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Front Cover: *Porites* colony encrusted by red algae in waters of San Salvador, Bahamas; see paper by Fowler and Griffing., p. 41. Photograph by Pascal Kindler, 2011.

Back Cover:. Dr. Jörn Geister, Naturhistorisches Museum Bern, Keynote Speaker for the 15th Symposium and author of "Keynote Address – Time-Traveling in a Caribbean Coral Reef (San Andres Island, Western Caribbean, Colombia)", this volume , p. vii. Photograph by Joan Mylroie.

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SURVEYING AND HABITAT MAPPING OF A CURAÇAO REEF

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ABSTRACT

The combination of video analysis and geographic data collection provides an inter-disciplinary approach to coral reef surveys. A 2009 field study in Curaçao (Habitat Reef) aimed to develop a non-invasive approach to collecting both spatially referenced and video data of ten transects along the near-shore reef slope ranging from 4 to 16 m depth. A GPS buoy apparatus was created to allow divers to collect benthic information on the reef while obtaining GPS coordinates of their locations. Video transects performed along the same paths were analyzed to collect data on the live stony coral percent cover and species presence within every 25 cm quadrat along each 50 m transect. Data were brought into a GIS program to create maps of the study area and its characteristics. Still images of the video transects and percent coral cover information indicate that, despite an extensive field study, little similarity was found between the transects. These results suggest that Habitat Reef is far more ecologically complex than we predicted and that a more intensive sampling effort is required to make conclusions on the species and coral cover composition of the study area.

INTRODUCTION

Numerous methods currently exist for obtaining data on the ecological characteristics of coral reefs (Rogers, 1990). One reason for this variety is that no single method is the most appropriate for every purpose (Jokiel et al., 2002). Some are designed for rapid, *in-situ* health assessment, while others are meant to gather large amounts of data on a particular site at one time. Traditional *in-situ* field methods are often invasive, drilling permanent structures into the substrate as location reference points. *Ex-situ* methods are more in-depth and less invasive, providing an overall snapshot of a reef's coral cover percentage, health and biodiversity indices, biological distribution, and sediment levels. Common *ex-situ* methods include the analysis of digital imagery, or video footage, of quadrats or transects (Jokiel et al., 2002; Kohler and Gill, 2006; Alquezar and Boyd, 2007) obtained during a brief field study and analyzed at later time in a laboratory setting.

Video transects are used to obtain still frame images of the coral located along transect lines. These images are analyzed visually to determine the percent coral cover of the image area by individual observation. There are substantial benefits to the extra effort of visual analysis as opposed to using coral point-count software packages designed to perform the same task (Kohler and Gill, 2006), including the ability to detect rare species and small specimens that greatly impact the overall percent cover and species diversity data (Jokiel et al., 2002; Lam et al., 2006). Additionally, the recent transition to high-definition (HD) video from standard quality video has greatly increased the quality of still frame images produced for analysis. Visual analysis also does not require an individual to become proficient with new software as the point-count method does, but both methods require that the individual be able to accurately identify corals. One shortcoming to visual analysis methods is that they are often much more time intensive than other methods (Jokiel et al., 2002; Alquezar and Boyd, 2007), but improved video quality expedites the process of finding and identifying coral colonies. For studies that intend to determine coral cover percentages and species distributions, visual analysis offers more accuracy in identification and cover estimation.

Visual analysis has been shown to be a reliable, non-invasive method for providing accurate information about a coral reef environment. Projects using visual analysis in combination with GIS technology are in practice today (NOAA NOS, 2008) and similar field techniques are being employed in Australian reef surveys (Roelfsema and Phinn, 2009). As tools for assessing coastal zones, these methods can be applied to coral reefs throughout the tropics to promote conservation and proper management efforts.

This research stems from a coral reef ecology course project that aimed to establish new methods for reef field surveying that took place in August 2009 in Curaçao, Netherlands Antilles (Figure 1). The goal was to assess habitat quality through video records of the environment and to incorporate coral-cover percentages along transects into a map of the study site. With accurate geographic locations known of each transect, the survey can be replicated to study changes over time at specific locations, such as in percent coral cover or colony mortality. Images created as still frames of the HD video can serve as an additional layer to the GIS framework; by integrating an image file into the map at associated GPS points, one will have the ability to navigate the study area by all methods of analysis used in this project. Further, the addition of GIS technology to the visual transect analysis allows greater application of these data to provide an adaptable habitat assessment that is accessible to a variety of locations and users.

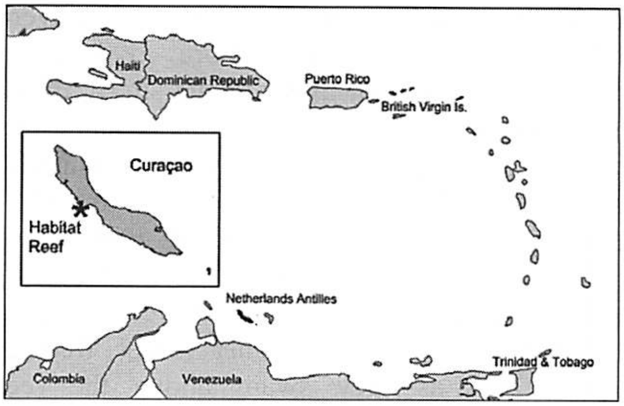

Figure 1. Study Location – Habitat Reef, leeward coast of Curaçao, Leeward Antilles.

METHODOLOGY

Field studies in August 2009 piloted a GIS/Video assessment method in which video transect data and logged GPS points along the transects were incorporated into a GIS bathymetric map database. Data were collected in order to thoroughly assess the habitat and provide a holistic view of the reef environment. Three methodologies used were to 1) observe and record environmental characteristics, 2) represent data in a map format, and 3) create a video analysis procedure.

Environmental Characteristics

In order to provide an accurate representation of the environment surrounding the transects, depth and temperature data were collected along the near-shore reef slope throughout the spatial range of the study. Initial dives were designated for 1) making observations on areas of high coral density, sand patches, extensive rubble, and massive coral heads and 2) recording spatial data associated with these locations with GPS units (see *Mapping* below) and Reefnet underwater sensors. Divers carried a pair of Reefnet sensors (Reefnet Sensus, Reefnet Sensus Pro) as they swam above the reef substrate along each transect to obtain depth and temperature data from the environment surrounding the transects. These data are linked with geographical coordinates to provide a spatial representation of the temperature range throughout the study area.

Mapping

The bathymetric data as well as the data and images obtained from the video transects were combined with the use of a GIS to create a spatial representation of the environment. Spatial information on the environment was gathered by handheld GPS units on a buoy towline apparatus.

Handheld GPS units used in the study (AMOD AGL 3080 GPS Photo Tracker, Magellan Triton 200, Garmin Colorado 400t) were time calibrated according to Greenwich Mean Time (GMT). Local time in Curaçao in August was 4 hours behind GMT and GPS output datasets were adapted to provide local time at -4:00 GMT. Spatial and temporal data were synchronized in the output of each unit. Reefnet output data was synchronized with the GPS units as well, and the video camera clock was set to reflect -4:00 GMT.

To create the GPS buoy towline apparatus, a GPS unit was housed in multiple waterproof bags inside a waterproof casing attached to a small floating buoy. The end of a meter tape, identical to one used to create the transect lines, of at least 50 feet in length was attached to the buoy. This meter tape could be extended or retracted onto its reel depending on the depth of the individual towing the unit. The end carried by the diver was weighted with a small bag of diving weights (3-4 weights, 6-8 lbs) to keep the line taught. In order to ensure that the GPS unit remained directly above the transect or other designated area, the air bubbles from the diver swimming along this path were observed to see that they broke at the same surface location as the GPS buoy (Figure 2).

GPS data output from each device was formatted to read in decimal degrees units. Output was imported into Microsoft Excel as .xml file formats and saved in comma-separated variable (.csv) file formats.

All spatial analyses were performed using ArcEditor (ArcMap and ArcScene) software, Arcversion 9.3.1 (ESRI, Inc. 2009). Data were collected as Geographic Coordinate System (GCS) projections in the WGS 1984 datum and transformed into Universal Transverse Mercator (UTM) projections to view and edit in map projects. Latitude and longitude data points are mapped as point shapefiles in ArcMap. Raster files were created to represent the spatial distribution of depth and temperature as separate shapefiles.

Pansharpened and multispectral images were purchased from Quickbird (Digital Globe, Inc.) as basemap imagery. The blended panchromatic image used in maps created for this study is a blend of a high-resolution (60-70 cm) black and white pansharpened image and a multispectral image with 2.4 m pixel resolution. Shoreline images obtained from Google Earth

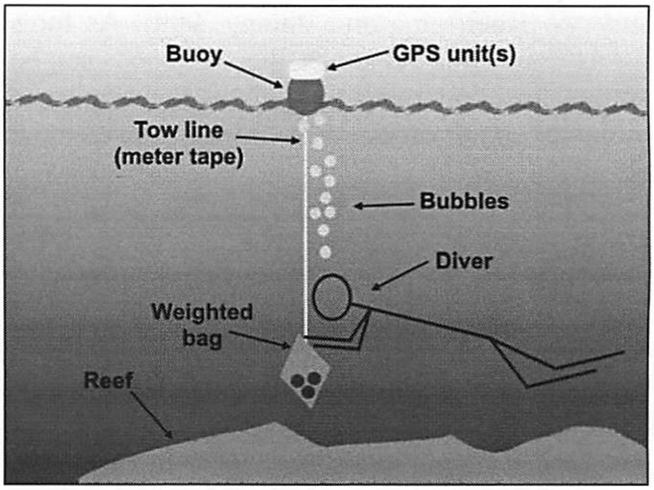

Figure 2. GPS buoy towline diagram.

were also georeferenced for basemap imagery.

Video Transects

Each video recorded of the 2009 CRE reef transects was analyzed to obtain digital images along the reef that identify the location and composition of the coral biodiversity of our study site. These images were created with a high-definition (HD) digital video camera to correspond with GIS data at the latitudinal and longitudinal locations of the coral colonies based on their associated time and transect location information.

The location of each video transect was designated with meter tapes laid on the reef and secured in place with 3 or 4 dive weights. Ten 50-m transects were established along the habitat, with approximately 15 m separating each, perpendicular to the shoreline and parallel to the reef slope. The entire study site covered an area of approximately 7500 m^2. We surveyed 500 m of transect, obtaining data at 25 cm intervals, to total an area of 125 m^2 from which our data were obtained (16.67% of the entire study site). Ten transects were positioned parallel to the 'guide rope' placed on the reef by the dive operator, with approximately 20 m separating the guide rope from transects 5 and 6 to the North and South, respectively. This rope extended from the dock to the base of the reef slope and served as a guide for SCUBA divers as they swam toward the reef and returned to shore. Each transect began at a maximum depth of approximately 50 ft (15 m) parallel to the guide rope, although the reef habitat extended far beyond this depth to approximately 120 ft. This maximum depth was chosen as a safety measure for the divers performing multiple passes along the transects.

The time function of the video camera was set to match the local time of -4:00 GMT recorded by the GPS units to synchronize data analysis.

Two parallel lasers attached to the video camera housing were used to indicate a measurement of 25 cm along the substrate perpendicular to the transect line. The use of laser sights as a non-obtrusive technique for scaling the video procedure follows an approach similar to other video-transect methods (Rouphael and Inglis, 1997; Tratalos and Austin, 2001; Schmitt et al., 2002; Roelfsema et al., 2006; Alquezar and Boyd, 2007) that manage for consistent video resolution. From these two laser points, a 25 cm^2 grid was extrapolated for video analysis.

A screen shot of the transect video was recorded at each 25 cm progression along the transect line starting at 0 m. The individual performing all video analyses used the laser points to determine a "visual grid" based upon the 25 cm line between the two laser sights (Figure 3). Within the visualized 25 cm^2 grid, the individual determined the percent coverage of live corals in each of the four "quarters" at each grid location. The total coverage within these quarters was summed ($\leq$ 400%) and divided by four for a more accurate final cover percentage.

Species and genus identification were verified with Humann and Deloach field guides (Humann and Deloach, 2008) and via personal communication among research participants. Only stony corals were identified for this study and AGRRA species codes (Lang et al., 2010; Table 1) were used for categorization.

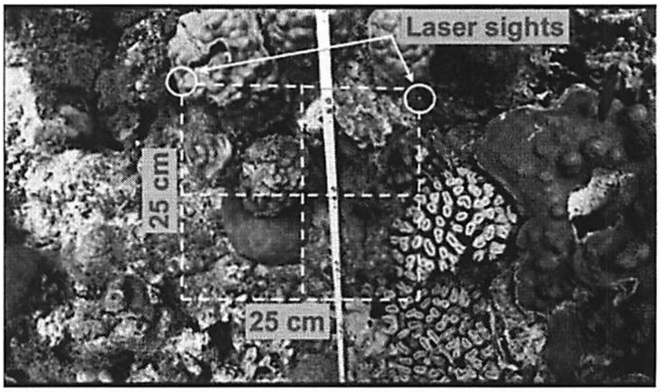

Figure 3. Still image of HD video transect with visual grid illustration.

Precision of Location

Two GPS units were attached atop one buoy to compare the coordinate readings of each

Table 1. AGRRA coral species codes used for this study.

Code	***Scientific Name***
AGAR	*Agaricia spp.*
CNAT	*Colpophyllia natans*
DCYL	*Dendrogyra cylindrus*
DSTO	*Dichocoenia stokesi*
DLAB	*Diploria labrynthiformis*
DSTR	*Diploria strigosa*
EFAS	*Eusmilia fastigiata*
FFRA	*Favia fragum*
MAUR	*Madracis auretenra (mirabilis)*
MMEA	*Meandrina meandrites*
MILL	*Millepora spp.*
MANN	*Montastrea annularis*
MCAV	*Montastrea cavernosa*
MFAV	*Montastrea faveolata*
MFRA	*Montastrea franksi*
PAST	*Porites astreoides*
PPOR	*Porites porites*
SSID	*Siderastrea siderea*
SRAD	*Siderastrea radians*
UNKN	*unknown*

unit. The average distance of 0.44 m ($\sigma = 0.056$ m) between the two units suggests that we had less than half a meter difference in readings between the two units at any given location. High variability on our first day of data collection using the GPS buoy setup increased error in our data precision, skewing our data from the true average difference between units. Additionally, depth data from the paired Reefnet units were averaged in order to provide an accurate representation of the bathymetric features.

Coordinates taken at the end of the dock verified the accuracy of the GPS data with satellite imagery at the site and served as the benchmark for our transect coordinates.

Statistical Analysis

Quantitative and graphical analyses for species and percent coral-cover data were completed with JMP 8 (SAS Institute, Inc.) and Microsoft Excel.

RESULTS

Bathymetric Map

A detailed bathymetric map created a spatial representation of depth ranges within the study area (Figure 4). These data were obtained during separate dives with the intention of collecting data points throughout the majority of the reef directly offshore from the resort. The total depth range of the surveyed area was measured from <1 to 18 m. Transects were placed along the reef slope between 4 and 16 meters.

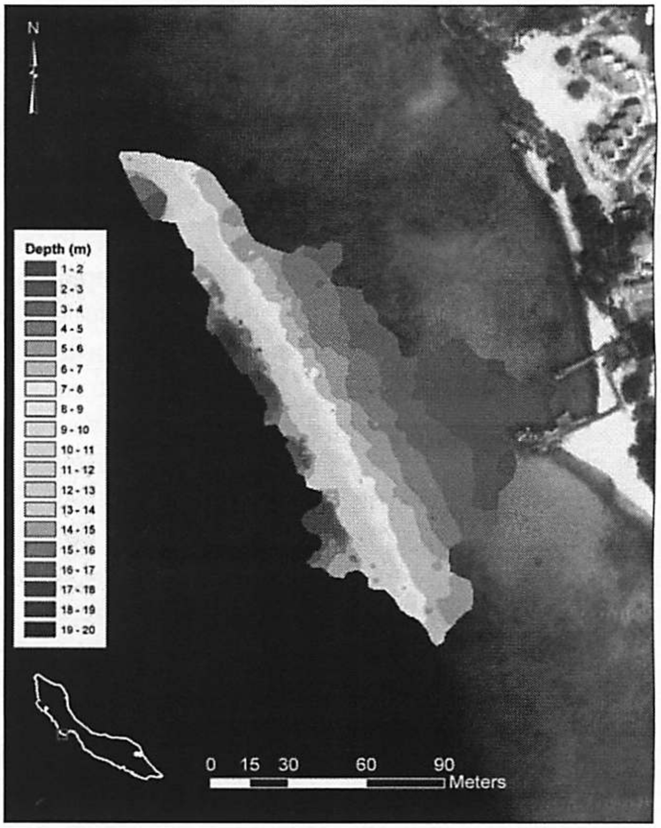

Figure 4. Depth ranges within the Habitat Reef study area.

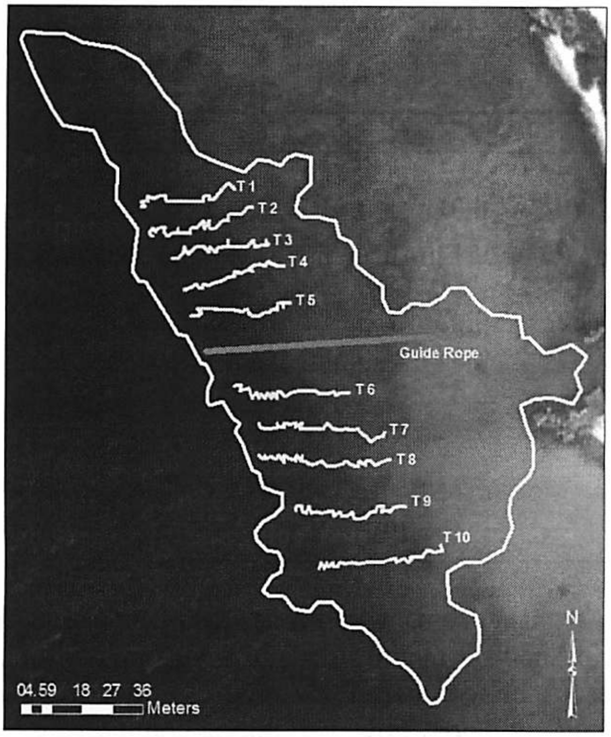

Figure 5. GPS transect data points and transect locations.

Transect Map Location

Transects were spatially represented as point series in additional map layers. Lines created and coordinate information provided by GPS points indicate the location of each transect (Figure 5).

Coral Cover

Assessments revealed an average of 5.406% ($\sigma = 2.229$) stony coral cover within the transect depth range (4-16 m). The majority of the reef at <6 m depth had very little coral cover and consisted primarily of sand and rubble which reduces the overall percent cover for each transect. When the shallow sandy areas (<6 m) were removed from analysis, the average stony coral cover along transects at a 6-16 m depth range increased to 5.734% ($\sigma = 3.635$). We observed 18 stony coral species with 4-6 dominant species (Figure 6). Maximum percent cover of a single species was 20.1% for *Montastrea annularis* ("MANN") and minimum percent cover of a single observed species was 0.04% for *Favia fragum* ("FFRA"). Unidentified species ("UNKN") contributed to 1.34% of the total observed coral cover.

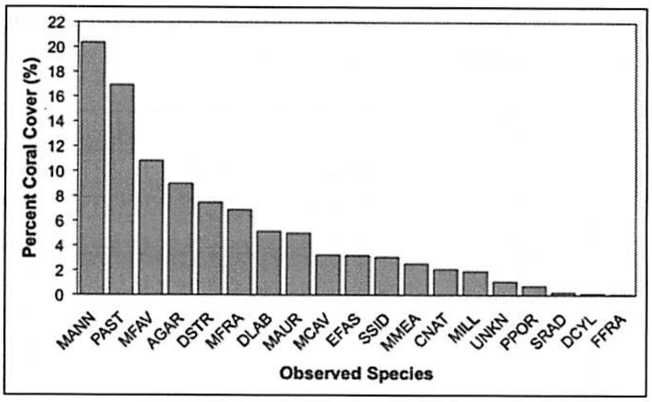

Figure 6. Coral-species percent cover within the Habitat Reef study area. AGRRA species identification is given in Table 1.

Coral distribution along the transect generally increased above depths of 6 m, approximately 20 m from the beginning of each transect (Figure 7). As data were collected on each transect, "spikes" of percent coral cover were also observed at regular distance/depth intervals. A comparison of the zones among multiple transects shows that this visual zonation occurs regularly throughout the habitat area.

Analyses

Spearman rank analyses provide information about the relationship between each

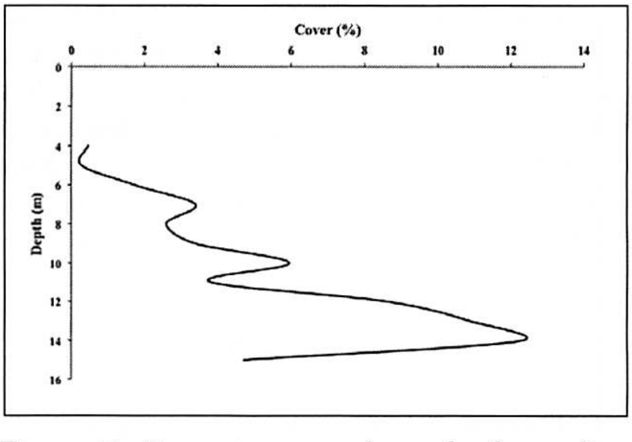

Figure 7. Percent cover along depth gradient. Points represent average percent cover calculated at every 1 m interval.

Table 2. Spearman rank order of abundance comparisons and associated p-values (bold values with '' indicate significance, $p < 0.05$).*

ALL	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
ALL	0.488	0.409	0.263	0.221	0.878	0.459	0.072	0.825	0.276	0.665
T1	T1	0.836	0.053	0.603	0.789	0.390	**0.010***	**0.017***	0.166	0.390
T2		T2	0.425	0.342	**0.041***	**0.043***	0.330	0.396	0.237	0.979
T3			T3	0.096	0.441	0.375	**<.0001***	0.070	0.517	0.969
T4				T4	0.201	0.682	**0.036***	0.333	0.189	0.833
T5					T5	**0.007***	0.621	0.399	0.801	0.594
T6						T6	0.456	0.289	0.621	0.771
T7							T7	0.181	0.293	0.963
T8								T8	0.107	0.558
T9									T9	0.932
T10										T10

transect and the study area. The overall rank order of species abundance was compared with individual rank orders of abundance to identify variation (Table 2). Results indicate that only seven of 45 comparisons among transects had significant relationships ($p < 0.05$), two of which were inverse relationships. These results suggest that no individual transect rank orders were significantly related to the overall rank order, thus suggesting that no single transect could provide an accurate representation of the entire reef.

No adjacent transects show significant positive correlations, suggesting that the reef characteristics differ even within a 15 m range between transects. Although transects 5 and 6 are numerically adjacent and are positively correlated (Table 2, $p = 0.0072$), they are separated by twice the distance of physically adjacent transects because the guide rope lies between them. There is a potential influence of the guide rope on these two transects, as diver traffic is heaviest along this section of the reef, but the data do not support such an influence.

DISCUSSION

Previous research confirms the applicability of video transect analyses and the high quality data one can obtain from video footage (Roelfsema et al., 2006; Tratalos and Austin, 2001; Roelfsema and Phinn, 2009). The visual grid analysis method designed in this study has yet to be compared to computer-based point-count methods, however initial comparisons of the respective methods in each analysis and the ability to include all observed coral cover in the visual grid analysis method suggest that our method is comparable to if not more comprehensive than point-count methods. As the literature also makes clear (Rogers, 1990; Jokiel et al., 2002), multiple survey methods are necessary for different research goals. For surveys that aim to create permanent databases of reef characteristics, video analysis is a reasonable method to choose. Further, the use of a GIS is helpful in studies that aim to map features of a reef and obtain non-invasive data on a site, but are not seeking the extensive spatial characteristics that can be obtained by remote-sensing technology. Ultimately, visual analyses take the guesswork out of research by improving a researcher's ability to identify reef characteristics such as coral species and percent cover in a laboratory setting. The advancements of HD video quality increase the speed and accuracy at which these identifications can be made.

The data collected in this study provide accurate representations of the methods performed in the field and of the environmental features of the study site. In terms of the usefulness of the field methods used for spatial-data collection, researchers were able to follow simple procedures in order to obtain useable data from the GPS and Reefnet units. A reference point on our satellite imagery verified the accuracy of our data and show that GPS data collected in the field are capable of producing accurate locations even without a base station reference. The creation of a transect map accomplished the goal of identifying transect locations without performing invasive field methods such as drilling rebar poles into the substrate or constructing permanent concrete buoys and latitude and longitude coordinates along each transect allow us to easily return to the same locations for repeated studies.

Preliminary results of this study suggest that the Habitat Reef is ecologically complex and that more sampling is necessary to make conclusions about the overall species composition and cover. Although the ten completed transects cover a 150-m stretch of the shoreline reef and 125 m^2 of observed habitat - far more area than most coral surveys include - we do not have conclusive information on the composition of the stony coral community. Research has provided insight into the levels of diver presence required to produce lasting effects on corals from fin strikes and similar damage (Hawkins and Roberts, 1997; Medio et al., 1997; Talge, 1992; Zakai and Chadwick-Furman, 2002) and further studies are necessary to make conclusions on the relationship of diver impacts on coral cover composition at this reef location.

The question remains unanswered as to how extensive a sampling effort needs to be in order to make conclusions about the coral cover composition of a reef (Hill and Wilkinson, 2004; Brandt et al., 2009). With uncertainty after such extensive data collection, how much more sampling is required in order to obtain enough data? Accurate predictions of the sampling effort required in a field survey are crucial to the continued development of this survey method as well as others. Researchers, environmental managers, local residents and divers are interested in various characteristics of a coral reef ecosystem and, with quality data, each can make more informed decisions concerning reef health, appropriate management practices, and their own interactions with coral reefs.

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