BENTHIC HABITAT AND BATHYMETRY MAPPING OF SHALLOW WATERS IN PUERTO MORELOS REEFS USING REMOTE SENSING WITH A PHYSICS BASED DATA PROCESSING

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ABSTRACT

We applied remote sensing techniques using WorldView-2 images with high spatial resolution and field verification to map the bathymetry and benthic habitats of the Puerto Morelos Reef National Park in the Mexican Caribbean. These images were processed using the standardized physics-based data processing of EOMAP’s Modular Inversion and Processing System (MIP). To generate a detailed benthic habitat map we developed a two level-classification scheme based on biological and geomorphologic characteristics. These images showed high effectiveness for mapping benthic habitat. Further improvements will emphasize and focus on the selection of regional specific main spectral components and the automation of the radiometric fine tuning. The main contribution is the generation of a detailed benthic habitat map representing functional classification by combining both maps. These studies serve for the management of marine areas in Mexico and could be extended to the entire Mesoamerican Reef System.

Index Terms— remote sensing, bathymetry, benthic habitats, WorldView-2, Mexico

1. INTRODUCTION

The Mexican Caribbean is the northern part of the Mesoamerican Reef System, the second largest barrier reef in the world, with its coral reef-seagrass-mangrove ecosystems. Collectively the nations that border the Caribbean encompass a major global marine biodiversity hot spot [1], Puerto Morelos is a Marine Protected Area (National Marine Park) and Ramsar Site (No. 1343) [2] covering 91.2 km2, however, the region is routinely under continuous pressure from frequent natural disturbances by hurricanes and tropical storms and due to human impacts of different types and intensities driven mainly by the massive tourism industry. In order to monitor the status and habitat changes in this protected area, baseline knowledge of the spatial distribution of shallow coral reefs and other benthic habitats is required. In this study we applied remote sensing techniques using WorldView-2 / DigitalGlobe Inc. (WV2) images with high spatial resolution and field verification (ground truth data) to map the bathymetry and benthic habitats of the Puerto Morelos Reef National Park (PM).

2. METHODOLOGY

We used two WV2 satellite images (8 multispectral bands, 2 m spatial-resolution) to map the bathymetry and the benthic sea floor coverage of shallow waters (< 16 m) of PM. These images were analyzed using the standardized physics-based data processing of EOMAP’s Modular Inversion and Processing System (MIP). It includes corrections for sun glitter, the adjacency effect and the atmospheric and water constituents retrieval algorithms. In addition MODIS/Aqua satellite data were processed in order to carry out radiometric intercalibration. The water depth and the sea floor albedo for the WV2 images were iteratively calculated in combination with the spectral unmixing of the respective bottom reflectance derived from the subsurface reflectance. This analysis is based on an alternative algorithm to reduce the difference between satellite measurements and modeled spectral responses [3][4] (Fig. 1).

In August 2010 we conducted a field work campaign (optical and visual) to obtain ground-truth data of benthic habitats as well as a bathymetric data of the study area. We measured water depth every second using a multi/dual frequency echo sounder SyQwest Bathy 500 DF, considering corrections using differential GPS positioning accuracy Leica 1200. Additionally, in 131 stations (5 x 5 m) species occurrence and coverage were recorded to
characterize different benthic habitats of the coral reef system, (coral communities, seagrass beds, algae and sediments). Each sample was documented by digital photos.

The bathymetry and the derived products (slope and aspect) were the inputs for the geomorphological classification process (second level). Criteria to delineate the different classes were established according to published references [8][9][10] and adapted to the case study. A detailed benthic habitat map consists of two integrated levels. We used the in situ data to validate the satellite based bathymetry and to train the cover classification. In order to evaluate the accuracy of the satellite bathymetry, a linear regression analysis on two subsets based on depth ranges: 1 < z ≤ 16 m and z > 16 m was applied.

### 3. RESULTS

In situ data, used to validate satellite bathymetry, covered 42,059 points (109 transects), ranging from 0.8 to 31.9 m. The satellite bathymetry values ranged from 0.2 to 23 m, with a root mean square (RMS) of 1.1 and showed a correlation coefficient R=0.98 (p=95%). Nevertheless, in the scatterplot the scattering increases after 16 m (Figure 2a). The analysis on subsets shows that the linear dependence between the bathymetry and the degree of correlation decreases after 16 m (R=0.97, with RMS=0.68) (Figure 2b and 2c).

The satellite-based bathymetry provides more detail than the in situ data in shallow water areas, because the echo sounding data consists only of equidistant (200 m) measure lines and the difficulty of reaching the shallowest part of the reef with the boat carrying the echo sounder. In shallow water regions near the coast, depth differences of 10 cm could be clearly identified. Possible errors are sparsely distributed and mostly located in the areas of breaking waves (back & fore reef and extreme shallow waters < 2 m Figure 2a).
The satellite classification analysis allowed us to distinguish two levels of classification: For the first level, a cover map, five classes could be spectrally separated. Table 1 shows the classification scheme of the classes recognized in the map.

Table 1. Classification scheme of the cover map.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coral communities</td>
<td>Hard bottom with sclerantian corals, octocorales and hexacorallia (fire corals), associated with encrusting red algae and sponges.</td>
</tr>
<tr>
<td>Sediments</td>
<td>Soft bottom dominated (80%) by sand and clay substrates, as well as coral rubble (gravel and fragments).</td>
</tr>
<tr>
<td>Seagrass</td>
<td>Soft bottom dominated by seagrass with varying presence of macroalgae</td>
</tr>
<tr>
<td>Macroalgae</td>
<td>Hard bottom dominated by macroalgae. In some areas this class can be associated with coral communities.</td>
</tr>
<tr>
<td>Mixed vegetation</td>
<td>Seagrass and algae in different proportions, without a clear dominance of any vegetation types.</td>
</tr>
<tr>
<td>Not classified</td>
<td>Includes land not covered by the ocean, docks, ships, clouds and depths greater or equal to 16 m (based on optical restrictions of the WV2 images).</td>
</tr>
</tbody>
</table>

The second level is a geomorphological map (Table 2). The predominant vegetation of the lagoon are seagrasses beds. The Back reef generally presents a mosaic of hard coral, octocorals and algae. Due to the geomorphologic characteristics of PM the fore reef presents an unusual extension for a Caribbean fringing reef (Figure 3).

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Lagoon</td>
<td>Starts at the coast line and extents as far as the last overhand step that at the beginning of the back reef, including the calcareous sand accumulation zones (sand valleys).</td>
</tr>
<tr>
<td>Back reef</td>
<td>The progressive or abrupt transition between the lagoon and the reef flat from the last overhand step on the lagoon side toward the reef structure to 1.5 m of depth, where the Reef crest starts.</td>
</tr>
<tr>
<td>Reef crest</td>
<td>The shallowest part of the coral reef structure above 1.5 m depth around the breaking zone and includes the reef flat.</td>
</tr>
<tr>
<td>Fore reef</td>
<td>The slope from the reef crest toward the ocean. It includes the shallow and deep fore reef.</td>
</tr>
<tr>
<td>Coral mounds and channels</td>
<td>This system consists of reef mounds with elongated forms separated by sediment channels not wider than the coral mounds in areas where there is no well-defined reef crest. This kind of structure can be found at varying depths depending on the reef system.</td>
</tr>
<tr>
<td>Continental terrace</td>
<td>Defined as the plain covered by vegetation and sediments in areas where reef structures are absent; this class includes large canals for sediment transportation perpendicular to the coast line.</td>
</tr>
<tr>
<td>Not classified</td>
<td>Includes areas not covered by the ocean, docks, ships, clouds.</td>
</tr>
</tbody>
</table>

Figure 3. Maps of the Puerto Morelos Reef National Park: (a) cover; (b) geomorphology and (c) bathymetry.
4. CONCLUSIONS

We demonstrated the effectiveness of using the WV-2 for mapping benthic habitat. Besides the possibility to map larger areas at high spatial resolution than with conventional methods, mapping is repeatable by applying the standardized physics-based process, with time series data. The use of satellite images improves considerably the bathymetric maps for the shallowest parts of the reef and very accurate until 12 m of depth. Habitat characterization showed the potentials of this approach for generating detailed habitat maps. Further improvements will emphasize and focus on the selection of regional specific main spectral components and the automation of the radiometric fine tuning. The main contribution is the generation of a detailed benthic habitat map representing functional classification by combining both maps (geomorphology and cover). These studies serve for the management of marine areas in Mexico and could be extended to the entire Mesoamerican Reef System.

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6. REFERENCES


