REMOTE SENSING AS A TOOL TO DESCRIBES SEDIMENT BOTTOM FACIES IN COASTAL ENVIRONMENTS

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ABSTRACT

A study of sediment bottom distribution was conducted on the nearshore area of Puerto Rico. The objective of this study is characterize the beach sand sources in the coastal environment using remote sensing. The qualitative and quantitative description of these sources played an important role in understanding the possible causes of shoreline changes. In this study, we identified and described sediment bottom types based on composition and textural characteristics. Thematic Mapper images (band 1) were used for data acquisition. The spectral band was used to analyze bathymetry, bottom types and sediment distribution.

Two main bottom types were discriminated based on the radiance distribution. These are carbonate and mixed sands due to the similarities founded between the images and sediment maps. According to the data, higher radiance values were found from Isabela to Camuy, that could be related with the presence of lighter materials as carbonate sands. Lower radiance were measured at Mayaguez due to the presence of darker material as terrigenous sands. Discrimination of bottom marine facies is difficult to perform with TM due to the small ranges of radiances measured on the Puerto Rican nearshore waters.

INTRODUCTION

Coastal changes have occurred in Puerto Rico, with erosion causing major problems. Erosion results from the interaction of many physical variables such as waves, winds, tides, currents, and storms which act on the more easily weathered geomorphic features such as dunes, alluvial deposits, beaches and other loosely consolidated coastal features. Human activities, such as the construction of river dams, have drastically reduced the supply of sand to the beaches. Coastal structures (jetties and riprap), and sand mining have also caused dramatic coastal changes.

The objective of this study is characterize the beach sand sources in the coastal environment of Puerto Rico using Remote Sensing techniques. The qualitative and quantitative description of these sources played an important role in understanding the possible causes of shoreline changes. The use of remote sensing was valuable, especially when classical coastal field work was not easily performed due to the logistics and time involved in the collection of data from all beach sites. As an important part of the study, an evaluation of how the remote sensing techniques such as multispectral image processing can contribute to a successful description and quantification of the coastal sediment and marine bottom facies around the Island. The identification and description of bottom types was important because this permitted an accurate, easy and less time consuming assessment of coastal resources..

Since Puerto Rico is an island, the coastal features and their intelligent use can be uniquely different from many long continental coastlines. The results of this research may be used to develop geomorphic models for the coastal areas of Puerto Rico and other Caribbean
islands. Part of the final discussion is how each factor contributes to coastal change in order to identify potential management controls.

METHODOLOGY

Multispectral image analysis of Thematic Mapper (TM) images were used to describe sediment bottom types in the nearshore area where studies of bottom sediment facies were not available. Sediment descriptions were based on the spectral definition of the combination between sediment composition and texture. Sand shoals, and hardground were also identified. The images were collected by the Landsat-5 satellite. TM images have 7 spectral bands with a spatial resolution of 30 meters, except for the thermal infrared channel that has a resolution of 120 meters. In this study, the useful spectral bands are located between the visible and near infrared ranges which are 4,3,2,1 TM channels. This combination penetrates shallow water and details water turbidity, bathymetry, and sediment types. Band 1 was used to analyze bathymetry, bottom types, and sediment distribution in this research. Band 4 offers definition between land and water (mask build-up). Earth Resources Laboratory Applications Software (ELAS) was selected as the image processor software. ELAS was used for preprocessing (rectification, masking, calibration, atmospheric correction) and classification procedures.

Rectification

Raw, remotely sensed image data gathered by a satellite or aircraft are representations of the irregular surface of the earth, therefore a rectification procedure was performed to fix the image to the approximate real geographic position. A rectification method was performed assuming TM pixels are located in relative position because the sensor is in a stable platform (Landsat satellite). TM scenes have a displacement of 7.5 degrees clockwise from the geographic north at Puerto Rico. A rotation procedure was done using the Rectify module from ELAS Software using the known displacement angle.

Masking

A separation between land and ocean was made to reduce the numbers of pixels involved in the image processing and to improve the identification of changes in digital values in the ocean that cannot be easily detected when land was included. Spectral band 4 was used to define the relative boundary between land and ocean. Descriptive statistics were used to define the mean value of the pixels related to land areas (Ch4=53). A DBAS program was written to build the mask (program 1) (Miller, personal communication, 1993).

```
DBAS
in sp lp
T num 0000 T nam ex
10 if (CH 4-53) 20, 40, 40
20 ch0 = ch1
30 return
40 ch0 = 0
50 return
60 end
```

Calibration

A transformation from raw digital values to radiance values was done with an applied atmospheric correction algorithm. This algorithm was written to apply only to radiance values. The calibration was done using the followed algorithm:

\[
L_\lambda = L_{\min} + \left( \frac{L_{\max} - L_{\min}}{Q_{\text{cal max}}} \right) Q_{\text{cal}}
\]  

(eq. 1)
where \( Q_{\text{cal max}} \) = Range of rescaled radiance (256) and \( L_{\text{max}} \) and \( L_{\text{min}} \) were calibration values for the TM sensor published after 1984 (EOSAT, 1985). Calibration values were obtained for all the spectral bands used in this study (Table 1).

### Table 1. Calibration values from Thematic Mapper sensor after 1984.

<table>
<thead>
<tr>
<th>Band TM</th>
<th>( L_{\text{min}} )</th>
<th>( L_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.15</td>
<td>15.21</td>
</tr>
<tr>
<td>2</td>
<td>-0.28</td>
<td>26.68</td>
</tr>
<tr>
<td>3</td>
<td>-0.12</td>
<td>20.43</td>
</tr>
<tr>
<td>4</td>
<td>-0.15</td>
<td>20.62</td>
</tr>
</tbody>
</table>

The calibration algorithm was applied to the raw data using the DBAS module of ELAS (program 2) (Miller, personal communication, 1993).

10 \text{ if (ch1-0) 20, 20, 40} \\
20 \text{ cho=0} \\
30 \text{ return} \\
40 \text{ cho=-0.15+} \frac{1536}{256} \times \text{ch1} \quad \text{(Program 2)} \\
50 \text{ return} \\
60 \text{ end}

Calibration procedure was applied to each spectral band used (based on the TM calibration values after 1984). Transformation from radiance to reflectance values was not done because reflectance calibration values were not available.

### Atmospheric Correction

Local atmospheric corrections were made using a clear water pixel algorithm. This algorithm postulated that atmospheric effect was identified and quantified assuming that a deep ocean body can act as a black body when the image is displayed in the near infrared sector (TM band 4). The theoretical values of pixels in a black body approached 0 (no radiance) because energy was absorbed. Based on this assumption, all the radiance values found in ocean pixels as a scattering were due to atmospheric effect (Table 2).

### Table 2. Clear water pixel values (radiances) from TM scene at Puerto Rico

<table>
<thead>
<tr>
<th>Spectral TM Band</th>
<th>Radiance values (watts/cm (^2) sr(^{-1})) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.77</td>
</tr>
<tr>
<td>2</td>
<td>1.95</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

* radiance values were defined using channel 4 for Puerto Rico TM scenes.
A DBAS program (program 3) was applied based on these assumptions for each spectral channel used (Miller, personal communication, 1993).

```
10 if (ch1-0) 20,20,40
20 cho=0
30 return
40 if (ch1-4.77) 50, 70,70
50 cho=0
60 return
70 cho=ch1-4.77
80 return
90 end
```

**Image Processing (Classification)**

An unsupervised classification was selected for image processing. This procedure identifies groups (cluster) based on differences in radiance values. Unsupervised classification is the process of defining such clusters and matching them to informational categories (Campbell, 1987). Some advantages are: 1) no extensive prior knowledge of the region is required; 2) The opportunity for human error is minimized; 3) classes are more uniform than ones identified by a supervised approach (Campbell, 1987). The SRCH module (ELAS) was used to run the unsupervised classification. In this study, an unsupervised classification was performed on a geographical site (Mayaguez) where field recognition was well detailed for category definition (Morelock, *et al.*, 1983; Otero, *et al.*, 1992; Gilbes, 1992). Bottom categories were defined after the classification procedure was done. A training file based on these clusters was applied to other unknown nearshore areas for bottom categories identification.

**RESULTS**

General bottom type discrimination was conducted for nearshore areas using image analysis. According to the data, higher radiance values were found from Isabela to Camuy (Table 3). High radiance values could be related to the presence of lighter materials. It is possible that high radiance values could be also related to white from the presence of high wave energy in the northern waters. Lower radiance values were found at Mayaguez-Añasco due possibly to the presence of darker material such as terrigenous sand and mud. Discrimination of bottom marine facies is difficult to perform (on the Puerto Rican nearshore waters) with TM due to the small range of radiances (Table 3).

<table>
<thead>
<tr>
<th>Location</th>
<th>Spectral Band</th>
<th>*Radiance values (watts/cm² sr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combate</td>
<td>1</td>
<td>0-5.23</td>
</tr>
<tr>
<td>Combate</td>
<td>2</td>
<td>0-7.05</td>
</tr>
<tr>
<td>Mayaguez</td>
<td>1</td>
<td>0-3.60</td>
</tr>
<tr>
<td>Mayaguez</td>
<td>2</td>
<td>0-4.36</td>
</tr>
<tr>
<td>Isabela</td>
<td>1</td>
<td>0-10.38</td>
</tr>
<tr>
<td>Camuy</td>
<td>1</td>
<td>0-10.26</td>
</tr>
<tr>
<td>Cangrejos, Loíza</td>
<td>1</td>
<td>0-5.94</td>
</tr>
<tr>
<td>Cangrejos, Loíza</td>
<td>2</td>
<td>0-5.66</td>
</tr>
</tbody>
</table>

*after atmospheric correction*
Two main bottom types were preliminary well discriminated based on radiance value distribution. These were probably carbonate and mixed sands due to the similarities found between the images and sediment maps. Terrigenous bottom sediment deposits were not included as a general category in this study, because discrimination could not be made due to the presence of suspended sediment in the water column in areas of terrigenous influx. However, a category related to river sediment (suspended material) was included. Bathymetric changes could be also confused with the sediment component categories due to the relation of the sediment component with changes in depths occurring on the map.

Five bottom type categories were observed in the nearshore area at Combate. A detailed facies map was not available to make comparisons between the image and the position of the nearshore environment. Therefore, qualitative description of the bottom facies indicated that two categories could be related to low radiance materials such as terrigenous sand and biogenic dark muds. These categories were located parallel to the shoreline and northward on Combate Beach. Higher radiance values were found seaward of the nearshore. These could be carbonate and mixed sand deposits. Two main categories were found from Guanajibo to Añasco on the west coast of the Island. These were probably mixed and carbonate sand. Low radiance values were found near Río Grande de Añasco and Río Yaguez. These are indicative of suspended sediments coming from the rivers.

A no radiance category (black feature) is evident along the insular margin at Isabela. This feature was mainly located from the middle to the seaward side of the margin with a northeast orientation. No data were available for the identification of this feature. But, this could be related to the presence of a submarine hardground such as eolianite, rock and/or submarine channels that could be connected to submarine canyon systems. A narrow deposit of low radiance material was found close to the shoreline. This deposit could be dark biogenic or terrigenous sands. Higher radiance values were found from the nearshore to seaward. These could be extensive mixed and carbonate sand deposits according to Grove, 1983.

Continuous low radiance categories are shown parallel to the shoreline at Camuy. This could be the presence of suspended sediment coming from Río Camuy located to the northeast. Extensive higher radiance categories are indicated seaward from the nearshore. A no radiance category (black) was identified on the outer shelf at Camuy, which could be eolianites and/or a deep channel that connects to a submarine canyon.

Radiance categories were not well defined from Boca de Cangrejos to Piñones at Loíza. Poor discrimination could be related to spatial resolution due to the size of the features in the area, a presence of a narrow insular shelf, and the input of river material along the area. Therefore, a narrow deposit of low radiance materials and higher radiance sediments can identify along the shoreline. A sediment facies map was not available for comparisons.

**DISCUSSION**

Based on the result obtained in this research, it was determined that TM band 1 (0.45 to 0.52 µm) was the more useful spectra band to identify bottom types since it can penetrate deeper waters than other bands. This makes it simpler to discriminate the bottom features that can not be normally detected using shorter wavelengths. General sediment bottom facies such as carbonate and mixed (carbonate and terrigenous) sediments were successfully defined, according to the correspondence of these classes with sediment categories defined by published sediment type maps (Grove, 1983; and Pilkey, et al., 1987). This finding is extremely favorable.
in defining the physical limit of sediment deposits when these cannot be discriminated using classical field work procedures.

Two main constraints to the method were identified in this study. These are: 1) the low range of radiance values in the nearshore waters of the Island; and 2) the poor spatial and spectral resolution of TM images. The low radiance range (0-13 watts/cm² sr⁻¹) found in the Puerto Rican nearshore waters created some difficulties in discriminating details between different sediment categories. Therefore, a masking process was conducted to eliminate the high radiance values coming from land to improve the identification of clusters in the low radiance distributions. River mouth areas were also masked to reduce the influence of suspended sediment in the discrimination of the bottom features, when a TM image is used. It is also possible that using an image with higher spectral resolution will improve the identification of sediment bottom features on areas with small radiance ranges. This could make it easier to discriminate between features such as: 1) terrigenous sediment vs dark carbonate sediment; 2) eolianites vs dead coral; 3) deep channels vs hardgrounds; that could not discriminated using TM images in this study. TM spatial resolution was not appropriate for mapping bottom types in Island systems due to the physical dimensions of bottom features (less than 30 meters). Images with spatial resolution of less than 10 meters are recommended for mapping bottom features.

CONCLUSION

Two main bottom types were discriminated based on radiance values distribution. These were carbonate and mixed sands as determined from the similarities between the images and sediment maps. Discrimination of bottom marine facies is difficult to conduct with Landsat TM (poor spatial and spectral resolution) due to the small ranges of radiances measured in the Puerto Rican nearshore waters

ACKNOWLEDGMENTS

I wish to say thanks to Mrs. Barbara Morelock and Dr. Jack Morelock for their review of the manuscript. The National Aeronautic and Space Administration (NASA) provided financial support for my work and training. Dr. Armond Joyce and Dr. Richard Miller at the Stennis Space Center helped me in the preparation of the remote sensing work. To the Larsip staff, from the Electrical Engineering Department, especially to Ing. Peter Van der Meer and Víctor Díaz who helped me in all image processing computer work.

REFERENCES


