Using IKONOS Images to Evaluate Coral Reefs in Low versus High Sedimentation Environments

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Abstract.-The growing concern about the future of the world's coral reefs brings the opportunity to implement diverse and effective techniques to monitor the condition and changes of reefs from time to time. Effectiveness of these techniques is variable and would depend on the morphology and condition of the site. The ultimate goal is to monitor these complex ecosystems over large areas without spending the time required during extensive fieldwork and data interpretation. The use of remote sensing techniques offers such opportunities. The aim of this study is to assess the effectiveness of satellite images from the commercial sensor IKONOS from two different reef sites in Western Puerto Rico. Several classifications were conducted on the images to test the accuracy of the data and their value to make habitat and benthic maps of coral reefs. Results were compared with published data from the sites and demonstrate the great potential of the IKONOS sensor for coral reef studies. The more complex the reef site (e.g. Mayagüez) greater the uncertainties found with the classification results. Nonetheless, the high resolution of the classifications makes this sensor optimal for highly diverse and constantly changing reef sites if proper signal corrections are performed.

INTRODUCTION

Coral reefs are one of the most important and valuable marine habitats in tropical to subtropical latitudes. These are complex biological, physical and chemical systems (Stanley Jr., 2001) that interact together to form these magnificent structures in which 200-4000 tons of $CaCO_3$ per hectare per year are deposited. Wood (1999) defines reefs as "discrete carbonate structures formed by in-situ or bound organic components that develops topographic relief upon the seafloor". Reefs are capable of modifying the surrounding hydrodynamic environment serving as barriers to wave action and controlling sedimentation. Economically coral reefs may be used as an important resource for tourism, fish nurseries and as a source for chemicals important to the pharmaceutical industry.

Reefs are one of the most endurable ecosystems of the earth through time, but at the same, one of the most fragile (Stanley Jr., 2001). During the past twenty to thirty years a decline in coral reef diversity and abundance is being observed in the Caribbean due to anthropogenic and natural causes. Most of the decline throughout the Caribbean region has been attributed to increased coastal development, agriculture and discharge of sewage and industrial waste into the ocean leading to high terrigenous sediment influx, increased nutrient levels, overfishing and habitat modification (Acevedo et al. 1989; Morelock et al. 2001).

Worldwide concern about the future of coral reefs has lead to increased implementation of effective monitoring techniques to observe the condition and changes within reefs, identification of damage and, if possible, prevent future deterioration of them. A common problem that coral reefs scientists confront is that many monitoring techniques have to be developed with limited amounts of money and time. This is particularly important for very large coral reefs like the Great Barrier Reefs of Australia and Belize where an international consortium of scientists and several years of intensive fieldwork would be required to document the changes and conditions of the reefs with accuracy, before it is too late for its recovery. Remote sensing becomes a promising tool to complement coral reef studies over large areas and allowing time-effective documentation of the features of a reef system.

Although the use of remote sensing imagery to study coral reefs can be traced back to the 1980's, extensive application of this tool is limited. Coral reefs are very diverse, complicated features that will make any image interpretation difficult without proper knowledge of the conditions of a certain place. Extensive field validations are to be implemented. In addition, the signal registered in remote sensor is highly modified by atmospheric effects (e.g. scattering, absorption), reflection, refraction, water column and bottom effects, making necessary the application of complicate algorithms to correct for these effects to make the data more accurate. Most multispectral and hyperspectral sensors lack the spatial resolution necessary for detail classifications and mapping. Nevertheless, it is a powerful tool that with proper management can result in unimaginable amounts of valid information useful for environmental resource planning by government agencies. This study presents a comparison made in two distinctive coral reef environments using the commercial sensor IKONOS to evaluate the accuracy and value of remote sensing techniques for coral reef studies using this particular sensor.

Materials and Methods

Due to the high spatial resolution of the IKONOS sensor (1-m panchromatic, 4-m multiband), it represents a unique opportunity to evaluate its utility for coral reef studies using remote sensing techniques. The higher spatial resolution allows better classifications, compared with other multispectral sensors (e.g. Landsat TM ~30-m) resulting in more accurate maps. In this study, IKONOS images from two different reef sites (Figure 1) were obtained and processed with the purpose of comparing the conditions of the two sites and assess the accuracy of the method. For the two sites, a distinction of reef habitats was made according to published data.

Figure 1. Map of Puerto Rico with location of study sites. 1-Shelf reefs near Mayagüez Bay; 2-Fringing Reefs, southeast Mona Island

Study sites

The IKONOS images come from different coral reef sites in Western Puerto Rico. The sites were chosen in order to evaluate the response of the sensor on reefs developed under different oceanographic conditions. Near Mayagüez, reefs occur on a platform (i.e. shelf reefs) approximately 15 km wide (Morelock et al. 1983) near Punta Guanajibo. A line of submerged coral reefs also marks the shelf edge (Morelock et al. 1983). Reefs on this area are affected by high terrigenous sediment brought in by three major river systems (Río Grande de Añasco, Río Yagüez and Río Guanajibo). The structure and bathymetry (Figure 2) of the platform is very complex due to its complex sedimentological history and the rise and falls of sea level during most of the Quaternary (Morelock et al. 1983). According to Morelock et al. (1983) three sedimentary facies are recognized in the Mayagüez platform (Figure 2). First, coral reef sediment and hardground are located on elevated areas and secondly, reef-influenced muddy sand occurs in deep areas, sometimes as deep channels within reefs. A third sedimentary facies occurs near the coastline and consists of terrigenous muddy sand (Figure 3). In addition to high sedimentation, waste and sewage waters from the Puerto Rico Water and Sewage Authority and from the tuna processing plants are discharged to the Bay, increasing the amounts of nutrients locally.

Reefs in Mona Island, located approximately 42 miles west of Puerto Rico, occur as fringing reefs on the south coast of the island. These reefs are subjected to higher wave energy due their location in the middle of the Mona Passage with very clear waters not affected by river runoff.

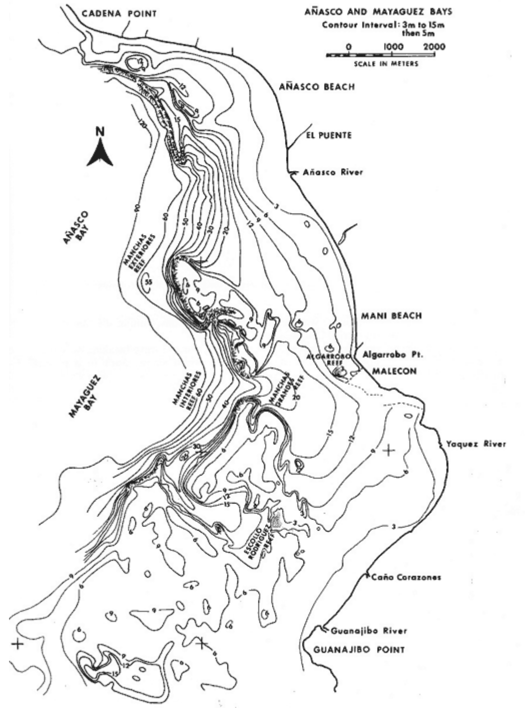


Figure 2. Bathymetry of Mayagüez platform (from Morelock et al. 1983).

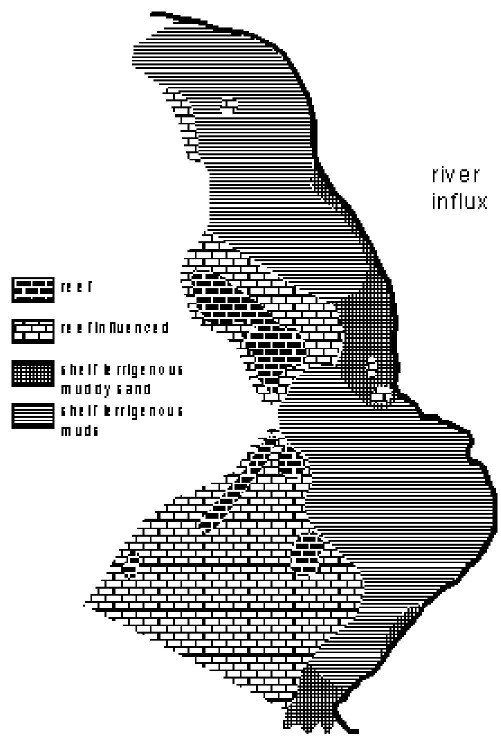


Figure 3. Sediment facies of the Mayagüez platform (from Morelock et al. 1983)

Unlike Mayagüez, the reefs in Mona are abundant in the coral species *Acropora palmata* (Morelock, 2002).

Preprocessing

The IKONOS images were obtained from the Geological and Environmental Remote Sensing Laboratory (GERS) of the Department of Geology of the University of Puerto Rico at Mayagüez (UPRM). Images were already georeferenced. The images from both sites were originally organized as mosaics, therefore they looked differently and the best portion of the mosaic was chosen (this includes cloud cover, reef location, etc.). All the processing was conducted using ENVI software from the Computer Lab in the Department of Geology at UPRM.

Due to its high spatial resolution, ocean images from the IKONOS sensor tend to have a wave/glint effect. A correction for this effect was made using the software Deglint v1.1, designed by Eric Hochberg from the University of Hawaii. The correction is based on the assumption that water is virtually opaque in the near infrared (NIR), therefore pixels with glint in the NIR should have similar contribution in the visible bands. For the program to operate, pixels with maximum and minimum radiances are identified so that the glint contribution of each pixel can be estimated. During this process, atmospheric corrections are also employed. No water column or bathymetric corrections were applied due the limited time of the study and because of the limitations of the IKONOS sensor regarding these matters. In addition, no field validations were conducted due to time limitations. All spectral information that was used for classification was based on published data (e.g. Hochberg et al. 2003).

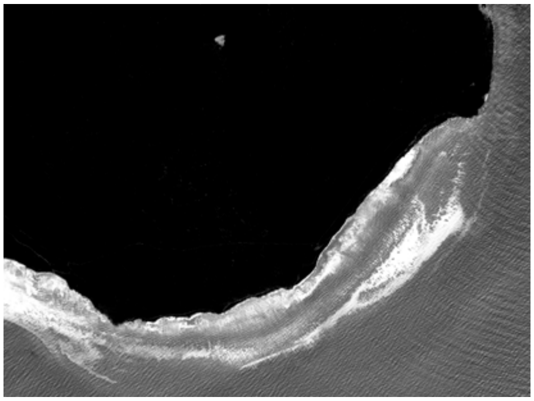
Classifications

Once preprocessed, gray and true color images were generated. This served for the purpose of preliminary observation of features, to familiarize with structure and morphology of the reef and to compare the images with published data (i.e. Morelock et al. 1983), prior to identification of the regions of interest (ROI). Several classifications were conducted on each image. Unsupervised classifications were made using the K-Means and Isodata methods, while for supervised classifications the methods Minimum Distance and Maximum Likelihood were preferred. Probably due to its size, only a Minimum Distance supervised classification was conducted on the Mona image.

Based on the geology of the reefs and the features observed on the gray and true images, classes from each site were selected. For Mona Island, six classes were identified, while from Mayagüez reefs, five classes were identified. A summary of the classes for each location is presented in Table 1.

Table1. Summary of classes identified for each reef location

Mona	**Mayagüez**
Beach sand	Open ocean
Lagoonal, nearshore sand	Carbonate sand
Sand in deep forereef	Sea grass
Deep forereef corals	Coral reef
Crest corals	Sediment (terrigenous or carbonate muddy sands)
Open ocean	



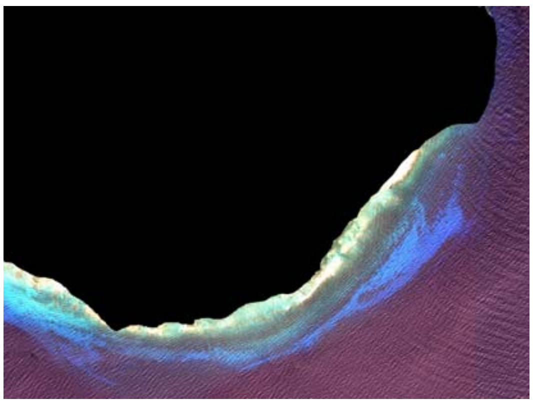


Figure 4. Gray (top) and true color (bottom) images generated from the Mona images after using Deglint v1.1.

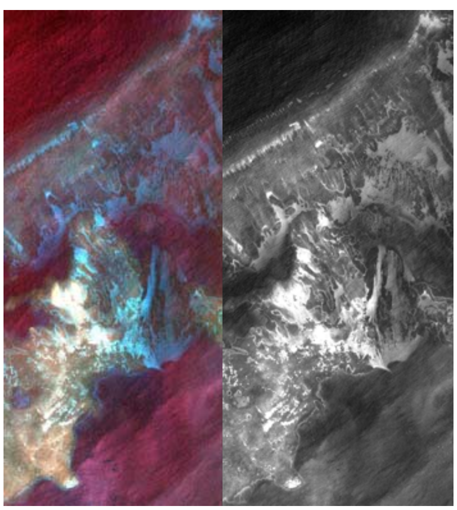


Figure 5. True color (left) and gray (right) images from Mayagüez reefs after preprocessing.

RESULTS

After surface roughness corrections, true color and gray images from the reef locations were generated. Although there are still some red "spots" on the images, the wave/glint corrections significantly improved the quality of the image (Figures 4 & 5).

Unsupervised classifications from Mona Island were very inaccurate resulting in only two distinguishable major units, even though a mask was placed on the island (Figure 6). This results contrast markedly with the supervised classification (Minimum Distance) where the location and boundary of classes is more accurate. Still, there is some mixing of classes between boundaries and in deeper portions of the reef. (Figure 7).

On the other hand, although the supervised classifications conducted on the Mayagüez image show better boundary resolution, these are very similar to the unsupervised counterparts of the same area (Figures 8 & 9). It is evident in this case the complexity of the area, compared with Mona. There is more mixing and greater errors in the classification probably due to these complexities. In general, supervised classifications were quite accurate in the results, based on published data and knowledge of these areas.

DISCUSSION

It is evident, especially in the reefs of Mayagüez, that is very necessary the application of water column corrections to obtain the best results and the best accuracy from the IKONOS images. The reefs in Mona fringe on a narrow platform that goes deeper quickly. However, the reefs in Mona follow a

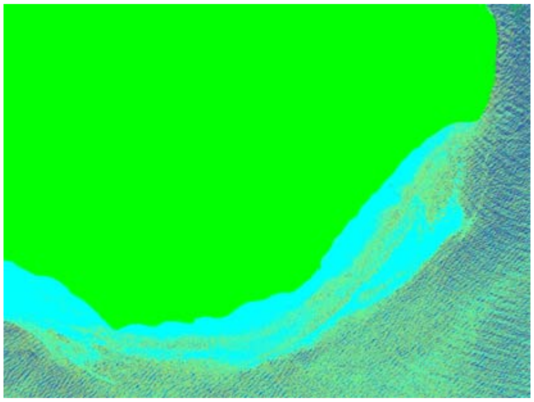


Figure 6. Results of unsupervised classification for Mona reefs with the K-Means method.

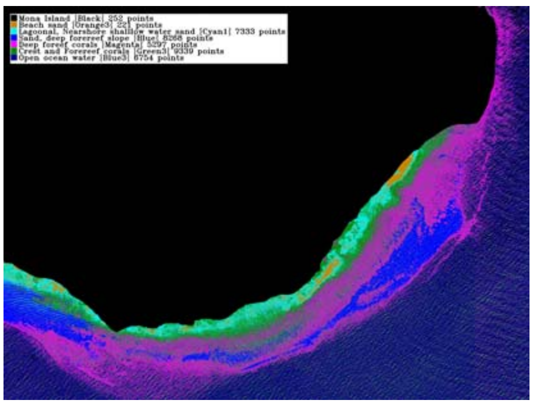


Figure 7. Results of supervised classification for Mona reefs with the method Minimum Distance.

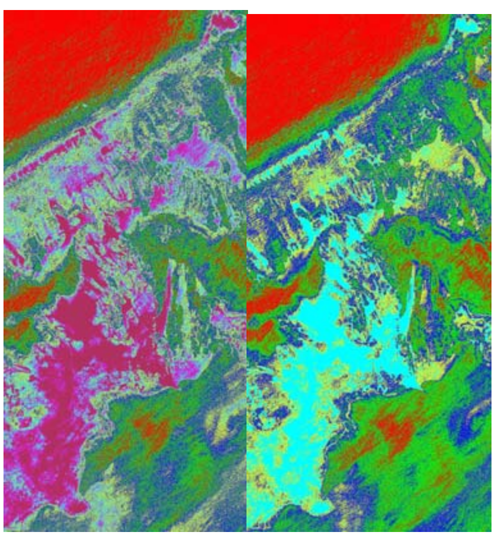


Figure 8. Results of unsupervised classifications for Mayagüez reefs. Left Isodata method, right K-means.

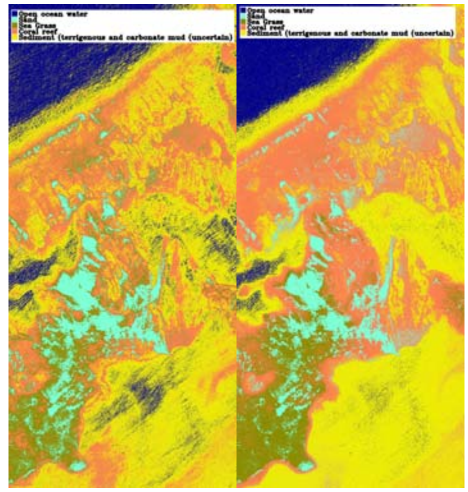


Figure 9. Results of supervised classifications for Mayagüez reefs. Left is Minimum Distance and right is Maximum Likelihood.

typical Caribbean zonation pattern with branching corals in the crest and shallow forereef and progressive abundance of massive corals in the deeper portions of the forereef. Patches of reef sand can be seen clearly in the image and were classified accordingly.

For Mayagüez, the complex bathymetry caused mixing of deeper sediment facies with the open ocean class. In addition, deep areas consisting of reef sand (upper right of image) were classified as coral reef. These effects could be corrected if the signal from the water column is removed. Since the IKONOS sensor has only four bands, and only three bands remain after surface roughness corrections, removal of the water column becomes a challenging task. Nonetheless, is not impossible. Intensive field measurements will help make such corrections possible. It is also desirable to validate the results of similar studies like this to improve the interpretations.

In summary, considering the simple analyses conducted in this study, it can be concluded that future applications of the IKONOS sensor for coral reef studies promise to be a valuable tool. Using proper signal corrections, it would be possible to complement field studies of coral reef with remote sensing data and in the near future, depend less on fieldwork data to monitor these important tropical marine ecosystem.

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LITERATURE CITED

Acevedo, R., J. Morelock, and R.A. Olivieri. 1989. Modification of coral reef zonation by terrigenous sediment stress. *Palaios* 4: 92-100.

Hochberg, E.J., M.J. Atkinson and S. Andréfouët. 2003. Spectral Reflectance of coral reef bottom-types worldwide and implications for coral reef remote sensing. *Remote Sensing of Environ.* 85:159-173.

Morelock, J. 2002. An Introduction to the geology and oceanography of Mona Island (http://cima.uprm.edu/~morelock)

Morelock, J., K. A. Grove and M. L. Hernandez-Avila. 1983. Oceanography and patterns of shelf sediments, Mayagüez, Puerto Rico. *Jour. Sed. Petrology* 53 (2): 371-81.

Morelock, J., W. Ramírez, A. Bruckner and M. Carlo. 2001. Status of coral reefs, southwest Puerto Rico, *Caribb J. Sci. Special Publication #4*, 57 pp.

Stanley Jr., G.D. 2001. Introduction to reef ecosystems and their evolution. In *The History and Sedimentology of Ancient Reef Systems*, ed G.A. Stanley Jr., 1-39. New York: Kluwer Academic Publishing.

Wood, R. 1999. *Reef Evolution*. Oxford University Press, Oxford England.