An Exploration of the Potential for 'Opti-Acoustic' Seabed Classification

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LONG-TERM GOALS

Optical and acoustical data processing are two powerful remote sensing techniques for sea floor classification. Our research goal is to explore the potential for the fusion of these two data sets to extend classification capabilities beyond traditional methods.

OBJECTIVES

Specific objectives are (1) to evaluate the utility of optical and acoustical techniques for shallow water bottom mapping using feature extraction and statistical processing methods; and (2) to evaluate the utility of integrated "opti-acoustical" processing relative to individual optical and acoustical methods.

APPROACH

Our approach is based on the premise that geological and biological variability of the sea bottom is expressed in the diversity of shapes of optical reflections and acoustic echoes from the seafloor (Preston et al. 2000). Exploiting this concept requires data-acquisition equipment capable of capturing detailed measurements of radiance or acoustic pressure as well as techniques for extracting features from these signals and for classifying signals using those features that are rich in bottom information. This phenomenological approach contrasts with approaches based on physical models of bottom backscatter and techniques for fitting observed echoes. By following this complementary, phenomenological approach, we hope to gain new insight into relationships between the physical and biological attributes of the seabed and the corresponding optical and acoustical responses.

Three data sets were acquired simultaneously during surveys for this project: (1) hyperspectral data collected with a Satlantic hyperspectral tethered spectral radiometer buoy (HTSRB); (2) acoustic data collected with a Quester Tangent Corporation (QTC) QTC VIEW System V at 50 kHz; and (3) video data collected using a camera mounted to the acoustic transducer pole.

An unsupervised approach was used to classify the HTSRB and acoustic data sets both independently and together as a single, fused, opti-acoustic data set. Calculations were performed with the software QTC IMPACT, which clusters signal features using a modified k-means algorithm (QTC 2002). The features computed in IMPACT are based on the shape of the input signal and are designed to exploit known characteristics of acoustic echoes (Collins and Lacroix 1997).

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14. ABSTRACT
Optical and acoustical data processing are two powerful remote sensing techniques for sea floor classification. Our research goal is to explore the potential for the fusion of these two data sets to extend classification capabilities beyond traditional methods.

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This work is a collaboration between the University of Miami and Quester Tangent Corporation (QTC). Pamela Reid and graduate students Art Gleason and Eric Louchard from Miami contribute experience in carbonate sedimentology and optical seabed classification. William Collins and Jon Preston from QTC have expertise in acoustic seabed classification and the QTC equipment being used.

WORK COMPLETED

Hyperspectral, acoustic, and video data were acquired near Lee Stocking Island (LSI), Bahamas in June 2001. Over 25 sites were visited by SCUBA divers in June 2002 and Aug. 2003 to collect more detailed "ground truth" than could be discerned from the video alone. Additional surveys were conducted along the barrier reef at Andros Island, Bahamas, and seaward of Carysfort Reef, off Key Largo in the Florida Keys because, relative to LSI, these locations had more extensive coral development, greater overall depths, greater variation in grain size, and a larger depth range of most bottom types.

RESULTS

Optical Seafloor Classification

Feature-based classification of hyperspectral data correlated well with video classification. Prior to clustering using QTC IMPACT, a modified version of the Hydrolight (Sequoia Scientific, Inc., Bellevue, WA) software was used to recover bottom reflectance (R_b) based on the HTSRB measurements (Louchard 2003). This procedure successfully removed the effects of light absorption by the water column (Louchard 2003). Subsequent clustering of R_b spectra using IMPACT defined seven optical classes, which were reduced to three major bottom types (sand, seagrass and pavement/hardbottom) using one half of the video data (Fig. 1A). Accuracy assessment using the second half of the video data gave an overall accuracy for HTSRB classification in the Adderly Cut area of LSI of 81% (Fig. 1B). This level of performance is consistent with previous efforts to classify tropical coastal seabeds using optical data (e.g. Mumby et al. 1997 using maximum liklihood classification; Louchard et al. 2003 using a look-up-table approach). The results were encouraging given that the features in IMPACT were designed for acoustic echo waveform analysis.

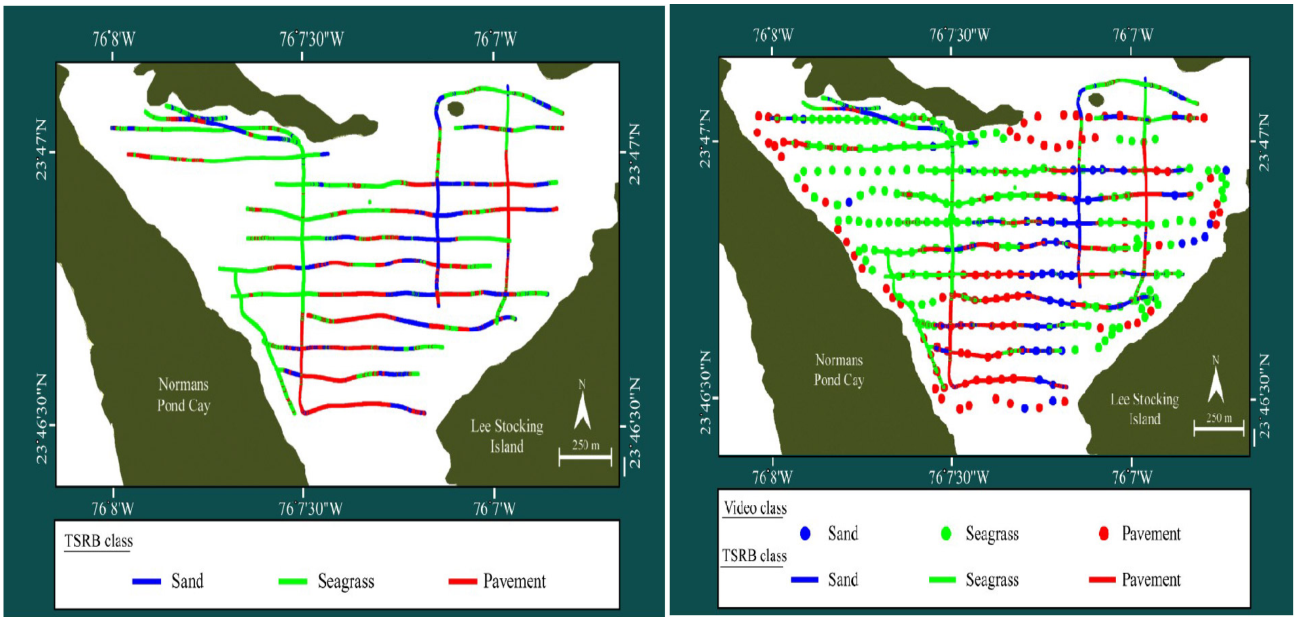

Figure 1: HTSRB classification for Adderly Cut, LSI (left, Fig 1a). HTSRB and video classifications (right, Fig. 1b) showing good correspondence in most locaitons.

Acoustic Seafloor Classification

Acoustic class assignments did not show a one-for-one correspondence with video classes. After clustering by IMPACT, the data from Adderly Cut, LSI, defined six acoustic classes (Fig. 2). Three of the classes (red, blue, and white on the track lines, Fig. 2) were associated with specific video classes (hardbottom, seagrass, and sand, respectively). There was, however, mixing between the classes and, in the case of the remaining three classes (yellow, brown, black, Fig. 2), there was little correlation.

Further investigation performed by SCUBA divers during June 2002 begins to explain the discrepancies between the acoustic and video classifications. In Figure 2, dive sites are plotted as solid circles colored according to the diver description (see legend). “Zones of Acoustic Similarity”, as defined by subjective grouping of color patterns, are outlined in black and designated by letters (A, B etc). Color combinations comprising each ‘Similarity Zone’ are indicated in the legend. In most cases, dive sites with similar seabed descriptions fall within equivalent Zones of Acoustic Similarity, leading to interpretations of these Zones (see legend); exceptions are labeled sites 1-5. These are all of the sites in less than 2.5 meters of water, suggesting that classification was not successful in very shallow areas.

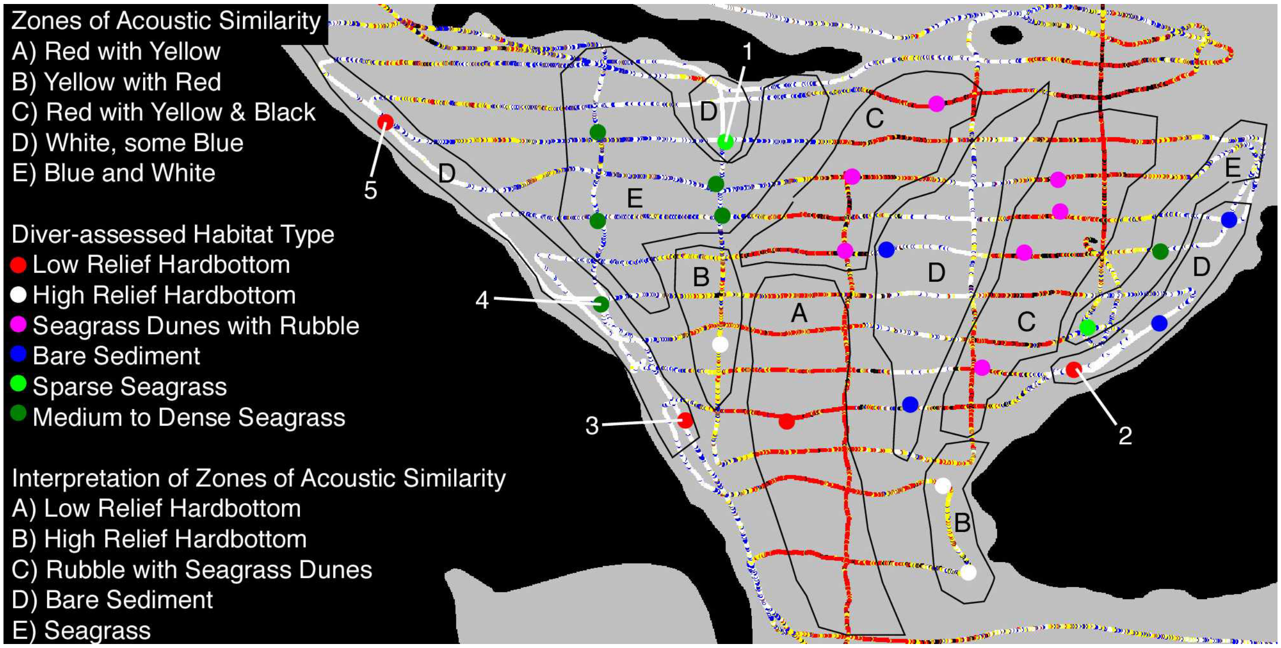

Figure 2: Unsupervised acoustic classification of the Adderly Cut area. Acoustic classes, represented by colors of the track lines, often occur in mixtures due to the patchy bottom in this area. They are grouped into "Zones of Acoustic Similarity" (A-E) based on combinations of classes. Dive sites are shown as large dots colored according to diver-description and are used to interpret the Zones.

Acoustic Zone C (Fig. 2) is a rubble-covered hardbottom interspersed with seagrass-stabilized sand dunes over 1 m high. The co-occurrence of seagrass and hardbottom within a small area comprises a distinct and unexpected substrate combination that does not fit within a simple, three-class framework of sand, seagrass or hardbottom. The unsupervised classification allows this bottom type to emerge as a mappable unit, although it is defined by a mixture of acoustic classes, not by a single class.

Further insight into the physical influences on acoustic diversity is found in results of the acoustic surveys at Andros and Carysfort reef. Acoustic data from these sites were combined and clustered into seven classes. Twenty-five dives were conducted to gather habitat descriptions, sediment samples, and sediment thickness measurements. The diver descriptions help to assign qualitative bottom type descriptions for the acoustic classes (Fig. 3). The acoustic classification can be described in terms of thickness of sedimentary cover over bedrock (red, yellow, black and brown classes), large and small-scale roughness (red, pink and green classes), and grain size (brown, black, and blue colors).

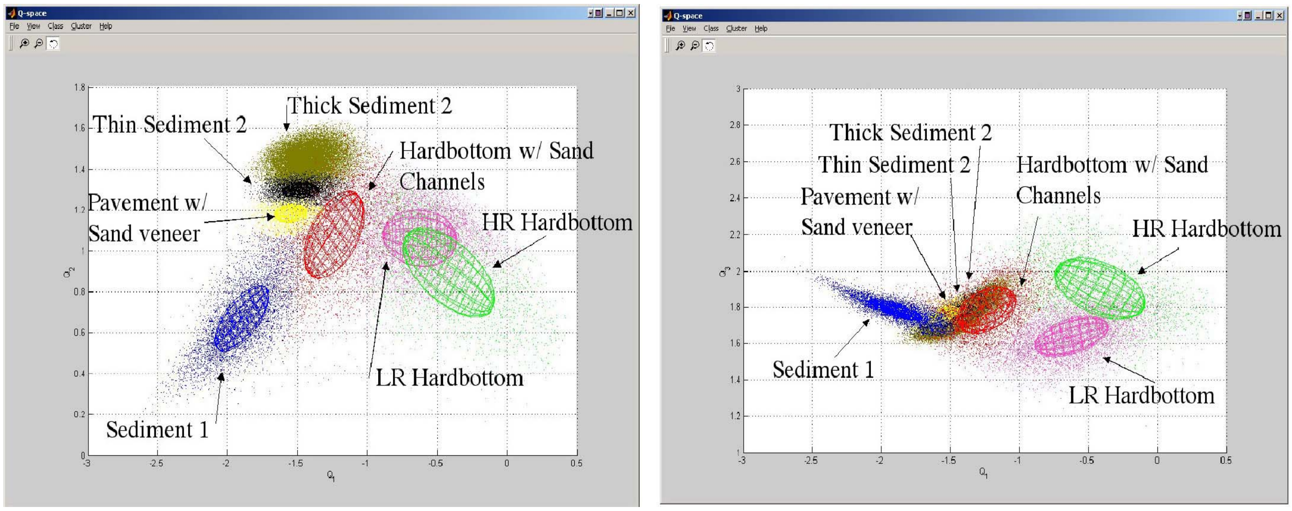

Figure 3: Interpretation of acoustic end-member classes from Andros and Carysfort based on diver site descriptions. Fig. 3a (left) shows the first two principal components of the features computed for the combined Carysfort / Andros data set. Fig. 3b (right) shows the first and third principal components. Cluster labels are based on diver descriptions from 25 sites. HR: high relief; LR: low relief; Sediment Type 1, fine sand; Sediment Type 2, coarse sand.

Opti-acoustic Seafloor Classification

A fused optic-acoustic classification was accomplished by concatenating the features computed by IMPACT for the hyperspectral and acoustic data sets at each location along the survey tracks. The result (Fig. 4) demonstrates that a distinct, mixed seagrass / hardbottom class naturally falls out of the fused data set. For this analysis, the video data were re-classified to reflect the diver descriptions by including a new “mixed” bottom type in addition to sand / seagrass / hardbottom. Note how closely the “mixed” bottom type corresponds to Zone C in Figure 2, but in this case it is a single class rather than a mix of three classes. These findings indicate that fusion at the ‘data’ stage rather than the ‘results’ stage may be a path to more meaningful seafloor maps.

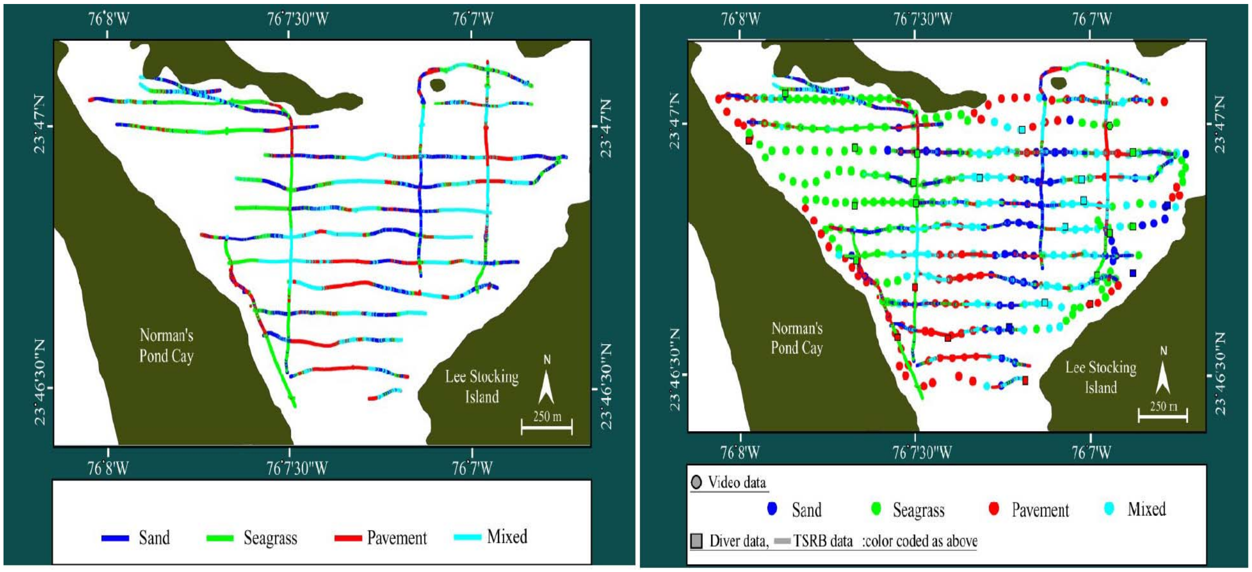

Figure 4: Opti-acoustic classification for Adderly Cut, LSI (left, Fig 4a) and opti-acoustic classification with video classification and diver habitat assessment superimposed (right, Fig. 4b). Video data were re-classified to include a "mixed" class to reflect the seagrass / hardbottom habitat described by divers.

Summary of significant findings and unresolved issues

Feature-based unsupervised seabed classification of water column-corrected hyperspectral data is comparable in accuracy to supervised maximum likelihood or look-up table approaches. Can better results be obtained by extracting a suite of features purposely designed for optical data?

Acoustic diversity in shallow carbonate environments, as mapped using a phenomenological approach, is spatially coherent. The resulting classification scheme does not, however, necessarily relate well with a visual division of classes based on video mapping. What are the physical properties of the seafloor that drive acoustic discrimination within shallow carbonate environments?

Acoustic classes have some overlap with optical classes, but also provide additional information. The fused, opti-acoustic classification identified at least one distinct bottom type not clearly recorded by either the optical or acoustic data individually. What are the characteristic bottom types in shallow tropical environments that can be discriminated using optical and acoustic remote sensing data, individually or as an integrated data set?

IMPACT/APPLICATIONS

Results to date indicate that acoustic diversity is distinct from optical diversity, offering the potential to provide additional, complementary information for benthic classification. In addition, our findings indicate that benthic habitats do not necessarily correspond to individual acoustic classes, but may instead be defined by 'Zones of Acoustic Similarity', comprising combinations of individual classes. Future efforts to merge optical and acoustic data sets are, therefore, likely to lead to identification of specific benthic parameters, including physical properties that cannot be differentiated using optical and acoustic signatures individually. By using optical and acoustical technologies in tandem within the photic zone, classification schemes may be extended beyond water depths where significant spectral reflectance can be detected by optical sensors on airborne or satellite platforms. Results will be important for military, management and fisheries applications requiring benthic habitat maps.

RELATED PROJECTS

Award Number: N000149710010. Composition, Texture and Diagenesis of Carbonate Sediments: Effects on Benthic Optical Properties

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