AC 2012-3837: EXPLORATORY INVESTIGATIONS IN USING REMOTELY OPERATED VEHICLES TO GROUND TRUTH UNDERWATER RESOURCES IDENTIFIED FROM REMOTELY SENSED AERIAL IMAGERY

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Exploratory Investigations in using Remotely Operated Vehicles to Ground Truth Underwater Resources Identified from Remotely Sensed Aerial Imagery

Abstract

Antigua and Barbuda, like many other developing nations, has historically faced exploitation of its natural resources in the shadows of national progress. Activities linked to the growth of tourism, urbanization, and agriculture have resulted in reduced biodiversity, land degradation, hydrological changes, and reduced water quality. The need to protect valuable resources without stalling national development has lead to the implementation of the sustainable island resource management mechanism (SIRMM) project in the twin-island nation. The SIRMM, a project based largely upon remote sensing (RS) and geographical information systems (GIS), seeks to document the islands' resources and will allow for integrated ecosystems management in all subsequent major development. To date, most of the terrestrial resources observed from the RS aerial imagery have been confirmed via extensive surveys. However, those resources occurring below the waves have proven much more difficult to quantify. Time-consuming, costly, and dangerous ground-truth efforts, undertaken by local unpaid fishermen, have proven largely ineffective and occur much too infrequently to provide the necessary data coverage. This paper describes the use of remotely operated vehicle (ROV) platforms, the VideoRay, made available through partnership with the University of Maryland Eastern Shore (UMES). The paper also describes the initial explorative experience shared between UMES and the Environment Division of the government of Antigua and Barbuda in attempting to efficiently and safely build their data repository. The results of 6 confirmatory missions are also included, which corroborates that the use of such platforms can easily increase the rate at which RS aerial data can be confirmed. Also highlighted are the benefits of such collaborative research activities between institutions of higher learning with access to technologies that may be beyond the reach (due to limited technological literacy or financial constraints) of agencies in developing countries.

1. Introduction

1.1 Antigua & Barbuda: Development in the National Interest?

The act of balancing national development against preserving natural resources is a challenge almost all countries have faced, with some doing so more successfully than others. However, in light of the current global economic conditions, many small and developing nations are learning that not maintaining the right balance between the two may spell dire consequences much sooner than later1. The measures associated with economic growth and development are inextricably linked to activities that routinely and permanently alters the local environment, and is especially noticeable in smaller, less developed countries[1]. The twin island nation of Antigua and Barbuda, in the Eastern Caribbean, is one such example of a country which has historically struggled to conserve resources at the expense of a booming tourism industry after the collapse of its sugar economy1. According to an official release from the Environment Division within the Government of Antigua and Barbuda, such activities have lead to reduced biodiversity, land degradation, hydrological changes, and reduced water quality[1].

Recognizing the consequences of missteps at this juncture, the government embarked upon a plan to strategically document and quantify all available island resources as a measure of gauging the potential effects and even losses due to any future development[2]. To this end, the sustainable island resource management mechanism (SIRMM) project[2] was implemented in 2006. The SIRMM is a geographical information system (GIS) database relying on remotely sensed (RS) aerial images, acquired in 2010, as the basis for identifying the island's resources2. Using the digitized images within a GIS mapping application, consultants (at the time there were no local officials trained in the use of the software) were able to create areas with homogenous resource characteristics, which could then be verified by persons on the ground[2]. To date, the terrestrial resources have been all but verified, while approximations (largely accurate) were made for those offshore[3]. "Ground" truthing for resources below the waves were based largely upon feedback from local fishermen, a system which proved inconsistent, dangerous, and inefficient. From this experience described by officials at the Environment Division, it was clear that to obtain comparable accuracies to that of the terrestrial database, a more effective verification method was needed.

1.2 Looking beyond the Shore: Remotely Operated vehicles

While many may argue that nothing can replace witnessing something firsthand, they must admit that recent technological advances can provide some of that same "wow" factor. The area of remotely operated vehicles (ROV's) is one such field where the "wow" is almost second nature. Since first taking to the oceans as military platforms in the 1960's, ROV's have become the backbone of the majority of marine surveillance and monitoring activities[4]. Aptly put by Borchardt in 2008, "ROVs can map the sea floor, explore the ocean depths for scientists, and locate shipwrecks for archeologists"[4]. ROV's can be manipulated safely from the shore, or a launch vessel, removing the operator out of harm's way, and furthermore can be deployed more readily when conditions are less than optimal[4]. Advances in ROV technology and the availability of lower cost platforms have made them a viable alternative to traditional data collection methods[5,6].

Outside their applications in industry, researchers are finding novel uses for these platforms in the furtherance of knowledge. In 1999, Norcross and Mueter described the use ROV's to locate and quantify juvenile flatfish, coaxed from the sediments using a "tickler" around Kodiak Island, Alaska6. Recognizing the importance of seagrass communities, McDonald, Coupland, and Kendrick utilized an ROV to detect changes in cover due to anthropogenic as well as natural causes in 2006[7]. Their research was able to demonstrate that the use of ROV's in conjunction with transects were able to detect changes on the order of 15% for uniform and 30% for irregular distributions respectively, therefore increasing monitoring efficiency and eliminating the need for destructive sampling[7]. In a more challenging setting, researchers were able to observe the behaviors of fish in association with cold water corals at depths in excess of 3,300 ft. on the continental shelf off the southwestern coast of Ireland[8]. In a similar study, albeit in a warmer location, never before seen deep-sea corals reefs were observed using ROV's on the Angola Margin, off the African continental shelf[9], a testimony to the versatility, and efficacy of these platforms as monitoring tools.

1.3 Crossing Borders: International Collaborative Learning & Research

According to Wagner and fellow researchers, "International scientific collaboration, where scientists work with their counterparts in other countries towards a common research goal, is growing as a percentage of all scientific activity."[10] Moreover, joint efforts between scientifically advanced nations (SAC's) and those that are described as scientifically developing (SDC's) or lagging (SLC's) are those which show the most promise but are still underrepresented[10]. According to the researchers, building scientific capacity in SDC's and SLC's through access to infrastructure, investment, and personnel available to conduct scientific research and technological development can lead to greater excellence in science[10]. It is in this same spirit, and guided by the University of Maryland System mandate for international outreach that UMES is making its VideoRay ROV available to the Environment Division of the government of Antigua and Barbuda. As first described by Wagner, and then Schuett, both parties must benefit mutually as a result of collaboration and there must be tangible results[10,11]. In this instance, the Antigua and Barbuda government is given access to a tool that will aid greatly in efficiently and safely building their data repository, while the researchers satisfy system mandates, philanthropic expectations, and are provided access to meaningful data.

2. Materials and Methods

2.1 Research site

The Caribbean island of Antigua (W61' 48", N17' 03"), located in the Leeward island chain of the Lesser Antilles, was the site of a series of exploratory dives using an ROV submersible. The roughly 108 square mile island, depicted in figure 1, is bound to the west by the Caribbean Sea and to the East by the Atlantic Ocean and is home to an array of marine and coastal ecosystems including mangroves, deep and shallow bays, offshore islets, and coral reefs. Seven sites, representing locations similar to those described above, were chosen to evaluate the efficacy of an ROV to quantify and ground-truth natural resources previously identified through remotely sensed aerial imagery. The sites (listed in order of date visited) were Winthorpe's Bay, Hawksbill Bay, Fitches Creek Mangrove, North Sound National Park, Maiden Island, and Indian Town Point.

2.2 ROV Dive Platform

Data were collected in the form of live digital video streams from the VideoRay PRO 3XE ROV (VideoRay LLC, Pennsylvania) recorded at the seven dive sites. The VideoRay PRO 3XE ROV platform consisted of the submersible with front and rear facing cameras, 330 ft. neutrally buoyant tether, and control panel with a 15 inch color display [Photograph 1]. Power for the ROV platform was supplied in two ways depending on the site being assessed. For the shore accessible dive sites, power was provided using a 750 watts continuous power Schumacher XI75DU Inverter (Schumacher Electric Corporation, Illinois) connected terminally to a 12 volt DC car battery while the vehicle's engine was running. For Sites requiring boat access, power was obtained directly from the ship's onboard inverter. The ROV's live videos were streamed from the control unit's external display to a laptop computer using ShowBiz DVD 2 (Arcsoft Inc, California) where they were saved and cataloged for later analysis.

2.3 Data Collection

Similar to the methodology described by Soffker, Sloman, and Hall-Spencer[8], recordings were made using the VideoRay's forward facing camera with an approximately 20 degree negative tilt. As much as possible, given constraints such as water depth, structure, and current, the ROV was maneuvered to remain less than 10 ft. above the bottom. ROV path was more investigatory in nature and mostly determined by objects of interest versus conducting a true transect. Once an object or area of interest was identified that corresponded to the expectations of the SIRMM base image, the particular feature was noted and its deepest taxonomy[12] identified if possible. Moreover, corals communities were evaluated for vigor and classified into 4 categories; (1) live coral, (2) coral rubble, (3) mixed living and dead coral, and (4) sand-clogged coral, a system first described in 2004 by Klages[13], and used in other similar expeditions[8,14,15]. In a similar fashion, sea grass occurrence were also categorized based upon the percentage of the substratum obscured[16]; (1) 0 - 25%, (2) 26 – 50%, (3) 51 – 75%, and (4) 76 – 100%. The presence of significant epiphytism or death/decay (> 25% prevalence respectively) was also noted.

2.4 Data Analysis

The integrity of the approximately three hours of video accumulated during the dives was verified using VLC media player (VideoLAN Org, France). Videos were checked for adequate lighting, visual artifacts, and signal dropping as these were issues experienced previously during trials. Once verified, still images were captured from the videos using ScreenHunter 5.1 (Wisdom-soft, Canada) whenever an object of interest was identified. Thereafter, the images were processed (sharpened and contrast increased) using Adobe Photoshop CS4 (Adobe Systems Inc, California) for inclusion in this study's findings and other outreach and educational applications. In addition to the creation of still images, the dive videos were also used to assess the veracity of the SIRMM at the specified locations.

3. Results and Discussion

3.1 Comparison of RS Data to ROV Ground-truths

3.1.1 Winthorpe's Bay

The RS aerial image forming the basis of the SIRMM depicts Winthorpe's Bay as a broad, lightly concave water body on the northeastern coast of Antigua. Initial analysis of the area indicates the presence of widespread dark regions, suggestive of extensive seagrass meadows within close proximity to the shoreline. From local knowledge of the area, the assumption seems correct as copious amounts of manatee and turtle grass (Syringodium filiforme and Thalassia testudinum) are regularly deposited along the shoreline due to the strong Atlantic wave action experienced in the area. Analysis of the ROV's video confirmed this, by showing extensive seagrass meadows within 100 ft. of the launch point [Photograph 2a]. Furthermore, examination of video from the launch site revealed a healthy community associated with the immediate sandy substratum and 3d pier structures, a surprising find given the belief that the local ecosystem had been damaged due to the repeated offloading of sand and petroleum products at the site [Photograph 2b].

3.1.2 Hawksbill Bay

Located on the western tip of the Five Islands peninsula, Hawksbill is a shallow, sandy, open bay, bounded by a mix of sandstone and limestone headlands on either end. For this investigation, Hawksbill exemplifies an area which faces pressures from the activities of tourism; an extensive hotel and villa complex on site and drainage from other facilities further afield. Videos from the area revealed an environment more varied than depicted on the RS SIRMM base image. Indeed, the majority of the area consisted of uninterrupted sandy substratum, however closer to the northern headland, expanses of living and dead coral and limestone rubble were encountered, with small communities of various brown macroalgae species intermixed. As the ROV was maneuvered further afield, small, distinct coral communities were found to be flourishing [Photograph 3].

3.1.3 Fitches Creek Mangrove

Dives at the Fitches Creek Mangrove proved the most difficult of all the sites. Poor visibility due to high concentrations of suspended solids, and the area's very shallow depths made attempts at investigating this location with the ROV less than accommodating. While indications from the RS data did hint to some of these issues, they became quite apparent when the ROV was launched at the site. Despite the difficulties, the video feeds did show the presence of extensive turtle grass beds throughout the area, a fact that was not readily apparent from the RS data [Photograph 4a]. Unlike the meadows experienced at other dive sites, the grasses here did showed signs of stress, likely attributed to the increased turbidity in the area. Furthermore, the majority of the grasses were actually heavily coated with detrital materials and sediments which can further reduce viability[17]. During this dive, the small and agile ROV was also able to provide a fish eye's view of the normally unseen tangle of mangrove stilt roots, although great care was needed to avoid getting the umbilical tangled [Photograph 4b]. The images recorded a snapshot of the complex mangrove community showing small schools of juvenile fish as well as crustaceans, mollusks, and will be useful materials for the Marine Botany (BIOL 202) and Marine and Estuarine Ecosystems (BIOL 600) offerings at UMES.

3.1.4 North Sound National Park & Maiden Island

These locations were chosen to demonstrate the ROV's launch ability on board a vessel and its usefulness in quick and efficient monitoring of offshore resources. From the RS base image, North Sound National Park appears to be an open area of relatively shallow water on the island's northeastern coast dotted with islets, fringe reefs, and distinct patch reef systems. Within the park, both types of reefs were surveyed as well as the areas immediately surrounding these structures, and upon reviewing the ROV's videos, the expectations from the RS data were met [Photo 5a]. As one of the islets described previously, Maiden Island provided an interesting and unique opportunity to demonstrate the ROV's utility. The large artificial fringing reef was constructed as a breakwater to protect development on the island[18]. However, as with many artificial reef systems, their presence alters both the physical and biological characteristics of the surrounding area necessitating frequent monitoring[19], easily achievable with devices such as the VideoRay [Photograph 5b]. Nonetheless, a variety of stony and soft coral species were transplanted to the site to encourage local fauna and flora to the area and therefore improve the stability, and viability of the project. Videos from this site did not disappoint, and demonstrated a very diverse and healthy, albeit young reef community.

3.1.5 Indian Town Point

Located on the island's Eestern Atlantic coast, Indian Town Point is representative of the deep, high energy bays found on the island. Besides limestone outcroppings, and deep patch and fringing reef systems, examination of the RS aerial image also showed the distinct patchy dark areas, previously identified as seagrass meadows, similar to those seen on the lower energy north eastern coast. Due to the craggy, rugged nature of the surrounding area and strong wave activity, there were significant challenges in getting the ROV safely in the water and the control-unit close enough to the shoreline. Once launched, maneuvering the ROV also proved quite difficult as strong currents were experienced from the surface all the way to the bottom, 30 feet in some instances, and thus could be a limitation of its use in similar settings. Nonetheless, the communities observed here, sea grass meadows, macroalgae stands, and expansive reef formations, demonstrated great diversity and appeared to be in pristine condition despite the high tourist activity in the area from the surrounding hotels [Photograph 6].

3.2 Coral Reef and Seagrass Meadow Health

The ROV, as a monitoring platform, proved especially useful for qualitative measures of coral reef and seagrass meadow health. Only 4 of the 6 sites surveyed had observable reefs based on the SIRMM base image as well as the videos recorded by the ROV (Table 1). Hawksbill Bay, based upon the areas surveyed appeared to be the only site where corals seemed to be negatively impacted. While anthropogenic inputs from facilities within the region may be partly responsible for some of the dead coral observed, the presence of limestone rubble also at the site hints to mechanical weathering due to wave action as the major contributor. The deep patch reefs found at Indian Town Point were the most diverse encountered during the investigation with vast schools of assorted reef fish using the structures as habitat. The artificial fringe reef created at Maiden Island, while appearing healthy, did show evidence of being an immature habitat due to the presence of young coral formations throughout.

Seagrass communities were the most prolific coastal habitat encountered during the investigation. Meadows occurred in 4 out of the 6 sites surveyed with only one location, Fitches Creek Mangrove, exhibiting any significant signs of stress (Table 2). Despite this fact, the densest meadows were actually encountered at this location with turtle grass being the dominant species encountered. The most extensive meadows were found in Winthorpe's with a mix of turtle and manatee grass, turtle being the predominant species. The only site where manatee grass dominated was North Sound where it was found chiefly within the sandy crowns of patch reefs and surrounding the base of their superstructure.

4. Conclusions

From the experiences of this cooperative venture, it is evident that the use of ROV's can greatly improve the ground truthing of phenomena observed in RS imagery. The major complaints from officials at the Department of Fisheries and the Environment Division in the Government of Antigua and Barbuda were issues of consistency and reliability of data gathered by local fishermen. By collaborating with these agencies, it was demonstrated that the use of technologies, such as ROV's, can reduce, if not completely eliminate the aforementioned issues. In fact, the utilization of ROV's offers the additional benefits of increased safety by either allowing the retrieval of when conditions may be less than optimal or completely removing humans from potentially dangerous environments.

While arguably, the cost of such platforms may pose significant barriers to entry for small governments or agencies, the opportunity for dialog and collaboration should be viewed as a viable alternative to outright equipment acquisition. In this particular collaboration, the government agencies were able to acquire some of data required to complete the national business in a technically advanced and efficient manner although funding may not be readily available to purchase a VideoRay or similar platform. While operating as benefactors/ facilitators, UMES researchers were able to forge new international relationships, satisfy outreach obligations, and retrieve firsthand scientific data and material useful for course offerings. While first level benefits such as these are oftentimes the driving force, opportunities for experiential learning, especially in the areas of technical literacy and societal development, should also weigh heavily when deciding to conduct collaborative research. In fact, it is under these circumstances where true learning occurs.

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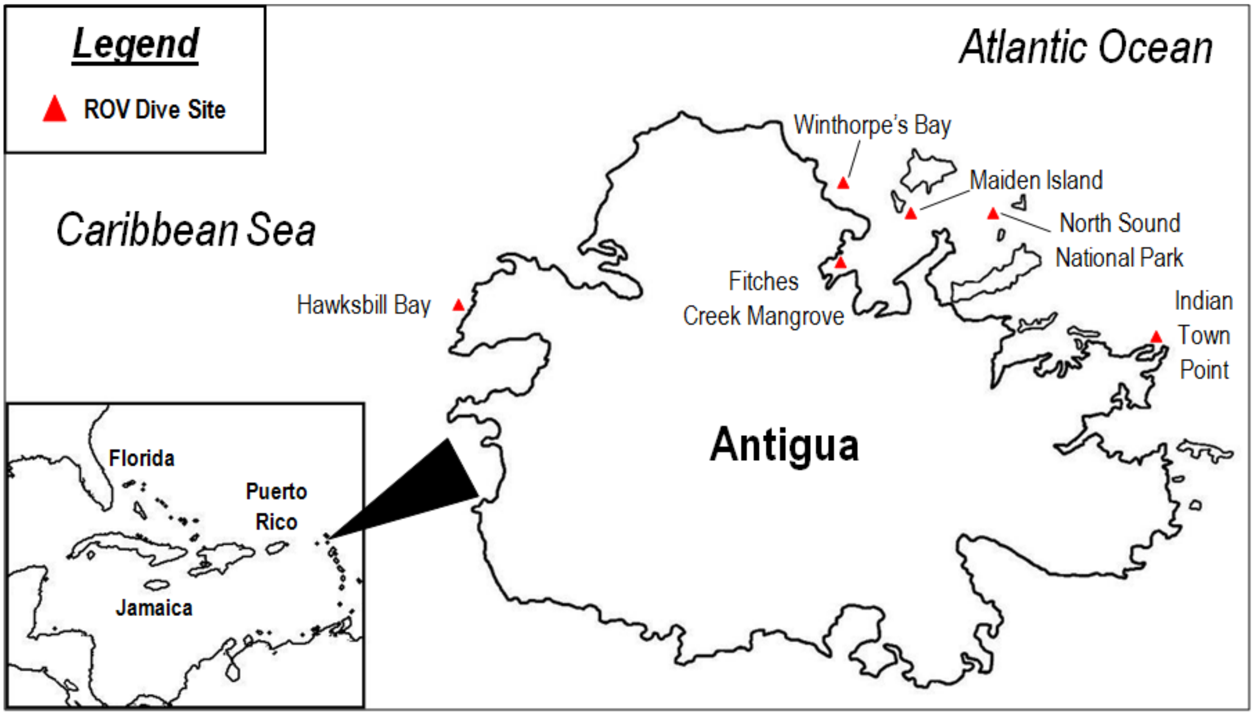


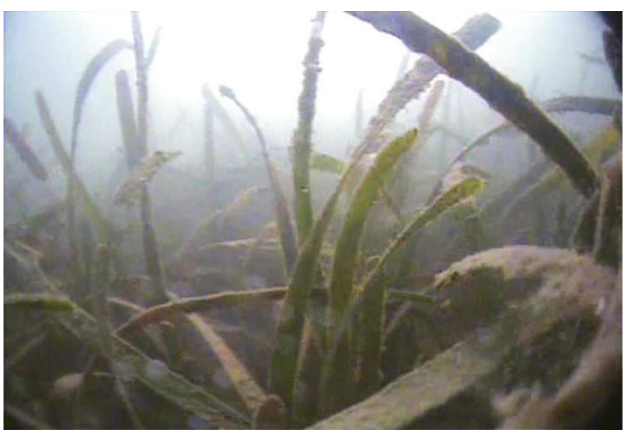
Figure 1. Map of Antigua showing location of ROV dive sites.

Photograph 1: Typical VideoRay ROV Setup for Shore Accessible Site; (A) Submersible, (B) Tether, and (C) Control panel. Inverter not shown.

Photograph 2a: Turtle Grass (*Thalassia testudinum)* Meadow at Winthorpe's Bay, Antigua.

Photograph 2b: Thriving Community Associated with 3d Pier structures at Winthorpe's Bay, Antigua. Clockwise from Top Left; Banded Butterflyfish (*Chaetodon striatus)* and Sergeant Major (*Abudefduf saxatilis*); Bipinnate Sea Plume *(Pseudopterogorgia bipinnata)*; Cushion Star *(Oreaster reticulates)*; and Great Barracuda *(Sphyraena barracuda)*.

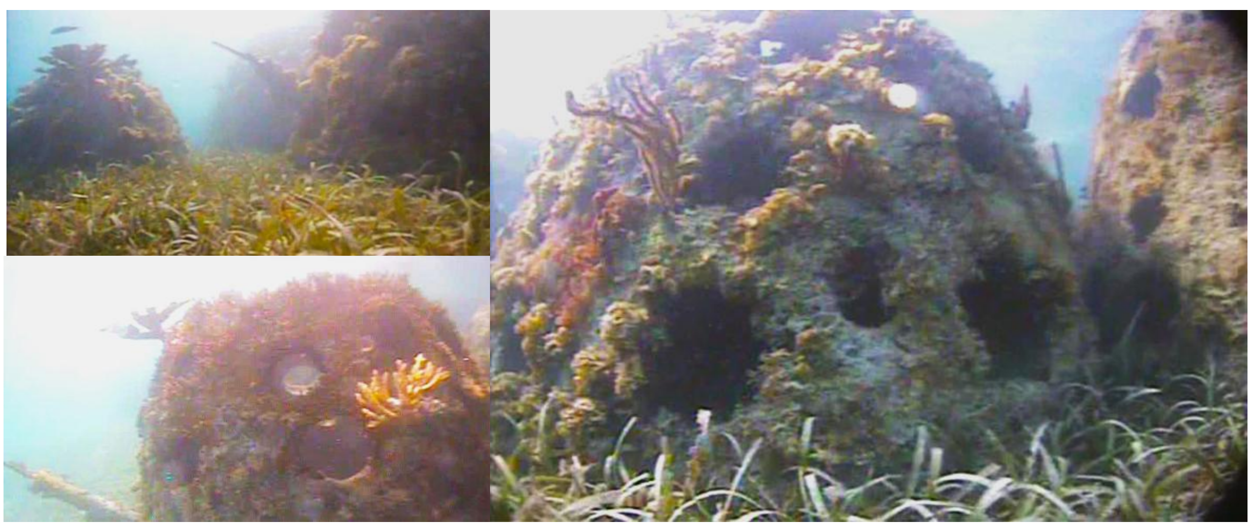
Photograph 3: Variety of Benthic Habitats encountered at Hawksbill Bay, Antigua. Clockwise from Top Left; Sandy Substrate with unknown algae spp.; Common Brain Coral *(Diploria strigosa)* encountered in deeper waters; and mixed substrate comprised of coral (living and dead) with limestone rubble and variety of brown algae.



Photograph 4a: Turtle grass with evidence of stress from high sediment concentrations, Fitches Creek Mangrove, Antigua.

Photograph 4b: A View within the Complex Mangrove Root System, Fitches Creek Mangrove, Antigua.

Photograph 5a: Extensive Manatee Grass *(Syringodium filiforme)* meadows with Large *Gracilaria parvispora* encountered at North Sound National Park.



Photograph 5b: Detailed view of the artificial reef structures showing various species of young corals and dense sea grass stands encountered at Maiden Island, Antigua. Clockwise from Top Left; Elkhorn *(Acropora Palmata)* formations; Porous Sea Rod *(Pseudoplexaura spp)*; and Young Staghorn *(Acropora Cervicornis)*.

Photograph 6: The Deep Patch Reef Community at Indian Town Point, Antigua. Clockwise from Top Left; School of French grunt *(Haemulon flavolineatum)* and Large Ten-Ray Star *(Madracis decactis)* Formation; Solitary Mustard Hill *(Porites asteroids)* Coral; Y Branched Algae *(Dictyota spp)* (Foreground); and Solitary Pillar Coral *(Dendrogyra cylindrus)*.

Table 1: Percentage of Total Time each Coral Health Indicator was Observed During Dive.

Coral Health	Winthorpe's	Hawksbill	Fitches Creek	North Sound	Maiden Island	Indian Town
Live	0	34	0	73	100	81
Dead	0	12	0	2	0	9
Living and Dead	0	50	0	2	0	7
Sand clogged	0	4	0	23	0	3

Table 2: Percentage of Total Time Substratum was obscured due to Seagrasses During Dive.

% obscurity	Winthorpe's	Hawksbill	Fitches Creek	North Sound	Maiden Island	Indian Town
0 - 25%	53	0	11	14	23	12
26 - 50%	36	0	3	79	48	83
51 - 75%	11	0	18	7	23	5
76% - 100%	0	0	68	0	6	0