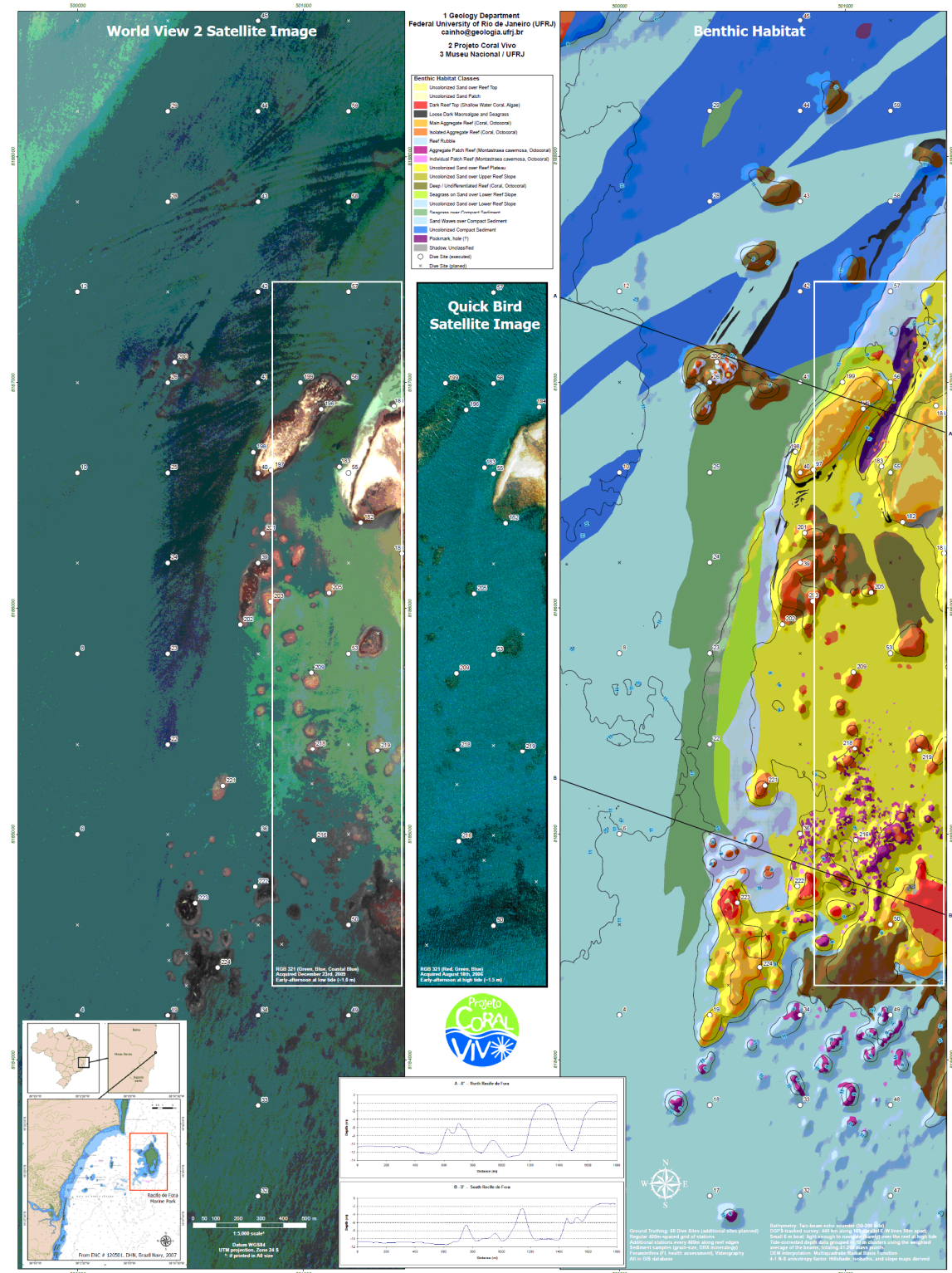3 Museu Nacional / UFRJ

Figure 3: A poster product, "High-Resolution Satellite Imagery and GIS Aid Benthic Habitat Mapping at Recife de Fora, Bahia, Brazil," originally presented in A0 PDF format and printable at a scale of 1:5,000.