

A diver in a blue wetsuit and black tank is swimming in clear blue water. In the foreground, there are several white vertical pillars, some of which have coral growing on them. The diver is positioned in the upper half of the frame, slightly to the right.

Best Practices for

Propagation and Population Enhancement

CARIBBEAN *Acropora*

RESTORATION GUIDE



An underwater photograph of coral reefs, showing various types of coral structures in shades of brown, orange, and white against a blue-green water background. The title 'AUTHORS & AFFILIATIONS' is overlaid in large white serif font.

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Glossary of Terms

Genetic diversity: the number of variants (“alleles”) of each gene that are present in the population and how these variants are distributed among individuals.

Genotypic diversity: the number of genetically distinct individuals in a population.

Propagation: the process of cutting/pruning/fragmenting a large coral into smaller pieces called “fragments.”

Colony: a coral unit with the typical *Acropora* morphology; with an attachment to the bottom and a complex multi-branch canopy.

Fragment: a section of a coral colony branch used for nursery propagation and outplanting.

Puck: a cement disk, cone or pyramid used to secure fragments to propagation platforms during the nursery stage or to the reef substrate for outplanting activities.

Pedestal: any structure (e.g., cement or PVC) used to raise coral fragments from a nursery module to limit the impacts of sedimentation, burial and competition from other organisms.

Corals of Opportunity: loose, living coral fragments that are apparently free of disease, algae or boring sponge infestation but have broken off from a larger colony and remain loose on the substrate in such a way that these fragments have a reduced chance of stabilizing naturally and low survivorship probability. These fragments can be rescued from the reef and can provide valuable material for establishing new colonies within a nursery.

Population enhancement: addition or outplanting of nursery-grown coral fragments and colonies to wild stocks.

Resilient: coral colonies or populations that withstand disturbance without undergoing significant mortality and/or that recover quickly from a disturbance.

Clone: exact genetic copy of parent colony.

Preface

The significant decline of *Acropora* corals throughout the Caribbean is well documented, prompting the development of *Acropora* propagation and restoration efforts to enhance the natural recovery of this threatened keystone component of coral reefs. The purpose of this guide is to share the collective knowledge of a community of scientists and restoration practitioners who have been working both independently and collaboratively to restore populations of *Acropora* corals throughout the Caribbean. By sharing lessons learned from years of experience of in situ *Acropora* propagation and coral population enhancement in Florida and the Caribbean, we want to increase the success of others' efforts and accelerate conservation and restoration at a regional scale. The field of coral restoration is evolving rapidly, and the ideas and best practices described here should be considered guidelines to be adapted for individual propagation or restoration projects based on local environments and project-specific goals. This guide provides best current practices for nursery and outplanting design and methodology. We use case studies to illustrate how these practices have been implemented in various projects throughout the Caribbean. While most of the information included in this guide is based on experience working with *A. cervicornis*, additional information and considerations have been included for *A. palmata*. It is our hope that the information presented will provide a useful foundation to support the work of other scientists, practitioners, managers and local communities who are working to enhance *Acropora* populations.

CHAPTER ONE

INTRODUCTION: The Case for *Acropora* Propagation and Population Enhancement

The Importance and Decline of Coral Reefs and *Acropora*

Coral reefs offer coastal protection, are centers of high biodiversity and provide essential habitat to a wide range of recreational and commercially important species of fish and invertebrates. Although they make up only a small percentage (<1%) of the marine environment (Veron et al. 2009), coral reefs are home to one-third of all known marine species (Reaka-Kudla 1997, 2001). The coastlines of 100 countries are protected by coral reefs (Moberg and Folke 1999), shielding them from coastal erosion and protecting mangrove and lagoon habitats that support many life stages of important marine species (Johnson and Marshall 2007). These fragile ecosystems also support fishery resources that provide an important food source for humans. In addition to these physical resources provided by coral reefs, their intrinsic beauty draws and supports billions of dollars in tourism each year.

The coral genus *Acropora* is a major reef-building taxon found in Florida and throughout the Greater Caribbean (Jackson 1992). As recently as the 1980s, these fast-growing corals formed dense, three-dimensional thickets in intermediate (5–20 m) water depths, contributing significantly to reef growth, island formation, coastal protection and fisheries habitat (Shinn 1966; Bruckner 2002). The open structural framework of these densely populated *Acropora* thickets provides essential habitat for fishes, turtles, lobsters, crabs, echinoids and gastropods (Bruckner 2002).

A significant global decline in living coral coverage has occurred in recent decades in response to many anthropogenic and environmental disturbances such as coastal development, sedimentation, invasive species, storms, high sea temperatures, disease, pollution, overfishing and eutrophication (Hughes et al. 2003; Grimsditch and Salm 2006). Experts predict that one-third of all reef-building corals are at risk of extinction (Carpenter et al. 2008); fully 75% of reefs are highly threatened by the compounding effects of local stressors and factors associated with global climate change (e.g., ocean acidification, sea level rise, thermal stress, disease, cyclones) (Hoegh-Guldberg 1999; Buddemeier et al. 2004; Baker et al. 2008; Veron et al. 2009; Burke et al. 2011).

A large portion of the recorded decline in coral abundance in the Caribbean region is actually due to the dramatic loss of *Acropora*. Acroporid coral populations have declined 80–90% throughout the Caribbean and western Atlantic since the late 1980s (Bruckner 2002), and both *A. cervicornis* (staghorn coral) and *A. palmata* (elkhorn coral) were listed as threatened species under the U.S. Endangered Species Act in May 2006. In 2008, both species were listed as critically endangered on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species.

The most severe threats to *Acropora* corals are diseases, predation, temperature-induced bleaching and physical damage from tropical storms. In addition to these main threats, eutrophication, sedimentation, anchor damage and vessel groundings also cause significant impacts locally.

Historic *A. cervicornis* patch reefHealthy *A. cervicornis* patch reef

The decline of staghorn and elkhorn corals, as well as other dominant species, has changed many coral reefs from spectacular three-dimensional living structures to flat stretches of seascape with much lower structural complexity. The loss of these species results in a major loss of reef function and structure. A reef that has lost its living cover and its structural complexity no longer provides the ecological, economic and societal services that people expect from coral reefs.

Nurseries as a Tool for *Acropora* Propagation and Population Enhancement

Various coral restoration techniques have been tested throughout the Caribbean and worldwide. The “coral gardening” methodology, in which coral colonies or fragments are grown in underwater nurseries and then transplanted back onto degraded reefs, has been applied successfully at various scales (Rinkevich 2000; Shafir et al. 2006; Amar and Rinkevich 2007). In Florida and the Caribbean, coral nurseries have been designed to maximize *Acropora* survivorship and productivity while minimizing negative impacts on existing wild populations. The use of nurseries for *Acropora* propagation is increasing rapidly, and this approach is now being used in many countries in the Caribbean (Figure 1. Young-Lahiff 2010). By utilizing the natural process of asexual reproduction through fragmentation, nurseries provide a sustainable source of *Acropora* corals to be used for population enhancement (Figure 2. From 1 to 1000 Corals).

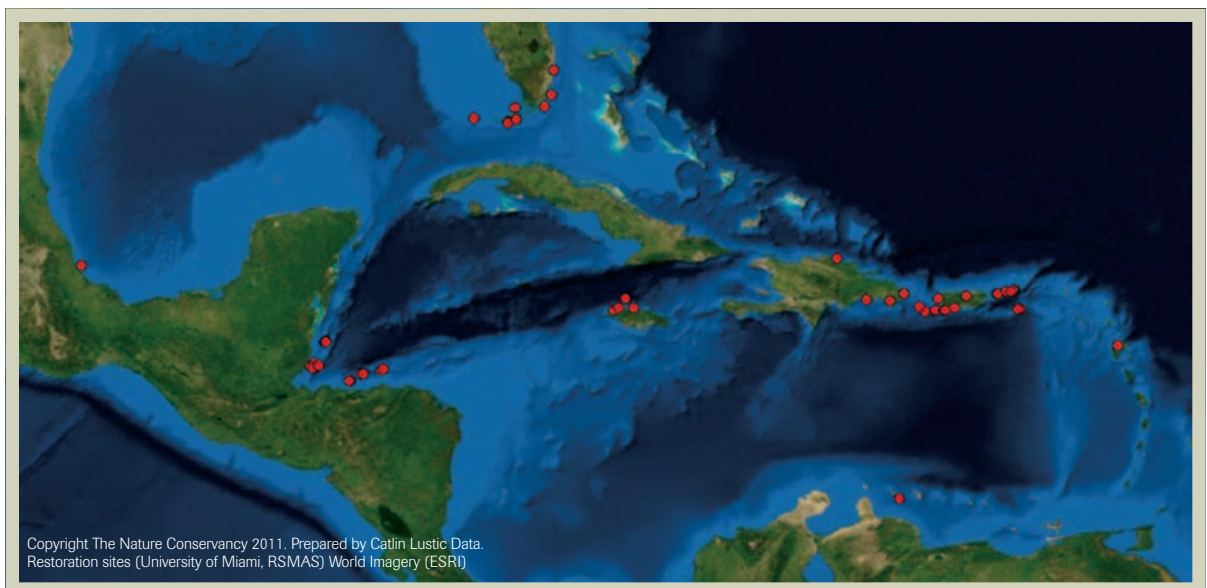


Figure 1: Map of *Acropora* propagation and population enhancement projects in the Caribbean. Information from these projects was collected by C. Young-Lahiff, University of Miami.

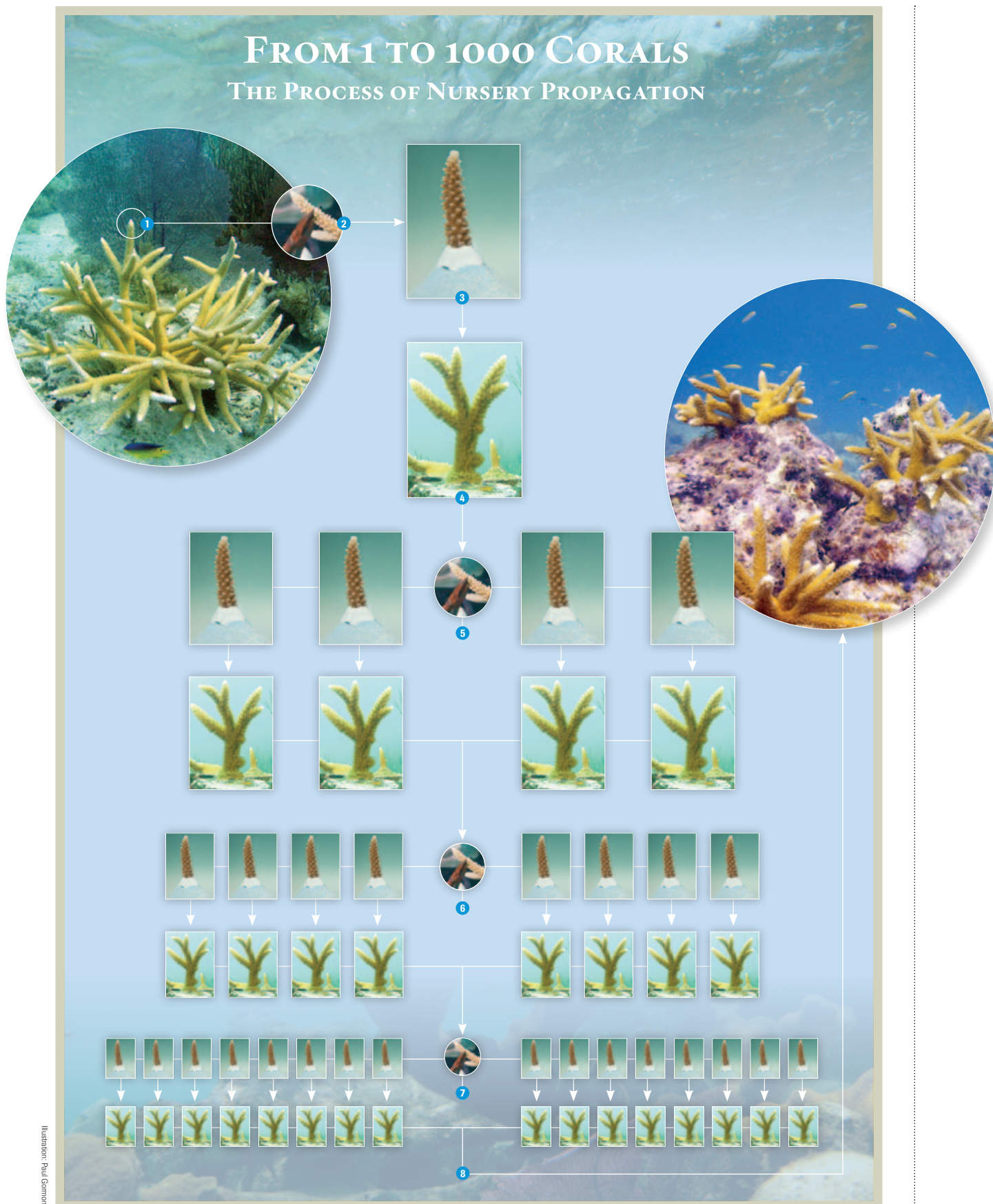


Figure 2: The process of fragmentation to get from one clipping to many outplanted corals. Healthy wild colonies (1) are clipped/fragmented (2) then these coral fragments are grown in an underwater nursery (3). Once the corals grow large enough (4) they are clipped again (5,6,7) to produce more corals. These corals are then outplanted (8) to existing reef areas.

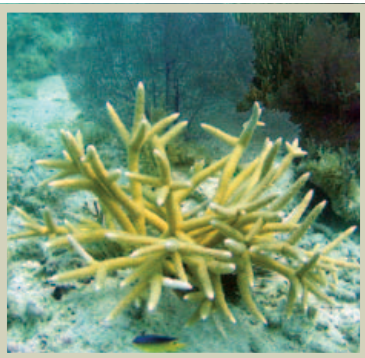
CHAPTER TWO

How *Acropora* Corals Work

Taxonomy

The genus *Acropora* is in the family Acroporidae and the order Scleractinia (true stony corals). Although there are several hundred species of *Acropora* throughout the Indo-Pacific, *A. palmata* (elkhorn coral) and *A. cervicornis* (staghorn coral) are the only two species described within the Caribbean. They are fast-growing, branching species that tend to be particularly vulnerable to threats such as temperature extremes, storms and disease. *Acropora prolifera* is a hybrid of these two species, and its reproductive capabilities are unknown.

Photo: Meghan Johnson



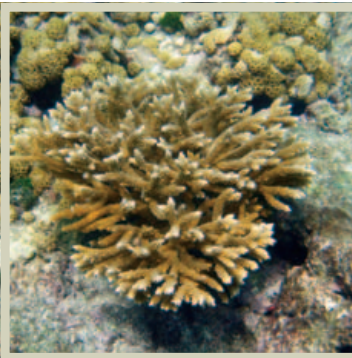
Acropora cervicornis (staghorn coral)

Photo: Kerri Anon-Lewis



Acropora palmata (elkhorn coral)

Photo: Meghan Johnson



Acropora prolifera

BOX 1: WHAT DO ACROPORA NEED?

- ✦ Corals require hard substrates with optimal conditions for growth and survival (low sedimentation and decreased competition from other species).
- ✦ Corals require relatively clear, well-circulated water.
- ✦ *Acropora* spp. thrive in a fairly narrow temperature range of ~20–30° C. Outside that range, they are more prone to bleaching and disease impacts.
- ✦ *A. palmata* is generally restricted to shallow waters < 5 m, whereas *A. cervicornis* has a larger depth range and can flourish to at least 20m in depth.

Reproduction Woes

Acropora corals rely heavily upon asexual reproduction via fragmentation, and although sexual reproduction does occur, they have shown very little success of sexual recruitment, likely due to the low abundance of surviving parent colonies as well as declining water quality and reduced substrate availability. While asexual reproduction through fragmentation can result in expansion of local populations, this reproductive mode yields new colonies that are genetically identical to the parent (i.e., clones). Overreliance on asexual fragmentation limits the number of genetically distinct colonies, both at local scales and throughout the species range.

Reduced genotypic diversity suggests that there may not be enough genetically distinct parents to ensure successful sexual reproduction. Because corals like *Acropora* have physiological barriers to prevent the crossing of gametes (sperm and eggs) from the same parent, multiple distinct parent genotypes are required within a spawning area for successful gamete fertilization. Thus, unless multiple genetically distinct individuals are in proximity to each other to reproduce, genotypic diversity may not increase over time. By increasing population numbers and the number of distinct parent genotypes at local scales through propagation and transplantation of nursery grown fragments, sexual reproduction and recruitment are expected to have higher success rates ultimately aiding in the natural recovery of the species.

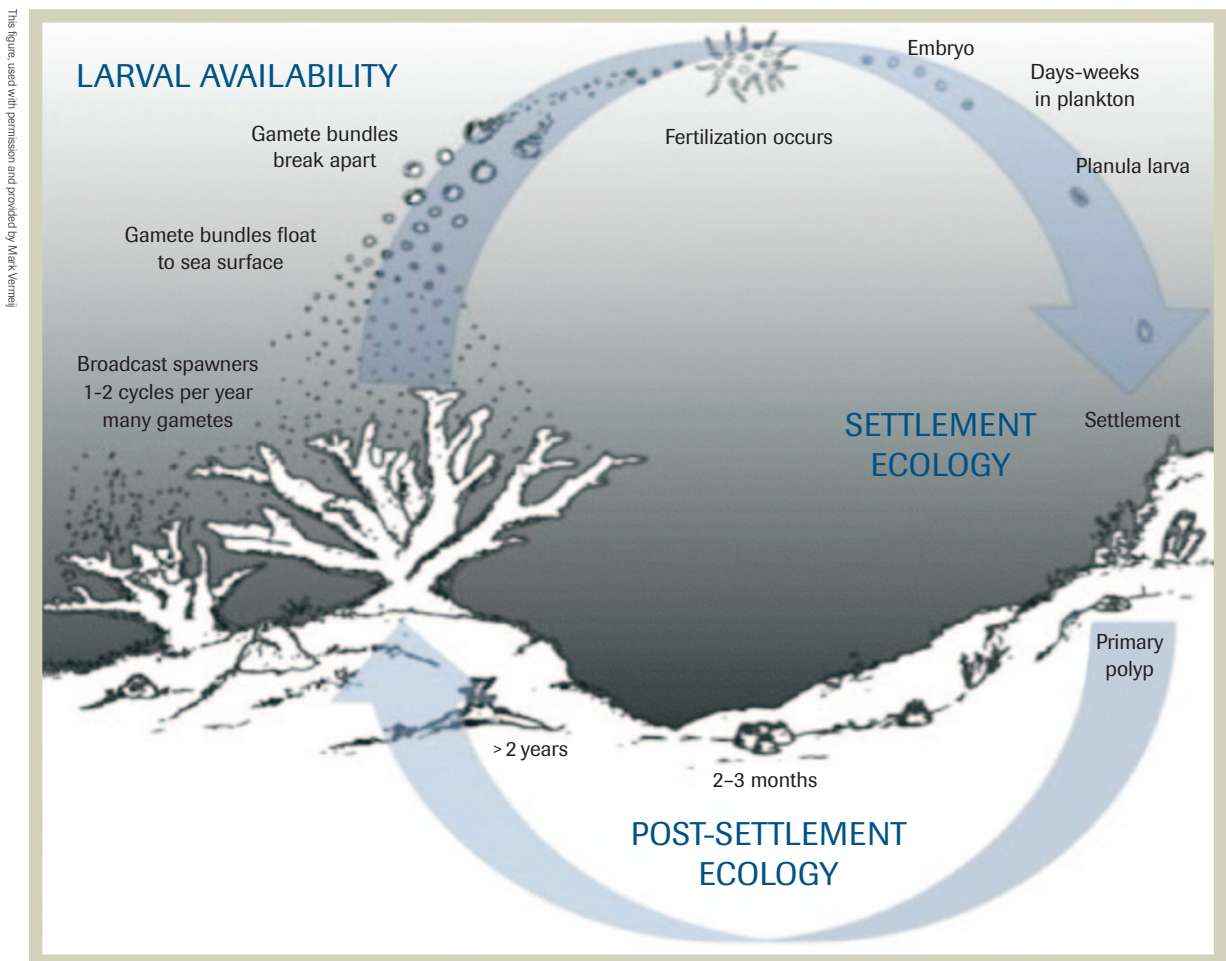


Figure 1: Life cycle of *Acropora* corals. *Acropora* corals reproduce both sexually and asexually through fragmentation (not shown in this figure). Fragmentation is a simpler mode of reproduction with fewer vulnerable stages and an important strategy for many *Acropora* corals. The techniques described within this guide are based on the natural capacity for fragmentation in these species.

Restoration Genetics

Consideration of genetic factors is essential because long-term success of restoration efforts may be influenced by genetic and genotypic diversity of restored coral populations. The field of restoration genetics uses molecular methods to study these types of diversity and aims to restore the genetic diversity of species.

WHY IS RESTORATION GENETICS IMPORTANT TO CORAL RESTORATION WORK?

Breeding and outplanting efforts can have detrimental consequences on the long-term survival of the species in two ways:

1. Inbreeding depression is a reduction in fitness due to mating of relatives. Data on inbreeding of corals does not exist but it is a concern during late life stages in captive and restored populations of plants (Husband and Schemske 1996; Frankham 2005).
2. Outbreeding depression can result from mating between distantly related individuals or mating between individuals that are strongly adapted to local conditions (ecotypes).

BOX 2: GENETIC CONSIDERATIONS

How can restoration genetics be incorporated into your project?

Considerations for collections:

- ✦ Initial collections for the purpose of creating a captive breeding population should capture as much of the local genetic diversity of the species as feasible.
- ✦ *Best case:* Determine genotypes for every coral brought into the nursery and keep accurate records during fragmentation so that the genotype of every coral is known.
- ✦ *Second best:* Determine the genotypes of a subset of corals in the nursery and make sure corals are collected from a wide range of sites and habitat types.

Considerations for outplanting:

- ✦ The risk of outbreeding depression may be reduced by avoiding the movement of individuals or mixing of gametes from distant populations.
- ✦ Genotypic diversity should be maximized within an outplant site to increase chances of successful cross-fertilization and decrease chances of inbreeding depression.

CHAPTER THREE

Coral Gardening Methodology

There is no “one size fits all” approach that applies to all locations, regions and environmental conditions. Therefore, propagation and restoration activities should be adaptive and flexible enough to account for the inherent variability in the response of corals to their local environment. Nursery and outplanting designs should account for variation in factors such as water conditions (e.g., depth, wave energy, turbidity), habitat suitability, competition and likelihood of human impacts.

The following guidelines are provided as first steps towards the selection, design and construction of potentially successful nurseries based on the collective experience of practitioners in this field.

Nursery Setup

Goal: Select appropriate nursery site, choose site-appropriate nursery design and construct durable, cost-efficient propagation platforms that will provide adequate attachment and growth environments for nursery corals.

SITE SELECTION

The first step in nursery design is to choose an appropriate site. There are several factors to consider in site selection to promote nursery success.

- **Existing Wild Populations:** Local knowledge of the distribution and status of remaining populations should guide site selection. Habitats or reef areas that harbor healthy *Acropora* populations likely provide adequate environmental conditions for the growth of corals in nearby nurseries.
- **Depth:** Nurseries should be constructed in depths where the species is typically found. Successful *Acropora* nurseries have been established in depths of 2–10 m. Deeper locations may protect against storm damage and boating impacts, but can result in reduced growth. The logistical complication of diving to deeper depths may also make such locations impractical. Shallower locations may be more susceptible to sedimentation, thermal fluctuations and UV stress. Most importantly, the depths of donor colonies, nursery sites and outplant sites should be similar.
- **Water Motion:** Ideal nursery locations are those that provide moderate to low water movement without causing excessive physical damage to the platforms and corals. Be cognizant of changes in seasonal weather patterns that may dramatically affect site conditions at different times of the year.

- **Bottom Type:** Suitable bottom type will depend on the type of nursery being installed (see “Nursery Design” section for recommendations). Fixed nurseries can be deployed on most bottom types (e.g., sand, small rubble, hardbottom) but may require different anchoring methods (e.g., rebar, cement). Floating nurseries are typically deployed on sandy substrates, but can be deployed on other bottom types as well. Both rubble and sediment movement in high-energy habitats should be considered a potential source of damage to corals.
- **Size of the Area:** The area chosen for nursery deployment should allow adequate room for expansion to accommodate additional colonies over time.
- **Adjacent Habitat:** Local conditions should be considered when evaluating an appropriate proximity to reef. Areas on or adjacent to healthy reefs with adequate trophic structures can provide both a source of herbivores and a source of coral predators. The status of coral populations in adjacent reefs can be used as proxies for nursery growth conditions.
- **Competitors:** Coral competitors like algae and sponges can rapidly colonize nursery platforms and overgrow the nursery corals, even at significant distances away from natural reef habitats. Where these organisms are prevalent, periodic cleaning will be needed to minimize damage. Predator removal will be necessary in areas where worm and snail populations are a source of mortality to nursery corals.
- **Human Activities/Impacts:** Nurseries should be deployed in areas with minimal human activities to minimize coral and platform damage. Areas where human activities are limited, such as Marine Protected Areas (MPAs), are ideal locations for nurseries. MPAs also provide an improved trophic structure with an increased abundance of herbivores such as fish and urchins that may keep algae under control, as well as abundant predators that may control the abundance of corallivorous snails and worms.
- **Accessibility:** The ease of access to a nursery site is a key consideration, especially when frequent or particularly time-intensive maintenance is required. Deploying shallow nurseries close to home base minimizes fuel, boat and diving costs.
- **Number of Nurseries:** A logistical trade-off exists between the number of nursery sites that can be established and the attention and maintenance that can be afforded to each site. Having multiple nurseries in different environments will minimize the likelihood that a given disturbance, such as a disease outbreak or storm, will destroy the entire nursery stock. Nurseries can also serve as genetic repositories during extreme temperature events (e.g., cold water events) if the wild colonies that were collected from do not survive these disturbances in other areas of the reef (Schopmeyer et al. 2011).
- **Permitting:** It is important that necessary permits are obtained prior to the start of any restoration activity. Practitioners should work in collaboration with local management agencies to select sites that are appropriate for the propagation of corals and avoid conflicts with other uses and activities.

BOX 3: A CAUTIONARY APPROACH: MAKING THE CASE FOR PILOT/TEST DEPLOYMENTS

Even the most experienced reef ecologists may not be able to fully predict the potential of a location as a good nursery site. Even when all physical and biological factors described here have been considered, there may be some unexpected or unmeasured factor that may jeopardize the long-term survivorship and growth of corals at the selected sites. Thus, it is highly advisable, if the resources are available, to deploy a test nursery platform and fragments at the selected nursery sites to evaluate nursery conditions. While it may be impractical to deploy a large number of these test nursery platforms and corals for long periods of time, the biggest potential problems (too much water motion, algae or predator problems, etc.) can often be detected within a few months after deployment. These pilot/test deployments can be extremely useful and provide the information needed to make the decisions that will maximize the likelihood of successful nursery deployment in the long run.

Moreover, if explicit guidelines are incorporated into the management plan (e.g., no more than 25% mortality of newly established fragments within the first two months), these test deployments can be used to formally test whether the nursery sites meet the project requirements.

DESIGN

There are many nursery designs that have been used successfully throughout the Caribbean, including both floating and fixed designs. Each design provides different benefits based on each location's specific environmental conditions and project goals. This section will describe each design and the pros and cons of each type.

Nursery Types

- 1) **Floating or Mid-Water Nursery** – typically involves lines or frames attached to the bottom with anchors and suspended off the sea floor utilizing subsurface floats. (See Case Studies 1, 2, 5 and 6.)
- 2) **Fixed-to-the-Bottom Nursery**
 - **Block Nursery** – typically involves the deployment of cinder blocks or cement slabs that are anchored to the bottom. This type of nursery is used extensively in Florida. (See Case Studies 2 and 3.)
 - **Frame Nursery** – typically involves different types of metal or plastic mesh frames or PVC structures that are attached to the bottom with anchors. This type of nursery, as well as a hybrid platform that combines a rebar frame with suspended lines strung across the frame, is used extensively throughout the Caribbean. (See Case Studies 1 and 4.)

Floating/Mid-Water Nursery Design – Example: Line Nursery



Materials: A line nursery can be broken down into four main components: a tethering or anchoring device, a flotation device, horizontal lines and coral attachment devices.

❶ Anchoring Device

- In sandy or grassy habitats, nursery lines can be attached to the bottom using duckbill anchors, rebar, anchoring screws or even a heavy weight. On hardbottom habitats, an eyebolt cemented to the bottom will work as a tether. For rubble bottoms, a heavy weight is appropriate.

❷ Flotation Device

- Flotation devices such as Styrofoam floats or plastic bottles are readily available in most areas and work well. The floats can be tied to the tethering device by sturdy, durable line, such as nylon cord, polypropylene rope or monofilament fishing line.
- The tethered floats are typically spaced at 3–6 m intervals and connected to each other with multiple, parallel horizontal lines from which coral colonies are suspended.
- The depth at which subsurface buoys are located will be determined by the depth of the nursery, diameter of the nursery line, and permit requirements that take into consideration the local boat traffic.

❸ Horizontal Lines

- The horizontal lines connecting vertical tethered lines can be made from monofilament or nylon cord, and should be vertically spaced at least 0.75 m apart.

❹ Coral Attachment Device

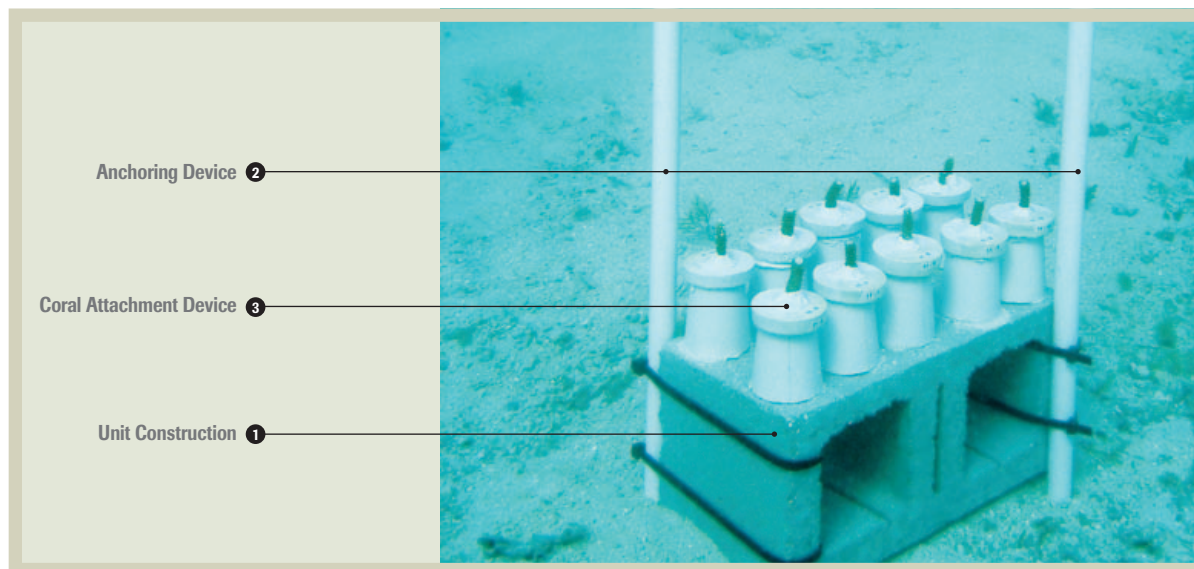
- Corals can be attached to the horizontal lines using vinyl-coated wires, cable ties or monofilament fishing line. Horizontal spacing between corals can be as close as 5 cm, but more space should be provided for larger corals.

- Each coral can be tagged with small plastic or metal tags imprinted with an identifying number. The tags can be incorporated into the wire that is between the coral colony and the horizontal wire.

Important Considerations

- Line nurseries may provide the best method for rapid growth and branching of small fragments. Most line nursery efforts have shown significantly increased growth in fragments suspended off the bottom, with branching occurring in all directions and with greater frequency.
- However, it also appears that faster growth may result in changes to the density of the coral skeleton, resulting in fragments that are more fragile and prone to breakage. As a result, corals grown using the line methods will likely still need to be secured to a puck before outplanting to increase skeletal density and facilitate stabilization.
- Line nurseries may not be the preferred method in areas with intense boating and fishing activities that may result in line entanglement and breakage.

Fixed-to-the-Bottom Nursery Design – Example: Block Nursery



Materials: A block nursery consists of a modular unit such as a concrete block or concrete slab that allows for simple deployment, replication, and attachment to the bottom. This type of nursery design works well in sandy bottoms, but can also be deployed in hardbottom areas.

① Unit Construction

- Nursery blocks, typically cement blocks or cement slabs, serve as a base to which cement or PVC pedestals are attached with epoxy. These pedestals are used to keep the corals away from the bottom and minimize sediment burial and smothering.
- The pucks can be attached to the pedestals using epoxy and provide an attachment point for coral fragments. Pucks can be removed from the pedestals and used for outplanting.

② Anchoring Device

- Blocks can be attached to the bottom using a rebar section.
- When using rebar or metal rods as anchors, putting a PVC sleeve over the anchor allows for easier cleaning and provides a convenient handhold for divers, thus minimizing physical damage during maintenance.

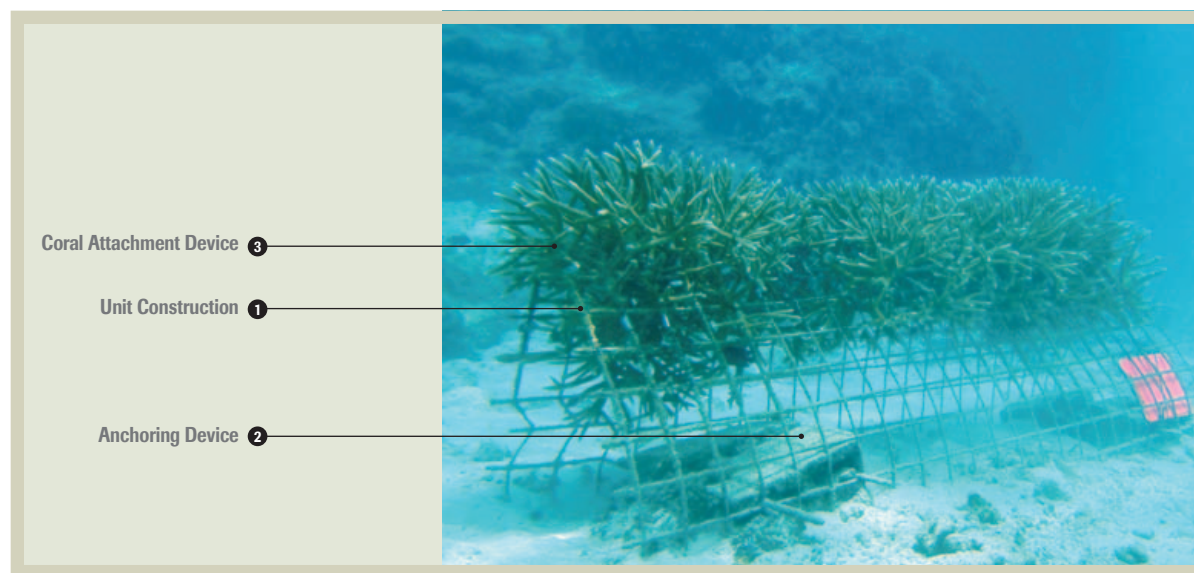
③ Coral Attachment Device

- Corals can be attached to a cement disk, cone or pyramid using plastic ties, wire or two-part epoxy that is easily mixed underwater.

Important Considerations

- Fragment orientation on pucks can influence growth and branching patterns. Fragments mounted horizontally have two growing ends and can grow faster than fragments mounted vertically that have a single growing end. In areas with limited sedimentation and algal overgrowth, horizontal fragments can provide higher production. However, horizontal fragments initially have a larger portion of their live tissue in contact with sediments and macroalgae and may experience higher initial mortality. Therefore, it is recommended that a combination of both vertical and horizontal orientations be used initially to determine the best method based on specific nursery conditions.
- When deploying blocks, leave sufficient space between units to allow for diver movement during nursery maintenance activities to minimize damage (e.g., from fin contact).
- Block nurseries need to be deployed in areas that are large enough to allow for nursery expansion as second and third generations of corals are propagated from the original fragments.
- Spacing and orientation of blocks should be designed to allow for easy separation and identification of first-generation fragments and subsequent second- and third-generation fragments.
- The number and spacing of corals mounted on each block should take into consideration the maximum size that corals will be allowed to grow between fragmentation events.
- The design and spacing of the coral blocks and pedestals should allow for cleaning activities (e.g., algae removal) to minimize damage to corals during these activities.
- Materials used should be easily moved or deployed by divers, and should be entirely removable if the site needs to be relocated.
- The location of blocks in relation to nearby reef habitats should be considered to reduce potential impacts from recreational or commercial fishing gear and boating activities.
- Blocks attached to the bottom are good platforms to use in areas with heavy boating and fishing activities due to their low profile.

Fixed-to-the-Bottom Nursery Design – Example: A-Frame Nursery



Materials: Frames can be built from a number of materials, including PVC, rebar and metal or plastic mesh. While the actual shape and size of the frames can vary, the basic design consists of a rigid or semi-rigid structure that keeps fragments away from the substrate and provides ample space for fragment attachment and growth.

① Unit Construction

- Frames can be built in a variety of shapes, including A-frames, circles, or domes.
- Metal frames (rebar, wire mesh) can be coated with epoxy or fiberglass resin prior to deployment to limit algal growth, delay frame degradation and to improve cleaning efficiency.

② Anchoring Device

- The frames can be attached to the substrate using a variety of anchoring methods, including rebar, cement weights or concrete blocks.

③ Coral Attachment

- Corals can be attached to the frames using wire or plastic ties.

Important Considerations

- The mesh size of the frames can play a role in fragment survivorship. While a smaller mesh size can provide more attachment points for fragments, smaller holes tend to be colonized by damselfish more frequently. Territorial damselfishes or “farmer fish” can kill coral polyps, thus providing substrate for algal attachment and growth, and can significantly disturb nursery corals. Bigger mesh size provides less attachment substrate but also provides less refuge for damselfishes and allows for better access for predatory fish. In general, a mesh size of 10–15 cm provides a good compromise.
- The initial spacing of fragments on the frames should allow for individual fragment tracking and enough space for fragment growth. Overcrowding of fragments within frames will lead to fusion of fragments and reduced growth, and will make the removal of coral competitors more difficult.

- As with block nurseries, frames should be spaced within the nursery site to enable diver access for maintenance (cleaning, fragment monitoring) while still conserving space for future nursery expansion.
- If colonies will be fragmented sequentially, it is advisable to leave empty space within frames to accommodate new fragments.
- A nursery platform that combines aspects of frame and line nurseries is the line-frame nursery that has been used in the Dominican Republic, Honduras and Belize by Dr. Bowden-Kerby and colleagues. This platform consists of a rebar frame attached to the substrate (PVC can also be used). The height of these frames can be 1–1.5 m from the substrate. Ropes or lines are tied across the top surface of the frame, providing horizontal attachment for fragments.

BOX 4: COMPARISON OF NURSERY TYPES

There are multiple parameters to consider when choosing a nursery design. Below is a comparison of three types of nurseries.

Comparison of Nursery Types	Line	Block	Frame
Use of vertical space	Better	None	None
Predation	Lower Rates	Higher Rates	Higher Rates
Water flow and circulation	Better	Reduced	Reduced
Can be raised or lowered in the water column to respond to weather events	Yes	No	No
Can be relocated prior to storms	Yes	Yes (but more difficult)	Yes (but more difficult)
Cheap and easy to set up (all materials are readily available)	Yes	Yes	Yes
Maintenance	Low	High	High
Growth rates	Higher	Lower	Lower
Hazard to marine life	Higher Potential	Low Potential	Low Potential
Suitable for shallow areas	No	Yes	Yes
Can be deployed in sand or rubble	Yes	Yes	Yes
Long-lasting	No	Yes	Yes
Ease of anchoring	Yes	Yes	Yes
Provides immediate habitat for fish and invertebrates	No	Yes	Yes
Macroalgae accumulation	No	Yes	Yes

Coral Collections

Goal: Minimize impact to donor colonies and maximize survivorship of fragments and nursery corals.

SITE SELECTION

Once a suitable site for the coral nursery has been selected and materials have been deployed, corals will need to be collected to serve as nursery stock. The first step in coral collections is to choose collection sites. There are several factors to consider when choosing these sites.

- **Existing Wild Populations:** As in nursery selection, knowledge of natural healthy populations of *Acropora* coral within a reasonable proximity to the selected nursery site will be critical in guiding collection efforts. The overall size and health of potential donor colonies are important and affect both the health of subsequent fragments collected from the donor and the potential impacts to the donor. Minimizing impacts and pressure on colonies present at any particular site is an important part of the goal stated at the beginning of this section.
- **Size of the Area:** The geographic area from which wild donor colonies are harvested should be large enough to ensure genetic diversity between collected corals while minimizing transport time between the collection site and the nursery.
- **Proximity to Nursery Site:** If monitoring of wild donor colonies is required, close proximity to the nursery site may be an important logistical and financial consideration. Also, minimizing transport times helps to reduce stress and likelihood of damage to newly collected fragments.
- **Number of Sites:** Collecting from a variety of areas or habitats may further increase the likelihood of genetic variation within the nursery as well as the ability of nursery-reared corals to adapt to different habitats and environmental conditions.
- **Permitting:** Local permitting and marine zoning in certain areas may also guide the selection of collection sites.

Methodology

- **Tools:** Small branch clippings from wild donor colonies can be collected using a variety of cutting tools, including stainless steel surgical bonecutters, diagonal electrical wire cutters, needlenose pliers, etc. For colonies with thicker branches, PVC cutters have also proven effective. Taking care to cut the branch cleanly and evenly ensures optimal survival of the fragment as well as rapid healing and recovery of the donor colony. See Figure 3.
- **Transport:** Widely varied methods have been tested and used for transporting coral fragments, and the selection of one particular method should depend on the conditions at each nursery site. Fragments taken from donor colonies should be transported to the nursery site as quickly as possible to minimize stress and placed in the shade to maintain temperature and

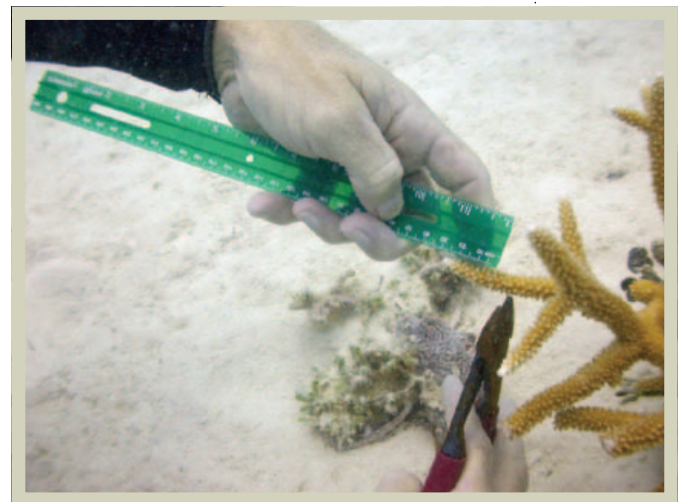


Figure 3: Collecting fragments of *A. cervicornis*

Photo: Ken Nedimyer

reduce exposure to sunlight while transporting. For short time periods (<2–4 hours), transporting coral fragments in seawater is preferred. Once collected, coral fragments are typically placed in a small watertight bag or container, providing an easy and secure method for transporting as well as allowing for separation of fragments if multiple donor colonies are sampled at the same collection site.

- **Donor Colony Tracking:** To allow for donor (possible genetic) tracking, each fragment should be given a unique identifier that will allow it to be tracked back to its parent colony once at the nursery. This will allow for accurate tracking during subsequent creation of second- and third-generation fragments, as well as during outplanting efforts, to ensure potential genetic diversity at a given restoration site. If monitoring the donor colony over time, tracking fragments back to their parent colony may also provide insight into overall health and survivorship of fragments in the nursery (for methods, see Nursery Operations section).
- **Monitoring of Donor Colonies:** If the monitoring of parent or donor colonies is required or desired, then the following information should be collected at the time of collection and at subsequent monitoring events:
 - 1) colony size (maximum diameter)
 - 2) number of branches
 - 3) percent live tissue (nearest 10%)

In addition, colony condition (coloration, presence of disease, lesions, damselfish lawns) and abundance of predators (snails, fireworms) should be noted. This information can be used to evaluate the impacts of fragment collections and the stability of wild *Acropora* colonies over time.

Important Considerations

The following are important considerations that should guide coral collections.

- **Temperature:** Water temperatures at the time of collection may be a significant factor in the initial survival of the nursery colonies. For example, in the Florida Keys, collections from donor colonies, as well as fragmentation of nursery corals, are usually limited to the cooler months (October-May) to prevent compounding fragmentation stress with temperature stress.
- **Size:** In general, fragments from the donor colony branch tips as small as 3 cm in length will provide viable tissue for successful propagation of nursery colonies; however, fragments with multiple branches or that include more of the thicker base branch material show more rapid growth and branching when introduced to a nursery setting.
- **Corals of Opportunity:** Corals of opportunity can provide valuable material for establishing new nursery colonies. Additionally, harvesting fragments from corals in areas which may be lost due to permitted coastal construction activities or as a result of other human impacts such as vessel groundings can provide viable tissue for nursery propagation. In some cases it may even be possible to collect corals that are attached to artificial substrates such as sea walls, docks, unpermitted artificial reef sites, etc. In many cases permitting or other regulations will allow greater numbers and sizes of these “corals of opportunity” to be collected than would be allowed to be harvested from wild donor colonies, since they may have a high risk of damage or mortality. When using corals of opportunity, it is important to ensure that the collected corals are free of disease, algal overgrowth and boring sponges to minimize the chance of introducing these

to the nursery or eventual outplanting sites. If the coral of opportunity is large and has unwanted or dead areas, those portions can often be clipped away until the coral skeleton is completely clean or lacks boring sponges or other organisms. See Figure 4.

- **At-Risk Corals:** At-risk corals are live coral branch tips that are growing on the end of dead branches. This is a common occurrence for both acroporid species and presents an opportunity to collect corals from a known, standing colony without damaging any live tissue.



Photo: Ken Nedelger

Figure 4: Corals of opportunity, *A. palmata* fragments

Nursery Operations

Goal: Maintain coral health and maximize growth and survivorship of nursery-reared corals.

Methodology

- **Maintenance:** Basic maintenance should be conducted on a regular basis, using simple hand-held tools, in order to allow for establishment by newly mounted fragments to substrates (line, pucks, frames, etc.), thus maximizing fragment growth and health. The exact amount of effort, in both frequency and time required on-site, will vary greatly depending on the nursery design, the location, number of corals in-nursery and the length of time that materials have been deployed *in situ*. Because maintenance activities do not require extensive knowledge of coral biology, training volunteers and recreational divers to assist with maintenance provides a valuable resource.

Typical maintenance activities may include the following:

- removal of algae and other fouling organisms (tunicates, sponges, hydroids, etc.) by hand or with small brushes (See Figure 5).
- active propagation and fragmentation of corals to increase nursery stock available for outplanting.
- removal of coral predators such as snails, fireworms and damselfish.
- stabilization of broken or damaged fragments using epoxy or other mechanisms.
- repairing of damaged modules, line materials, attachment materials and/or anchoring materials.
- isolation or removal or treatment of diseased corals (as described in Box 4).
- construction or installation of materials for expansion and propagation of nursery corals.

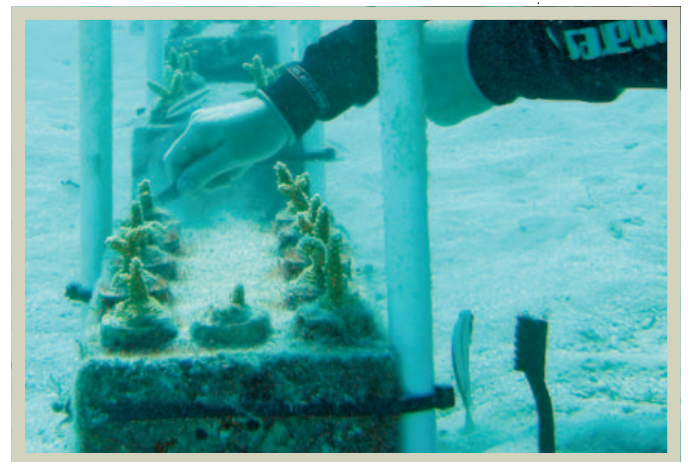


Photo: Kermit Arroyo-Lewis

Figure 5: Cleaning coral disks in the nursery

BOX 5: DISEASE MANAGEMENT OPTIONS

Densely clustered corals raised in a nursery may be more vulnerable to disease outbreaks, and preventative management to reduce the risk of an outbreak may be required. A nursery design that provides appropriate space between corals minimizes the incidence and spread of disease. Outbreaks of disease can be actively managed in several ways if resources allow, and using one or a combination of these procedures can minimize the spread of this disease.

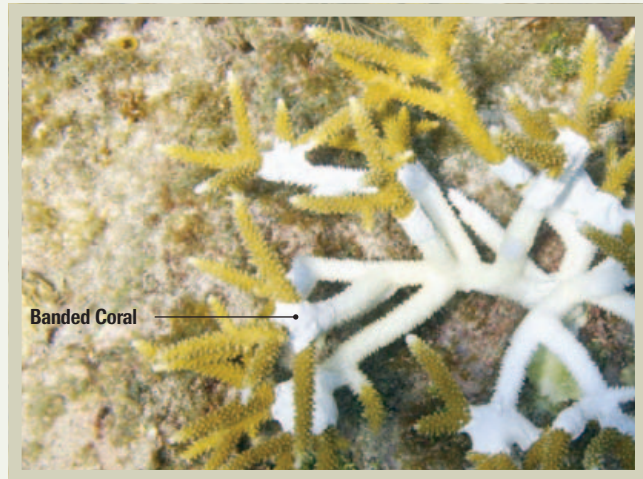


Photo: Ken Nedelger

Diseased *A. cervicornis* colony banded with epoxy to prevent further spread of disease

- ✦ **Colony Isolation:** The first step in managing the spread of the disease is to isolate the infected coral and remove the coral from the main nursery area to a quarantine area at least 5 m away. A sandy buffer zone between the main nursery and the quarantine area is preferable.
- ✦ **Pruning:** If enough is available, live tissue above/beyond the band of infection can be pruned and mounted. As a general rule of thumb, if 5 cm of live tissue remains on the branch, it can likely be successfully pruned, tagged and reattached.
- ✦ **Banding:** If underwater epoxy putty is available, a band of epoxy can be applied to the infected area to arrest the spread of disease. This band should cover the entire disease band and up to 1 cm of the adjacent live tissue. Corals that have at least 3 cm of live tissue beyond the diseased band are likely to respond well to epoxy banding. If the disease is caught early and is limited to a small area at the base, an epoxy patch can be applied that covers the diseased area and up to 0.5 cm of the adjacent live tissue. Modeling clay can also be used for making bands when epoxy is not available.
- ✦ **Manage Transmission Vectors:** Various fish, snails and worms have been implicated in the transmission of disease. Removing these suspected transport vectors can reduce the potential spread of disease and increase the effectiveness of disease prevention and treatment.

- **Tools:** Typical tools used within the nursery include: wire and nylon brushes, cable ties, pliers or cutters, epoxy, plastic flexible rulers or calipers, underwater paper, clipboards, pencils, gloves, identification tags, camera with underwater housing.
- **Monitoring:** Establishing a routine method for assessing overall coral condition in the nursery will aid in understanding the comparative success between genotypes or provide important insight into nursery setup or design methodologies that may need to be modified. Simple visual assessment can be quickly accomplished with minimal effort and provide important information, including the presence or absence of predators, bleaching, disease, tissue loss or mortality, or other general indicators of overall coral health.

Typical monitoring parameters include the following:

1) **Growth Measurements**

- Initial measurement: when a fragment is brought into the nursery after transplantation, the fragment is measured for total live tissue. (Figure 6, image A and B)
- Fragmentation measurement: each time a colony in the nursery is fragmented, the live tissue of the donor colonies and the fragment removed should be measured. This measures total production of the colony over time.

2) **Number of branch tips** – branch tips should be considered any tissue >1 cm.

3) **Maximum branch width** – width of branch at base of colony or fragment.

4) **Condition** – disease, predation, bleaching, algal and other overgrowth, breakage, tissue loss.

5) **Mortality** – number of fragments or colonies with complete tissue loss.

6) **Attachment or stabilization of fragments or colonies** – e.g., loose or cemented to platform, loose or intact cable ties.

7) **Water quality** – collecting basic information on water quality, such as temperature and light, can be accomplished with simple and affordable instruments (e.g., Hobo loggers) and can provide useful information on the conditions within a nursery.

8) **Photographs** – photographs of nursery colonies can provide a valuable permanent visual record of these parameters.

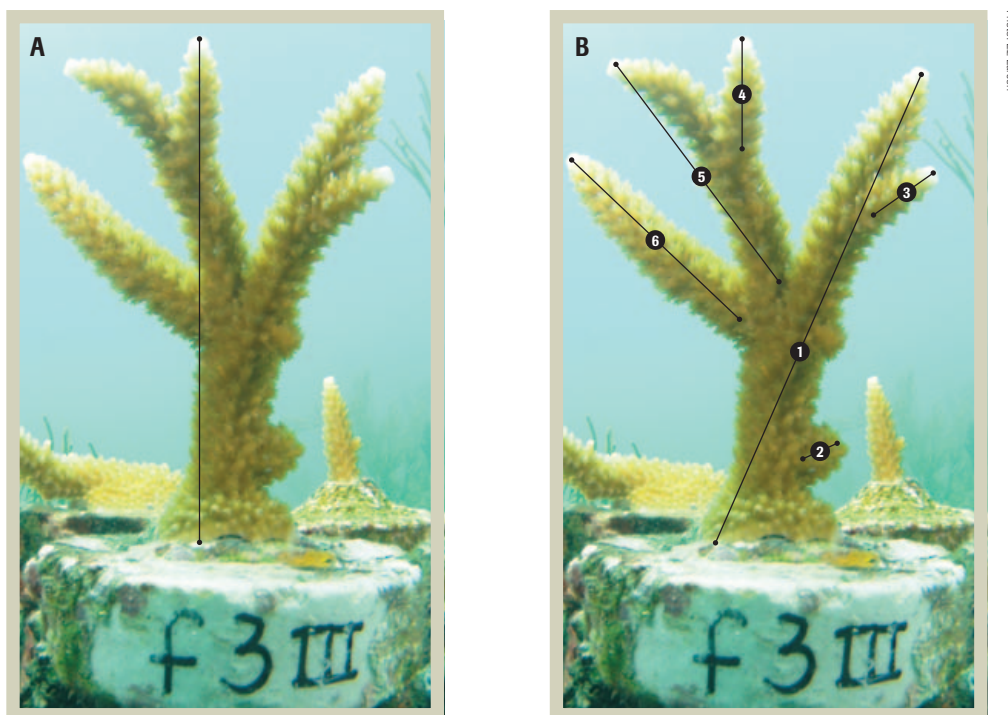
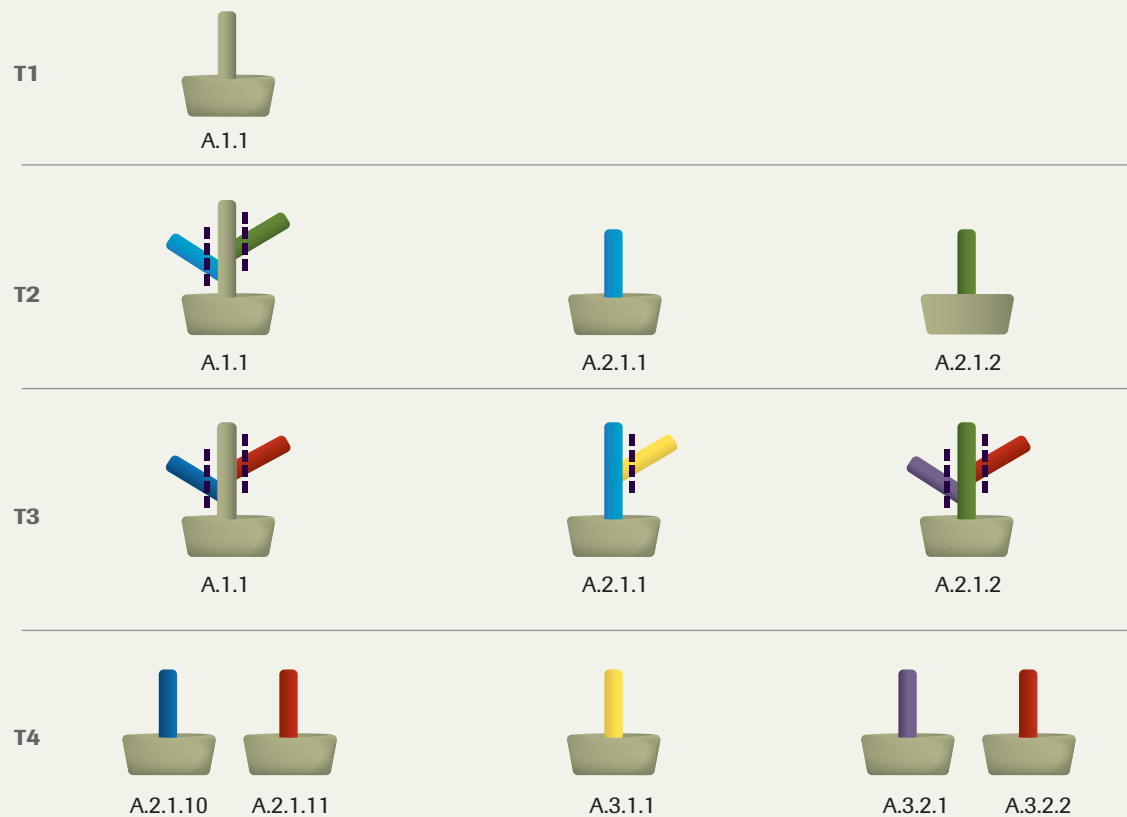


Figure 6: *In situ* measurements of nursery fragments; linear growth and tissue extension. Image A is diagramming the linear growth measurement (maximum height). Image B is diagramming the tissue extension measurements, all measurements 1– 6 were added together to get total live tissue for the fragment.

- **Tracking:** Tracking of individual fragments or colonies for growth or productivity (by individual or genotype) may be required or desired. Tracking individual fragments within the nursery can be achieved by the use of tags, color codes and/or position mapping. Various methods exist for marking fragments, depending on the method used to mount or stabilize the fragment. If using small concrete discs, the identification number can be placed directly on the disc using permanent markers or pens. Clear epoxy coating over the identification number provides long-term protection from fouling. However, this method requires significant effort prior to going in the field in order to have discs pre-numbered prior to fragmenting colonies. External tags can also be used, especially in the case of fragments suspended from lines or attached directly to hard substrate. Color coding can be achieved through the use of colored wire ties, zip ties and tags (color fading may be an issue over long periods). If resources allow, photographing fragments with a visible scale can be a valuable tool in tracking and monitoring fragments in the nursery, providing a photo record of size and overall health of fragments over time but also facilitating identification of nursery colonies due to lost or overgrown tags or identification. If breakage occurs and coral identity cannot be determined, having a “miscellaneous” coral category and/or nursery structure may be useful.

BOX 6: SCHEMATIC OF NURSERY FRAGMENT IDENTIFICATION AND ORGANIZATION.

Below each puck in the diagram are example identifiers of each fragment. Letter indicates colony genotype, first number indicates generation; second number indicates where the donor fragment came from; and the third number is a count of fragments from a specific donor. Dashed lines represent clippings of the fragments removed. T1–T4 is an arbitrary time scale of fragment growth. Fragments A.2.1.10 and A.2.1.11 are the second time A1.1 was fragmented, so the fragment number (last number in the identifier) will start at 10.a.



Outplanting

Goal: Outplant enough nursery-grown colonies from a variety of different donor colonies or genotypes to enhance the potential for sexual reproduction and recruitment, thereby enhancing the ability of the population to contribute to its own recovery.

SITE SELECTION

When choosing outplant sites, be sure to do your homework to understand your local area. There are several factors to consider in site selection which can be key to outplant success or failure.

- **Existing Wild Populations:** Let the distribution and status of the remaining wild coral population guide your decision; habitats that harbor healthy *Acropora* populations likely provide adequate environmental conditions for outplanted colonies.
- **Depth:** Outplant sites should be similar to the depths of the nursery sites and the existing wild populations in the area.
- **Water Quality:** *Acropora* corals require good water quality to thrive, including low sedimentation and turbidity and relatively minimal temperature fluctuations over daily, monthly or annual time frames. Extremely high and low temperatures or drastic fluctuations can cause coral mortality.
- **Bottom Type:** Hard, stable substrate allows for secure attachment of outplants; avoid areas with an abundance of rubble to prevent damage during storms.
- **Size of the Area:** The size of the outplant site should depend on the number of corals to be outplanted. Typical spacing of outplanted corals is 0.5–2 m. The area chosen for outplanted corals should allow for adequate spacing to promote coral growth.
- **Space Competitors:** Organisms that compete for space such as gorgonian canopy, encrusting sponges, *Palythoa* and algae should be avoided.
- **Predator Abundance:** Sites should be evaluated for predator abundance prior to transplantation, noting the presence of corallivorous snails, fireworms and damselfish. Avoid sites with large populations of such predators or include predator removal within management plans.
- **Wave Exposure:** Choose sites with moderate to low energy environments to reduce the risk of damage to the outplanted corals.
- **Origin of Parent Colonies:** Unless required or desired for specific restoration goals, outplanting corals long distances away from collection sites should be avoided.
- **Current/Historical presence of *Acropora*:** In the absence of surviving *Acropora* populations, outplant sites should be located where a historical presence of *Acropora* has been noted. In addition, outplant sites in waters of the United States should be within areas designated “critical *Acropora* habitat” by NOAA’s National Marine Fisheries Service.
- **Human Activities/Impacts:** Outplants should be deployed in areas that are remote from human activities that could damage corals. Areas where human activities are limited such as Marine Protected Areas (MPAs) are ideal locations for outplants. MPAs also provide an improved trophic structure with an increased abundance of herbivores such as fish and urchins that may keep algae under control, as well as abundant predators that may control the abundance of corallivorous snails and worms.

- **Number of Outplanting Sites:** A logistical trade-off exists between the number of outplanting sites that can be established and the attention and maintenance that can be afforded to each site. Having multiple outplanting sites replicated in different environments will minimize the likelihood that a given disturbance, such as a disease outbreak or storm, will wipe out the entire outplanted population.
- **How Much to Outplant:** It is important to leave enough coral tissue within the nursery to allow for continued growth and expansion. Thus, outplant only a small fraction of available corals each time to ensure tissue is left from each collected genotype at the nursery (do not outplant all units of a given genotype!).
- **Health/Condition/Size of Outplanted Corals:** Each nursery coral should be evaluated prior to outplanting to ensure that only colonies that present a visual suggestion of good health are placed out on the reef. Colonies to be outplanted should meet the following criteria:
 - 1) For *A. cervicornis*, have at least 5 cm of linear growth; for *A. palmata*, at least 5 cm in diameter.
 - 2) Show no visible signs of disease or injury.
 - 3) Have actively growing tips.
 - 4) Have 100% live tissue and no lesions.
 - 5) Show robust coloration (golden-tan to a dark brown).

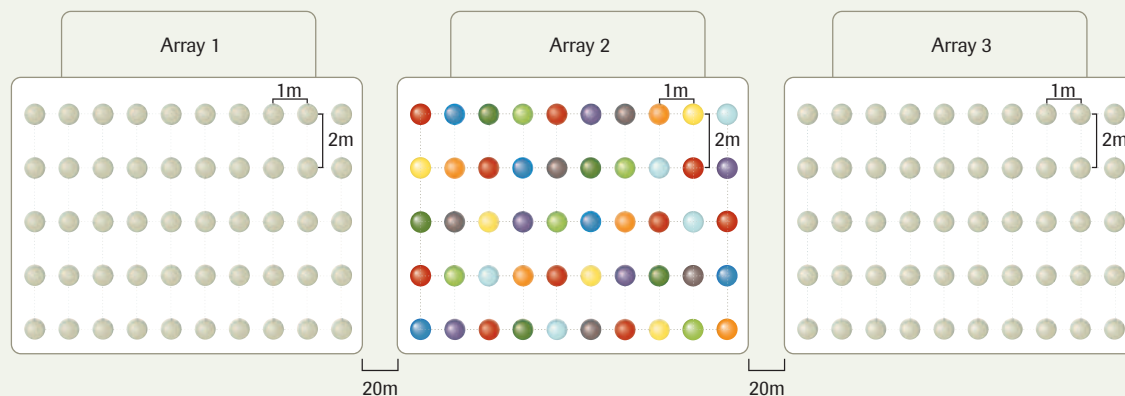
DESIGN

Basic guidance for the outplant sites includes:

- 1) Avoid dominance of colonies from the same donor colony (and genotype) within each site.
- 2) Include colonies from as many donor colonies (and genotypes) as are available in the nurseries.
- 3) Outplant at a variety of sites to spread risk of mortality.
- 4) When possible, outplants should be deployed within replicated plots where different genotypes are replicated within and among plots.
- 5) Appropriately space outplants within plots and between plots within sites to allow access for monitoring and maintenance.
- 6) Maximum spacing of 50–100 cm between colonies within plots will likely increase the potential for cross fertilization of gametes during spawning events.

BOX 7: EXAMPLE OUTPLANTING SITE

Each color in Array 2 represents a different genotype. Each row has a representative from each genotype ($n=10$). Appropriate spacing of genotypes allows for maximum potential for cross fertilization. Each site will have three arrays, with at least 10 genotypes per array and at least five replicate fragments of each genet per array, where possible.



Methodology

- **Transport:** Widely varied methods have been tested and used for transporting corals, and the selection of one particular method should depend on the conditions at each unique nursery site (for methods, see Coral Collections section). See Figure 7.
- **Coral Attachment:** Corals can be attached directly to the reef or using attachment platforms like masonry nails or cement pucks. Outplanted corals can be wedged into holes or crevices or secured using epoxy, cement, wire or plastic ties (for examples see Figures 1 and 2 from Case Study 1).
- **Tracking:** There should be a unique identifier for each coral being outplanted (for methods, see Nursery Operations section).
- **Monitoring and Maintenance:** Ideally, all outplants should be monitored after the first month and quarterly thereafter for 18 months. The monitoring should include a visual census of survivorship, with notes on condition, including bleaching, disease, predation and breakage. Suggested maintenance includes the removal of snails and fireworms from outplants and reattaching broken fragments at the outplant sites. The level of maintenance will depend on environmental factors, funding and goals of each project.



Figure 7: Corals transported in plastic bin to an outplant site

Photo: Liz Larson, Nova

CASE STUDY 1

Acropora cervicornis Restoration Using Multiple Nursery Designs in Punta Cana, Dominican Republic



Background

Historically, *A. cervicornis* was found on the shallow reefs in the Punta Cana region of the Dominican Republic. At present, there are sparse but healthy colonies of *A. palmata* but an extremely low abundance of *A. cervicornis*. The goals of this project were to propagate the few surviving staghorn genotypes within a protected nursery setting and rebuild enough coral biomass to start to repopulate the depleted Punta Cana reefs. This has been achieved through the use of multiple nursery platforms.

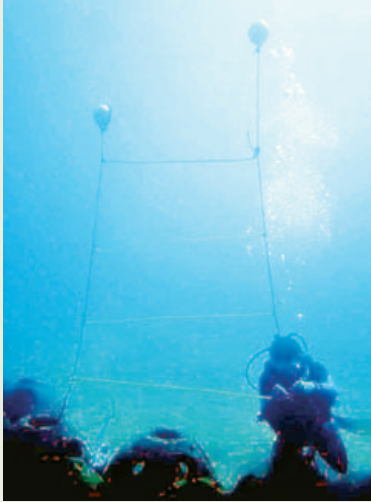
Nursery Location

Punta Cana region of the Dominican Republic

Nursery Site Description

- Shallow sand patch (5.8 m) located below the surrounding shallow reef flat where wave energy dissipates.
- Close to potential outplant locations.
- Adjacent to a reef inlet for oceanic water, which offers excellent water flow.
- Mooring buoy located at the site to prevent anchor damage.
- Informal no-take-zone agreement between local resorts and fishermen keep fishing impacts low; healthy fish and invertebrate populations contribute to low algal cover and low predator abundance.
- Close to resorts – creates an educational resource and provides for local stewardship.
- Absence of current natural *A. cervicornis* populations in the area provides a unique research and management opportunity to evaluate the success of creating a viable population through the outplanting of second-generation fragments and to determine what habitat characteristics contribute to success.
- Currently, the nursery holds >1000 fragments of *A. cervicornis*.

Nursery Design

A-Frame Nursery	Line Nursery	Rope Table Nursery
 20cm x 20cm epoxy-coated wire mesh (3mm) secured to the substrate with cement weights and rebar; fragments attached with plastic cable ties and tagged using aluminum tags.	 Vertical polypropylene lines anchored with cement weights and suspended by sub-surface buoys with thin lines strung between vertical lines; fragments attached by threading and tagged using aluminum racetrack tags.	 Polypropylene line strung between 10' sections of 5/8" metal rebar rods attached to metal legs made by bending rebar into the sand; fragments attached by untwisting segment of line and threading the fragment through.

Coral Collections

- 25 fragments were originally collected from four colonies and placed in the nursery.

Nursery Operations and Maintenance

- Regular cleaning – algae and sedimentation.
- Replacement of degraded nursery materials.
- Frequent predator removal.
- Use of underwater signs and education of tourists by resort staff to abate human impacts.
- Construction of light nursery structures designed to be moved away from sources of predation and repaired in case of storm or anchor damage.
- Use of epoxy-coated wire mesh to prevent algal overgrowth and aid in cleaning.
- Use of many types of metal poles, rods and rebar to withstand weight of growing colonies.

Outplanting

- Outplant sites just offshore (ocean-side) of the reef flat in 3–4.5 m of water.
- 11 sites between Punta Cana and Cap Cana, including the reef surrounding the nursery (Figure 1).
- Large (>2 m in diameter) and healthy colonies of *A. palmata* surrounding the outplants.
- Most common and successful technique is to attach fragments with small plastic cable ties to 4" masonry nails driven into the reef substrate (Figure 2); other fragments secured into small holes and crevices in the reef substrate with underwater epoxy or cement.
- Currently >300 thriving *A. cervicornis* colonies on the reef flat at the Acuario sites as a result of outplanting; additional >1000 fragments outplanted to 11 sites in March 2011.
- High fragment survivorship (97.4%); plots have had very high retention rates (85%) of fragments, indicating that outplanting techniques are successful.

Lessons Learned

Fragment your Colonies. Fragment colonies at least twice a year to keep them growing vigorously and to avoid platform collapse from oversized colonies. Overgrown colonies attract damselfish that create algal lawns and promote algal overgrowth. It is difficult to measure and maintain colonies that are oversized and fuse with neighboring colonies.

Spread your risk. By utilizing multiple types of nursery structures, the risk of losing all fragments due to storm damage and predation is minimized. All supplies, except for the underwater epoxy, are readily available in the Dominican Republic.

Evaluate your options. A-frames proved to be the most cost-effective and simplest method, with most construction taking place on land.

Use all available tools. Simple wedging, or placing fragments into holes or crevices, does not have retention rates as high as when they are secured with nails, epoxy or cement.

Find protected sites. Fragments do not have high survivorship when placed on shallow, high-energy reef flats, but are more successful on deeper, more protected areas.

Enlist help. Outplanted plots closer to reef ledges have less predation from fireworms and snails than plots further on the reef flat, due to the presence of higher trophic predators.

Avoid predators. Select sites where predator abundance is low; avoid *Agaricia* stands commonly inhabited by juvenile snails; inspect colonies of *Diploria* and *Montastraea* to ascertain if snails are locally abundant; and avoid dead *A. palmata* fragments, which commonly shelter fireworms. Ideally, trials should be conducted using a smaller number of corals to determine if an outplant site is adequate.



Figure 1: Example of an outplant plot using corals from the Punta Cana coral nursery.



Figure 2: Coral fragments are successfully outplanted by securing them with two plastic cable ties to masonry nails driven into the reef substrate. The coral tissue grows over the cable ties within two to three months, and fragments secure to the substrate.

Funding and Partners

The coral nursery was established in 2005 by Dr. Austin Bowden-Kerby and the Punta Cana Ecological Foundation with funding from the Punta Cana Ecological Foundation and Counterpart International. In 2010, the nursery was expanded in collaboration with the University of Miami and funding from Counterpart International and the Frohring Foundation.

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Photos

Courtesy of: Diego Lirman and Victor Galvan

CASE STUDY 2

Recovery of *Acropora cervicornis* in the Upper Florida Keys through modifications of multiple nursery designs



Background

Historically, *A. cervicornis* was commonly found on the forereef and patch reefs off the Upper Florida Keys. Over the last two decades, populations have decreased ~80–90%. Multiple stressors such as coral bleaching, disease, hurricanes and the loss of the long-spined sea urchin, *Diadema antillarum*, have contributed to their decline. The goals of this project are to aid in the recovery of *A. cervicornis* in the Upper Florida Keys by enhancing coral production through the modification of varying nursery designs.

Nursery Location

Tavernier Key, FL

Nursery Site Description

- Originally chosen for a live rock aquaculture farm.
- Fine sand bottom in ~30 feet of water.
- Site selection criteria: good water quality, protection from storms, easily accessible.
- Currently holds >15,000 *A. cervicornis* corals from 90 different genotypes.

Nursery Design

Each design has been modified over the last 10 years to reduce maintenance requirements and increase coral production.

Block Nursery



Block nurseries are constructed of a concrete slab or block, cement filled PVC pedestals and cement pucks of various shapes (round, triangular, etc.). The blocks are anchored with rebar covered with PVC sleeve and zip ties. Corals are attached to the pucks using underwater epoxy.

Line Nursery



Line nurseries are constructed of vertical polypropylene lines anchored to the substrate with duck-billed anchors and suspended using small sub-surface buoys with thin horizontal polypropylene lines strung between vertical lines. Fragments are attached using colored wire ties to track genotypes.

Coral Tree Nursery



Coral tree nurseries have simple frameworks that resemble the shape of a tree. The trees are tethered to the seafloor, and have sub-surface buoys. The trees can move up and down in the water column by adjusting the length of the tether. Corals are attached with wire line or monofilament.

Coral Collections

Fragments of *A.cervicornis* were collected from 95 donor colonies to supplement genetic diversity in the nursery.

Nursery Operations and Maintenance

- Regular cleaning – algae, sponges, sedimentation.
- Predator removal (snails, fireworms).
- Disease management – band corals with epoxy to stop the spread of the disease on an individual coral, isolate diseased corals, remove fish that may transmit disease (butterfly fish, damsels).

Outplanting

- More than 1500 corals have been successfully outplanted to 31 sites on 10 different reefs off the Upper Florida Keys.
- Site selection criteria: good water quality, deeper water on outer reef sites, low fishing and anchoring pressure.
- Corals grown on the block nurseries are outplanted on pucks epoxied to the substrate. Corals raised on line or tree nurseries are epoxied directly to the substrate.
- Corals are outplanted to areas where populations of *A. cervicornis* used to be present to avoid mixing with native colonies.
- Corals were observed spawning in 2009, just two years after outplanting.
- Overall survivorship of outplanted corals is approximately 70%. Prior to the cold water event in January 2010, overall survivorship was approximately 80%.

Lessons Learned

- *Spacing matters.* When setting up a nursery, use adequate spacing between the blocks to minimize the spread of disease. Spacing of outplants plays a significant role in reducing the transmission of disease from one group of outplants to the next, and reduces the attraction of predators.
- *Visit often.* If outplanting to reef areas with heavy recreational diving or fishing pressure, there may be significant breakage after one or two years. This can be managed successfully by regular re-attachment of loose fragments (Figure 1). Removing snails and fireworms is just as important, especially during the first year.
- *Avoid unnecessary damage.* Avoid sand areas and extensive loose rubble to prevent damage to outplanted corals and increase survivorship of broken fragments.



Figure 1: Outplant sites can be managed by regular re-attachment of loose fragments

Funding and Partners

The coral nursery was established in 2000 using *A. cervicornis* corals that settled on a privately owned permitted live rock farm within the Florida Keys National Marine Sanctuary off Tavernier Key, FL. It was expanded in 2005 in partnership with The Nature Conservancy through the TNC/NOAA Community- Based Partnership Program. The nursery was further expanded in 2008 with a project funded by Sea Life Inc., Disney Wildlife Conservation Fund, and NOAA Fisheries. It was again expanded in 2009 supported by The Nature Conservancy and the NOAA Restoration Center, U.S. Department of Commerce, with funding from the American Recovery and Reinvestment Act (Award #NA09NFF4630332).

Author

K. Nedimyer

For Additional Information

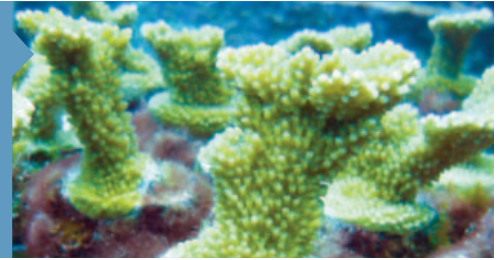
www.coralrestoration.org

Photos

Courtesy of: Ken Nedimyer

CASE STUDY 3

Acropora Restoration in Isla Mujeres National Park, Mexico



Background

The decline of *Acropora* in this region has mainly been caused by higher frequency and distribution of disease, and also by the effects of climate change. The purpose of the nursery is to provide sources of fragments for restoration when groundings or hurricanes impact natural reefs.

Nursery Location

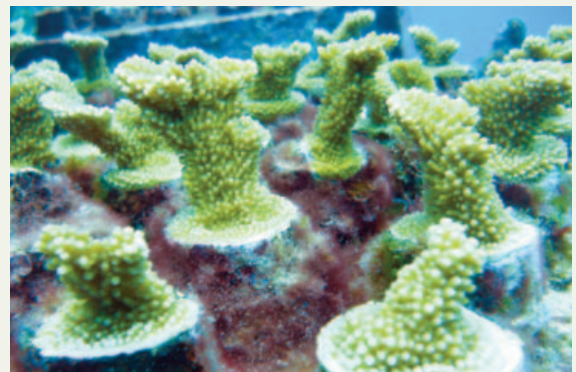
Isla Mujeres—Cancun National Park, Quintana Roo, Mexico

Nursery Site Description

- Close to naturally occurring *Acropora* colonies that could provide donor material.
- On sandy or calcareous bottom to avoid impacts if structures should come loose during storms.
- Water depths between 10 and 30 feet.
- Moderate current flow to maintain good water quality.
- Little or no transit of boats and minimal human activity.
- Nursery currently holds > 900 fragments of *A. palmata*, *A. cervicornis*, and *Agaricia agaricites*.
- Special inland nursery in aquariums holds ~300 fragments.

Nursery Design

Block Nursery



Square blocks of 50 x 50 cm made of a mix of concrete and silica form a platform for structures on which the coral fragments are mounted. Each fragment is mounted on a plastic “male” connector that is then screwed onto the “female” connector attached to the concrete block. The mix of concrete and silica creates a pH similar to that of calcareous rocks on the reef, and it has been observed that this helps initial survival and growth of coral fragments.

Coral Collections

- Fragments were collected from healthy wild colonies. When possible, naturally broken corals from these wild colonies were chosen.

Nursery Operations and Maintenance

- Regular cleaning – algae.
- Size monitoring every two months.
- Because of the materials chosen, there is no need to change degraded materials.
- The nursery was initially deployed in three different reef areas. Survivorship results indicated the best site, where 100 more concrete blocks are planned to be deployed.
- The inland nursery requires more attention for cleaning, feeding and monitoring for disease. The main purpose of this nursery is to evaluate if it is possible to accelerate growth with more food (*Artemia nauplii*).

Outplanting

- 60 corals from the inland nursery were attached to a concrete block at the in-water nursery after 11 months in aquarium conditions (July 2011).
- Outplanting from the in-water nurseries is scheduled for Fall 2011.
- Outplanting sites are located in Isla Mujeres Bay, near two of the nurseries.
- Both sites selected for the outplanting were impacted earlier by boat groundings.
- *Acropora* colonies are already present at both sites.

Lessons Learned

Collect healthy corals. Survivorship of corals that were collected from the bottom was not as high. Although they were naturally broken, they may not have been healthy enough to support further fragmentation.

Evaluate your options. Several designs were used during outplanting to attach the corals, but the best used PVC connectors, which can be screwed on or out easily.

Spread your risk. Nurseries were placed in different areas of the reef. One nursery was located near the reef crest, which was thought to be a good area. This nursery had less than 70% survivorship. This was likely due to poor water quality, since patches of yellow turf algae were seen around the site.

Funding and Partners

The National Park Costa Occidental de Isla Mujeres, Punta Cancun, Punta Nizuc (CONANP-SEMARNAT), the Regional Center of National Institute of Fisheries in Puerto Morelos (CRIP-INAPESCA), Quintana Roo, Mexico, and the Department for Environment Food and Rural Affairs (DEFRA), United Kingdom.

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Photos

Courtesy of: Roberto Ibarra Navarro

CASE STUDY 4

Acropora palmata Restoration in Veracruz National Park



Background

The *Acropora* Restoration Program in Veracruz National Park began in 2007 with the goal of recovering sites damaged by ship groundings. The program aims to initiate coral recovery and promote natural restoration through the increase of coral cover.

Nursery Location

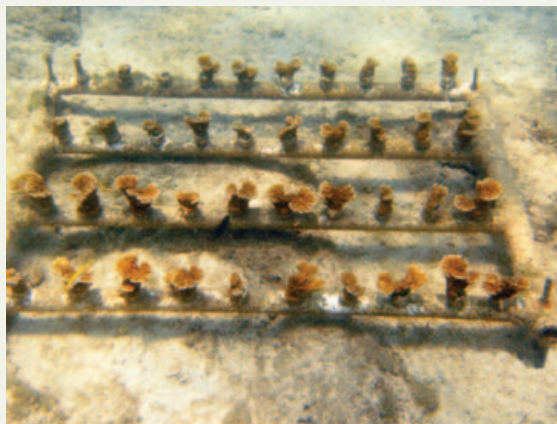
Veracruz, Mexico

Nursery Site Description

- The first nursery was built in 2008 at Anegada de Adentro reef.
- Rock substrate area in approximately 3–6 m of water.
- Site selection criteria included: good protection, reef lagoon, shallow area, limited wave action, easily accessible and near a donor population.
- The nurseries can hold > 1000 *A. palmata* corals located on 10 fixed nursery structures.

Nursery Design

Fixed Nursery



Fixed nurseries are constructed with PVC structures and PVC and PET connectors that are anchored with threaded rod. Corals are attached using cement, which is cheaper than epoxy and readily available in Mexico.

Coral Collections

- Corals were collected from known sources of *Acropora* colonies from one donor area (Anegada de Adentro Reef, atypical growth of *A. palmata* population).
- Only naturally detached, or corals of opportunity were collected.

Nursery Operations and Maintenance

- Repair and reattachment of loose structures and coral fragments after storms.



Figure 1: Outplanted *A. palmata* corals on the fore- reef crest

Outplanting

- 3600 *A. palmata* corals have successfully been outplanted to the forereef crest (Figure 1).
- Corals were outplanted back to the same reef that they were collected from (but in the forereef).
- Corals were attached to the reef using cement. A special dispenser made of PET bottle necks and plastic bags was created to distribute the cement in the water.
- Survivorship of outplanted corals is approximate 85% after three years.

Lessons Learned

- *Spacing Matters.* Predation by snails and fireworms was an issue in the beginning when the outplants were placed close together. Colonies were then spaced 2 m apart, and new colonies were placed around old outplanted corals, which reduced the predation impact.
- *Enlist help.* Choosing a nursery site with high densities of the long-spined sea urchin, *Diadema antillarum* and *Equinometra sp.* reduced the level of algae maintenance.
- *Evaluate your options.* When the PVC nursery structures were made bigger to hold more fragments, it resulted in weaker structures that could not resist strong currents and waves. Thicker PVC was used to strengthen the structures, but this created difficulties in attaching the connectors and fragments to the PVC.

Funding and Partners

Funding is from the federal government through the national protected area administration (PNSAV), the state government through the Aquarium of Veracruz and small private donations from dive shops and divers.

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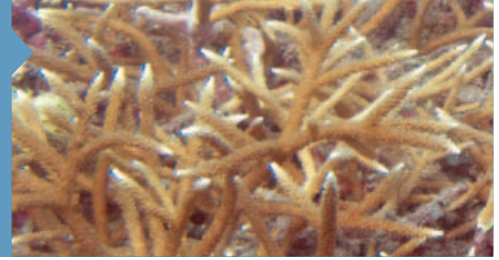
www.oceanus.org.mx

Photos

Courtesy of: Gabriela Nava-Martinez, Miguel Garcia-Salgado, Miguel Roman-Vives

CASE STUDY 5

Acropora cervicornis Restoration at the M/V Margara grounding site in Puerto Rico



Background

In April 2006, the M/V Margara grounded off the south coast of Puerto Rico. The primary purpose of the *Acropora* nurseries was to outplant corals into the restored and stabilized areas of the impact site to augment coral recruitment and recovery.

Nursery Location

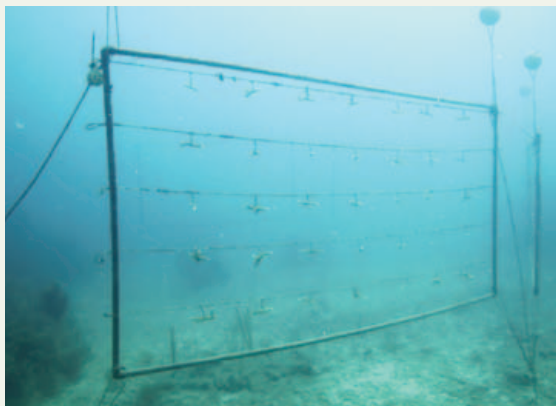
Guayanilla, Puerto Rico

Nursery Site Description

- FUCA nurseries were anchored in 40–50 ft of water in the sand/rubble depressions of the reef.
- Visibility is typically poor, but there is good exposure to swells and currents.
- The nursery currently holds >1,500 corals.

Nursery Design

Floating Underwater Coral Apparatus (FUCA) Nursery



FUCAs are line nurseries constructed of a 5' x 10' PVC frame to provide support, with four horizontal monofilament lines. Holes are drilled in the horizontal PVC for attachment points to create a total of six lines for attaching corals. The FUCAs are anchored with helix anchors and supported by floats. Fragments are attached to the monofilament lines using rubber-coated wire (thermostat cable).

Coral Collections

- Corals were collected at the grounding site, in an attempt to stabilize >1000 fragments.

Nursery Operations and Maintenance

- Require little to no maintenance.
- The line nurseries are cleaned and maintained during nursery expansion and outplanting.
- Site checks are usually performed after large storm events (hurricanes) to check for damage.

Outplanting

- Outplant events typically occur twice a year.
- Corals have been outplanted from the line nurseries to the restored parts of the grounding impact site (Figure 1).
- Corals were reattached using a variety of methods (epoxy, cable ties, cement and by wedging the corals into the reef so that they are stable).
- Stabilizing transplants without the use of any foreign materials is successful, but the use of epoxy, cable ties and cement will increase transplant stability and survival.
- Survivorship of outplanted corals is approximately 90%.



Figure 1: Corals outplanted to the restored parts of the grounding impact site

Lessons Learned

- The FUCAs have a PVC frame that prevents the nursery from collapsing as the corals grow and get heavier.
- Larger PVC frames (10' x 10') were too large for the vertical arrangement. Corals on the upper half of the nurseries grew more slowly, and additional buoys had to be added as the corals grew larger. Smaller PVC frames (5' x 10') proved more effective and easier to work with.
- Helix anchors seem to work better than duck-bill anchors if the substrate is more rubble than sand.
- Having a site with good circulation, swell exposure and fish to clean the nurseries will help prevent biofouling on lines.

Funding and Partners

Work to date has been funded by case money from the M/V Margara grounding and NOAA's Restoration Center.

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Photos

Courtesy of: Sean Griffin and Tom Moore, NOAA Restoration Center

CASE STUDY 6

Acropora Restoration using buoyant line nurseries in Oracabessa Bay, Jamaica



Background

Along the Jamaican north coast, *Acropora* declined through the 1980s, punctuated by Hurricanes Allen in 1980 and Gilbert in 1988. In 2005, with the help of Dr. Austin Bowden-Kerby and the Discovery Bay Marine Laboratory, line nurseries were introduced in Montego Bay and were later modified and expanded to Discovery Bay in 2006 and Oracabessa Bay in 2009. The goal of the current Oracabessa Bay project, a private contract, is to produce a snorkeling garden for the Goldeneye Resort and develop habitat for the newly gazetted Oracabessa Bay Fish Sanctuary. Single-line hurricane resistant/self-planting systems were trialed from June to July 2010.

Nursery Location

Oracabessa Bay, St. Mary, Jamaica

Nursery Site Description

- Well-developed buttress formations with few fish.
- Nursery anchors were set in a clean-sand, high-albedo location of 7 m depth within easy swimming access from shore parking. Vertical self-planting systems were set in adjacent and somewhat deeper water of similar conditions.
- Good wave and long-shore generated water motion without obvious sediment inputs.
- Near or adjacent to fish-holding structure.
- Though anchored at 7m, final coral depths were from 2.5 - 6m depths along the vertical structure.
- Design based on modifications to previous nurseries in Montego and Discovery Bay, Jamaica.
- The line nurseries currently hold ~800–1000 corals.

Nursery Design

Line Nursery



Line nurseries are constructed of paired ¼" laid polypropylene lines anchored with galvanized steel helix (sand-screw) anchors at one end and held taut with mid-water buoys (1.5–2 L PEET plastic drink bottles). Initial iterations used permanent surgeon's knot drop-loop attachment points, good for larger corals; however, tied drop-lines are preferable for very small corals.

Coral Collections

Fragments of *A.cervicornis* were collected from two donor colonies, both within 30 m of the nursery site. Fragments of *A.palmata* were also collected from two nearby donor colonies.

Nursery Operations and Maintenance

- From 2009 to 2010, these nurseries were observed, cleaned, maintained and added to every six to eight weeks.
- Regular cleaning of algae – as much as time and resources allow.
- Replacement of degraded nursery materials, and addition of buoyancy to overweighted lines.
- Adjustment of nursery lines after storms.
- Clipping of diseased corals after storms.
- Regular fragmentation of corals to avoid overweighting the lines with large corals and prevent damage caused by corals knocking together.
- Ongoing community/stakeholder communication to avoid human impacts.
- Due to ongoing wear and crystallization of the monofilament line, the horizontal nurseries are replaced after 1–24 months.

Outplanting

- More than 200 40 to >100 cm (total branching length) corals have been outplanted to three sites 500 m east of the nurseries in March, June and July 2011.
- Outplant sites were buttress slopes with good water movement but some depth and/or structural protection from storm waves.
- Well urchin-grazed and within easy snorkeling access from the client resort.



Figure 1: Corals outplanted on high promontories of the reef

- Corals were planted to high promontories of the reef rather than in hollows to maximize light exposure and water flow and minimize sedimentation and cryptic predator damage (Figure 1).
- Corals were wired directly to small upward reef projections on these promontories using galvanized steel binding wire. Where small projections were not present, a galvanized nail was sunk. Note: Galvanized coating must be aged to reduce zinc toxicity.
- Corals were checked periodically in the initial two weeks to ensure wire tightness and substrate adhesion before wire decomposition.
- As this was not a scientific effort, only maintenance and passive photo-monitoring is being done.

Lessons Learned

- *Value.* Be aware of the value of your work, and be sure that your stakeholders share this value. Where possible, charge for use, with this money going into maintenance, education and associated conservation programs.
- *Limited Fouling Locí.* Minimizing structure reduces fouling organisms and the associated cleaning time and costs. Monofilament line holds less fouling flora and fauna than a concrete block, rope or rebar, and a drop-line exposes the sample to less fouling than a drop-loop.
- *Fish-cleaning.* Set at least one end of each nursery within 2 m of fish-holding structures such as reef. As all fouling organisms are fully exposed to grazing, a small number of fish may keep the system clean. Distance from the structure upwards will also restrict fish use and grazing, so taller nurseries will see greater fouling on upper rungs. Setting the structure adjacent to a high stone or wall may allow ongoing fish access.
- *Design Modifications.* Initially this site used drop-loops on the nursery lines. Drop-line attachments on the line nurseries were added to upper lines to reduce fouling and allow use of smaller corals. However, this attachment method is unsuited to larger corals, as it does not control for swinging or horizontal rotation of the samples, and they knock together.
- *Regular Monitoring or Observation.* Regular visits and gardening are essential in both the propagation and early outplanting stages; no less than bimonthly, with more being better. This allows timely removal of entangling algae and repair. As this is largely observation, local fishers or people engaged in watersports may perform this with some training.

- *Use Strong Anchors.* Although the anchor type is flexible, it is imperative that the anchor be strong. Tying to reef, submarine cables, wrecks or other permanent anchors is good, but concrete blocks, even buried in the sand, may pull out or move during storms.

Funding and Partners

Initial design development was supported by the Doctor's Cave Beach Club and the Montego Bay Marine Park Trust, with minor support from the University of West Indies (Mona) and the Discovery Bay Marine Laboratory. Dr. Austin Bowden-Kerby, whose line nurseries inspired these designs, provided initial training in 2004. All work in the Oracabessa Bay was funded by the Goldeneye Resort, Oracabessa, St. Mary, Jamaica.

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Photos

Courtesy of: Andrew Ross

CASE STUDY 7

Ex situ Culture of *Acropora cervicornis* for Restoration in Florida



Background

Staghorn coral (*A. cervicornis*) populations in Florida have been substantially depleted over the last 30 years. This same time period has seen great strides in *ex situ* captive coral care in tanks and aquaria, both private and public. It is now commonplace to see aquaria with healthy, growing corals; propagation of those corals in tanks and greenhouses has allowed for widespread distribution among coral aquarists, greatly reducing the demand on wild populations. The goal of the project is to take captive propagation technology and apply it to the field of reef restoration.

***Ex situ* Location**

- University of Florida's Tropical Aquaculture Laboratory (TAL) in Ruskin, FL
- Nova Southeastern University (NSEU) in Dania Beach, FL

Aquarium Description

- TAL's tanks are in an isolated, recirculating tank system, referred to as "closed-system," since there is not a constant flow-through of new water to this tank system, just occasional water changes. The closed system includes a pump for recirculating the water, a chiller to keep summer temperatures lower, a protein skimmer (foam fractionator), a calcium reactor and a simple Carlson surge device made from a 55 gallon plastic drum. Saltwater is made using synthetic sea salt (Instant Ocean®) and RO/DI filtered freshwater.
- NSEU's tanks are in a system that utilizes a constant flow of fresh seawater drawn from a well which is referred to as "semi-open." The source water is filtered with a protein skimmer (foam fractionator) and ozone. The system also has surge devices, a temperature controller and pumps for circulation in the tanks. A phosphate remover and calcium additions were included once it was noted that the respective water quality parameters were outside the ideal range.
- All of the tanks are constructed of fiberglass and have shelves of plastic grating for the corals to sit on. These shelves keep the corals close to the surface for good light penetration and ease of care. They also allow for the whole group of corals to be easily removed for tank cleaning.
- Systems rely on ambient sunlight filtered through shade cloth to light levels approximating those at water depths where these corals grow.
- Currently the systems hold only a fraction of the number of corals originally collected, as most of them have now been outplanted for this study. Once the final results of this particular study are complete, it is the intention of the authors to modify techniques as may be necessary and to expand the capacity of the coral propagation systems to house a larger number of corals.

Coral Collections

- A total of 120 fragments of *A. cervicornis* were collected from two known genotypes from the Coral Restoration Foundation's offshore nursery in Tavernier, FL. 60 were taken to TAL and 60 were placed back in the offshore nursery for growth comparison.
- A total of 300 fragments of *A. cervicornis* were collected from 50 colonies from Broward County reefs. 100 went to TAL, 100 to NSEU, and 100 were placed in an offshore nursery in Broward County.

Operations and Maintenance

- Water quality monitored and maintained weekly including temperature, pH, salinity, alkalinity, calcium, nitrates and phosphates.
- Monthly water changes (~50%) performed during major cleaning events (removing algae from the bases the corals were attached to and walls of the tanks).
- For this study, the corals were not fragmented after they were placed in culture. Growth measurements to date suggest that coral colonies could be fragmented as early as two years after establishment from 5 cm starting fragments.

Outplanting

- After one year in culture, 72 fragments were outplanted onto Molasses Reef in the Florida Keys in 20 blocks of four fragments each (Figure 1).
- The corals were planted near the edge of a broad spur in approximately 25 feet of water.
- Molasses Reef has been the site of many previous outplantings, and the great success of those outplantings made this reef an ideal natural laboratory.
- Fragments were grown on plaster pyramids (Figure 2). The corals, with their bases, were then glued onto the reef with epoxy putty after the attachment site was scraped clean of algae, detritus, etc.
- The outplanting site is visited once a month for a cursory observation. Full monitoring of the condition and growth of the corals is performed every four months. Because of the nature of the study, no maintenance is performed on the corals other than reattaching broken pieces to the substrate with epoxy putty when necessary.
- Preliminary observations are showing that almost all of the corals outplanted have not only survived but are growing well.

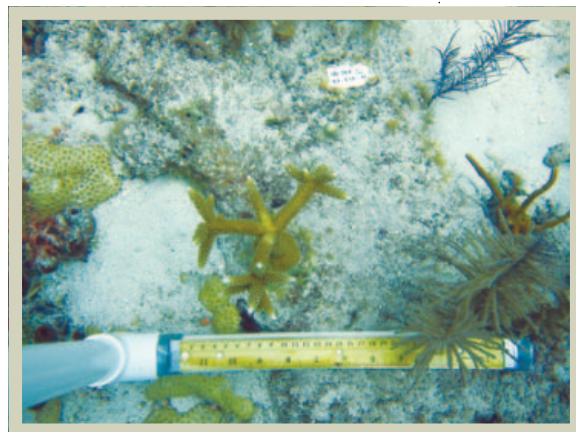


Figure 1: Outplanted coral at Molasses Reef in the Florida Keys

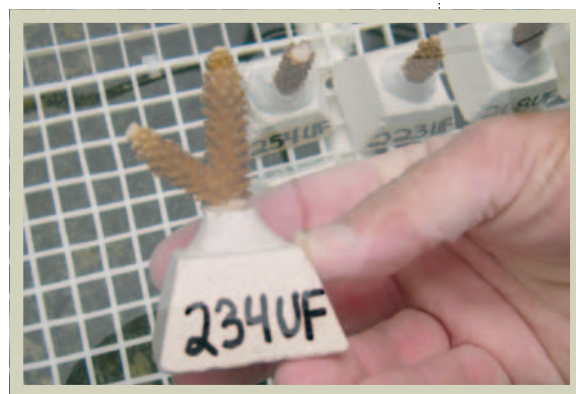


Figure 2: *A. cervicornis* fragment attached to substrate for culture in closed system tank at TAL

Lessons Learned

- *Monitor often and adjust when necessary:* *Ex situ* coral fragments can be lost quickly if any of the water quality parameters are allowed to drift beyond acceptable limits. The overall health and growth of the corals can also be adversely affected when water quality parameters are only just outside ideal conditions.
- *Ex situ vs. in situ culture:* Preliminary results from this study comparing the survivorship of outplanted fragments grown *in situ* at the Tavernier nursery and *ex situ* at TAL show little difference. Both techniques produce a very high percentage of healthy, growing corals. However, corals kept at TAL were slightly lighter in color and the number and morphology of branches was different to those corals kept in the offshore nursery. What impact if any this might have on restoration success is yet to be determined.
- *Benefits of ex situ culture:* Coral predators are excluded and beneficial organisms such as algae-eating snails and hermit crabs are usually introduced to assist with algae and detritus removal. Regular observations, occasional algae removal and routine filtration maintenance are all that are typically required. The greatest advantage is the easy access to corals for regular maintenance.
- *Quarantine:* Any animals brought into a land-based tank system with an existing population must be quarantined prior to introduction. Diseases in enclosed systems multiply and spread rapidly and can be very difficult to control.
- *Ex situ vs. in situ outplants:* Initial results show that growth rates differ between the two culture methods once the *A. cervicornis* colonies are outplanted onto a natural reef. Although there is very little difference in survivorship, the corals cultured in the offshore nursery have a higher average amount of growth and branching.
- *Outplant healthy corals:* Initial concerns relating to the release of captive animals back to the wild have been mitigated by ensuring strict biosecurity measures, careful tracking of the source and chain-of-custody of corals and the development of a coral health certificate that must be issued by a USDA-accredited veterinarian who has also been trained in coral health assessment, within 30 days prior to any outplanting.

Funding and Partners

This project was funded through the Florida Fish and Wildlife Conservation Commission's Wildlife Legacy Initiative grant. This study was only made possible through the partnership between the University of Florida's Tropical Aquaculture Laboratory, the Florida Aquarium Center for Conservation, the Coral Restoration Foundation, John G. Shedd Aquarium, Nova Southeastern University, Mote Marine Laboratory, Florida Atlantic University, Pathology Consulting Services, National Oceanic and Atmospheric Administration and the Florida Keys National Marine Sanctuary.

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Photos

Courtesy of: Scott Graves, University of Florida Tropical Aquaculture Laboratory

Case Study Notes

CHAPTER FIVE

Summary and Broader Benefits

The field of coral restoration is evolving rapidly. The ideas and best practices described here should be considered as guidelines to be adapted to local environments and project-specific goals. In this guide, we have summarized lessons and provide advice that can be considered the best *current* practices for *Acropora* restoration efforts. Based on our experiences from Florida and the Greater Caribbean, the benefits and impacts of enhancing coral populations and reef status are clear and compelling:

- Nurseries can provide an important scientific research platform in addition to restoration benefits. Conservation of these species is still impaired by knowledge gaps, especially related to disease mitigation and how genotype plays a role in individual performance of colonies and population resilience.
- Projects like these are opportunities to build strong partnerships between scientists, managers and conservation practitioners working in a diverse array of organizations (academic, government and non-government).
- Nursery-based coral gardening provides a vehicle for raising awareness of local communities and visitors about the importance and fate of corals and reef ecosystems. These types of projects are an ideal opportunity to engage local communities in real-world solutions to local (and global) problems. Engaging the community can increase public support for conservation and restoration, both for these and other imperiled species, and encourages ownership of long-term solutions ranging from sustained funding for restoration and monitoring to policies that reduce threats to corals and coastal ecosystems.
- Coral reefs create nursery habitat and provide protection from large predators for many vertebrate and invertebrate species. Restoration of this species could bolster Caribbean ecosystems in general. Restoration of these corals can increase important habitat for fish.
- Restoration should directly benefit regional economies and communities. Coral reefs and associated habitats provide critical habitat for fishery resources that represent an essential source of food for humans. Over 500 million people rely on coral reefs for their food and livelihoods. Coral reef species have been used in the treatment of cancer, HIV, cardiovascular diseases and ulcers. Corals' porous limestone skeletons have been used for human bone grafts. Healthy restored corals play an important role in tourism and recreational fishing, two important income sources for coastal U.S. and Caribbean communities.

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