Best Practices Manual for Caribbean *Acropora* Restoration

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CONTENTS

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Puntacana Ecological Foundation Director: Jake Kheel

Project Coordinator: Victor M. Galvan

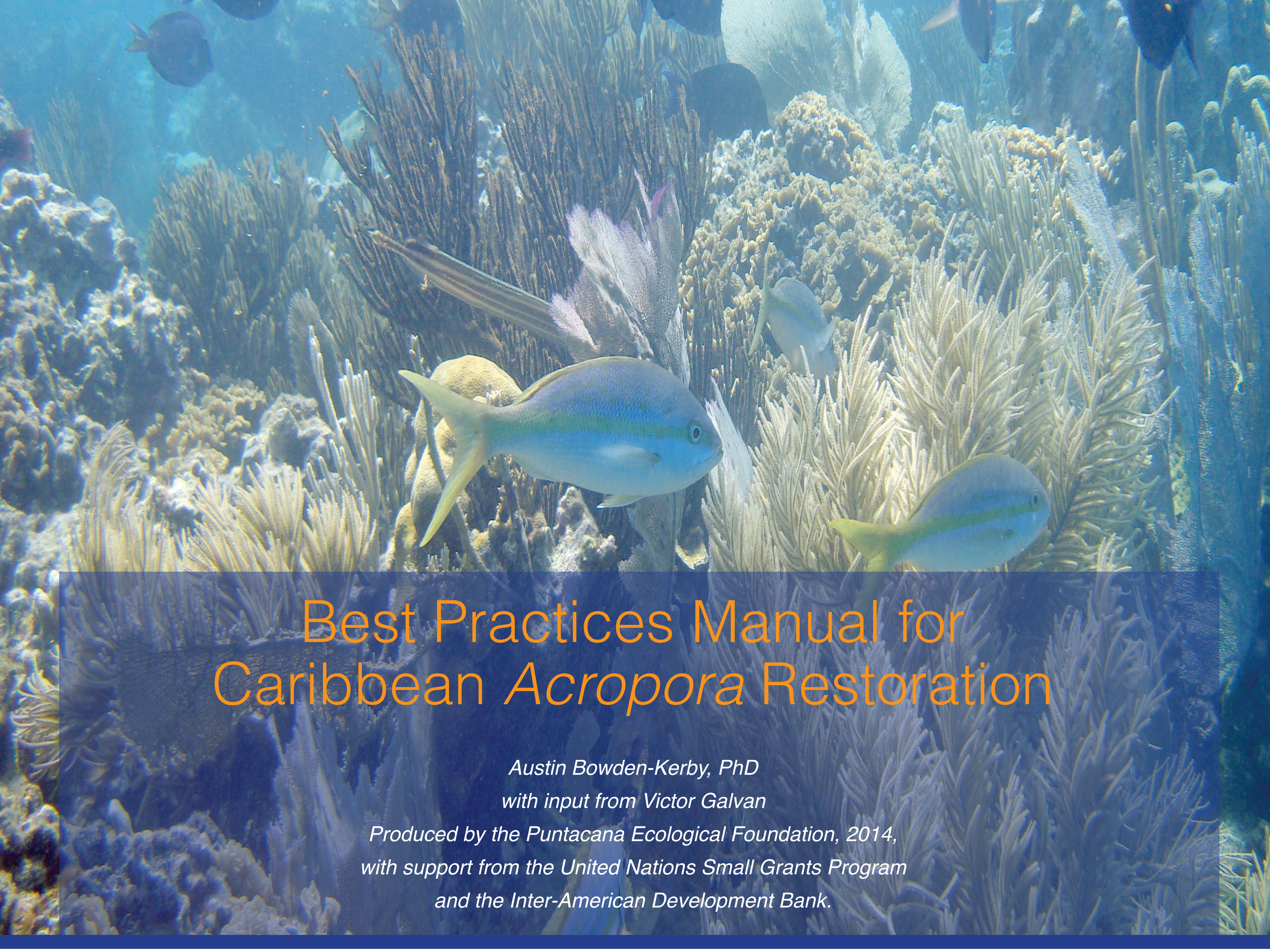
Editing: Guzman Benady Comunicación, SRL; Design: José A. Hernández Familia

A History of the Caribbean *Acropora* Restoration Project

The author of this course, Dr. Austin Bowden-Kerby, pioneered the concept of planting Staghorn corals in the Pacific Islands in the mid-1980s. He moved to Puerto Rico in 1993 to conduct extensive restoration research on Caribbean Staghorn corals for his PhD studies, and much of the research methodology used regionally was developed at that time with support from the University of Puerto Rico's Sea Grant Program. In 1999 the US NGO Counterpart International hired Dr. Bowden-Kerby and adopted the program, which was first implemented in Fiji. Counterpart's Coral Gardens Caribbean Initiative began in 2004, with sites established in Jamaica, Honduras and the Dominican Republic.

The Coral Gardens Initiative uses corals and coral replanting as a tool for involving multi-stakeholder groups in coral reef conservation and to raise awareness levels in communities and the tourism industry. The initial over-arching goal of the program is the sustainable management and conservation of coral reefs to enhance livelihoods within the fisheries and tourism sectors. The Caribbean program focuses on the conservation and restoration of threatened *Acropora* corals as a point of common action. While based on the best available science, the work is not strictly academic or research based, but focuses on empowering reef users to better understand and interact with coral reefs in positive ways and to learn through hands-on restoration actions. **The goal of the program is not to replant large sections of the reef with corals, but to prevent the few surviving coral genotypes from being wiped out altogether.** A second goal is to restore and nurture small yet genetically diverse *Acropora* coral populations using nursery-reared fragments to encourage the natural recovery of denuded reefs.

At each site, the program relies on the tourism industry, community volunteers and the dive industry to continue the work. Two sites were initially set up in the Dominican Republic: one in the community of Sosua, Puerto Plata and the other in Punta Cana, La Altagracia. In 2009, the Puntacana Ecological Foundation, the managing institution for the Punta Cana coral nursery, signed an agreement with the University of Miami and Counterpart International to expand the Coral Gardening initiative. Today there are eight coral nurseries established countrywide including Punta Rusia, Sosua, Las Terrenas, Los Cacaos, Palmar de Ocoa, La Caleta, Bayahibe, and Punta Cana; with as many as four more nurseries being planned for 2014. There are now coral nurseries in most of the tourism hotspots in the Dominican Republic! Four of the eight nurseries are now managed by local institutions with their own full-time dedicated staff. The other four (Punta Rusia, Sosua, Los Cacaos, Punta Cana) are still being directly managed by the Coral Restoration Coordinator and four interns at the Puntacana Ecological Foundation. The Punta Cana coral nursery remains the largest of the nurseries with over 1,900 fragments being propagated and >2,000 fragments being returned to natural reefs between 2011 and 2012. Countrywide, over 3,000 fragments are being propagated and some 21 genotypes are being tracked; six more are awaiting genetic confirmation. The coral gardening initiative acceptance level is now at its highest, with local and regional tourism industries showing high interest and involvement. The *Acropora* restoration initiative is now one of the largest coral restoration programs in the Caribbean. *Acropora* restoration programs are also being carried out by NGOs and researchers in Florida, Puerto Rico, the US Virgin Islands, Jamaica, Belize and the Bahamas.



Best Practices Manual for Caribbean *Acropora* Restoration

Austin Bowden-Kerby, PhD
with input from Victor Galvan

Produced by the Puntacana Ecological Foundation, 2014,
with support from the United Nations Small Grants Program
and the Inter-American Development Bank.

Introduction

This Manual is being produced as a supplement and to complement the recent publication: "*Acropora* Restoration Guide: Best Practices for Propagation and Population Enhancement" produced by Johnson et al. 2011 for The Nature Conservancy (TNC). Rather than publishing an entirely new restoration manual, we have chosen to focus on documenting advances that were not included in the TNC manual and documenting successful methods that have not yet been described in detail, adding the important *Acropora* restoration work that has incorporated climate change adaptation in its design. We recognize that many people who work with corals do not have a strong background in science, and may therefore need clear, straightforward, jargon-free explanations to strengthen their knowledge base. This work here represents such efforts.

Establishing an Effective Coral Restoration Program

Before planning any coral reef restoration work, we should consider what killed or degraded the local reef in the first place, and if restoration activities have a good chance of long-term success. For many reefs, long-term success will require working towards solving the root causes of why the coral reef has declined. Sites where problems such as poor water quality due to pollution are a factor or where conditions are worsening rapidly may not be successful as coral reef restoration sites.

For new areas, small trials over at least one year are recommended before deciding if restoration is feasible for that particular reef area. Adopting reefs that are not completely degraded or with signs of natural recovery may be a more effective strategy. Areas where a one-time or rare event is known to have degraded the reef, and where a lack of recruitment of coral larvae is thought to be the primary cause of the lack of recovery may show particular promise as restoration sites.

While any reef area can potentially be adopted, all reef areas of particular value to the community for fishing or tourism purposes should be considered priorities for coral conservation programs. Heavily used reef areas are impacted by fishers and visitors, and so a coral care and coral first aid program may be effective in lessening the long-term impact of small-scale but constant impacts that would otherwise lead to coral decline at the site. In such areas, certified coral gardeners (Coral First Aid PADI Distinctive Specialty certification available at participating dive shops) can help organize and promote a program between tourism operators and local volunteers to care for the reef at the main dive sites and snorkeling areas.

In summary, before establishing coral nurseries and replanting corals to restore damaged reefs, it is important to consider the following precautions:

1. Planting corals is NOT a “quick-fix” solution to coral and reef decline because it does not solve the root causes of coral reef decline.
2. Coral planting is only effective as a management tool when combined with other conservation strategies, such as no-take marine protected areas and measures to decrease reef damage.
3. Coral planting is only effective in some areas and under certain conditions.
4. If whatever killed the corals at a particular site in the first place continues to be a problem, it is useless to replant corals, only to watch them die later.
5. Involving the tourism, diving, and fishing community in restoration projects may be an effective long-term approach. The PADI Coral First Aid certification has been developed to help support this aim.

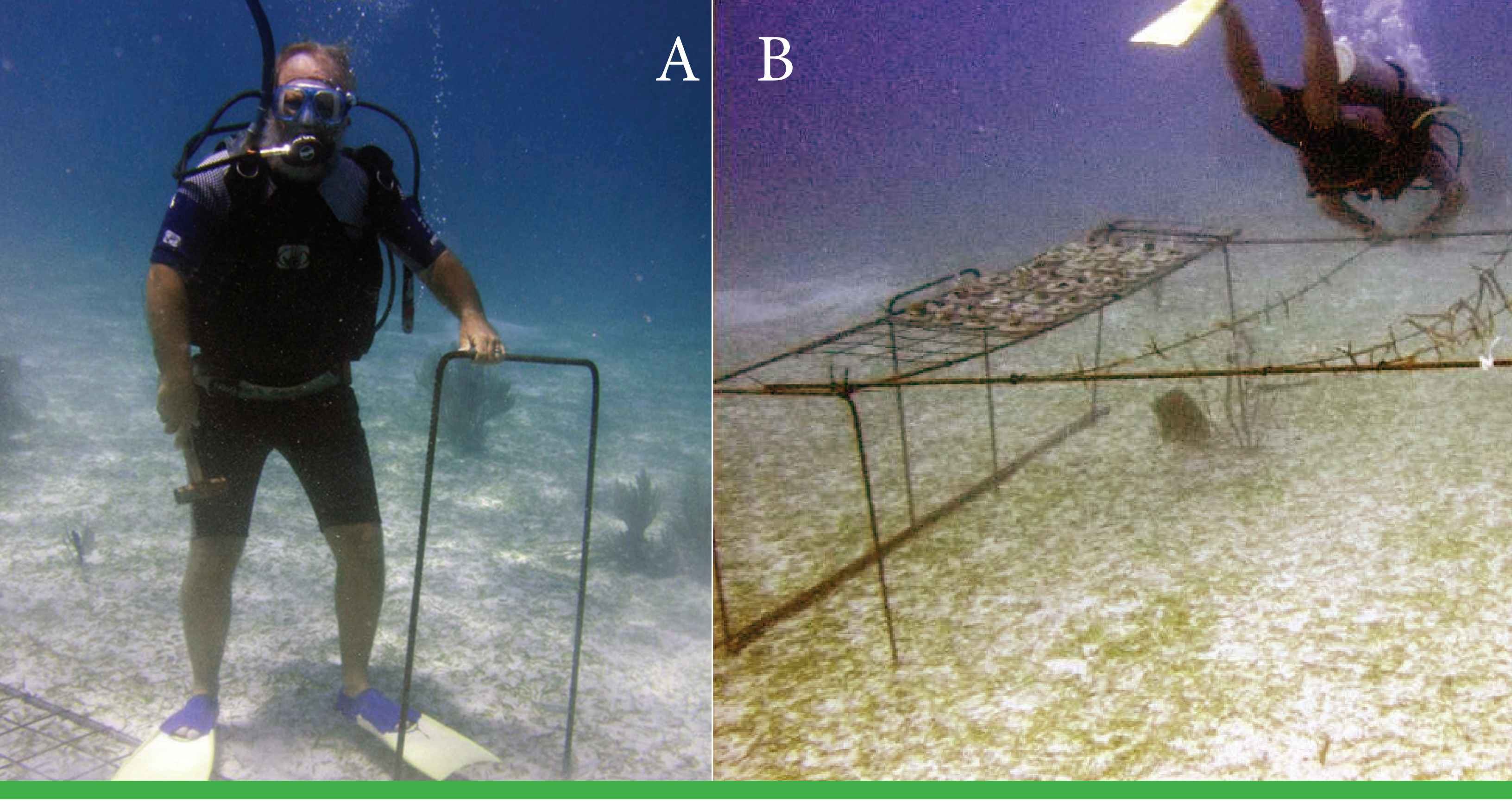
Building Long-lasting, Hurricane Resistant Steel Bar Tables to Support Coral Nurseries

The metal bar coral farming table is a long-lasting and hurricane resistant structure designed to keep the corals well above the substratum, avoiding contact with re-suspended sand and silt and nearly all predation from Hermodice fireworms, *Coraliophila* snails, and x*Stegastes* damselfish. The tables are used to support either rope culture or "cookie and tray" culture of corals, or both.

The underwater tables consist of 1.6 cm (5/8 inch) thick metal "bars" cut into 3.1 m lengths. These bars usually come in 6.2 m lengths, so cut each bar in half. You will need 8-10 cut lengths per table. Four of these pieces are then bent at the 1.2 m point from each end to form U-shapes, using metal pipes to get a good 90° angle, so that each U has two 1.2 m downward portions, with a shorter

61 cm span connecting them. The specific measurements of the legs and tables can be modified if required.

To build the nursery table first take four of the unbent/straight sections of the metal bars and lay them on the bottom to form a square on the intended site, as a guide for the leg placement. Next place one of the four leg pieces at a corner of and inside the square 5-10 cm in from the square edge. The legs should be placed at a right angle to the prevailing currents, so that the nursery offers less resistance to storm currents. Once placed in the correct position, drive the leg in about 30-40 cm with a sledgehammer. Install the second leg in the same manner so that it is opposite and facing the first leg to form a pair, each approximately 2.9 m apart. The third and fourth legs are then placed on the opposite side of the square, so that all legs are facing the same direction. Once all four legs are in place, the unbent sections of metal bars that formed the square guide for the table are then lifted up one by one and attached to the top position of the legs with heavy UV-resistant (black) plastic cable ties. The finished table is approximately 3 x 3 m in size and firmly fixed about a meter above the bottom.

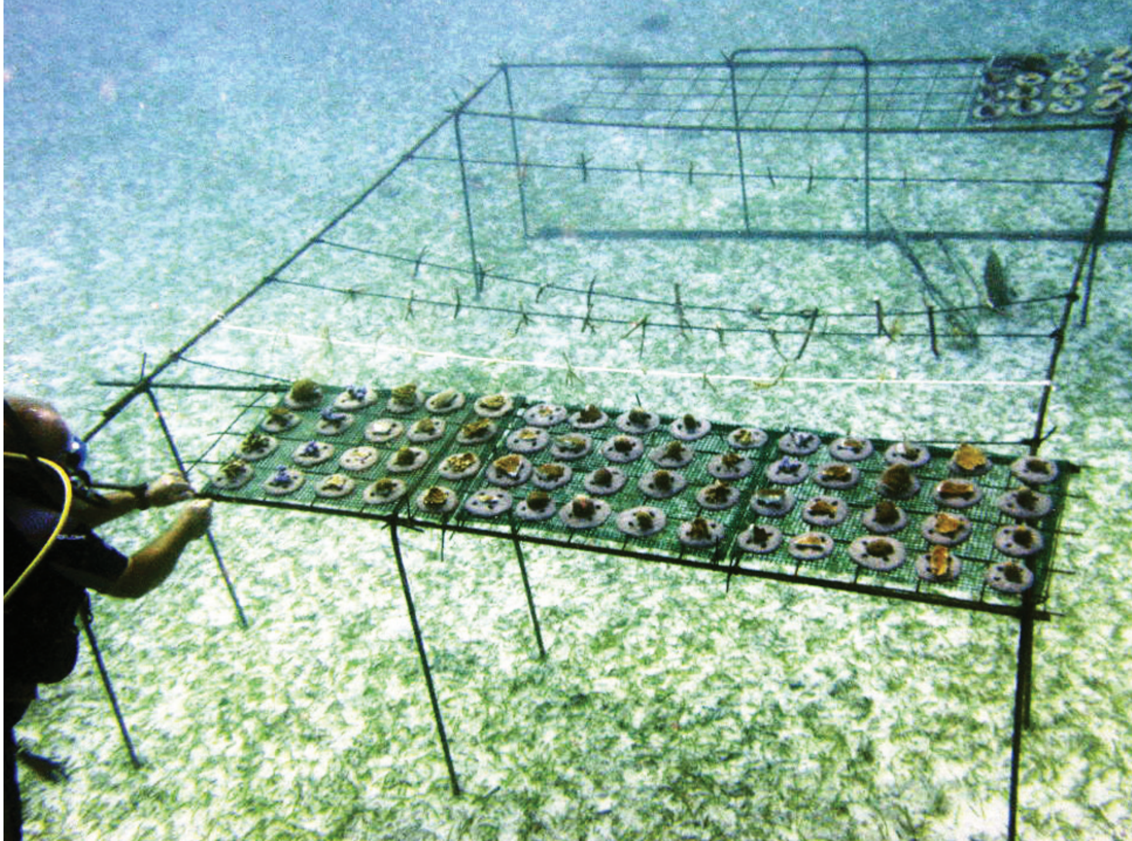


» a-b. Building the metal U-shaped legs for the coral nursery table (a). Nursery table completed and ropes with corals being added (b). Note the U-legs and various cross bars.

After the table framework is completed, ropes seeded with coral fragments can then be strung across the table, tied between the straight bars, creating an ideal space for propagating "mother" corals . The area of the table can be doubled by simply adding two additional U-legs and three 3.1m cross pieces. To increase the capacity of the table to bear additional weight, either extra U-legs can be added or heavier 19 mm (¾ inch) metal bars can be used.

For extra durability and resistance to storms, support braces can be added to the nursery table by pounding in additional U-legs at a 45° angle and attaching them to each supporting U-leg on the table.

If the cookie tray method (described later) is to be used on the table, an additional U-leg is added between each pair of legs to support the additional weight, and a second metal bar, plus a 60 cm x 3 m section of heavy mesh wire affixed to support the trays. If rope culture is not desired, a simple modification of the tables for cookie and tray culture is possible and involves two U-legs pounded in only 2 m apart, with two of the straight bars attached at the top, extending 50 cm beyond the U-legs on each side, to form a stable 60 cm wide x 3 m long surface for attaching the cookie trays. you will learn the following in more detail:

» A metal table with both a rope culture section and cookie trays at the ends.
Note the use of plastic mesh to support the cement cookies.

Methods Analysis and Lessons Learned

Benefits:

- Nursery tables are ideal for avoiding major problems with predators, re-suspended sand, and silt.
- Table nurseries can support heavy coral growth and are thus ideal for long-term production of second generation corals trimmed regularly from "mother" colonies
- If properly located and reinforced, table nurseries can be hurricane resistant and long lasting, potentially the longest lasting of the coral nursery methods developed to date.

Problems:

- The nursery must be installed over soft sand or gravel substrates so that the legs can be pounded in.
- Theft can sometimes be a problem; tables can be stolen and sold for scrap metal as they can easily be dismantled.
- Poor-quality ties can break and cause the table to come apart. In areas of high wave energy, cable ties are usually not strong enough to keep the table together and require additional re-enforcement. In areas with consistently high and strong wave action, other table designs are better suited.
- Snagging on anchors can cause severe damage to the structure.
- Electrolysis of the metal bars at the bent portions can occur if there is any contact with a different metal,

such as attached trays being galvanized with zinc and in direct contact with the iron bars.

Key Lessons:

- Tables can be modified for hard substrates by bending the bar tips of each U-leg outward at the bottom by 20 cm so that they can then be inserted into special concrete anchors.
- Use rope or durable plastic coated wire material to reinforce the key junctions of the metal bars forming the table.
- Use heavier 1.9 cm metal bars if establishing a longer-term nursery.
- For areas of stronger surge or currents, brace the tables with U-legs pounded in at an angle at the sides of the table and add a leg and additional bars in the middle of the table. Face the direction of the lines on the tables into the current rather than against the current
- To prevent anchor damage, mark the nursery site with buoys, or locate it where boating is uncommon or where anchors are banned.
- To prevent electrolysis and gradual erosion of the table or trays, use plastic coated mesh for the coral culture trays, or tie metal trays so that a plastic or cement piece prevents direct contact with the metal bars of the table. Never use bare copper electrical wire to tie iron bars and mesh together.
- Locate the metal tables where water flow is good, but where there is at the same time adequate protection from storm waves. Placing the tables at least one meter lower than the surrounding reef rock helps protect them, as breaking waves can then roll over the top, leaving the corals unaffected.
- To reduce the chances of theft, if possible locate the tables within a no-fishing reserve or under the watchful eyes of security personnel at a tourism resort. Community involvement with the project may also reduce the risk of theft as people become aware of the importance of the work.

» Staghorn corals growing on a metal table rope nursery.

Rope Culture of Corals on Metal Nursery Tables

Long-term Culture of Mother Colonies

The rope culture method for growing "mother colonies" of Staghorn corals takes place on the metal tables described previously. Ropes 0.95 cm thick are planted with 10-25 cm Staghorn coral fragments, simply threaded into the rope by untwisting the rope to open up a hole between the major strands and inserting the coral branch, with the strands then released to tightly hold the fragment in place.

Branches are spaced 30-40 cm apart on the ropes, which are then tied across the metal table, each rope spaced 30-50 cm apart so that they run parallel to each other. The distance between the ropes remains adjustable over time, while the distance between coral colonies on a rope is not. The fragments quickly overgrow the rope and branch out in all directions. The mother colonies are trimmed to produce second-generation corals in the form of fragments.

Culture of Tiny Fragments on Monofilament Line on the Nursery Tables

When trimming corals, the goal is to produce fragments in the 10-30 cm size range, however inadvertently some small 0.5-5 cm fragments are formed that are either physically too small for the outplanting methods, or that would have very high mortality rates if plated directly to the reef. However these small coral fragments can be saved by re-attaching them to the ropes on the nursery table. This is possible by tying each fragment securely to thin (~9 kg) fishing line and then threading the fishing line into the rope so that the tiny coral fragments are suspended and dangling 10-15 cm or so below the ropes, spaced about 10 cm apart (as done in Jamaica by Andrew Ross). This method can also be used to intentionally fragment corals as tiny fragments to increase their biomass where *Acropora* is exceedingly rare, or where only a single remaining branch represents a specific genotype. This modification of the rope nursery method, using additional dangling lines to secure individual coral colonies, can also be used with larger 10-15 cm branches for the production of complete (non-fragmented) coral colonies for use in restoration.

Methods Analysis and Lessons Learned

Benefits:

- The corals on table nursery ropes can be allowed to become much bigger and heavier, so an annual trimming will do.
- Staghorn corals have been shown to grow fastest on the ropes than in any of the other methods tried. This faster growth may be related to increased water flow and the greater availability of nutrients and light.
- Corals can grow successfully on ropes even in highly silted environments where any other method would quickly result in coral death; as long as there is active water motion.
- Snail and fireworm predators find it very hard or even impossible to get into the rope nurseries from the surrounding environment. Although small snails can often be found on older rope nurseries, apparently settling onto the corals from tiny larvae in the water column.
- The corals on ropes attached to the

» Colony damage when mother colonies are allowed to over-grow and rub with each other, making the colony susceptible to infections.

tables are very resistant to storms, despite the associated jostling.

- Mother colonies can be grown for years on ropes secured to metal tables.
- Damselfish tend to be absent from the mobile corals while fixed corals on frames often become infested with damselfish.

Problems:

- Ropes in some sites have to be cleaned regularly of seaweeds and hydroids, especially in imbalanced ecosystems with few fish. Filefish appear to be important for the control of hydroids, while juvenile parrotfish seem to be most important for seaweed control.
- When mother corals are left untrimmed for over a year, they become very large and heavy, touching and crowding nearby colonies and in some cases also dragging the bottom. Corals must be trimmed at least once per year in order to maintain a healthy nursery. “Over mature” corals can grow to over a meter wide and can result in the basal area attached to the rope to die due to senescence. The corals may also rub together, causing wounds that are susceptible to infection.

» A butterfly fish stripping coral tissues off of a Staghorn coral colony and potentially spreading disease (lower right). Butterfly fish tend to target the corals in the summer, especially leading up to the spawning season when the coral tissues are filled with developing gametes.

- Disease on over-mature corals is most often circumstantially associated with the presence of four-eye butterfly fish, Chaetodon, which picks at the corals to eat the coral polyps, sometimes moving back and forth from diseased corals to healthy corals, spreading disease throughout the nursery.
- Dead bases and points of rope contact eventually become weak through bio-erosion by sponges, allowing the outer living portions of the coral colonies to break off from.
- The ropes become completely ingrown into the coral colonies and so the corals cannot be easily removed: they can never be removed intact in one piece without cutting the rope up.
- Table nurseries can eventually collapse due to increase weight and drag if corals are left to “over-mature”.

Key Lessons:

- Trimming the corals strongly rejuvenates the colonies, preventing senescence and encouraging strong overgrowth of the ropes. Trimmed colonies can potentially live for many years, while colonies left to their own eventually die at the bases and become detached from the ropes.

- This method is designed to produce permanent or semi-permanent mother corals for regular trimming. If the method is used to produce corals for harvesting and outplanting, the branches need to be attached to the ropes using line external to the ropes.
- When branches break off the ropes and fall to the substrate, they normally die within days on sand or within weeks on seagrass, however if branches fall onto clean rubble they have a high probability of survival.
- Some breakage is inevitable and can provide an additional source of outplants, as long as the fragments are able to survive on the bottom until discovered, therefore rubble is the preferred substratum below rope culture tables. However, such an ideal situation is rarely found and can result in some predation as predators inhabit rubble areas as well. Locating the tables over clean rubble has the advantage in that any breakage that falls onto the substrate normally survives until it can be collected and replanted. Seagrass and sandy rubble are better than sand for short-term fragment survival, but not as good as clean rubble. Falling onto sand is quickly fatal to coral fragments.
- Staghorn fragments taken from basal regions of the colony grown significantly slower than branches taken from the younger/ outer portions of colonies.
- Locating the coral nurseries in no-take areas and nearer to healthy reefs, so that fish will visit the structures and clean them, helps lower the problem of algal and hydroid overgrowth. Frame nurseries (described below) can provide habitat for fish and can be located to the side of table nurseries for good effect in helping keep the ropes clean.
- Butterfly fish predation is concentrated during the late spring and summer months, apparently targeting the

corals when they are most nutritious and packed with gametes as they scale up to their summer reproduction period. This problem often occurs where mother corals are allowed to become "over-mature" or very large.

- If deeper than 3 m, locate the nursery over bright white sand, where reflected light can counteract any decline in photosynthesis due to depth. Locating the tables over white sandy bottoms in general seems to positively affect coral growth, reflecting light onto the shaded side of the corals. When using a light meter over clean white sand under the culture table, the light reading in the down direction can equal the light reading of the meter in the upward direction. Locating the corals over seagrass would decrease upward reflected light, as the photosynthetically active radiation (PAR) would be essentially used up by the seagrass. The only downside to bright light is that the corals may be more susceptible to bleaching when the water becomes unusually warm.

» Cookie tray cultivation method. Cement cookies used successfully to grow Elkhorn corals.

Cultivation and Outplanting Using the "Cookie Tray" Method

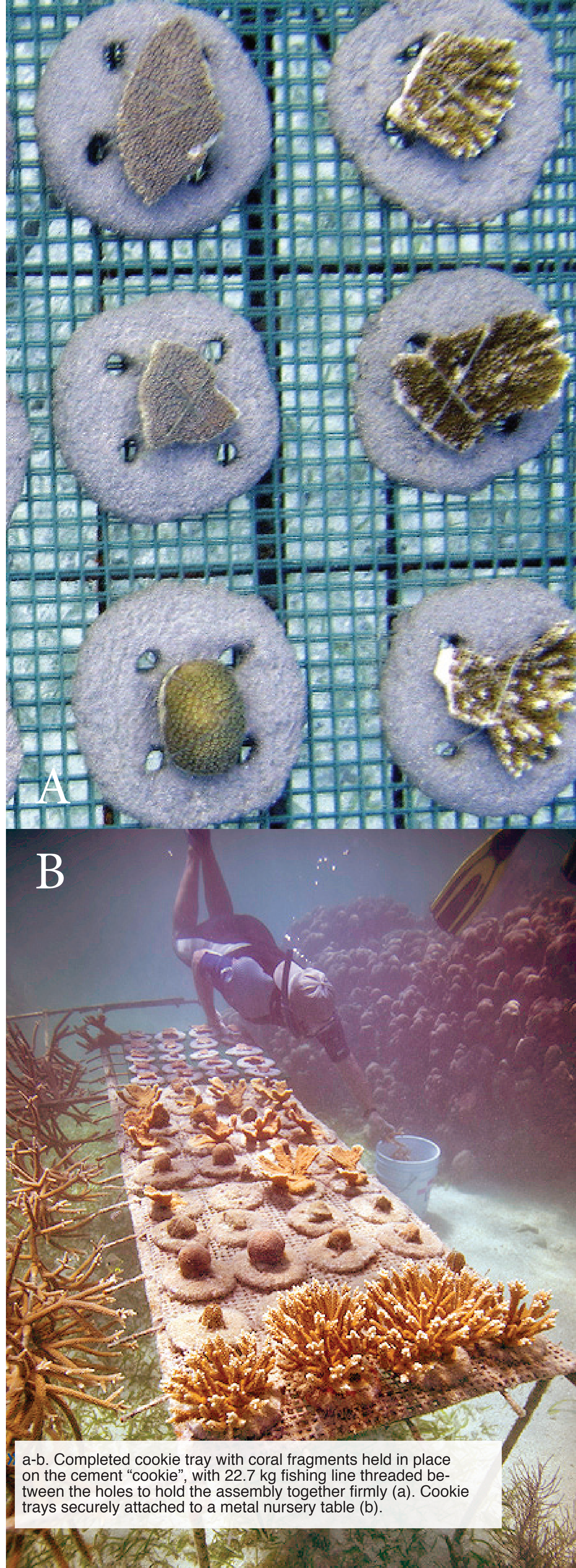
Another method used on the nursery tables besides rope culture is the "cookie tray" method. This method is particularly good for Elkhorn and Fused Staghorn corals and uses small 10-15 cm hand-made button-like cement discs with either two or four perforations. Fishing line is threaded through the holes in the discs and through the mesh of an underlying heavy wire mesh tray, so that the fishing line firmly holds the cookies to the tray and the coral fragments are held securely to

the cement cookie without any other attachment required. The completed trays are attached to the metal table described above, between two metal support bars. Rope culture can be easily mixed with tray culture on the same table.

Methods Analysis and Lessons Learned

Benefits:

- Once a sufficient basal area is produced, the middle portion of the coral tissue disc begins to swell, with the polyps becoming upright and apical in nature, and then the



a-b. Completed cookie tray with coral fragments held in place on the cement “cookie”, with 22.7 kg fishing line threaded between the holes to hold the assembly together firmly (a). Cookie trays securely attached to a metal nursery table (b).

» Coral Nursery Table with cookie tray method used to grow Elkhorn corals and other tightly branched and massive coral species.

swelling rather quickly erupts into a blade of coral. Within one year, a perfectly formed miniature Elkhorn coral is formed of the right size and shape for transplanting back to the reef.

- This method has been used successfully to grow Fused Staghorn Corals and species of non-Acroporid corals such as massive and tightly branched species.

Problems:

- Algal overgrowth is the main problem with the cookie tray method, wherever grazing fish are not abundant. The trays in many sites need regular cleaning with a toothbrush.
- Stinging hydroid overgrowth can sometimes be a problem, becoming a major irritation as maintenance is carried out.
- Non-Acroporid massive corals

Coral growth potential utilizing the Cookie tray method.

sometimes have the problem of coral death at the fishing line contact points due to algae overgrowth on the lines.

- Coral seed fragments can fall out of the array if the tray is transported or otherwise disturbed at an early stage before attachment to the table.

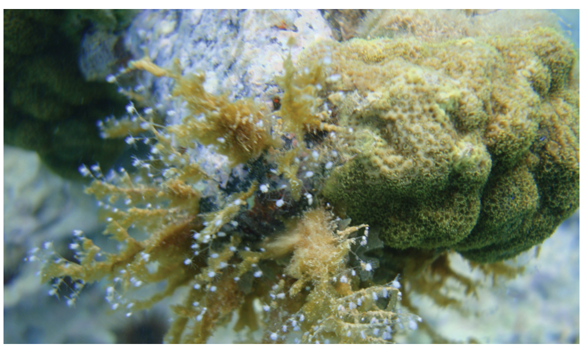
Key Lessons:

- Locating the culture table close to the reef and where reef fish can easily clean the table helps the corals thrive and lowers algal overgrowth considerably for the cookie tray method.
- No-take areas with abundant fish populations are ideal; otherwise try to locate the coral nursery where schools of blue tangs frequent the area. Abundant grazing fish help keep the trays clean of all but the inedible seaweeds, which may still need to be removed occasionally.

- In spite of good fish populations, cyanobacteria and unpalatable algal species can sometimes continue to be a problem at some sites, especially in areas with higher nutrient levels.

- Hydroid overgrowth is greatly reduced by the presence of particular species of fish (boxfish, puffers, filefish, etc.).

- Excessive overgrowth by algae or hydroids is indicative of some sort of ecological imbalance in the system that needs to be identified and if possible solved.



» A hydroid, notice the stinging white fuss at the tips.

- To lower the problem of seed fragment loss, the original two-hole design of the cement disc can be modified by adding two additional holes, which allowed the nylon monofilament to be a crossed over each fragment, holding the coral in place more firmly.

» Another example of cement cookies being used to grow other coral species.

- For Elkhorn corals, the cement discs should be at least 15 cm diameter to accommodate the basal overgrowth. Elkhorn corals have a strategy of stabilization and firm attachment before growing upward. If a cement disc is too small for the formation of the basal attachment, or if the corals are not harvested at one year, the mesh tray will become heavily encrusted by the coral, complicating harvesting for outplanting.

- If working with brain and star corals, the cement cookies should be woven into the tray and the coral fragments then glued to the cookie using superglue gel. This prevents the problem of microalgae growing on the fishing line and causing problems for the corals.

» a-b. A-frame nursery with all three Acropora species attached (a). Growing all three species in the A-frames is only for one year or less, as Elkhorn corals quickly become overgrown and is crowed-out by the other two corals (b).

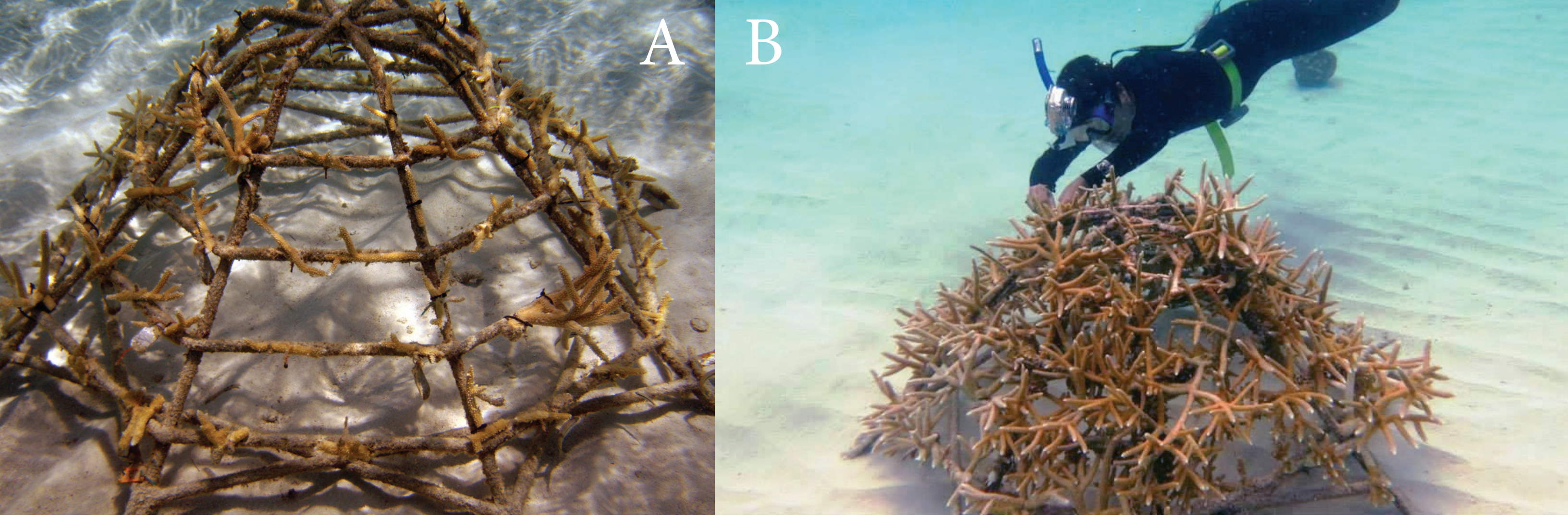
A-frame and Welded Rebar Frame Nurseries

A-frame

A-frame nurseries are described in detail in other manuals and therefore, their construction will only be briefly reviewed here. These structures are constructed of 2-3 mm 20x20 cm wire mesh cut and folded into an A-shape and then coated with epoxy resin. The frames are anchored with concrete blocks or specially made anchoring slabs, attached to the frame by short metal bars tied to the frame bottom with durable cable ties.

Welded rebar frames:

Welded rebar frames are a newer innovation (http://reefscapers.com/). These frames are made of 1.6 cm thick steel rebar sections welded together, often in a circular or star-shaped



» a-b. A good example of a welded frame after initial population with fragments (a) and an example of potential coral growth on the frame (b). Welded frames deployed on sand or seagrass are better protected from predatory snails and fireworms. The open nature of the frame bottom and interior creates habitat for fish to live, helping control Stegastes damselfish and preventing their infestation on the corals

hexagonal or octagonal arrangement. The welded bars are coated with a layer of sand and with one to four layers of epoxy resin to prevent them from rusting. Uncoated rebar frames will corrode quickly due to electrolysis from unlike metals being in direct contact and exposure to sea water. The size of the bars and the coating ensures that they will last for years. The heavy weight and low center of gravity means that the welded frames do not need any additional anchoring in all but the highest energy sites. However, if lighter bars are used and for areas prone to more severe currents, each leg can be tied to stakes pounded into the substrate and thus firmly pegged to the bottom. Frames of all types are the ideal nursery method for growing many coral genotypes closely together in the field are thus best for experimental comparisons and testing diverse sites for coral survival, growth, and predation, disease etc, to identify any underlying ecological problems as well as to locate promising sites for additional experimental or restoration work. The corals themselves can be thought of as complex biological sensors that respond to water quality, water flow, light, food availability, predation, etc., with mortality, branching and growth data being the end result of a combination of all these environmental factors. By comparing the growth and mortality of particular coral genotypes in multiple sites, the relative quality of the environment for coral growth and survival can then be ranked for each site, even if you don’t have high levels of funding and access to expensive monitoring equipment.

» Welded frames coated with epoxy to increase durability in saltwater.

Methods Analysis and Lessons Learned

Benefits:

- A-frames are very low cost and materials are readily available. There is no need for specialized equipment in their construction.
- A-frames and welded rebar frames create immediate fish habitat
- Frames can be deployed in relatively shallow water and on most substrates
- Metal rebar frames are easily deployed and can last for years
- Both types of frames are easily replicable for experiments and trials
- Epoxy coated welded bar frames on sand, seagrass, or rubble substrates last for years and will have a high probability of the corals surviving unassisted in the site over the long-term.

Problems:

- Smaller mesh wire A-frames creates ideal Stegastes damselfish habitat, which subsequently kills much of the coral, so mesh smaller than 10 cm should never be used.
- Hermodice fireworm and Coraliophila snail predation can be a major problem on rocky or cobble substrates with disturbed ecology.
- Coral-killing snails can appear on the frames in low numbers as the coral nurseries become older, apparently settling in from the larvae. Their small size can avoid detection initially.
- Elkhorn corals grow well on A-frames, but should be removed from the frames within a year, as the frames do not offer the long-term stability required for the corals to

reach adult size.

- Elkhorn corals can grow well on the welded bar frames for a longer period of time, but it is not recommended as the corals will eventually become top-heavy and will topple the frame. However, if the corals are intended to grow into “mother colonies” for regular trimming over many years, the welded frames then make an excellent choice as the nursery type.
- Welded frames might be vulnerable to theft when deployed in the field. Well made welded frames, although they might last many times longer than normal A-frames, have a high cost and require the use of specialized stools and skills to create them.

Key Lessons:

- Wider 20 cm mesh is ideal for preventing Stegastes infestation, as it does not shelter the damselfish, allowing predatory fish easy access to the space under the corals on the frame.
- Locate A-frames on sand about 2-3 meters from rocky reef areas that might harbor fireworms and snails as these coral predators are reluctant to cross sand. However, locating the frames too far from the reef prevents grazing fish from effectively cleaning the frames and overgrowth of algae and hydroids is the result.
- If an older A-frame is falling apart, trim the corals thoroughly and simply place a new frame on top of the old A-frame and secure the two frames together. When retiring old A-frames, attach the degraded frame onto a denuded reef where it can finish degrading while allowing the corals to become attached to the reef.
- Areas with small sized rubble substrates will often give good results, but larger rubble and cobbles provide shelter for fireworms so that frames rarely succeed on these substrates. Elkhorn rubble provides especially good fireworm habitat and should be avoided. If even a few pieces of Elkhorn rubble are present near your corals, they should be removed.

Comparative Evaluation of Nursery Methods

Of three cultivation methods presented here and currently used in multiple nursery sites in Honduras, Belize, Jamaica, and the Dominican Republic, A-frame nurseries have worked well for both Staghorn coral (*Acropora cervicornis*) and Fused Staghorn coral (*A. prolifera*), although they have proven less satisfactory for Elkhorn corals (*A. palmata*) over the long run. Rope culture often worked best for *A. cervicornis*, while cookie/tray culture worked best for *A. palmata.*

Comparison of nursery structure types

Table 1. Comparison of the relative effectiveness of nursery cultivation methods for each of the Caribbean *Acropora* coral species.

	Frames	Suspended ropes metal table	Cement cookies
Staghorn Coral	Very Good	Excellent	Unsatisfactory
Elkhorn Coral	Satisfactory	Unsatisfactory	Excellent
Fused Staghorn	Good	Excellent	Excellent

None of these methods works well for very small <1-2 cm fragments of either species. For very small fragments, cultivation on thin monofilament fishing line works best. These lines are suspended from ropes attached to nursery tables or suspended in an array from floating plastic bottles or buoys. For all methods juvenile parrotfish and surgeonfish are important in cleaning algae from the structures. However, the less edible algae need to be removed regularly by hand, depending on the season and the background nutrient levels of the site. Hydroids can sometimes become a problem, and are hard to remove, and when removed can sting the field worker! However, particular fish (species yet to be determined but possibly filefish) appear to do the job effectively.

Table 2 shows the recurring problems that occurred with the various methods and sites throughout the region.

Table 2. Matrix of Lessons Learned for Coral Nurseries and Planting Methods

Site key: PR=La Parguera Puerto Rico, JA=Discovery Bay Jamaica U1= Coral View Utila, U2= Low Keys Utila, R1= Bailey's Key Roatan, R2= Coral Key Roatan, G1=Posada del Sol Guanaja, G2= Island House Guanaja, PC=Punta Cana DR, SB=Sosua Bay DR, BZ - Belize

Symbol key: o = not a problem, + = a problem, ++ = a major problem, ? = possible problem but not sure, n/a = not answerable for the site due to the method not being carried out.

	PR	JA	U1	U2	R1	R2	G1	G2	BZ	PC	SB
Theft of materials was a problem	o	o	o	++	+	o	o	o	+	o	+
Boating damaged sites	o	o	+	o	+	o	o	o	o	o	+
Blocks anchoring A-frames housed *Stegastes* damselfish which harmed the corals	o	++	+	n/a	+	+	+	n/a	n/a	n/a	n/a
Small mesh A-frames were infested by *Stegastes* damselfish	+	++	+	n/a	+	+	+	+	o	o	n/a
A-frames were attacked by fire worms	n/a	++	+	n/a	+	+	++	o	o	+	+
A-frames on rubble or rock were attacked by snails	n/a	+	+	n/a	+	+	n/a	n/a	+	n/a	n/a
Disease was a problem	+	+	+	o	+	+	?	+	++	+	+
Bleaching was a problem	o	+	o	+	+	o	+	+	o	o	o
Mature corals are attacked by four-eyed butterflyfish,	o	?	++	n/a	?	++	?	++	o	+	+
Corals on ropes were attacked by *Stegastes* damselfish	o	o	o	o	o	o	o	o	o	o	o
Corals on ropes were attacked by fire worms *	o	o	o	o	o	o	o	o	o	o	o
Corals on ropes were attacked by *Coraliophila* snails *	o	o	o	o	o	o	o	o	o	o	o
Outplanted corals to reef rock were attacked by fire worms	o	+	+	n/a	n/a	?	+	?	?	++	++
Outplanted corals to reef rock are attached by snails	o	+	+	n/a	n/a	+	o	+	?	+	+

» * With the exception of small snail or worm recruits coming in from the larvae.

Trimming and Outplanting Nursery-reared Corals

Trimming of Mother Corals

Staghorn corals growing in nurseries must be trimmed when they mature, otherwise they begin to spawn during the late summer in the nursery, growth will stop, and disease will become a problem in the nursery. Size rather than age is the main factor in coral maturity, and trimming large mature mother colonies will turn back time producing many faster-growing juvenile corals out of one mature colony. A good portion of the "mother colony" is left in the nursery for propagation and the remainder become "seed fragments" used to expand the nursery or for outplanting into a restoration site on the reef. If *Acropora* corals are trimmed well before spawning (May at the latest), the corals will be kept in the faster-growing juvenile state, preventing sexual reproduction until a much larger and diverse population is produced. Water temperature should be considered before doing any trimming. It is not generally recommended to trim the corals if the temperature is over 32°C. Mother corals can be trimmed with cutting pliers, by grasping the branch 15-20 cm (depending on the desired fragment size) below the growing tip and twisting the wrist so that the coral branch snaps at a point just below the pliers. When the mother coral branches become 2-3 cm thick, a regular-sized carpenter's hammer can be used by simply tapping the branch 20-30 cm from the coral base. However, care should be taken in using this technique: a light tapping results in a single branch being produced, while more force sends a shock wave up the branch, causing the terminal 2-10 cm or so of the branch to fragment, forming numerous smaller pieces. It therefore works best to trim off the ultimate 10-15 cm of the branch with cutting pliers before using the shock fragmentation technique. When larger fragments are formed, they can be broken into smaller fragments (if required) by pulling the branch apart firmly at the joints, preventing the formation of small fragments if possible, as small fragments will die if not carefully replanted or suspended from ropes on fine fishing line. Larger fragments are also less likely to become overgrown by seaweeds and have a faster growth rate than smaller fragments. They can also be planted more easily with several points of contact with reef rock, decreasing the time to firm self-attachment. Outplanting methods should fit the size of the corals generated from the nurseries. Anything small but not too small (3-10 cm) can be planted in groups by using the technique of plugging them into balls of wet cement, as described later on in this manual.

Coral Planting Implemented as Part of Coral Reef Management

Coral planting should not be done as a

stand-alone activity but should become part of a jointly developed overall resource management plan with local fishermen, tourism industry, and local and national governments. Resource management and conservation plans should if possible include the establishment of permanent no-fishing MPAs, and the restocking of conch and other shell fish into the no-take MPAs if the recovery of these species is delayed due to severe overfishing, as well as monitoring to measure changes over time.

In many cases the coral planting work will be small-scale and mainly experimental; to learn why corals are not returning to a particular reef area, and to see if a solution can be found. However, where dredging has destroyed large areas of reef, and where such activity has been discontinued, there may be little hope for recovery without an active coral-planting program. For non-recovering areas, long-term work may be needed over many years, resulting in the gradual restoration of the reef. In the process of restoration, reef managers must also make sure that any donor reefs are not damaged and ensure that many kinds and genotypes of corals are used in restoration sites rather than only a few types, making the reefs more natural, more resilient to disease and stress, and better homes for fish and shell fish. Coral nurseries are important in ensuring that large numbers of corals are produced sustainably and without impacting other reef areas.

Methods in outplanting of Second Generation Coral Fragments Back to the Reef

Successful restoration patches have thus far have been located in waters from 1-9 meters deep, located in front of or behind the surf zone rather than in it. Branches should best be planted in the cool season when bleaching "post transplanting sunburn" will not be a problem, and so that the corals can become established well before the hurricane season. Any sites can be tried, as long as water quality and circulation are adequate to encourage growth. Unless some other *Acropora* corals are already thriving in the site, a small pilot transplant should be done six months to a year beforehand. The first round of transplanting from trimmed nursery corals could be focused on selecting some longer-term restoration sites, with a few fragments planted into several sites, rather than into only one site, and the results used to determine the best outplant sites for the second year's trimming. For all types of outplanting the full potential adult size of the coral when fully grown should be considered when selecting the specific spots for planting the corals, avoiding sea fans and slow growing massive corals, if possible giving a meter or more on all sides for unobstructed growth.

Outplanting techniques used most widely and effectively are:

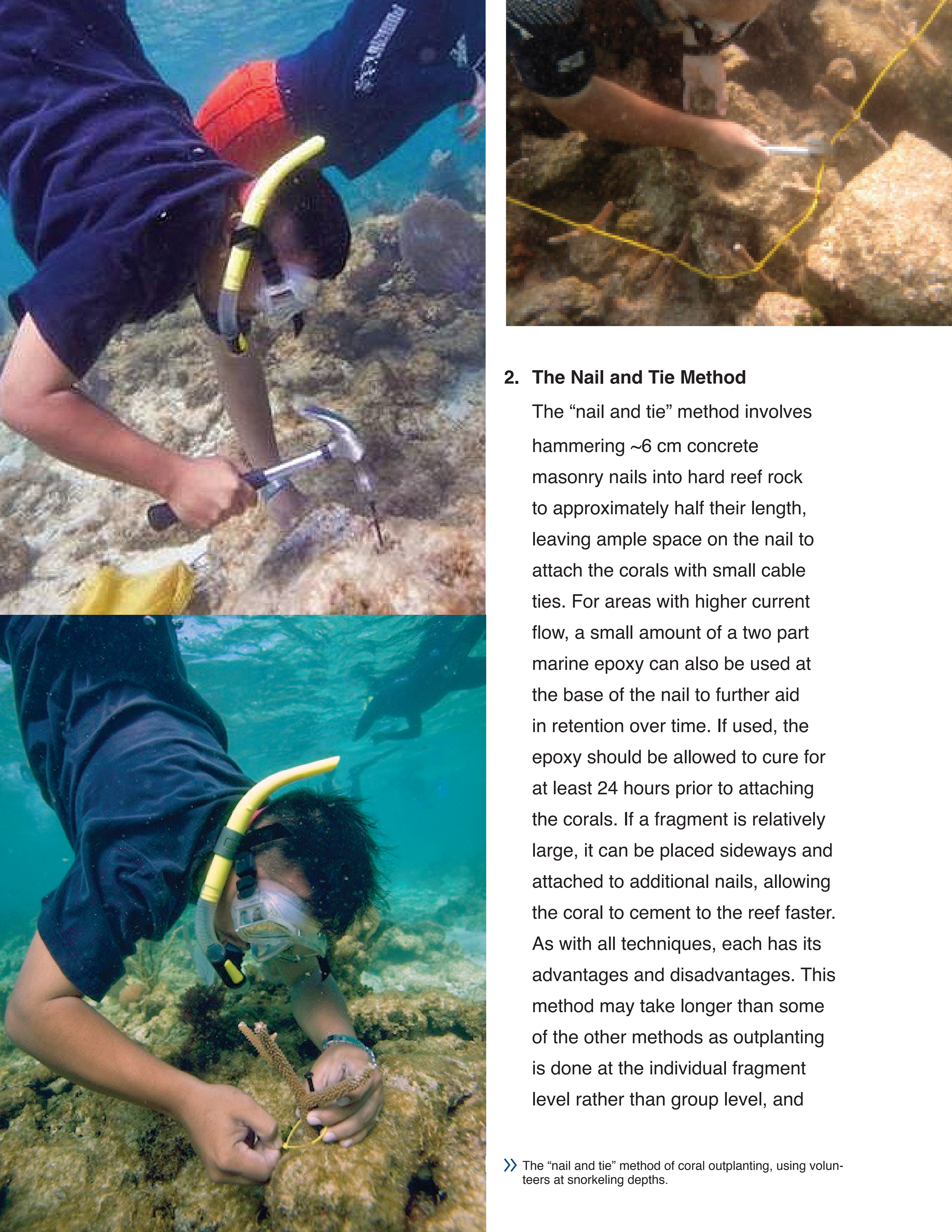
1. Plugging fragments into small holes and irregularities in dead reef rock where they self-attach to the reef.
2. Attaching coral fragments with cable ties to concrete nails hammered into the reef.
3. Attaching coral fragments to rope and nailing the rope to the reef at multiple points.
4. Cementing groups of small coral branches into balls of wet cement.
5. Cementing juvenile corals grown on cement discs to the reef. Each method can be customized to the reef location and all methods work well or less well dependent on site.

1. The Plug-in Method

The plug in method for outplanting consists of coral fragments being plugged into small holes in clean reef rock, avoiding living corals, seaweeds etc. Smaller fragments are wedged in an upright position, while larger >20 cm branches are best planted in a prone position, wedged into rough rocky substrate with multiple contact points, with the aim of speeding up attachment due to more contact points with the clean reef rock. Although this method is easy to carry-out, inexpensive and quickly done, the plug-in method does have a higher failure rate due to many of the fragments becoming dislodged before they can self-attach. A modification to this method that

a-b. Plugging in Staghorn coral fragments into clean, rough reef rock (a), and the same patch several months later, showing strong self-attachment of the corals (b).

results in higher survival involves the use of small balls of cement or epoxy after plugging in the fragments, securing the plugged-in branches by plastering a small cement ball at each coral base. Retention of fragments plugged without artificial attachment into reef rock varies greatly between sites, with high-energy sites not appropriate for simple plugging without additional cementation. However for sites of moderate energy or only occasional storms, high survival is possible, and for lower energy sites, artificial attachment is less necessary, especially for larger fragments and branches. A mortality rate of 50% at a moderately exposed site may sound too high, but it might be acceptable if thousands of coral branches are available each year from the nurseries and if manpower, funds, or time are too limited to do better. Surviving colonies will quickly grow to a biomass that will more than make up for the loss, and if left untrimmed mother colonies will begin dying.



2. The Nail and Tie Method

The “nail and tie” method involves hammering ~6 cm concrete masonry nails into hard reef rock to approximately half their length, leaving ample space on the nail to attach the corals with small cable ties. For areas with higher current flow, a small amount of a two part marine epoxy can also be used at the base of the nail to further aid in retention over time. If used, the epoxy should be allowed to cure for at least 24 hours prior to attaching the corals. If a fragment is relatively large, it can be placed sideways and attached to additional nails, allowing the coral to cement to the reef faster. As with all techniques, each has its advantages and disadvantages. This method may take longer than some of the other methods as outplanting is done at the individual fragment level rather than group level, and

›› The “nail and tie” method of coral outplanting, using volunteers at snorkeling depths.

›› Pegged rope method: attaching an outplanting rope with concrete nails (left), with results at one year (right). Small fragments have attached firmly to the dead reef rock and have grown into healthy colonies. Note the fresh predator damage on at least two colonies (bottom photo), which is to be expected in your sites. Predatory snails should be removed if possible.

especially if the nails are cemented with epoxy the day before. However, this method is very effective and allows the work to be done gradually and carefully, a few fragments at a time. Vertical surfaces can also be used, which some of the other methods do not allow for. Further, the nail method has been used successfully to outplant large to very large coral colonies (>50 cm), which can result in very high survival rates and increased reef complexity favored by many marine species.

3. **The "Pegged Rope" Method**

   The "pegged rope" method is one of the fastest methods of outplanting, and is ideal for dealing with large numbers of fragments. This method uses 0.6 cm (¼ inch) thick rope which is twisted so that the strands open up to allow for the insertion of a Staghorn coral fragment. The rope clamps down firmly on the fragment when the twisting is released. This is repeated every 10-20 cm along the rope until a necklace of coral fragments is created. The distance between each fragment is adjusted based on the fragment size, with small fragments attached only a few centimeters apart. The "pegged outplanting ropes" can be ten meters or more in length if the fragments are unbranched and are relatively small (10-15 cm each), which prevents tangling as they are handled. The completed outplanting ropes can be wound on empty plastic bottles to prevent tangling, immersed in buckets until deployment onto the reef. Be careful to ensure that the water in the buckets does not

›› Using the nail and tie method can allow large to very large colonies to be transplanted back to the reef. Notice that at least two points of attachment are used.

become too hot, shade the working area and/or change the water frequently. The risk of entanglement increases the longer the outplanting rope becomes, especially if branched fragments are included, so a 5 m line is recommended for branched fragments. Black-colored rope is recommended for this work if possible, not only because black tends to be more UV resistant, but because it blends in better with the environment, although even bright yellow rope becomes difficult to discern within a few months. When completed, the ropes are transported to the restoration site and planted using ~6 cm concrete masonry nails driven through the main strands of the rope. When pegging the rope to the reef, use at least one concrete nail per meter of rope, as the more stable the fragments are the more quickly they will self-attach to the reef. For reefs with a bit of complex structure, if a fragment is not in direct contact with the substrate, add a nail nearer to it, to pull the rope down. However, a few fragments suspended a few centimeters above the reef are fine, as they will grow and touch the reef within a few months. An improvement to the pegged rope method, if time and space allows, involves suspending the completed outplanting ropes from a nursery table for at least two weeks before pegging them onto the reef. This allows the coral fragments to heal any wounds before they are transplanted into the new environment

A primary advantage to using pegged outplanting ropes is that hundreds of fragments can be secured to the reef in a single dive with a fraction of the effort than would be required if using single fragment attachment to concrete nails. Another important advantage to the method is that most of the work takes place out of the water, using buckets on land or on a boat. Pegged ropes work well in both low energy and higher energy environments, as long as the ropes are pegged in securely. Yet another benefit is that the various coral genotypes can be regularly spaced, to encourage successful spawning when the corals grow to maturity. If the branches are spaced an equal distance on the rope, it is also possible to track each branch over time without excessive tagging, comparing genotype-based rates of growth, bleaching, or disease for example. The only deficiency of the method is that fragments further from the attached nails can sometimes be susceptible to movement and abrasion. While initially the ropes may look ugly and unnatural, they become mostly invisible within a year, once the corals begin to thrive and grow.


» The rosette outplanting method. Upper left: extruding cement balls from a plastic bag filled with viscous cement. Upper right: Fused Staghorn coral branches plugged into the cement ball. Bottom: the same outplant at one year; note the complete colony fusion and overgrowth onto the reef

4. **The "Cemented Rosette" Method**
   A cluster of small coral fragments, or a "rosette", is formed by plugging small coral fragments into ~10 cm balls of wet viscous cement that have been carefully placed onto small areas of reef rock cleaned with a wire brush beforehand. As the coral fragments grow they merge together and form a dense thicket of coral branches that behaves as a single larger colony and that tends to do better than smaller outplanted corals. This method normally works best for small 3-10 cm fragments, and these are simply pushed into the wet cement one fragment at a time until there is no more room for more. This forms a natural-looking rosette of coral branches, with 5-20 branches depending on the size of the cement ball. Fragments planted this way grow up and out in all directions and become a significant coral colony much faster than if they had been planted as a single fragment. When major trimming and outplanting is being done, lots of small fragments are created as a result, so a good strategy is to use the bigger >10 cm fragments for the pegged ropes or nail and cable tie technique, while the smaller <10 cm fragments are best used to create cemented rosettes. To make the cement, normal Portland cement


is mixed with water in a plastic bucket or basin with no sand or gravel used. It is important to get a loose clay-like consistency for the prepared cement, and so dry cement powder should be available to add back into the mix, should the mix be too thin. Only a few drops of water can make a big difference if the mix is too dry. Never use seawater for mixing cement, as the salt is a “crystal poison” that delays the hardening of the cement. The finished mix is put into plastic zip bags and taken down for immediate use, extruding the wet cement like toothpaste onto the prepared spots through a hole cut into the corner of the bag, or if the bag has a plastic zipper, by opening the bag an inch or so. The cement begins to set quickly, so it is important to use it within ten minutes or so, with one person applying cement and another cementing the corals. The working life of the wet cement can be extended by stirring it. Cementing of corals should be done on a calm day at slack tide, however if a small to moderate current or surge is present, small pebbles can be pressed one by one into the cement between the branches that are in place and this technique helps stabilize the coral fragments and speeds then curing time.

Top: Juvenile *Acropora palmata* corals growing on ~12 cm cement cookies at ten months, taken from the trays and awaiting transplantation. Overgrowth happens first forming a strong support followed by vertical blade formation and upright growth a few months later. Down: Cement cookies planted to the reef using balls of wet cement.

5. The "cement cookie" method

Coral colonies grown on cement discs or "cookies" should best be outplanted to the reef when they are about one year old. The method of planting uses 5 cm balls of wet viscous cement the consistency of bread dough, much like the cemented rosette method. At the time of outplanting, the farmed corals are cut from the nursery trays and brought into the restoration site where the specific spots for each are selected, with each spot cleaned using a wire brush and marked by placing the coral to be used directly on it. Cementing corals does not work well in strong surge or currents, so planting times should coincide with slack tides and calm winds. The cement cookie is gently pressed into the cement ball that is placed on horizontal areas of coral rock. No more than about five outplant colonies should be dealt with by a beginner at a time.

Outplanting strategies for reefs with abundant coral predators

A well-situated coral nursery typically produces several hundred to several thousand second-generation corals for replanting to the reef per year. However, it can be quite frustrating to plant hundreds of corals back to the reef only to see them killed off over time by predators. In some cases the corals thrive for months only to be discovered by predators and then quickly exterminated. Long-term monitoring and in many cases predator control is needed for the protection of such restored coral populations.

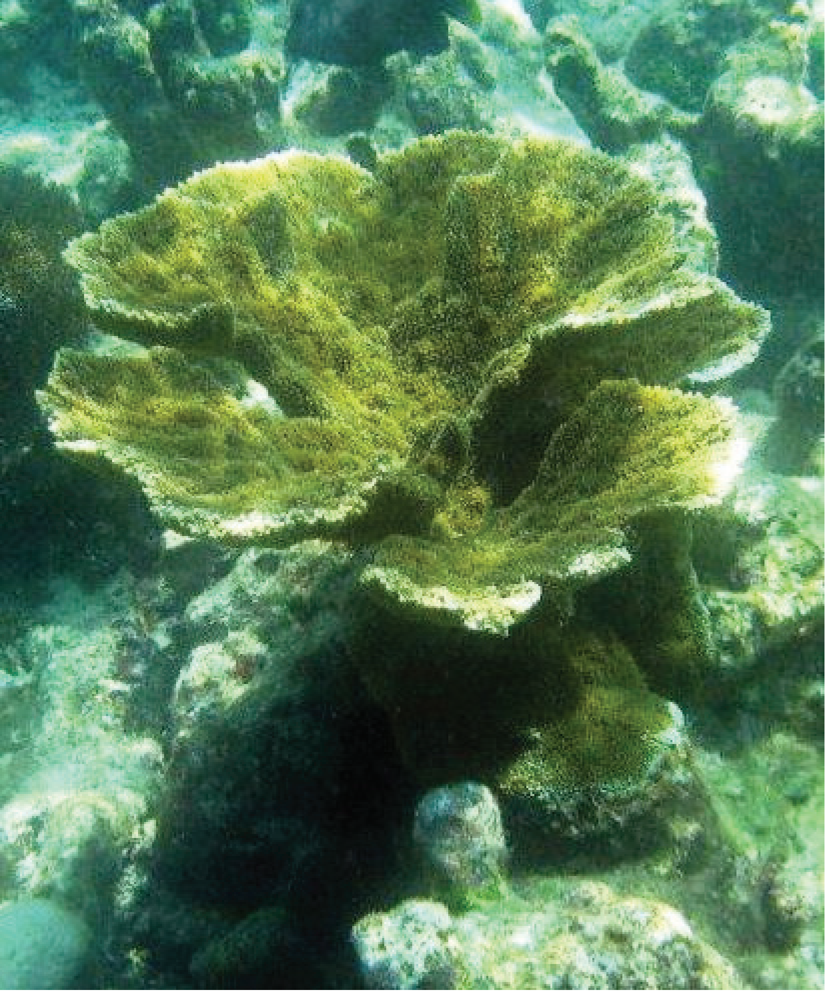
Second to stability and retention in the transplant site, the rate of predator attack has proven over and over to be vitally important to the success of the transplants. Many reefs are just too ecologically imbalanced to support an *Acropora* replanting program, as all outplants are either quickly or gradually eliminated by predators or overgrown by seaweeds. Careful site selection lowers coral transplant maintenance considerably, with less predator and seaweed removal required.

Each coral restoration site should where possible be entrusted to trained volunteers for once-monthly maintenance: predator removal, weeding, and monitoring. Massive numbers of planted corals cannot be cared for by a single person, so if possible trainees from tour guides, volunteers, fishermen, or newly certified Coral First Aid individuals, etc. can be recruited to adopt a patch of outplanted corals to care for and monitor. This "adopt a reef patch" approach seems to best way to go for effectively establishing healthy patches of the corals, as well as for encouraging volunteerism and a learning environment. Sites close to shore that do not require boat access, or situated where a volunteer visits regularly for work or recreation are more likely of succeeding.

In order to increase the chances of success of outplants on overfished reefs with unnaturally large numbers of coral predators (i.e. most of the reefs of the Caribbean), we need to be strategic by using all of the available information to our own advantage, such as: 1. Predatory

snails do not like to cross sand or seagrass, 2. Fireworms require a hiding place nearby, 3. Acroporid corals are the preferred food over all other corals for *Coraliophila* snails and *Hermodice* fireworms and they will leave other corals for the acroporids when these corals are introduced, 4. Stegastes damselfish also prefer acroporids over other corals for cultivating their algal gardens, 5. No-take MPA areas and less fished sites with lobsters and Spanish hogfish and other species tend to have lower predation rates on the corals, 6. Sites without living corals as an alternative food source do not host coral-eating snails, but fireworms can eat other things as well, and 7. Sites with healthy corals that have few predators and low predator damage indicate that predator abundance is low. Using this information, several strategies can be devised.

The priority outplanting sites would ideally be located within no-fishing MPAs where coral predators are kept in check. However even without the ideal natural balance, corals can be planted to locations where coral



›› Elkhorn “cookie” outplants at three months and at one year

predators have little shelter habitat, such as to flat low-relief areas. The predators in such locations would also find themselves exposed if they attempted to cross into the area from other areas of the reef in order to get to the outplanted corals. Sites with many holes and cavities and with larger cobbles and boulder-sized rubble should be avoided. However, where only a few pieces of larger rubble are present, the rubble can be removed, especially important for plates of dead Elkhorn coral, which provide excellent fireworm shelter habitat.

Another strategy seeks out reefs with surviving Staghorn or Elkhorn coral populations that are not under severe predator attack, and to work to increase the size and genetic diversity of these existing populations by outplanting nursery-raised corals.

Yet another strategy would seek out small patch reefs of less than 100 m^2 or so, surrounded by sand or sea grass, and then focusing efforts on establishing *Acropora* coral populations to these isolated reefs, where the amount of planted corals can easily overwhelm the few predators present, greatly lowering the predation rates. The predatory snails will not cross the sand and the worms are reluctant to do so as well. Efforts at removal of coral predators may then be able to virtually eliminate the predators from the isolated patch reef. A variation on this strategy is to locate the restoration patches on narrow reef front spurs separated by sand channels; however, some predators will still be able to move in along the ridge, but from only two directions versus all directions.

Selecting low predator outplanting sites

A best strategy for nurseries with hundreds of corals to outplant every year would be to use the branches to test multiple promising sites, monitoring the isolated outplants frequently, and to keep data on predation rates for one full year and then select the sites with the lowest predation rates for more extensive outplanting work.

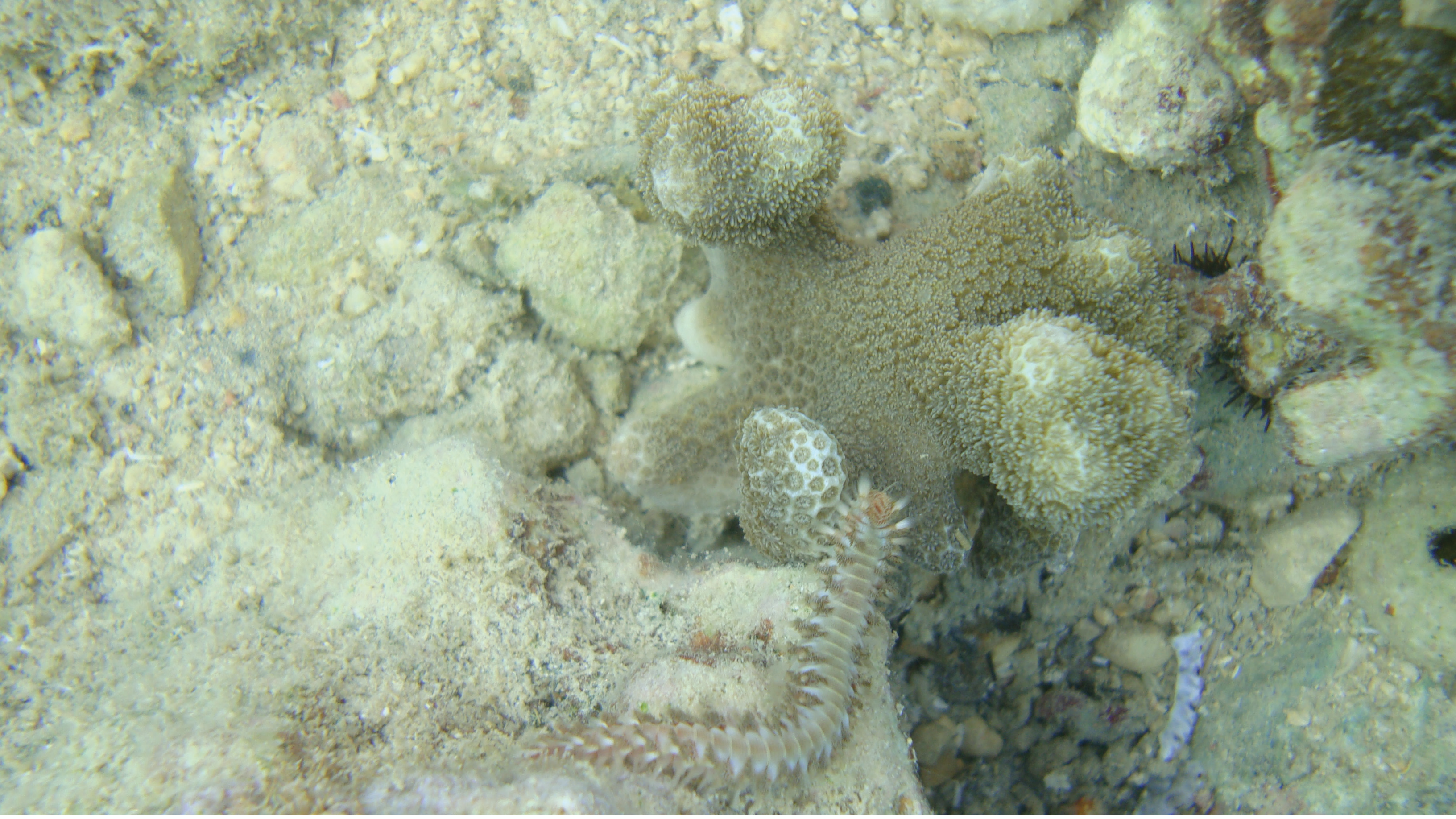
When the results are in, a fine-scale microhabitat analysis can also be conducted, helping determine the fine-scale patterns responsible for either success or failure, and helping with future site selection decisions. The basic question is whether or not there are things that can be identified that are in common between the most successful sites or between most poor sites, and using that information for future site selection. Things that might be important would be coral cover and coral species make up, shelter characteristics such as the abundance of cobble-sized rubble or reef crevasses, and factors that might hinder predator movement (sand of gravel patches, fleshy algae, etc). Fish and crustacean abundance and species makeup might also be relevant. This strategy requires time and resources, but is the best strategy for the long-term restoration of a reef system, and such information could have much wider relevance to restoration of *Acropora* corals throughout the region. If resources do not allow for this scientific approach, as long as sites are tested before outplanting begins and as long as the outplanted corals continue to have low mortality over time, understanding exactly why a particular site is successful is not as important as confirming that the corals in fact do well at the site.

While more data is needed, based on this author's experience in multiple sites in several countries, corals planted to isolated rocky patches relatively free of overgrowing seaweeds tend to do well, as do corals planted to small-sized rubble beds. Cleaning seaweed-choked patches of reef for outplanting coral fragments is not recommended, as this will result in a patch of corals that will require weeding throughout the year, as the remaining seaweeds tend to re-grow from small fragments left behind. It is much better to select reef patches that are already fairly clean of seaweeds, with sea urchins or fish doing most of the work for the coral gardener.

Areas with many lettuce corals (*Agaricia*) and brain corals (*Diploria*) are best avoided, as these species have been found to recruit and harbor juvenile coral-killing snails, sometimes in rather large numbers. Patches without corals will not harbor the snails, but if corals are present nearby, snails should be hunted and removed from within several meters of the transplants. The snails often lurk under the bottom lip of brain corals and in crevices between the lobes of star corals and lettuce corals, so we should pay special attention to checking known hiding places. The presence of *Diadema* and other sea urchins at the restoration site can help improve site cleanliness and fragment success, but an overabundance of sea urchins at a site can result in corals being grazed and wounded by the urchins.

The natural controls of *Coraliophila* snails, *Hermodice* fireworms, *Stegastes* damselfish, and four-eyed *Chaetodon* butterfly fish are not well known, but are thought to be groupers for damselfish and butterfly fish. The predators of snails are thought to be lobsters, hogfish, and perhaps octopus. The predators of fireworms are thought to be lobsters and crabs, although certain fish may also be important controls. If no-take areas are well established, they help maintain a lower level of coral predators. No-take MPAs with abundant fish and crustaceans would likely be the ideal situation for outplanting corals, as indicated by the very high level of success within Laughing Bird Caye National Marine Park in Belize, as compared to mostly unmanaged reefs in DR.

The ultimate long-term success of *Acropora* restoration depends on identifying these sorts of successful outplanting sites where the corals at some point require no further care and continue to persist and thrive on their own. It has become clear that the establishment of effective no-take areas is a vitally important step in the long-term restoration of the Caribbean corals.



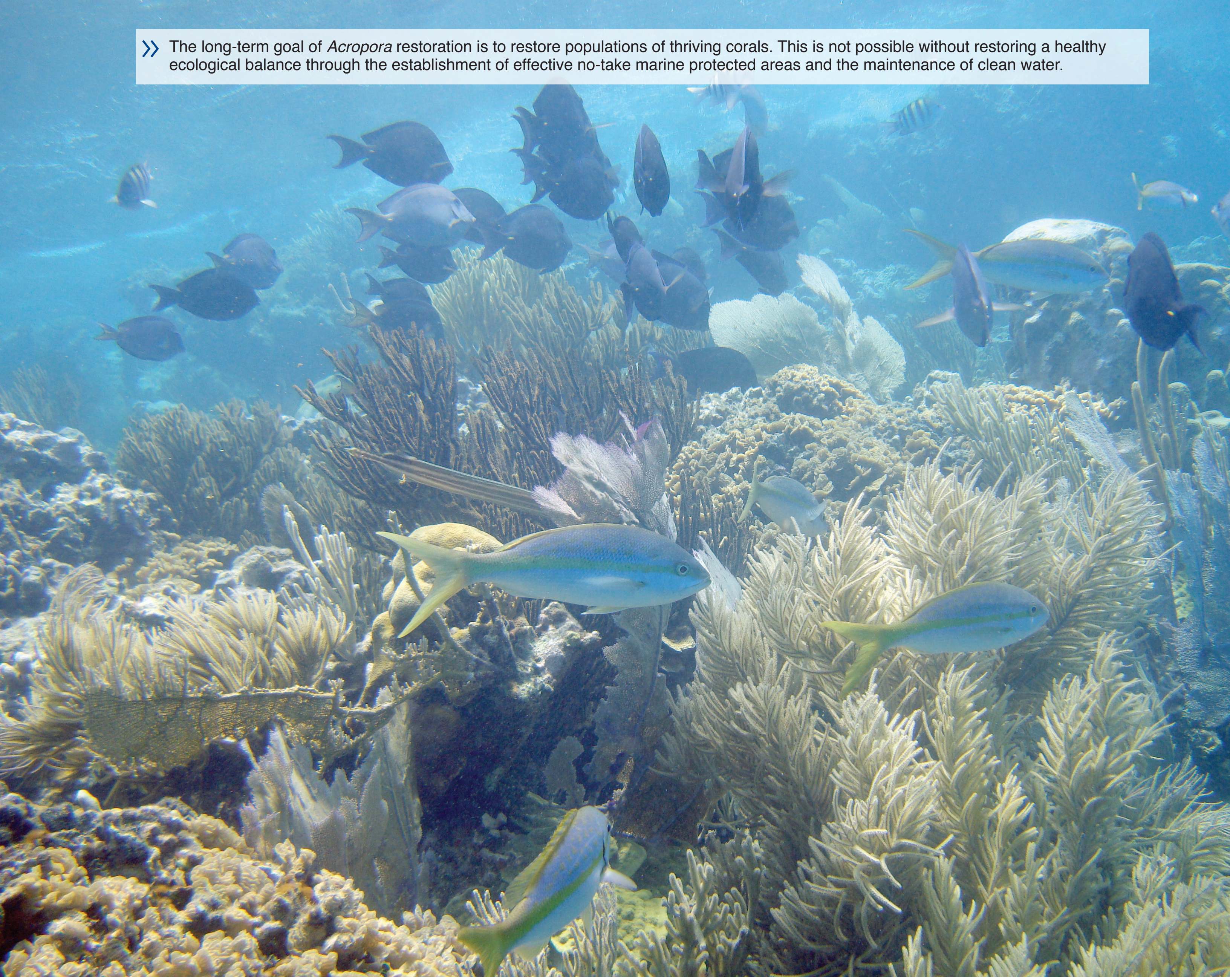
Innovations in Coral Predator Control

Fireworms tend to hide in the reef during the day, to emerge at dusk, however for reefs with few predators of the fireworms, they can often be lured out with bait anytime night or day. A new innovation in fireworm control is being used at Punta Cana, DR, with good effects in their nursery and outplants site; even for small fireworms. Traps are constructed from pieces of 2.5 cm diameter PVC pipe cut into 15 cm lengths. Both ends of the PVC sections are capped with PVC caps and one of the ends is perforated by drill with a 0.6 cm hole to allow fireworms to enter. The traps are weighed down using lead fishing weights or small amounts of epoxy cement. The traps are baited with a small piece of squid, which is very attractive to the worms. If fresh fireworm damage is visible, traps can yield results in as little as 5-10 minutes. The traps are excellent for volunteer snorkelers to deploy, re-collected every half hour

Fireworm trap developed at Punta Cana, Dominican Republic. Baited with squid, they have proven irresistible to fireworms, being effective in less than an hour at all times of day or night.

or so and uncapped on board to empty the worms into a bucket for disposal on land. Now that an effective control measure has been established for fireworms, modifications can be made to the method. For very heavy infestations of fireworms, it might be possible to make larger traps out of 0.6 cm wire mesh or metal cans punched with holes to catch dozens of worms at once. Another potential predator control measure for coral nurseries and restoration sites that is already being implemented by the Puntacana Ecological Foundation is to construct lobster sheds or *casitas*, and to actively attract or to even stock juvenile lobsters into the site. Designs and plans for these structures can be found online or obtained by contacting the Puntacana Ecological Foundation. However a functional no-take area may first be required in order for this strategy to work effectively. A no-take area in itself can provide protection from overabundant predators, and nurseries and restoration sites planted with endangered corals should provide additional justification and incentive for the establishment of no-take areas around them. How can these species be restored until the factors leading to their demise are addressed?

» The long-term goal of *Acropora* restoration is to restore populations of thriving corals. This is not possible without restoring a healthy ecological balance through the establishment of effective no-take marine protected areas and the maintenance of clean water.



Incorporating Climate Change Adaptation into *Acropora* Restoration Work

Climate change is widely recognized as the greatest long-term threat to the survival of coral reefs globally, and coral reefs are widely recognized as the most vulnerable of the planet's ecosystems to the impacts of climate change.

Recent work carried out in Belize by Lisa Carne and the author has focused on *Acropora* restoration as a climate change adaptation measure for coral reefs. We have made the case that climate change has been partly responsible for the demise of *Acropora* corals in the Caribbean because bleaching, disease, and hurricane frequency and intensity are all related to warmer temperatures. The restoration of these coral species should therefore qualify as a climate change adaptation measure for coral reefs, particularly if we focus on identifying and selecting thermally tolerant strains of corals for propagation in the nurseries.

Thus far, the only climate change adaptation option widely recognized for coral reefs is to increase coral reef health, through the management of non-climate related stresses such as pollution, sedimentation, and overfishing. *Acropora* restoration should now be considered an additional climate change adaptation option. When applying coral restoration as a climate change adaptation strategy, the work should involve seeking out and propagating bleaching resistant corals, with the goal of outplanting their second-generation progeny to reefs where thermal stress has decimated coral cover.

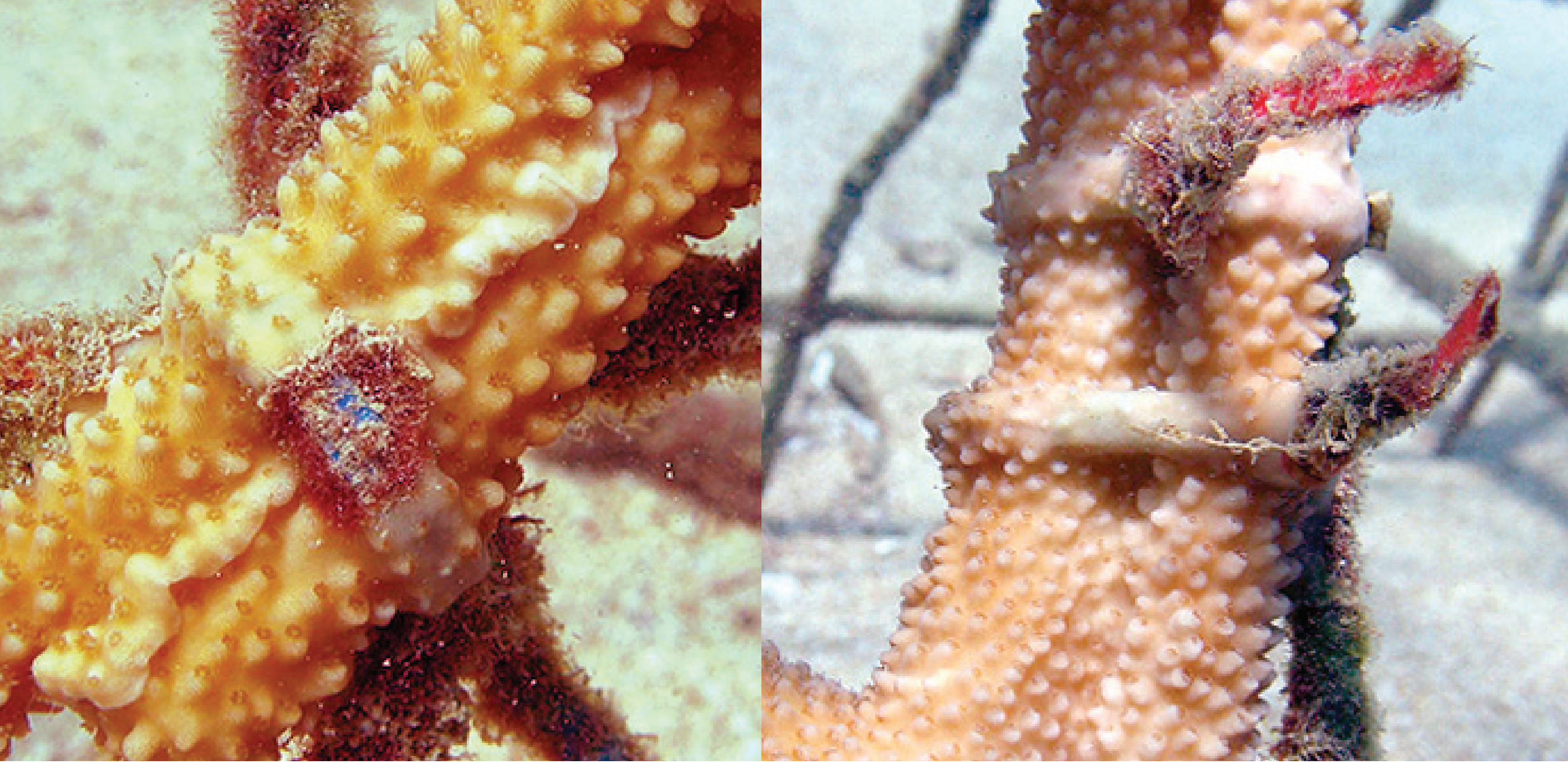
While it may seem difficult to identify thermally tolerant corals, many of the corals that have survived are thermally tolerant because the widespread bleaching has already occurred and the least tolerant corals are for the most part no longer in the population. The long-term objective of climate change adaptation for coral reefs should be the restoration of genetically diverse populations of the surviving more thermally tolerant corals to reefs where the species were formerly abundant.

A snapshot of a coral reef in the community of Punta Rusia, northern Dominican Republic.

Genetic Diversity and Caribbean *Acropora* Restoration

Incorporating a high level of genetic diversity into restoration efforts is vital if we are to maintain the species over the long term. Recent work by scientists on coral genetic diversity (*Shearer et al.* 2009) has indicated that ten randomly collected parent genotypes will preserve >50% of the genetic diversity within a coral species. However, the study indicates that it requires 35 genotypes to obtain >90% of the original genetic diversity. Even in Belize where the Staghorn corals are supposedly doing better than in the Eastern Caribbean, researchers were only able to collect twenty *A. cervicornis* genotypes over a four-year period from an extensive area of reef 40x40 km. While this represents over half of the original genetic diversity in the species, it looks like some of the original genetic diversity has been lost. At Punta Cana DR, 12 unique genotypes are being cultivated, and at the national level (as of Jan 2014), 21-24 Staghorn coral genotypes have been confirmed through genetic analysis and incorporated in to the various established coral nurseries over the past four years. Four additional populations have recently been found and are being tested and more populations are being discovered every year as people begin to look more closely. These efforts will continue to find and incorporate new coral genotypes into the nurseries, especially with more people looking as a result of capacity building, environmental awareness, and published educational materials undertaken by the Puntacana Ecological Foundation. On the encouraging side, the increased usage of GPS is helping map and locate new populations. Unfortunately for many reefs in the Caribbean a great amount of the diversity within the species may already be lost. Certainly a lot less than 50% of the genetic diversity remains at the (20x20 km) site level virtually everywhere. However, at the national level there is hope for finding, securing, propagating, and restoring much of the lost genetic diversity through exchanges of coral genotypes between sites, with the goal of outplanting propagated and diverse corals back to reefs where they will more effectively spawn and recombine their genetics.

The TNC manual on *Acropora* restoration expresses concern for "inbreeding depression" which is a loss of fitness when very closely related individuals breed together. They also mention the problem of "outbreeding depression" which is when distantly related individuals that have developed important adaptations to specific environmental conditions are bred together. While these concepts may best apply to endangered mammal and bird species, there is some evidence for genetic adaptation of Staghorn corals to specific environments.
Experimental work (Bowden-Kerby 2001) demonstrates that there are staghorn coral genotypes that are well adapted to both higher and lower energy conditions. There are two currently known distinct morphologies within *A. cervicornis*; a robust, thick-branched genotype and a more slender genotype, with no corals found thus far that are a combination of both characteristics.



Simple contact test to determine whether two colonies are genetically the same. Note the suture line that forms between different genetic individuals (left), plus a complete fusion of the branches between genetically identical branches (right).

When the two types are grown together in the nurseries they maintain their distinctness over many years, a clear indication that these differences are genetically based. The robust type is less common. Fragments attach quickly and overgrow whatever they touch. The coral invests energy into maintaining the basal part of the colony, with the basal portion growing thicker and thicker year by year, becoming as thick as 5-10 cm in diameter, and with coral colonies commonly growing up to 2 meters tall! The more common thinner-branched morphology invests less energy into maintaining the lower parts of the colony and fragments attach less quickly and vigorously. The thin-branched type reaches a maximum branch thickness and then stops growing in circumference, with the basal areas often dying. The colonies never get more than about a meter tall. The robust type appears to be ideally adapted to higher energy areas, while the thinner type appears to be adapted to calmer waters and damselfish infestation, investing less energy in the lower portions of the colony that are likely to be killed by damselfish. As the nurseries grown in scope and incorporate more and more coral genotypes, it might be important to segregate these two morphologies based on the environment of the restoration sites and in our work to restore natural reproduction.

Even without expensive and highly technical genetic testing, it is possible to determine if a population of staghorn corals is composed of one or more than one genotype by conducting a tissue contact test. This test simply ties two coral branches together from two different suspected genotypes and then observing whether or not the branches fuse completely, or if the branches build a tissue and skeletal wall between them. For a larger patch of Staghorn coral this would involve taking two of the most distantly separated branches, plus branches from any morphologically distinct colonies (color, branching angle, branch thickness, etc), and then tying them together on a frame and observing for a couple of months. The results are seen in the photographs on the previous page. Fortunately, *A. palmata* (Elkhorn coral) appears to be doing much better from a genetic diversity standpoint, as sexual reproduction still functions to a certain degree. Two distinct genetic types have been identified, one with more slender branches that dominates the Eastern Caribbean and the other with more plate-like branches that dominates the Western Caribbean. However, a mixture of both can be found throughout its range. Incorporation of Elkhorn corals into the nurseries and restoration sites is quite important from the standpoint of heading off future declines in the wild, which is already happening.

Acropora prolifera, (Fused Staghorn coral) should be considered just as important for conservation and nursery work as the other two species, as it is very likely to contain the genes of extinct staghorn coral lineages. Because the hybrid species is reproductively viable, it can back-cross with Staghorn corals and reintroduce the missing genes back into the coral population. Therefore Fused Staghorn corals should not be overlooked in restoration programs. The tightly branched growth form makes Fused Staghorn corals particularly well adapted to high light environments and to fending off predators of all types.

Acropora species continue to decline on most Caribbean reefs rapidly where under severe predation pressure and less rapidly where predation is less of a problem. Wherever *Acropora* corals continue to decline is of the utmost importance to locate and bring samples of the remnant populations into nursery collections in order to prevent further loss of the genetic structure of the species. We should also more fully realize that the remaining genotypes have already survived numerous disease epidemics, bleaching episodes, and various other stresses, and that these survivors represent the strongest of the strong climate change-adapted corals that may hopefully be more capable of withstanding future epidemics and bleaching episodes. To allow these genetic treasures to decline in the face of predators and other sorts of destruction now would be a horrible mistake. It is vital that a coordinated strategy somehow be developed and implemented in each country, bringing together all users of the ocean (fishermen, divers, surfers, resorts, etc.), to actively record new *Acropora* populations when they are found so that they can be incorporated into existing and new nurseries. It is important to note that the Puntacana Ecological Foundation, in collaboration with its project partners, is sponsoring the coral nursery work and they have also initiated programs such as hosting marine conservation and climate change adaptation conferences and developing specialized certifications such as the Coral First Aid PADI Distinctive Specialty course now being offered by the dive industry. Moreover, its scientific staff continues to develop new techniques and improve current methodologies to increase nursery efficiency and reduce mortality. Further, the Puntacana Ecological Foundation is now acting as the country's training center for *Acropora* restoration and assisting young professionals in the development of their careers through highly competitive internship opportunities. More information on internship opportunities can be obtained by contacting the project coordinator or the Puntacana Ecological Foundation.

One of the best measures of success in *Acropora* coral restoration will be the reestablishment of self-maintaining populations of diverse coral genotypes that are bleaching and disease resistant and that in turn spawn to restore sexual reproduction. These populations can be established through the outplanting of nursery reared *Acropora* corals as well as cross transplanting between mono-genetic populations on ecologically balanced reefs with low coral predator abundance.

Breeding Populations of *Acropora* and their Conservation

Over the past decade, researchers and monitoring teams throughout the Caribbean and Atlantic have located a few large "mega-populations" of staghorn corals. Mega-populations have been found off the Broward County, Florida, Roatan, Honduras, and off Punta Rusia. Recently a new large population has been identified in the Samana Bay area of the Dominican Republic by the project coordinator and local fishermen, which now awaits parametric measurements and baseline monitoring. It is likely that other large populations still exist in the region, with possible mega-populations reported for St. Thomas Virgin Islands, Belize, and Cuba. Unfortunately there are no other such reports of large populations for the entire region.

The mega-population in DR was studied in 2009 by a University of Miami team. Based on personal observations, the population at Punta Rusia is declining rapidly and is in danger of collapsing, with significant loss over the past few years due to predation and associated disease. In many cases, Staghorn corals are now only found as small isolated colonies. However, these populations are declining with each bleaching episode, with well-recorded populations wiped out at Discovery Bay, Jamaica and La Parguera, Puerto Rico during the 2005 bleaching event.

The few remaining larger populations of Staghorn corals appear to be the result of some sort of special local conditions, perhaps with less disease or lower water temperature during bleaching events. Such special conditions might be related to localize upwelling of cooler waters and possibly also to a lack of coral predators, which are the primary vectors for coral disease. While the few larger populations give us hope for the future, unless global warming is limited, bleaching will eventually affect these corals. It is hoped that by selecting the most resilient corals and propagating them in the nurseries, populations of these resilient corals can be created and restored to reefs where the species was formerly abundant, and that can survive the predicted and repeated onslaught of bleaching.

Photography Sources:
Victor Galvan, M.Sc. - Project Coordinator
Austin Bowden-Kerby, Ph.D. – Manual Author
Lisa Carne, M.Sc. Candidate

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