

Single-beam acoustic remote sensing for coral reef mapping

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Abstract. Several commercial single-beam acoustic seabed mapping systems have come to market in the last decade, but the potential for mapping coral reef habitats with these systems has not been systematically documented. Three datasets from the Florida Keys, USA, and the Bahamas, all acquired by a Quester Tangent Series V (QTCV), revealed that rock and sediment were reliably distinguished across multiple survey sites with accuracy ranging from 74%-86%. The utility of a simple rock/sediment classification scheme for assessing fish habitat and for objectively mapping habitat based on patchiness and relief metrics are discussed.

Key words: Acoustic seabed classification, QTC, fish habitat.

Introduction

Coral ecosystems that cannot be mapped with aerial or satellite imagery are both extensive and ecologically important. For example, over 55% of the Florida Keys National Marine Sanctuary (about 1540 square nautical miles) has not been mapped due to water depth or clarity limitations (FMRI 1998).

Acoustic systems are the natural solution for mapping areas where the seabed is not visible from overhead imagery. Single-beam, multibeam, or sidescan systems each may be used for acoustic seabed classification (Michaels 2007). The advantages of single-beam systems include relatively low costs, low data volumes, and easy portability.

Several studies have used commercial single-beam systems to map coral reefs (Hamilton et al. 1999; White et al. 2003; Moyer et al. 2005; Riegl and Purkis 2005; Riegl et al. 2007), but basic questions about what substrates can be reliably distinguished and how consistent classification schemes are in different areas have not been systematically explored. This project used a Quester Tangent Corporation (QTC) system to begin answering such questions.

Most evaluations of remote sensing technology or processing algorithms use data from a single study site. In contrast, the approach taken here was to compare results across multiple study sites in order to assess what seabed types could be mapped reliably by QTC across a variety of coral reef environments.

The objective was to determine what acoustic seabed classes were consistently distinguished across survey areas. The strategy used was to survey multiple sites using the same equipment, cluster the acoustic data from each site independently, and compare the accuracy of the resulting classifications.

Methods

The 50 kHz QTC Series V (QTCV) system described by Gleason et al. (2006) was used to acquire acoustic data during three surveys.

The first survey was conducted in the vicinity of Lee Stocking Island (LSI), Bahamas, on 16-20 June 2001 (Fig. 1). Approximately 145 km of track lines were surveyed along the bank top in water depths ranging from less than one meter to just over 10 m.

The second survey was conducted on 14 and 28 March, and 4 April 2002 offshore of Carysfort Reef, in the Florida Keys (Fig. 1). Fifty-two parallel transects, with a combined length of 124 km, were run across the upper shelf at depths of 3-35 m. This survey was described by Gleason et al. (2006).

The third survey was conducted at Fowey Rocks, also in the Florida Keys, about 45 km north-northeast of Carysfort (Fig. 1). The Fowey survey was conducted 12 and 20 October 2003 and included forty-one parallel transects, with a combined length of 72 km, across the upper shelf at depths of 3-40 m.

Acoustic data were processed with the IMPACT software package (version 3.4, QTC, Sidney, BC, Canada, 2004). Details of the IMPACT processing have been previously published (e.g. Preston et al. 2004; Gleason et al. 2006; Freitas et al. 2008). For the purposes of this paper, the key point regarding IMPACT is that the input to the program consisted of the raw echoes recorded by the QTCV and the output from the program consisted of: a) the optimum number of clusters into which the echoes should be split (as defined by Preston et al. 2004), and b) a label for each echo assigning it to one of the defined clusters.

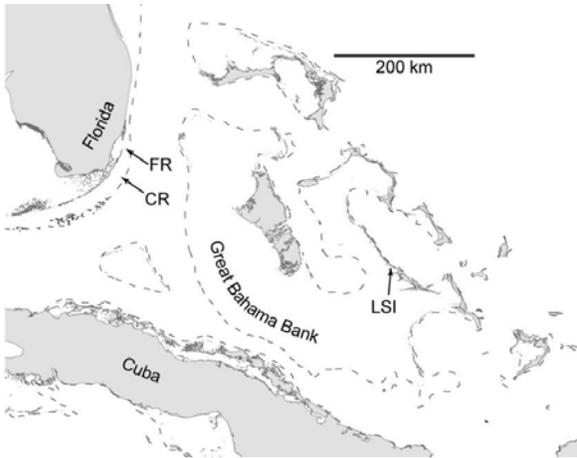


Figure 1: Location of Lee Stocking Island (LSI), Carysfort Reef (CR) and Fowey Rocks (FR) sites. Dashed line is the 200m isobath.

IMPACT's auto-clustering routine divides a dataset into distinct clusters based on echo shape, but, like any unsupervised classification routine, it cannot give these clusters descriptive names (e.g. reef, rubble, seagrass etc.). The clusters output from IMPACT, therefore, must be labeled by reference to other data sources. Cluster labeling for these surveys employed: comparison to satellite imagery, notes taken while snorkeling or drift diving, examination of the mean echo shapes for each cluster, bathymetric cross sections, and reference to previous seabed classifications at these sites (Gonzalez and Eberli 1997; FMRI 1998; Lidz et al. 2003; Louchard et al. 2003; Mobley et al. 2004).

Once the acoustic clusters had been labeled, they were quantitatively compared with "ground truth". The ground truth datasets acquired at each site were independent of the qualitative observations used for cluster labeling. Two types of data were collected for assessing the accuracy of the acoustic classification. Downward looking video images were acquired during the LSI survey, which was shallow enough and in clear enough water that the seabed was always visible from the surface. In contrast, the seabed was not visible from the surface at all times during the Carysfort and Fowey rocks surveys, due to deeper and less clear water. Therefore, at Carysfort and Fowey diver-based observations were acquired.

The video from the LSI survey was acquired with a Sony TRV 900 camera in an underwater housing that was mounted to the same pole that supported the transducer used for the survey (Fig. 2). Video was acquired in time-lapse mode, so that an entire day's worth of surveying could fit on one video tape. In time-lapse mode, the camera was set to acquire video (at full frame rate) for two seconds and then to pause for 28 seconds.

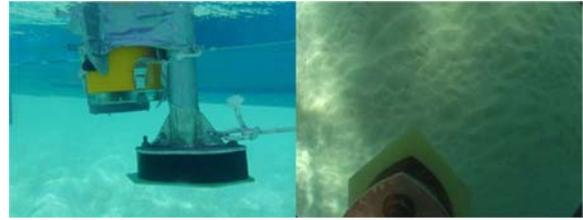


Figure 2: Left: Underwater photograph of pole-mounted transducer and video camera housing, as used for the LSI survey. Right: Sample frame grabbed from the video over a sandy seabed.

The entire LSI video data set consisted of 1502 two-second long clips. A single frame was extracted from each clip for analysis. For each frame, an analyst estimated the percent of rocky and sandy substrate. At the beginning of the day, the camera's clock was synchronized with a GPS unit. Using the time code embedded with each frame, the locations of the frames were determined from daily GPS tracks.

The diver-based observations collected at Carysfort Reef (N=22) and Fowey Rocks (N=15) followed the Bohnsack and Bannerot (1986) stationary reef visual census (RVC) method. The RVC protocol focuses on the collection of fish population data, but habitat data, including estimates of the percent of the seabed covered by rock, rubble, and sediment, are also collected (McClellan and Miller 2003). Estimates of substrate are the portion of the RVC dataset used for this analysis.

An error matrix (Congalton and Green 1999) was constructed for each survey site for comparison of the acoustic classification with the video/diver estimates of substrate. The comparison was made between each ground truth sample and the closest acoustic echo to that point. One refinement of the standard error matrix technique was necessary. The video/diver data was expressed as a fraction; the substrate at each point was X% sediment, Y% hard bottom, and Z% rubble. The acoustic classes, on the other hand, were discrete, so each entry in the error matrix was divided proportionally by the video/diver-estimated substrate (Gleason et al. 2006 have a sample calculation.)

Results

The LSI data clustered into nine acoustic classes. Only four of these classes, however, made up 96% of the total number of echoes. The cluster labeling process indicated that one of the acoustic classes, with 26% of the echoes, corresponded to hard bottom while the other three classes, with combined 71% of the echoes, corresponded to sediment. Comparison with the LSI video dataset indicated that the hard bottom/sediment acoustic classification had an overall accuracy of 74% (Fig. 3).

The Carysfort data clustered into seven acoustic classes. Only three of these classes, however, made

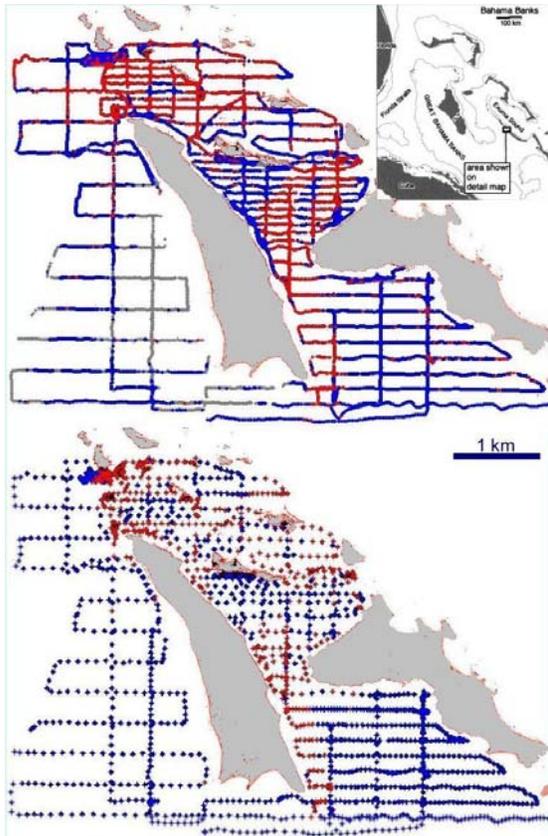


Figure 3: LSI acoustic classification (top) and video classification (bottom). Red and blue points in both plots indicate hard bottom and sediment, respectively. The two additional sediment classes in the acoustic classification are shown in grey (top). Islands are shown in grey in both plots.

up 94% of the total number of echoes. The cluster labeling process indicated that one of the acoustic classes, with 46% of the echoes, corresponded to hard bottom while the other two classes, with combined 48% of the echoes, corresponded to sediment. Comparison with the RVC substrate dataset indicated that the Carysfort hard bottom/sediment acoustic classification had an overall accuracy of 86%.

The Fowey Rocks data clustered into six acoustic classes. Only four of these classes, however, made up 97% of the total number of echoes. The cluster labeling process indicated that two of the acoustic classes, with combined 63% of the echoes, corresponded to hard bottom while the other two classes, with combined 34% of the echoes, corresponded to sediment. Comparison with the RVC substrate dataset indicated that the Fowey Rocks hard bottom/sediment acoustic classification had an overall accuracy of 78% (Fig. 4).

Discussion

The results showed that rock was well discriminated from sediment using the QTCV. Overall accuracy for the rock/sediment classification in the three surveys

ranged from 74% to 86%. Many maps with a coarse level of descriptive resolution that were derived from satellite imagery have overall accuracy in this same range (Mumby et al. 1997; Andrefouet et al. 2003).

It is worth considering whether a rock/sediment classification scheme is too simple to be useful. Even though the overall accuracy of the simple two-class acoustic seabed maps was comparable to coarse-level maps derived from satellite imagery, most image-derived seabed maps have more than just two classes. One difference between satellite or aerial imagery and acoustic data is that bathymetry is inherently part of the acoustic data collection, and is therefore available to complement the seabed classification. Adding even a simple rock/sediment classification to traditional bathymetric data has a strong potential to benefit habitat mapping.

One example of the benefits of adding a simple rock/sediment classification to traditional bathymetric data for habitat mapping is the ability to discriminate outcropping parts of the seabed. Hard bottom is known to be important habitat for many types of fish. Sometimes substrate can be inferred from topographic profiles, but in other cases interpreting the bathymetry alone can be misleading. Figure 5 shows an example from the Florida Keys where bathymetry alone provided a misleading picture of habitat.

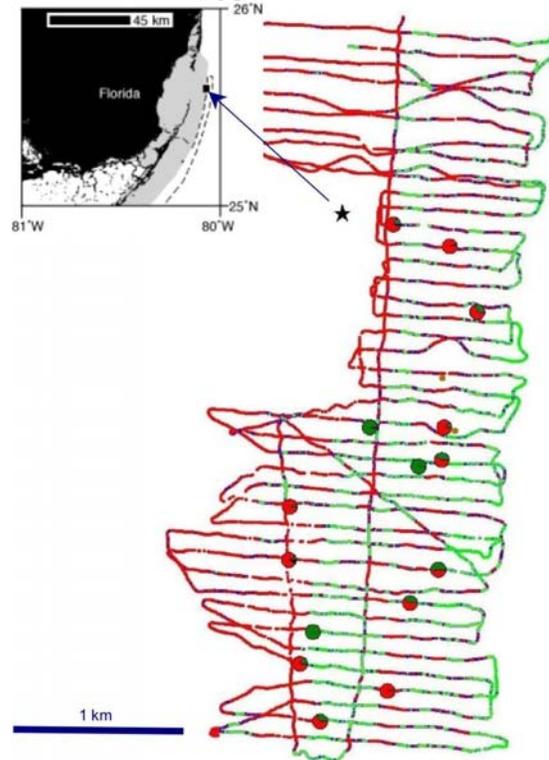


Figure 4: Fowey rocks acoustic classes (track lines) and diver estimated substrate (pie charts). Red and green represent hard bottom and sediment substrate for both types of symbols.

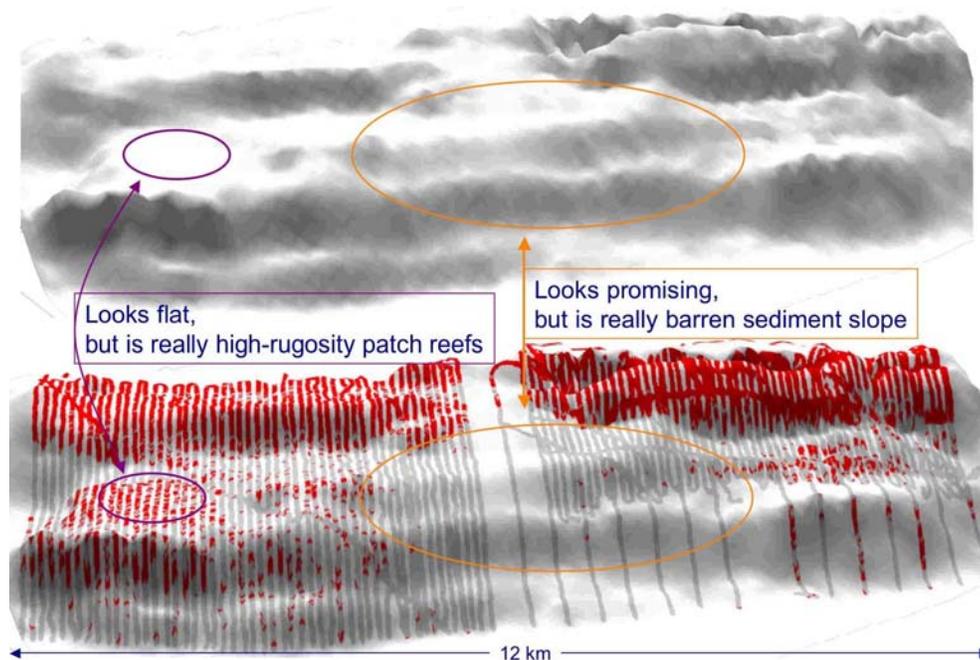


Figure 5: Example of the utility of rock/sediment seabed classification in interpreting bathymetry for fish habitat. Top panel: sunshaded bathymetry from single-beam echosounder depths interpolated to a 30 m grid along the upper slope seaward of Carysfort and Watson's Reefs, Florida Keys, USA. Bottom panel: Survey track lines superimposed on the same sunshaded bathymetry as the top panel. The track lines are colored red for hard bottom (rocky) and gray for sediment substrate. In both panels, oblique view is from the ESE, total along shelf distance is about 12 km, and depth ranges from 3 to 60 m.

Based on bathymetry alone (Fig. 5, top), the area in orange appears to be promising fish habitat because it contains two parallel ridges with steep slopes, and the area circled in purple appears to be a flat, featureless plain. When considering seabed type in addition to bathymetry (Fig. 5, bottom), a different interpretation becomes apparent; sediment covered the area in orange, providing little shelter for fish, while the area in purple was covered with small patch reefs, which would generally provide excellent reef fish habitat.

A second benefit to habitat mapping resulting from the addition of a simple rock/sediment classification to bathymetry is the potential to create an objective habitat classification scheme based on patchiness and relief. Franklin et al. (2003) proposed such a habitat classification scheme for coral reef environments. Patchiness was defined as the percent of the seabed within a certain radius of the point being classified that was covered with sediment. Relief was defined as the depth range within a certain radius of the point being classified.

Miller et al. (2008) used QTCV data and the Franklin et al. (2003) classification scheme to produce a benthic habitat map for the Navassa National Wildlife refuge. One of more than 100 transects used to create the Miller et al. (2008) map is shown in Figure 6; it illustrates the potential of QTCV data as input to the Franklin et al. (2003) classification scheme. The top portion of Figure 6 shows the

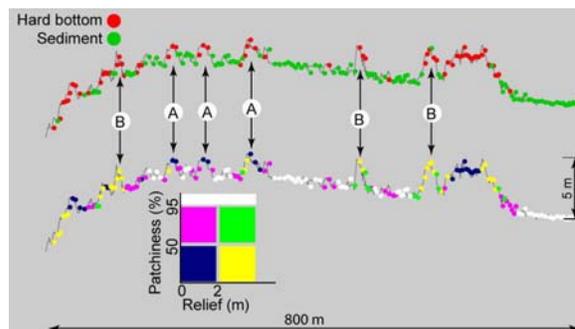


Figure 6: Cross shelf profile of part of the Navassa Island insular shelf. Top: Echoes colored by substrate only, red for hard bottom and green for sediment. Bottom: The same transect with echoes colored by a combination of local patchiness and relief. Patch reefs marked A and B were low and high relief, respectively.

transect plotted with echoes colored by substrate, while the bottom shows the transect plotted with echoes colored by both substrate and relief.

Two types of patch reefs are highlighted along the transect (Fig. 6). Reefs labeled "A" and "B" had similar cross-shelf width, but those labeled "B" had higher relief. Considering substrate only, these reefs were all the same class (hard bottom), but considering both patchiness and relief, the low and high relief patch reef categories were objectively discriminated (yellow vs. blue class).

Franklin et al. (2003) produced a habitat map of the Dry Tortugas using a classification scheme based on patchiness and relief, but the map was based on

qualitative interpretation. The advantage of using a single-beam acoustic approach, as described above, for this type of classification is that it is objective and automated.

Conclusions

The results of this study showed that the QTCV commercial single-beam acoustic seabed classification system discriminated rocky from sediment substrate with about 80% accuracy. This result was confirmed with surveys at multiple sites using the same QTCV system and different methods for ground truth.

Two examples were given demonstrating that even a simple rock/sediment classification can improve habitat mapping of coral reefs. One example showed that using substrate information improved an interpretation of fish habitat based on bathymetry alone. The second example showed that QTCV single-beam data were capable of objectively classifying habitat based on patchiness and relief, whereas previous efforts to do so had relied on subjective analyst interpretation.

Due to the robust capability to extract bathymetry and basic rock/sediment substrate classification, combined with low cost and portability, single-beam systems have the potential to complement other survey methods in coral reef mapping efforts.

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