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Use of Technical Diving to Study Deep Reef Environments in Puerto Rico

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Abstract

In 2007, researchers at the University of Puerto Rico – Mayagüez, Department of Marine Sciences initiated a Deep Coral Reef Ecosystems Studies (Deep CRES) project to study mesophotic coral ecosystems off southwest Puerto Rico at depths of ~50-100 m. To accomplish field operations, five divers from the Department of Marine Sciences were trained in open-circuit and closed-circuit rebreather (CCR) mixed-gas technical diving, and external oversight and guidance were brought in from the National Undersea Research Center at UNC-Wilmington. Using closed-circuit rebreathers, divers are currently working at depths of ~50-85 m and expect to extend this range in the near future. Technical diving is critical to the Deep CRES project as it allows for *in situ* surveying and sampling of deep reef environments. Divers have been able to make detailed observations of the geology, biology and ecology of these environments, careful and targeted collection of samples for more detailed studies in the laboratory, as well as precision deployments and recoveries of on-bottom oceanographic instruments. The utilization of CCRs allows for more efficient use of diving gases and, therefore, cost savings over open-circuit scuba. To support these activities a new diving-gas blending facility has been established at the Magueyes Island Marine Laboratory, allowing for on-site mixing, storage and filling of custom breathing gases. In addition to scientific goals, an important objective of the UPRM Deep CRES project is to establish technical diving capabilities and facilities at Magueyes Island Marine Laboratory to support future research in Puerto Rico and throughout the Caribbean.

Keywords: closed-circuit rebreather, mesophotic coral ecosystems, mixed-gas diving

Introduction

Although coral reefs have been a focus of intense study for several decades, few studies have examined reefs beyond depths of ~50 m (164 ft). This has largely been due to limitations of traditional open-circuit scuba techniques and the fact that most submersible or ROV (remotely operated vehicle) studies have focused on much deeper settings. In 2007, researchers at the University of Puerto Rico – Mayagüez (UPRM), Department of Marine Sciences initiated the Deep Coral Reef Ecosystems Studies (Deep CRES) project to study mesophotic coral ecosystems (MCEs) off southwest Puerto Rico at depths of ~50-100 m (164-328 ft). MCEs are defined as tropical to subtropical marine ecosystems found at depths of ~30 to 100 m (98 to 328 ft) and characterized by the presence of light-dependent (zooxanthellate) corals along with associated octocoral, antipatharian, sponge and algal communities (Mesophotic coral ecosystems, 2009). These ecosystems are especially important because they often contain unique flora and fauna, have a potentially large areal extant rivaling that of shallow reef systems, and, as they are further removed from terrestrial and anthropogenic influences than shallower environments, may serve as refugia for corals and other species during times of environmental stress (cf. Riegl and Piller, 2003). The UPRM Deep CRES project is a multidisciplinary study examining the biology, geology and ecology of these

environments and has three primary objectives, which are: 1) *characterization* of deep reef environments in terms of geomorphology, reef distribution, community composition and the interrelationships between these factors; 2) determine the *connectivity* between deep and shallow reefs in terms of ecological flow and examine if deep reefs act as refugia for species threatened in shallow reef environments; and 3) determine the *vulnerability* of deep reefs to anthropogenic stress.

The need for technical diving was recognized early in the planning stages of the project as the target depth range for study (50-100 m/164-328 ft) lies beyond traditional scuba depths and no-decompression limits. Although submersible and ROV-based studies have provided critical information on deep reef habitats, these techniques have substantial short comings. Submersible operations are costly and logistically complex and can put significant limits on the spatial extent of the study area and the frequency with which it can be visited. Additionally, in both submersible- and ROV-based research, the observer is separated from the surrounding environment making detailed observations and sampling difficult. Although AUVs (autonomous underwater vehicle) have been useful in making broad-scale surveys, they are not appropriate for use on steep slopes that are characteristic of the Puerto Rico Deep CRES study area (Singh *et al.*, 2004). Only diver-based research has the flexibility to make the detailed, high resolution observations (including photography) and careful, targeted collections necessary to study the structure and dynamics of deep reefs. Mixed-gas (Trimix) diving and closed-circuit rebreathers permit divers close-range access to the environment being studied and constitute the primary access methods used in this project. Closed-circuit rebreathers were chosen over open-circuit scuba as they required less equipment and could potentially provide extended bottom times.

Methods

Training

Five scientific divers from the UPRM Department of Marine Sciences were trained in open-circuit and closed-circuit rebreather (CCR) mixed-gas technical diving. The Deep CRES dive team consists of the Department's Diving Safety Officer, one faculty member and three graduate students. Technical training began in April 2007 with a ten-day open-circuit technical training program at the Key Largo Facility of the NOAA Undersea Research Center at the University of North Carolina Wilmington. Certifications acquired at this time included the following: TDI *Advanced Nitrox Diver*, *Decompression Procedures Diver* and *Trimix Diver* and IANTD *Trimix Diver*. In June 2007, divers began CCR training at Puerto Rico Technical Diving Center in Aguadilla, Puerto Rico. From June 2007 to December 2008, divers progressively moved forward with CCR training and practical experience and acquired the following certifications: ANDI International *Rebreather Diver-Level 2 CCR* and *Technical Rebreather Diver-Level 3 CCR* and IANTD *CCR Normoxic Trimix Diver* and *CCR Trimix*.

Diving Operations

To assist with establishing technical diving procedures and protocols at the UPRM Department of Marine Sciences as well as ensure that technical diving operations were conducted with the utmost regard for safety and professionalism, external oversight and guidance for the Deep CRES project were brought in from the NOAA Undersea Research Center at the University of North Carolina Wilmington. The study area lies off the southwest coast of Puerto Rico where a broad shelf extends ~8 km offshore before dropping abruptly to oceanic depths (Figure 1). Research thus far has focused on a ~12 km section of the upper insular slope from the shelf break at a water depth of ~20 m (66 ft) down to a depth of ~85 m (279 ft). The UPRM Department of Marine Sciences Magueyes Island Marine Laboratory serves as the base of operation and provides easy access to the study area. NOAA multibeam bathymetry of the area (Battista and Stecher, 2006) was used to help locate and characterize dive/study sites. The depth grid was used to create an image of slope with the Spatial

Analyst extension in Arcmap GIS software. The map of slope provided a representation of topographic features on the bottom that were used to locate sites of interest and to extract waypoints. The map also provided a visual aid during dive briefings so divers could visualize the bottom features in relation to the study site. A Seabotix LBV 200 ROV was used to conduct vertical profiles of the slope and, in conjunction with diver observations, help to characterize different regions and identify potential study sites. The ROV was useful as it could extend beyond depths currently accessed by the divers. Divers used Ambient Pressure Diving Ltd./Silent Diving Systems LLC *Inspiration* closed-circuit rebreathers with *Vision Electronics*.

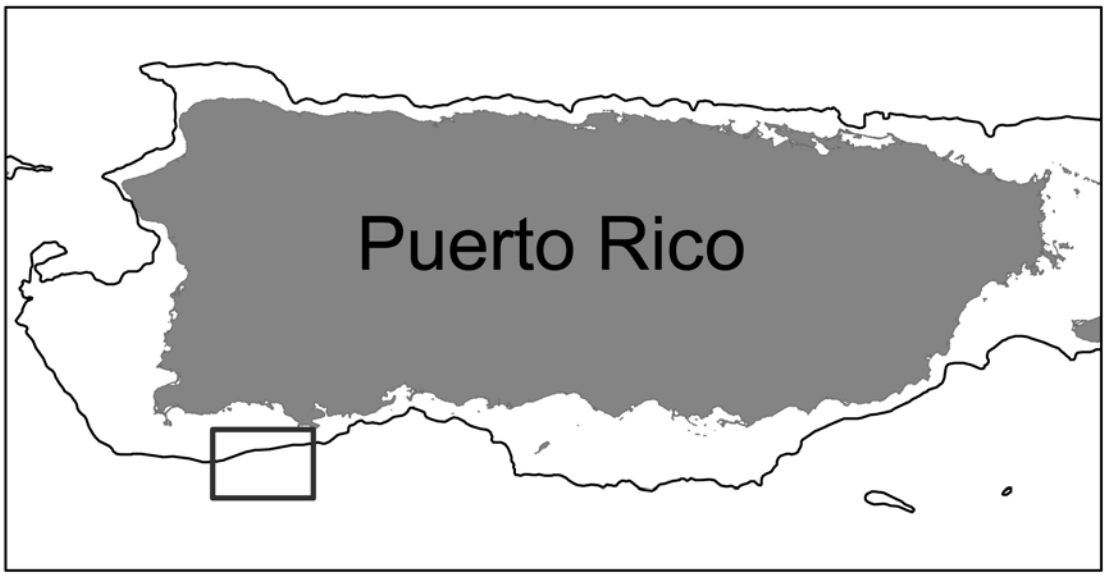

Figure 1. Map of Puerto Rico with 200 m (656 ft) depth contour showing location of study area (rectangle).

Equipment setups were centered on two-person buddy teams, with each team carrying enough open-circuit (OC) bailout gas to safely bring one diver to the surface in the event of rebreather failure. Given the high reliability of the equipment being used and the built-in redundancy within the rebreather unit (*e.g.*, dual oxygen controllers, dual displays, duel batteries, etc.), it was thought to be highly unlikely that both rebreathers on a buddy team would completely fail on a given dive. Both members of a buddy team carry OC bottom bailout mix that matches the diluent being used in the rebreather. In addition to the bottom mix, one member of the team carries EAN 36% deco mix, while the other member of the team carries 100% O_2. Two standard mixes for diluent/OC bailout are being used depending on the planned dive. For dives from 49 m to 61 m (160 ft to 200 ft) an 18/30 Trimix is used (*i.e.*, 18% O_2/30% He/52% N_2). This mixture has a maximum operating depth (MOD) of 68 m (224 ft) at a PO_2 of 1.4 atmospheres absolute (ATA). At 61 m (200 ft) and a rebreather PO_2 setpoint of 1.3 ATA, the mixture provides an equivalent air depth (EAD) of 37 m (120 ft). For dives from 61 m to 91 m (200 ft to 300 ft), a 12/50 trimix is used, which has a MOD of 107 m (352 ft) at 1.4 ATA PO_2 and an EAD of 38 m (126 ft) at a rebreather setpoint of 1.3 ATA PO_2. Divers use two decompression computers, the integrated *Inspiration* computer with a peak PO_2 setpoint of 1.3 ATA and a *VR3* set at a constant PO_2 of 1.25 ATA.

Results

Divers are currently working at depths from ~49 m to 85 m (160 ft to 280 ft) and expect to extend this range in the coming months. Diving is conducted from a live boat. Divers typically enter the water at the shelf break at a depth of ~20-21 m (65-70 ft). They then proceed down the steep insular slope to the target working depth, using geomorphic features as reference points and guides during the descent. Bottom times are typically 20-25 minutes, which includes both descent and actual time at the target depth. A typical profile for a dive to a maximum depth of ~61 m (200 ft) is shown in Figure 2. For this dive, divers entered the water at the shelf break and took ~5 minutes to descend down the insular slope to the target depth of 61 m (200 ft), where they had a working bottom time of ~15 minutes. At a run time of 20 minutes, they started their way back up the slope, essentially along the same route of the descent. Two, two-minute deep decompression stops were required at depths of ~44 m and 34 m (145 ft and 110 ft). As they arrived at the shelf break, very close to their entry point, the divers sent up a surface marker alerting the boat of their precise location as well as that they were entering the final decompression phase of the dive. On this particular dive, another ~40 minutes of decompression were required. During decompression, divers drift along with the surface marker and are followed by the boat. Thus, divers do not need to expend energy making it back to or staying on a stationary anchor point.

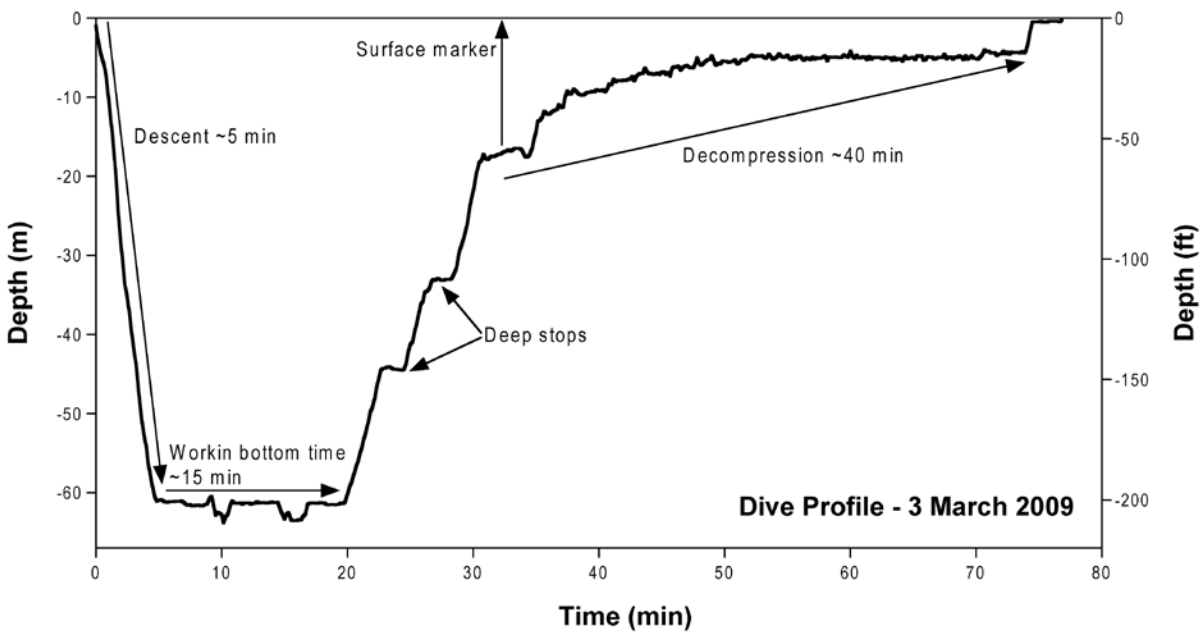

Figure 2. Typical Deep CRES dive profile for a dive to 61 m (200 ft).

In the current working depth range of ~49 m to 85 m (160 ft to 280 ft), divers have made detailed observations of geomorphology and benthic macrofauna as well as careful and targeted collection of hard substrates, sediment and macrofauna, primarily corals and algae, for more detailed study and positive identification in the laboratory. Divers have conducted over twenty continuous high-resolution benthic photo-transects ~10 m long by 40 cm wide at depths of 47 m to 70 m (154 ft to 230 ft). Individual photographs from the transects, each photo covering an area of ~40 by 60 cm (Figure 3), have been analyzed using CPCe point-counting software to determine relative abundances of major groups of benthos and substrate types (Kohler and Gill 2006). At each of these sites, rugosity measurements and fish surveys have also been conducted. Divers have deployed and recovered

several on-bottom oceanographic instruments, including three acoustic Doppler current profilers at depths of 40, 60 and 82 m (131, 197 and 269 ft). Thus far, surveys and collections have resulted in several new reports of species, primarily marine alga, in Puerto Rico or the Caribbean, new deepest reports of some species of corals in Puerto Rico, and several new species of marine alga are currently being described. Preliminary results of surveys describing the geomorphology and mesophotic coral ecosystems of the area were presented at the 18th Caribbean Geology Conference, Santo Domingo, Dominican Republic (Sherman *et al.*, 2008) and a more detailed paper has been submitted to Coral Reefs and is currently in review. Preliminary results of fish surveys were presented at the 11th International Coral Reef Symposium in Fort Lauderdale, Florida (Bejarano *et al.*, 2008). In addition to scientific goals, an important objective of the UPRM Deep CRES project is to establish technical diving capabilities and facilities at Magueyes Island Marine Laboratory to support future research in Puerto Rico and throughout the Caribbean. To this end, a new diving-gas blending facility has been established at the Magueyes Island Marine Laboratory, allowing for on-site mixing, storage and filling of custom breathing gases. These facilities continue to be improved and expanded upon as the Deep CRES project and technical diving operations progress.

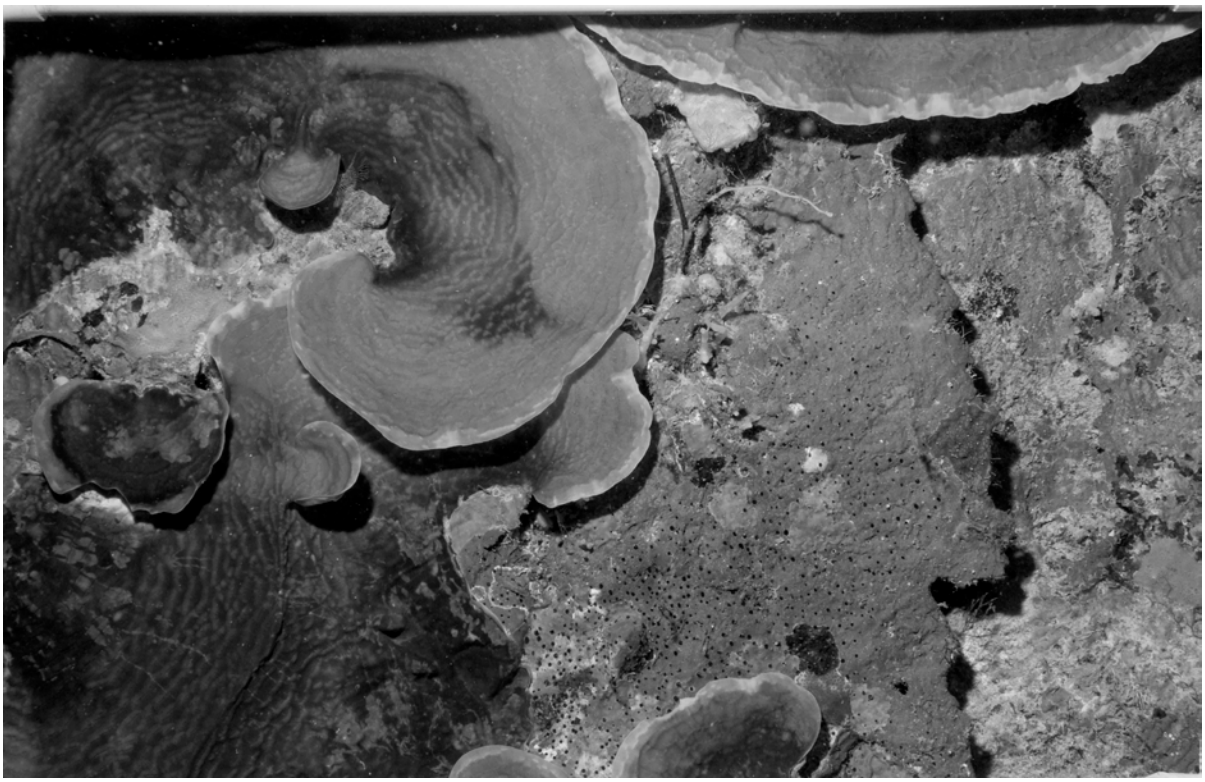

Figure 3. High-resolution photo-quadrat at a depth 76 m (250 ft). Image area is 40 x 60 cm.

Discussion

Advantages of CCR Technical Diving

Technical diving is a key component of the UPRM Deep CRES project. Full characterizations and an understanding of the fundamental ecological and geological processes that sustain and control deep coral reefs require a level of access and manipulation beyond that available from submersible- or ROV-based operations alone. The *in situ* observations of divers and their detailed and targeted sampling would not be possible using these other methods. Divers have greater maneuverability and

are able to reach hard-to-access areas such as caves or under ledges. Thus, the scientific goals and objectives of the Deep CRES project can only be achieved via diver-based operations. Divers have been able to conduct precision deployment and recovery of oceanographic instruments that similarly would not have been possible using ship-based or submersible-/ROV-based techniques. Positioning of the instruments requires detailed observations of geomorphology and substrate type to choose appropriate locations for deployment. Deployment of the devices requires precision positioning and anchoring that would have been impossible to achieve by other methods. In addition, observations by divers of the characteristics and conditions of the instrument sites are a crucial component of interpretation of the instrument data. Divers are also able to employ the same research methods used in the study of shallow reefs allowing for a more meaningful comparison of results across depths.

The use of closed-circuit rebreathers has provided distinct advantages over open-circuit scuba. To supply five divers with open-circuit equipment to cover all diving operations would have required the purchase of considerably more equipment (*e.g.*, BCs, regulators, double-tank setups with manifolds, etc.) than purchasing five CCR units. The rebreathers also offer more flexibility. It is easy to change diluent mixtures to suit the planned diving by either having multiple diluent tanks available with different gas mixtures or by simply emptying and refilling the small (12.5 ft^3) rebreather tanks. Changing gas mixtures with an open-circuit setup is much more involved and costly. Having multiple double-tank setups for each diver can be cost prohibitive. Having to empty and refill doubles with a total of at least 160 ft^3 of gas can be both costly and time consuming. CCRs maintain a constant PO_2 throughout the dive, optimizing the breathing mixture according to depth and negating the need for gas switches during decompression. The entire dive is completed on the rebreather loop. CCRs have distinct scientific advantages as well. Because bubbles are not released by the CCRs, marine life behavior (fish, marine turtles, etc.) in the presence of divers is more natural and surveys can provide more accurate information on composition and behavior of the community. CCRs also provide much more efficient use of breathing bases over OC scuba. Table 1 shows approximate amount of breathing gases used by the same diver during similar OC and CCR dives. For the dives examined, the diver used greater than an order of magnitude, or about 15 times, more gas on an OC scuba dive versus a CCR dive. Thus, the CCR provides more efficient gas use and, therefore cost savings, as well as reduces gas storage and mixing requirements.

Table 1. Comparison of open-circuit scuba (OC) versus closed-circuit rebreather (CCR) gas consumption.

Device	**Depth (m [ft])**	**Bottom Time (min)**	**Run Time (min)**	**Gas Consumption (ft^3)**			
				Trimix	**Nitrox**	**Oxygen**	**Total**
CCR	49 (160)	20	54	4	–	4	8
CCR	50 (165)	20	51	6	–	4	10
OC	49 (160)	25	52	106	32	20	158
CCR	52 (170)	19	52	4	–	4	8
OC	52 (170)	15	52	77	30	12	119
CCR	69 (226)	20	92	7	–	6	13
OC	67 (220)	25	91	153	38	28	219

Lessons Learned

Two years ago, the project started with a group of experienced scuba divers with little or no technical or CCR experience. It now has a team of experienced technical divers, comfortable in the use of CCRs and routinely working at depths of ~49 m to 85 m (160 ft to 280 ft). While no major setbacks

have been suffered during the process, it has been a learning experience, to say the least. NOAA multibeam bathymetry of the study area has proved to be a critical component of characterizing the environment and dive planning. GPS coordinates for optimum entry points could be extracted directly from the bathymetric data. Detailed bathymetric images also served as important visual aids during dive planning. Utilization of the bathymetric data has allowed divers to consistently access permanent benthic transect and instrument sites at depths up to ~82 m (270 ft) using only ~5 minutes of dive run time to reach the site.

Although technical CCR diving represents less overall equipment than OC scuba, on a given dive there is still a considerable amount of equipment that must be accommodated, including the CCRs, OC bailout tanks, personal dive gear, sampling equipment, camera equipment, etc. It was quickly realized that a larger dive vessel was necessary to accommodate technical diving. A larger Department of Marine Sciences vessel is currently being refurbished to serve as the primary platform for future technical diving. It is important to have knowledgeable surface support for technical dives. The surface personnel should be familiar with the entire dive operation so that they can provide routine assistance to the divers (*e.g.*, piloting the boat, assisting with water entry and exits, handling equipment, etc.) as well as being prepared to act in the case of an emergency. Surface-support personnel were not included in the original project plan, but were quickly added as the critical need was realized.

The individual studies being conducted are largely transplants of studies conducted in shallow reef settings. However, it is important to realize that a dive to 76 m (250 ft) is not the same as a dive to 15 m (50 ft). The amount of working bottom time is an issue. The diver also has many more diving-related factors to deal with (*e.g.*, closely monitoring depth, bottom time, PO_2, etc.) in addition to accomplishing scientific tasks. In many cases, the original research plan had to be scaled back to more realistic objectives attainable on deep technical dive. Similarly, on a given dive, it is important to focus on a few doable tasks. It is better to break a particular task into two successful dives than try to do too much on one dive and accomplish nothing. Technical diving of any sort obviously requires additional setup and planning time over traditional scuba. The additional complexity of CCRs adds even more time for setup, breakdown and routine maintenance. Actual time in the water is only a small part of the time that divers must commit to the project. The amount of time that divers have needed to commit to the project has turned out to be much more than expected.

The UPRM Deep CRES dive team has made tremendous progress over the last two years and achieved significant accomplishments. Still, progress on the Deep CRES project has been slower than planned. Planning does not always take into account delays resulting from equipment problems, unforeseen equipment needs, weather, other important commitments, etc. Most importantly, Deep CRES planning did not adequately take into account that technical diving is a gradual progressive process. Sufficient time is needed for divers to gain experience, comfort and confidence with new technologies, equipment and long, deep dives. The progression of the UPRM Deep CRES dive team provides an example of the time and tools necessary to establish a new scientific technical diving program.

Future Work

Work accomplished thus far has resulted in the formulation of a working model of the important controls on geomorphology and mesophotic coral ecosystems of upper insular slope environments. It is now time to test the model in other areas as well as explore new and different settings. There is an exceptional NOAA multibeam bathymetry dataset for Puerto Rico and the US Virgin Islands. It is hoped that, with additional funding, this dataset can be used to target new areas of research and exploration of the mesophotic realm.

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