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Mapping reef structure and bathymetry in Belize using Cobra-Tac

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Abstract. The Cobra-Tac underwater navigation system (RJE Int, Irvine, CA) was evaluated for its mapping capabilities in shallow (< 20 m) hard- and soft-bottom reef habitats. This study was conducted on the lagoon reefs around Wee Wee Caye, Belize. The Cobra-Tac was created as an autonomous underwater diving navigation system that measures depth and altitude for hydrographic and position mapping. It computes its geographic position underwater using a fluxgate compass and a Doppler velocity log. Our objective was to assess the Cobra-Tac's effectiveness as a measuring tool for the rugosity of reef structure and for mapping bathymetry. We found that the accuracy, density, and breadth of data collection are dependent upon speed of travel and altitude above the bottom. Also, multiple passes over the desired area may be necessary to best define the underwater topography in detailed resolution. One advantage over boat-based systems is that Cobra-Tac is diver operated and can be taken into shallow and complex habitats. Provided that the limitations of the system are understood, the Cobra-Tac is a powerful tool for easily mapping the topography of small-scale and shallow marine systems. It produces intelligible and informative bathymetric maps within 30 minutes of data download that are then ready to be used to delineate transects for biotic surveys.

Key words: reef mapping, underwater navigation, Cobra-Tac, Doppler device

Introduction

Coral reefs are complex habitats that support diverse assemblages of biota. The structural rugosity of a reef can be a good predictor of the diversity and abundance of organisms that inhabit reefs (Grigg 1994). While the topographic complexity of reefs is expected to be influential in the abundance of most fishes (Luckhurst and Luckhurst 1978; Gratwicke and Speight 2005), attempts to correlate reef structure with fish density and species richness has met with mixed success. For example, Chapman and Kramer (1999) found a significant relationship between rugosity and fish density for only 10 out of 26 studied species. McCormick (1994) compared six different metrics of topography as indicators of fish abundance. He found a significant relationship in only 18 of the 50 species studied. The reason for this apparent disconnect between topography and fish abundance was due to the difficulty of measuring reef topography on a scale appropriate to the fish survey (McCormick 1994). The most common method for mapping topographic complexity is the chain method developed by Risk (1972). This method is typically applied over areas of 10 m or less. Although this scale may be adequate for smaller fishes, it may not capture the habitat at scales relevant to larger fishes (McCormick 1994; Bartholomew et al. 2008). Some researchers have recognized the scaling problem. When the spatial scale of habitat characterization was expanded, it resulted in better estimation of the abundances of roaming fishes (Friedlander and Parrish 1998; Abesamis et al. 2006; Mumby et al. 2007; Bartholomew et al. 2008). New quantitative methods of characterizing topographic complexity in shallow marine systems at larger scales (100's of meters) have not been fully developed.

Current reef mapping technologies are time intensive. Sidescan sonar provides habitat assessment over broad areas, but topographic relief is difficult to extract. Sidescan sonar does not offer consistent resolution, as the relative height of the towfish above the bottom can vary during operation. Diver surveys provide accurate biological inventories but the collection of directly comparable quantitative topographic information is difficult. Other methods exist (Risk 1972; Smith et al. 1975; Aronson et al. 1994; Mumby et al. 1997; Maeder et al. 2002; Fossa et al. 2005), but each of them, while effective in gathering some metrics, is limited by cost, time, quantity, or quality of data.

To address this need for improved bathymetric mapping technologies, we tested the Cobra-Tac autonomous underwater navigation system (RJE International) for its potential to produce quick, high-resolution bathymetric maps of reef habitats. Cobra-Tac is a diver-operated acoustic Doppler profiler that utilizes tracking technology for underwater navigation.

Study Sites

The study sites were in Belize, Central America. Wee Wee Caye is a small island in the lagoon of the Mesoamerican Barrier Reef off Belize (16.76474288° N 88.142522° W). Southwater Caye is a small island abutting the barrier reef at 16.813567° N 88.080172° W. The surveys were performed in December of 2007.

Methods

Surveys with Cobra-Tac were conducted using a swimming or towed diver. Swimming divers navigated and operated the unit at various depths. A diver (or snorkeler given calm conditions and low speeds) was towed behind a boat (at speeds of 2-4 kt). The boat-towed setup allowed us to compare GPS readings directly with the Cobra-Tac navigational calculations.

The most effective data collection method involved towing or swimming the Cobra-Tac in a tight organized grid. In all cases, holding the unit absolutely horizontal so that the Doppler is aimed directly downwards is critical.

The unit requires the user to input initial GPS coordinates at the surface. The diver then swims the study site while the unit records the location and depth of four points (one for each beam) at one-second intervals throughout the survey. After the completion of the survey, post processing is necessary to create a three-dimensional map of the site. Maps are created with Surfer (Scientific Software Group) or the data can be exported to other software platforms.

Results

The Cobra-Tac and supplied software were readily capable of producing a three-dimensional image of a study site in about 30 minutes of post-processing. In addition, Matlab (Mathworks Inc.) was applied to the Cobra-Tac data to examine details and consistency of the original Cobra-Tac data set.

The Cobra-Tac's navigational accuracy was tested by performing swims along irregular tracks and then navigating back to the start point. Table 1 shows three trials where the start/end location was the same fixed structure. The results from these trials show an accumulated error between 8 and 31 m, which is well within the manufacture's specified 3-5% error. Accuracy could be improved by setting reference points along lengthy surveys for post-dive calibration.

Table 1: Distances traveled during each dive and the error from the starting point Cobra-Tac showed at the end of each dive

Approx. Distance Traveled (m)	Error in recognizing return to starting position (m)
500	8
1600	31
1600	27

The spur and groove reef mapped at Southwater Caye was created with a single pass of the Cobra-Tac operated by a snorkeler (Fig. 1). The spur and groove formations are clearly visible in the figure, but much fine-scale irregularity was lost due to the smoothing functions applied by the supplied software.

The channel immediately west of Wee Wee Caye was also mapped (Fig. 2). The map was created with 6 passes along the longer dimension of the channel, each the length of the channel in a single grid-formation tow. The island and the slopes of the shoals to the west and north are clearly visible in the image. The bathymetry of the channel-bottom, which otherwise is too deep to see from the surface, is also well defined.

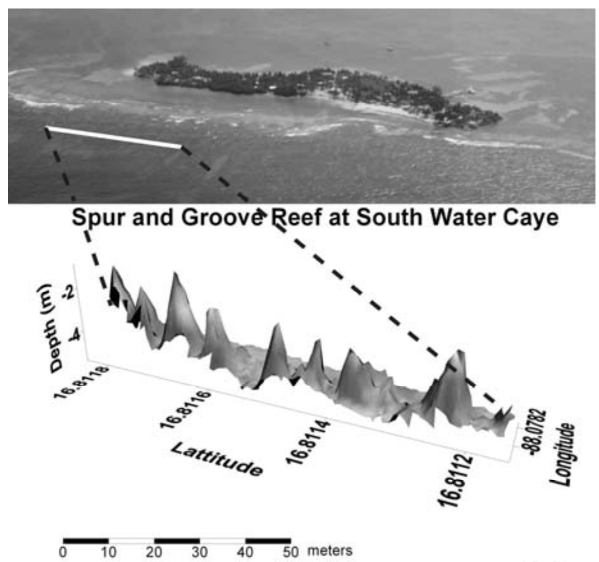

Figure 1: 3-D surface map (bottom) of single-pass transect over spur and groove reef at SouthWater Caye, Belize. The sampled area corresponds to the white line shown in the upper image.

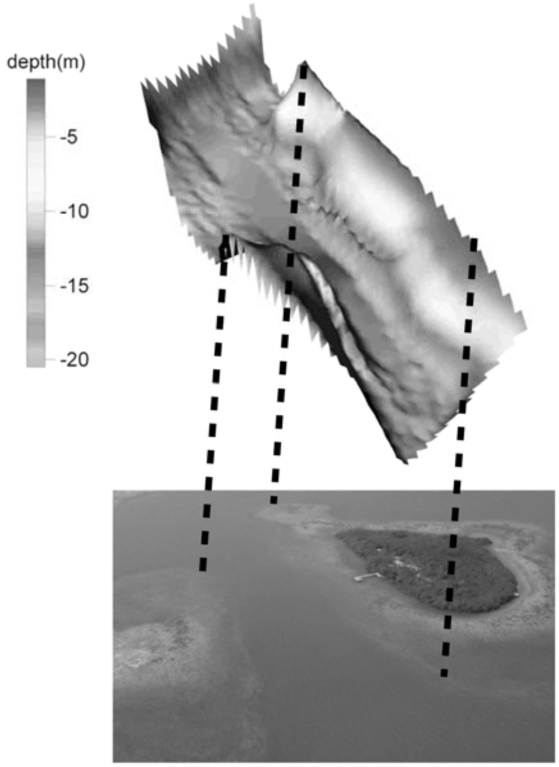

Figure 2: Surface map of channel west of Wee Wee Caye, Belize on top of aerial photograph of the caye. Dashed lines illustrate how the images line up.

To illustrate the necessity of adequate site coverage, the channel data set (Fig. 2) was reanalyzed using subsets of the total number of passes. Revised surfaces were created from these selected passes over the channel (Fig. 3). Too few passes resulted in inaccurate topographic detail.

The following formula was developed to determine the best mapping strategy for a given area in terms of how many passes (or tracks) are needed to yield optimum bottom coverage. The minimum number of passes, ***np***, over a study site is equal to the width of the site, ***w***, divided by the breadth of the beam angles. The breadth of the beam angles is equal to 2 times the height of the unit above the bottom, ***h***, multiplied by **tan (30)**, where 30° is the beam angle (Equation. 1).

(Equation 1) $$np = \frac{w}{2h * \tan(30)}$$

Artifacts in the data were sometimes a problem (Fig. 4) and difficult to differentiate with the Cobra-Tac supplied software (Surfer). It was necessary to post-process the data in Matlab in order to investigate apparent anomalies and remove artifacts, such as the extreme peak and pit seen in Fig. 4. The pit occurred in what we thought was a flat sandy bottom. The peak and pit formation were the result of the unit briefly tipping beyond level, allowing the unit to register far away points as an apparent bottom (Fig. 5).

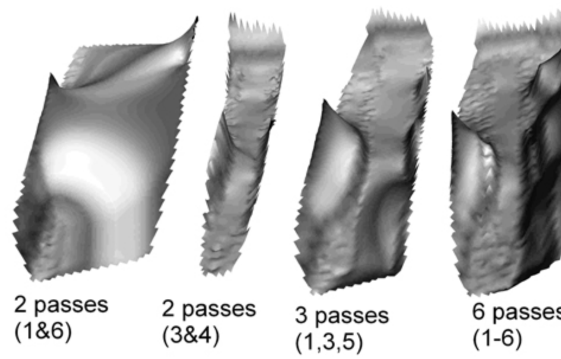

Figure 3: Surfaces created with different combinations of passes over the study site: passes sequentially ordered 1-6 going from west to east. 1 and 6 are the outermost passes of the 6 total.

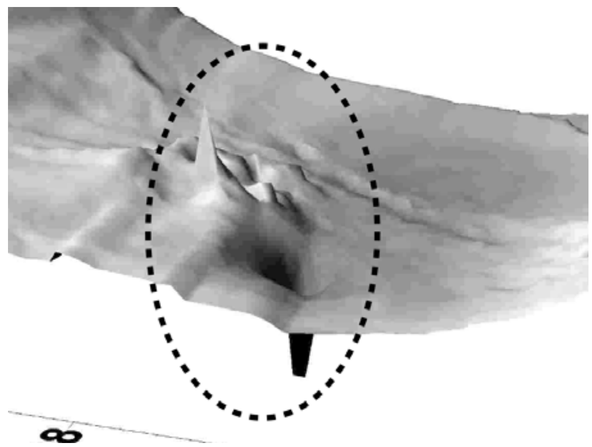

Figure 4: Selection from computer-generated surface of flat channel bottom, interpolated from bad data which resulted in anomalous structures visible within the dashed ellipse.

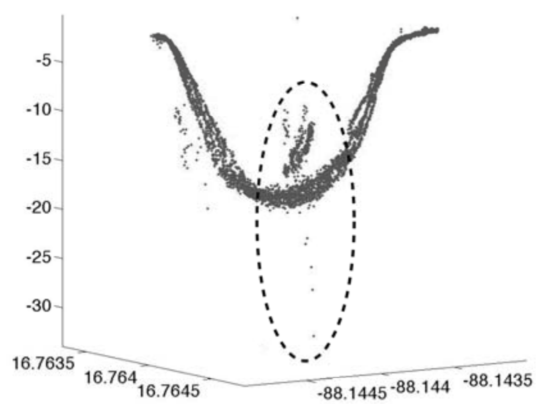

Figure 5: Matlab generated plot of cross channel survey data points as individual dots. Dotted ellipse indicates suspected outlier points, especially in lower portion of plot (below 20 m on z-axis).

Error in mapping can also result if all four of the Doppler beams do not record. The number of beams used to collect data and the complexity of surface recorded is related (Fig. 6). Repeated transects over the same location allow for more complex surfaces to be defined up to the limit of the beam resolution. The beam resolution can be calculated, in theory, based upon the specification of a 1.4° beam width. For example, at a height of 10 meters above the bottom, the spatial resolution is 0.28 m^2.

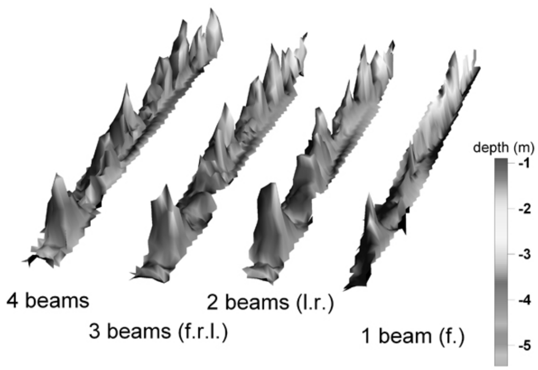

Figure 6: Surfaces created from 4, 3, 2 and 1 beams of the 4 beams on the Cobra-Tac. f= front, r= right, l= left. The complexity and accuracy of the 4 beams surface is significantly greater than that of the surfaces created from fewer beams.

Discussion

Cobra-Tac is a highly portable device that is capable of producing an accurate bathymetric map of a study site within 30 minutes of exiting the water. Waypoints of items of interest can be added while mapping underwater and displayed on the maps produced. The unit does not require a boat; therefore, it can be used in areas inaccessible to vessels. It can be towed behind a boat (with diver) but does not require any specialized apparatus beyond a towrope.

Cobra-Tac is not limited to working from the surface. This allows the device to be kept at a constant altitude above the bottom by a diver when moving over structurally complex habitats. Thus providing consistent resolution of bottom topography. The data are easily incorporated into GIS software, such as ESRI's ArcScene and ArcMap. With a luggage case for the unit and a laptop for data-processing, one can travel very easily with the Cobra-Tac.

The Cobra-Tac was able to map the bathymetry of local areas well. While the accuracy was fine enough to create bathymetric maps, our preliminary data were insufficient to assess if the Cobra-Tac will be a feasible tool for measuring fine scale rugosity (< 10 cm).

Data artifact creation is only avoided by maintaining vigilance while operating the unit and keeping it level. Data anomalies are easily investigated with Matlab, where a few outlying points can be recognized and removed. A shortcoming of the system is that the tilt sensor does not automatically filter data.

Overall, Cobra-Tac does create high-resolution bathymetric maps of reef areas. The effort of collecting and post-processing the data is simple and easy. A bathymetric map of appropriate resolution can provide a permanent record of the reef slope and medium to large-scale rugosity. Sampling over larger geographic scales (100's of meters) presents the opportunity for creating new metrics for habitat complexity at a landscape-scale. Such scales are more relevant for larger, commercially important fishes (Bartholomew et al. 2008). Additionally, Cobra-Tac is a non-invasive technique that does not require physical contact with the bottom or extraction of organisms or live substrate for laboratory measurement.

A device such as the Cobra-Tac has the potential for mapping changes in the structural complexity of reefs that may occur due to physical disturbance or coral mortality events. This is important, not only for monitoring the reef structure itself, but also because the loss of reef habitat results in decreased reef-associated fish biomass (West and Salm 2003). Such large-scale changes in reef structure have generally not been defined quantitatively over time due to technological limitations. Further field-work (in progress) will determine if the Cobra-Tac has the resolution and reproducibility to solve this challenge.

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