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CORAL REEF RESTORATION TECHNIQUES FOR REMOTE AND ISOLATED COMMUNITIES: PART I - LOGISTICS AND PLANNING

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ABSTRACT

In recent years, there have been notable advances in coral reef restoration demonstrated throughout the world; however, reef restoration can be an expensive endeavor. For countries with substantial financial resources (e.g., United States, Australia, etc.), large-scale restoration efforts can be readily funded; however, for smaller nations, or especially isolated island communities with limited tourism, restoration investment by government or well-funded NGOs is minimal. In response to the observed coral reef decline on San Salvador over the last 25 years, and around the world, a group of scientists and I are attempting to develop low-cost coral reef restoration techniques, targeted for remote and isolate communities. The research is being conducted on the shallow water patch reefs of San Salvador. The research is envisioned to occur in three parts. This paper (Part I) reports on the initial trial runs of underwater construction, overall logistics, planning, and manpower estimates. Parts II and III of this project, which would include rigorous scientific testing, are scheduled to continue over the next four to six years.

INTRODUCTION

In 1992, a long-term coral ecology and bleaching response study was initiated on San Salvador Island (McGrath *et al.* 2007). Based on the reductions in coral coverage observed both on the island and sites worldwide, I, circa 2010, initiated planning for experiments to identify and develop low-cost coral restoration techniques.

The restoration efforts seek to accelerate recovery of coral reef ecological functions and values, lost through mortality and erosion, by increasing the following: species diversity, reef rugosity, and hard substrate surface areas for Scleractinia coral colonization. The research is designed specifically to develop low-cost restoration efforts that could be implemented by indigenous personnel using locally available and/or recycled items.

Coral restoration costs can vary substantially depending on scale, techniques, and regional labor costs. For example, one hectare of restoration in the United States could easily exceed $150,000 USD (Bayraktarov *et al.* 2016). I hope to identify methods and materials to provide similar restoration to a similar area for under $1,000 per hectare (costs assume indigenous personnel volunteering time). A key component of the reef restoration is the transplant of live corals, either harvested (fragmented using a mallet and sanitized chisel) or "rescued" (corals collected after being recently dislodged from the reef to sandy locations). Coral mortality is certain if a dislodged coral is deposited on a sand substrate (Jaap 2000). Using these corals' living tissue as transplant material reduces the reliance on fragmenting healthy corals.

For this study, fragmented donor corals for transplant came from Gaulin Reef, a large reef tract about one mile from the Gerace Research Centre (GRC) and dislodged corals originated from Gaulin Reef, French Bay, Lindsay's Reef, Rice Bay, and Dump Reef (Figure 1).

FIELD SITE DESCRIPTION

Initial logistics and planning experiments were carried out on Rocky Point Reef, with Dump Reef used as a training ground. Rocky Point Reef is located 70-100 meters from shore. Water depths at high tide over the reef measure from 1 – 4 meters. At low tide, the tops of sea fans are often exposed, and water depths are less than 1.5 meters over large portions of the reef. Dump Reef is located approximately 10 meters from shore and

500 meters west of the GRC. Much of the water column above Dump Reef is very shallow (less than 1 meter) and makes an ideal training ground.

The reef restoration experiments were carried out in very shallow-water patch reefs for the following reasons: 1) shallow reefs and wave surge provide challenging logistics; thus, if restoration techniques can be shown as effective, it would suggest that restoration would work in deeper areas; and 2) as shallow water patch reefs are most often encountered by people, mastering reef restoration techniques on these reefs are imperative.

METHODS

Three major components of reef restoration were studied for incorporation into further studies: 1) underwater drilling, 2) construction of rugosity enhancing devices (REDs), and 3) coral transplant techniques.

Underwater Drilling

In order to place REDs, plugs with coral transplants, or other structures on the reef, holes must be drilled into the reef to hold rebar or other supporting elements of the structures. We experimented with different drilling techniques to create holes that varied in width from 0.4 to 1.5 cm in diameter, and from 0.7 to 20 cm in depth.

The first technique used a pneumatic air drill attached to a 15 m length of hose connected to a small air compressor located in a boat. Drilling into the reef surface was attempted using several drill bits, including small masonry bits up to a 1.25 cm diameter, 0.33 m long diamond-tip rock coring bit.

The second method used the same pneumatic drill attached to a pressurized SCUBA tank. The connections between the drill and tank were accomplished using an altered first stage SCUBA air octopus (Figure 2). The regulator was removed and connections were added to accommodate an air drill. The air tank pressure valve was opened in a similar manner to using a SCUBA tank, which powered the drill (using the same bits as previous).

A Nemo V2 Diver's submersible 1.75 cm electric drill was also evaluated. The drill, powered by a 6-volt battery, was used with various drill bits to make an array of holes.

Construction of Rugosity Enhancing Devices

REDs are solid structures designed to increase reef rugosity, provide structures to accept coral transplants, and/or allow for the fixation of tile collection plates. It was envisioned that because of the level of decline of coral reefs and prolific increase in macroalgae, simple transplantation would need to be augmented with the placement of REDs on the reef surface.

REDs were placed by drilling a hole into the reef surface. A piece of rebar was then inserted into the hole packed with marine epoxy. The RED (which contains a similar-diameter hole in the base) was then placed on to the rebar, and the hole filled with marine epoxy or underwater concrete. Within 48 hours, the RED is permanently affixed to the reef.

The RED construction experiments occurred in two phases. The first phase constructed several initial structures to be placed on the reef for a two-year period to determine initial material stability and potential for colonization. The initial structure was a 40 cm by 40 cm square that rested on a base 15 cm in dimeter by 20 cm in height, (Figure 3) all constructed from underwater cement.

After the initial RED was constructed, I experimented with other RED designs using a similar volume of material (Figure 4). The goal was to determine the largest durable branching structure that could be created that would provide adequate surface areas for colonization, areas to attach collection plates, and serve as a platform for the placement of coral transplants.

The preferred prototype structure was a winged or X-shaped structure that was supported above the reef surface by a 9 cm-diameter stalk, 30-40 cm in length. Each wing of the X measured approximately 30 cm in length, with the base of each wing 10 cm in width, tapering to 6 cm in width at the end (Figure 5). Larger variations of this structure were tested; however, the size and weight of larger structures resulted in difficulty maneuvering underwater by hand.

Photo Credit: Google Earth Imagery, 2020

Figure 1, Project research sites.

Figure 2 – SCUBA regulator and hoses modified to power air drill with an air tank.

Figure 3. Initial RED Structure placed on the reef

The structures were constructed using underwater concrete or marine grout. A mold for the structure was dug into the beach sand. Sand within 1 meter of the high-tide line provides enough saturation to retain the mold shape when dug (Figure 6).

Prior to pouring the concrete into the mold, a PVC rod (1.25 cm in diameter) was placed vertically in the middle of the mold. The PVC pipe was covered in clean plastic film (food wrap). After the PVC was placed, the concrete was then mixed and poured into the mold from the bottom up. As the concrete was being poured into the central stalk of the mold, a cylinder of 1.25 cm metal construction mesh, measuring 5 cm in diameter and the length of the stalk, was then inserted into the mold over the PVC pole, leaving at least 1.5

cm of concrete between the PVC and mesh and at least 1 cm of concrete on the outside of the mesh. In addition, metal construction mesh wings cut to approximately 75 percent width of each wing were inserted into the middle of the wing for additional support. The structures were then allowed to dry in the sand for approximately 48 hours, after which the hardened structures were removed by hand. The PVC was then removed, leaving a void in the central portion of the mold to allow for placement on the rebar. The clean film around the pipe allowed the PVC to be easily removed from the mold.

Coral Transplants

I tested a variety of techniques to affix transplanted or rescued corals back on the reef, including tying with cable ties or steel wire, attaching with epoxy, or fastening to ceramic plugs (Figure 7). Coral transplants have been studied, to date, for up to one year after transplant.

Figure 4. Experimental RED designs.

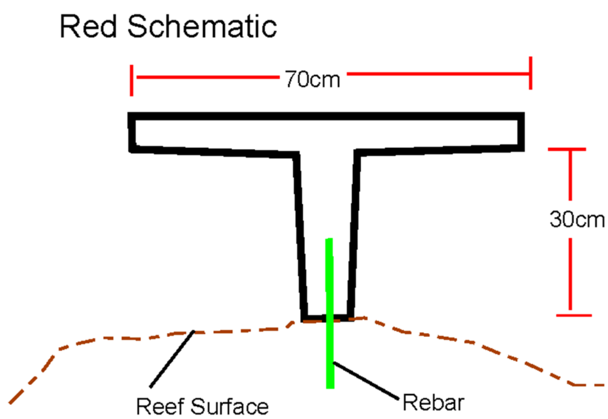

Figure 5. Profile view of RED.

Figure 6. Mold for REDs hand dug in beach sand.

Figure 7. Plug affixed to a piece of rock with a coral.

Coral fragments varying in size from 10 to 40 cm in length were attached to the reef surface and REDs by cable ties. For this method, the fragment was placed parallel to a flat surface and then a cable tie (at least 6 mm in width) was placed to secure the coral fragment to the reef. The use of steel wire was also tested in a similar manner. Steel wire varying in width from 0.5 mm to 2 mm was wrapped around the coral and the reef a number of times until the coral was secure to the reef surface; the wire was then cut and the cut end secured.

The epoxy tested was quick setting, commercially available marine epoxy. Epoxy was first applied to the side of a coral with dead tissue, the coral (with epoxy side facing the reef) was then pressed and held into place for several minutes.

Ceramic plugs (Figure 7) of 1.25 cm length were tested. Ceramic plugs serve as an excellent vehicle to transplant a hard coral to the reef's surface. For each plug, a coral fragment (or rock with attached coral) was set firm on the top ceramic plug with marine epoxy. The plug was placed in a submerged holding platform about 1.5 m below the water surface and 2 m above the bottom in Grahams Harbour in front of the GRC. After being allowed to cure for 24 – 48 hours, the plug was brought to the receiving reef. The coral with plug was then transported out to the reefs and the bottom of the plug was inserted into a pre-drilled hole with marine epoxy

RESULTS

All three drilling techniques proved effective, although, due to wave action in shallow areas, using a boat-mounted small air compressor should only be considered for locations with at least 3 meters of water above the reef surface. Working with a boat over a reef in waters less than 3 meters is not recommended. Wave surge and currents result in difficulty keeping the boat positioned whilst not having the hoses foul on the reef and/or having a vessel avoid isolated rock columns that rise vertically from the reef's surface.

The use of an air tank to drill into the reef worked well. Holes were drilled up to 1.5 cm in diameter and to depth of 20 cm. Use of an air drill did cause some vision obscuration due to bubbles, and the drilling was most efficient when two persons were employed – one person to drill and the other person to hold the tank and watch the air gauge.

For time and manpower estimates, a 1.5 by 15 cm hole can be drilled into the reef in approximately 15 – 30 minutes using 2 – 7 air tanks pressurized to 3,000 PSI. Smaller holes to accommodate coral plugs can be drilled much more quickly. Drilling up to 40 small holes per tank was achieved in testing. The efficiency of the drilling can be increased by obtaining proper fittings with less air leakage.

The electric drill was the most versatile as one person could easily manipulate the drill. The lack of wires, hoses, or additional weight made for the best versatility. With the electric drill, holes large enough to accommodate a coral plug were drilled at the rate of 1 hole per 1 – 3 minutes.

The Nemo electric drill retails for approximately $1,200 USD and may be outside of the price range of many communities; however, as many coastal communities have some association with SCUBA diving operators, the conversion of old SCUBA equipment to accommodate the drill plus the cost of the air drill and drill bits could be as little as $125 USD.

There were large variations in the rate of holes drilled, attributed mainly to working in the shallows where personnel were often hindered by wave surge, currents, drill bits, and air loss from poor connection fittings between the drill and air hose and performing much of the activities using snorkel gear. The use of SCUBA in deeper water produces more drilling efficacy, as wave surge is considerably lessened and divers can exert better physical pressure on the drill.

An initial RED structure did recruit coral colonization within one year of placement on the reef. The other X-shaped structures were placed on Rocky Point reef in an area that appears to be affected by wave action (as there are markedly fewer corals than other portions of the reef) and left for six years. After six years in place, the structures remained intact, except for two structures that appeared to have suffered a failure of the rebar. During the six-year period, the structures were afflicted by many storms, including Hurricane Joacain which hit San Salvador on September 30 and October 1, 2015 (Rothfus 2016). The hurricane battered the islands with winds of 178.6-207.6 kph (Curran 2016).

The different attachment techniques yielded interesting results. Metal wire, regardless of size or composition was, ineffective. The wire would often rust and break, allowing the coral fragment to become dislodged, sometimes in as little as 10 days. Similar results were documented with thin cable ties as well. The use of epoxy proved to be reliable means of attaching coral, especially when combined with a cable tie. In fact, we documented an instance of the coral growing over the cable tie. Ceramic plugs have worked very well in securing coral fragments to the reef.

Coral transplants have shown good initial success. *Acropora* sp. fragment plugs placed upon old *Acropora* sp. skeletons using either ceramic plugs or marine epoxy and cable ties had a 90 percent survival and averaged 8 percent new tissue growth from summer 2018 to winter 2019. *Acropora sp.* placed on REDs had poor survival (approximately 5 percent). It is unclear at this time if the poor survival was attributed to the REDs themselves or that the REDs are located in an area of poor conditions (high sedimentation and scour).

DISCUSSION

Based on the results to date, I have determined feasible low-cost methods to restore shallow water patch reefs using materials readily available in isolated coastal communities These materials include SCUBA tanks, air drill, drill bits, marine cement or Quickrete, aquarium epoxy, plastic plugs, hand saws, and chisels. Based on our initial results, two persons could drill enough holes to cover a 20 m x 20 m area of reef with coral transplants spaced every 0.5 meter in one day's time. Using efficiencies learned from the efforts documented in this paper, a work party of local persons could rehabilitate a small patch reef in several days. Thus, I have concluded that I will initiate Part II of the research, scheduled for 2021-2022.

In Part II, I will establish test plots for statistical analyses to better quantify and compare reef restoration results, refine manpower estimates, and test the scale of rehabilitation. We will collect a number of coral fragments from the inner reefs and recent storm damaged corals from Gualin Reef and transport them to the shallow waters adjacent the GRC. There I will erect a temporary coral processing station where we will fragment the rescued corals and affix them to small plugs. The small plugs will be affixed to the reef surface or REDs. We will construct REDs and will affix either plugs or place tiles on the facias for spawning coral collection. The tiles will be placed on the REDs in the later summer, prior to coral spawning on San Salvador, to increase potential colonization success. Through the placement of transplanted corals in close proximity to collection devices, we will determine approximate rates of colonization through the proposed restoration techniques.

In addition, the recent findings of coral microfragmentation (Page *et al.* 2018), will be considered and incorporated into the restoration efforts. Coral microfragmentation is a recent discovery by which the small fragments (less than 1 sq cm) of an intentionally fragmented coral will grow at an accelerated growth rate than normal coral growth rates, making it possible to rapidly increase the amount of coral biomass on the reef. I envision that a coral nursery/repository will also be established in front of the GRC. Future restoration efforts in Part II will incorporate additional measurements of labor efforts, survival rates and growth rates resulting from coral transplants and microfragmentation efforts, and coral recruitment.

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