Coral Propagation Efforts in Puerto Rico and the U.S. Virgin Islands

2017 Annual Report

Three year old *Acropora palmata* outplants on Great St. James Island in St. Thomas, USVI.

Abstract

Over 12,500 corals were outplanted from coral nurseries in Puerto Rico and the US Virgin Islands during 2016/17. Corals were transplanted to over 30 sites across the region (Figure 1). In addition, 11,000 at-risk fragments of *A. palmata* created by Hurricane Matthew and the M/V Noemi grounding were transplanted to over 20 different sites. Over the past 10 years, nursery operations have expanded exponentially from just two nurseries in Culebra to 16 nurseries across the region with over 12,000 corals in the nurseries across the region. The locations of the nurseries are located on the map in Figure 1 and a description of each can be found in Appendix I & II. Funding for this work was provided from NOAA's Restoration Center, Coral Reef Conservation Program, and Protected Resources Division in collaboration with The Nature Conservancy, Sociedad Ambiente Marino, HJR Reefscaping, Sea Ventures, Vegabajeños Impulsando Desarrollo Ambiental Sustentable (VIDAS), and the University of Puerto Rico.

Introduction

Both *Acropora cervicornis* and *A. palmata* have suffered dramatic declines throughout the entire Caribbean over the last few decades (Bruckner, 2002) which led to the inclusion of these species as "Threatened" under the Endangered Species Act in 2005. As a result of this decline, adult populations typically have low densities and genetic diversity, resulting in a reduction in genetic connectivity for this genus. The life history traits of this genus (fast growth rates and highly successful asexual propagation through fragmentation) have shown these species to be good candidates for coral nursery programs in the Caribbean (Highsmith, 1982; Lirman, 2010). As these populations continue to decline, proactive intervention is becoming increasingly warranted (Edwards and Clark, 1998).

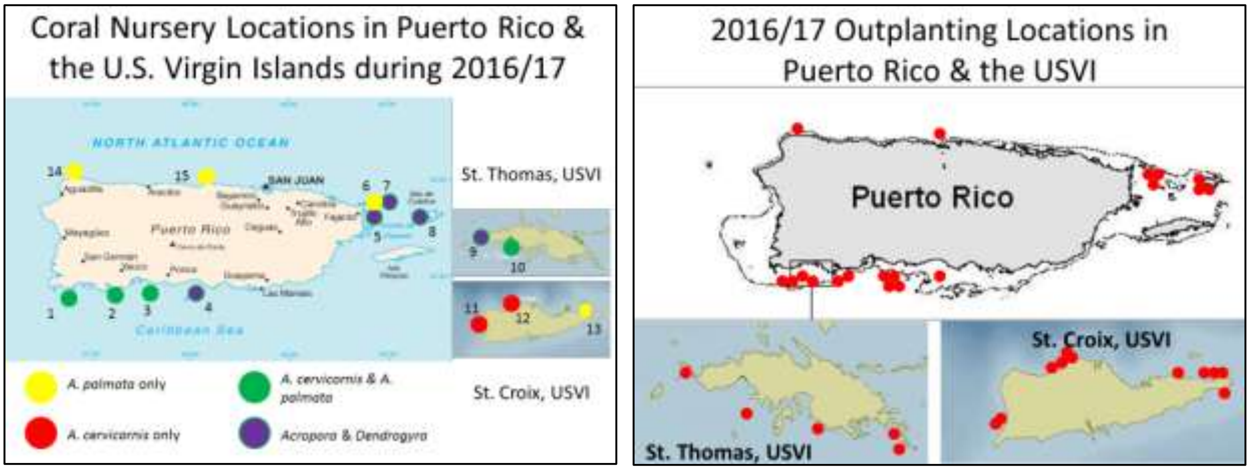

Figure 1: Location of coral nursery operations (figure on left) in Puerto Rico and the U.S Virgin Islands during 2017: 1) La Parguera (Atravesado, Margarita east and west, San Cristobal), 2) Guanica (Cayo Coral east and west, Andrea), 3) Guayanilla, 4) Cayo Berberia (East, West and Outer Bank), 5) Palomino (Sea Bass and Palominitos, 6) Lobos, 7) Diablo east and west, 8) Culebra (Bahía Tamarindo, Tamarindo Chico, Punta Soldado), 9) West Cay, 10) Flat Cay, 11) Fredericksted, 12) Cane Bay, 13) Teague Bay, 14) Shacks and 15) Vega Baja. Outplanting locations (figure on right) in Puerto Rico and the USVI during 2016/17. Red dots represent approximate locations of outplanting efforts.

Over the past 20 years, nursery operations have expanded exponentially from just two nurseries in Culebra to 26 nurseries across Puerto Rico and the USVI (Figure 1), with funding from NOAA's Coral Reef Conservation Program, the Restoration Center, and Protected Resources Division, the American Recovery and Reinvestment Act, and in collaboration with The Nature Conservancy, Sociedad Ambiente Marino, HJR Reefscaping, Sea Ventures, VIDAs, University of Puerto Rico, and the Gulf of Mexico Foundation. The majority of collected corals are "fragments of opportunity" (Figure 2) that have previously broken from the donor colony by natural events and/ or ship groundings, and are lying in sand or sea grass areas where they are not likely to survive (Lirman, 2000). When fragments are collected from whole colonies of *Acropora cervicornis* and *Acropora palmata*, they are collected from large healthy colonies with a minimum diameter of 1 meter and from reefs where there are healthy stands of *A. cervicornis* and *A. palmata.* Donor colonies usually recover in 3-6 weeks and show no additional mortality or disease after having the fragments removed (Lirman et al., 2010).

After establishment of a nursery during the first year, no additional coral collection is usually needed to expand the nurseries as the nursery sites will produce enough coral tissue *in situ* for both expansion and outplanting. Each year, coral outplants are transplanted from the nurseries to reefs impacted by groundings, storms or other physical impacts to aid in the restoration of the damaged reefs. Corals are also transplanted to reefs where populations were once prevalent but have declined in the past few decades because of disease outbreaks, storms and/or bleaching events to assist in the recovery of the coral populations. During outplanting, corals with different genotypes are clustered together to increase the chances for sexual reproduction of these species in the field. As mentioned previously, there has been a reduction in genetic connectivity for these species. The establishment of "reproductive thickets" may help increase connectivity in some areas (Lirman et al., 2010), and outplanting efforts in some areas have already succeeded at creating self-sustaining thickets (Griffin et al., 2015; Appendix III).

Figure 2: Examples of *A. palmata* fragments found in sand and sea grass that have a low probability of survival due to burial and abrasion by sediment. Segments of partial mortality can be seen on most fragments.

Methods

***Acropora cervicornis* Nurseries**

Once at the nursery site, collected *A. cervicornis* fragments are mounted on a variety of structures to promote growth and survival. Traditional methods included blocks, wire cages, and A-frames, but nurseries throughout the region are switching over to floating nurseries which include "Floating Underwater Coral Arrays" (FUCAs), Horizontal Line Nurseries (HLN) or Tables, or Trees (Figures 3 and 4). Floating nurseries have been shown to promote higher survival and growth rates compared to their benthic counterparts (Griffin et al., 2012; Hernández-Delgado et al., 2014). There is less disease due to the lack of predators on line nurseries and better water circulation. Line nurseries are also more durable during storm conditions and have withstood swells of at least 20 feet. Because of the low maintenance required for line nurseries, operational funds can focus on outplanting and nursery expansion.

Figure 3: Photos showing a typical 5' x 10' line nursery set up (left) and a tree (right).

Figure 4: Photos showing a typical 10' x 10' horizontal line nursery set up (left) and a one year old out-planted patch (right). (Photos from SAM)

***Acropora palmata* Nurseries**

Once *A. palmata* fragments are brought back to the nurseries, they are attached to structures in the nursery where they are allowed to recover. This typically involves cutting the corals into 5-10 cm fragments, growing them in the nursery for 1-2 years and then outplanting these colonies onto the reef. Nursery structures for *A. palmata* typically include blocks, BUCAs and PVC trees (Figures 5 and 6) although work is moving away from the blocks and focusing more on trees since they require less maintenance, are more resilient to storms, and have higher survival and growth rates. After a year in the nursery, new growth on these colonies can be used for creating additional colonies for outplanting.

Figure 5: Example of *A. palmata* being grown out blocks (left, photo TNC) and PVC trees (right, photo NOAA).

Figure 6: *A. palmata* fragments attached to concrete pucks placed in BUCAs made of PVC (left photo) and ready for outplanting after one year in the nursery (right photo).

Dendrogyra cylindrus **methods**

By adding tiles to the tops of the branches on the trees, we are now propagating *Dendrogyra cylindrus* in the nurseries (Figure 7). At-risk fragments are brought back to the nurseries. They are cut into 3-5cm pieces using a coral band saw with a diamond blade and mounted with epoxy onto PVC tiles (5cm x 5cm) that are bolted to holes in the tree branches. After a year or so, once the coral tissue has grown down to the tiles, the *D. cylindrus* colonies are ready for outplanting. They should be outplanted before the tissue has a chance to spill over the edges of the tiles and start fusing with the branches of the tree. If this happens, some of the coral tissue will be damaged when removing the corals from the tree. The corals can either be removed from the tiles or outplanted with the tiles. Epoxy or cement can be used to attached the corals to the reef, although cement is cheaper and stronger than epoxy. Outplant survival has been high (>90%), and this work is being scaled up in the nurseries across the region to increase the species diversity.

Figure 7: *Dendrogyra cylindrus* growing on trees in the nurseries.

Outplanting Design and Criteria

Colonies to be outplanted from nurseries onto the reef will meet the following set of criteria:

1) For *A. cervicornis*, have at least 10 cm of linear growth
2) For *A. palmata*, be at least 10 cm in diameter
3) Show no visible signs of disease or injury
4) Have 100% live tissue
5) Show robust coloration, suggesting good health

All corals will be outplanted using one of the following field-tested methods:

1) On a cement puck or disk that is securely fastened to the substrate.
2) Securely fastened to a nail that is driven into the substrate.
3) Securely fastened directly to the substrate
4) Stabilized into the reef using natural crevices or holes.

Site selection will be highly region-specific but the following general guidelines will be applied when selecting outplanting sites:

1) Suitable reef habitat and/or historic presence of the species (in recent decades).
2) Healthy environment for the given region
3) Part of restoration following physical impacts.
4) Increase genetic diversity at sites where there is low genetic diversity to increase chances of sexual reproductive success
5) Not within any permitted marine and coastal construction areas (i.e. dredging, beach nourishment projects, etc.)

Basic guidelines for the outplanting design for each nursery's core sites include:

1) Avoid dominance of one genotype at each site.
2) Maximize the diversity of genotypes from the available stock.
3) Outplant at a diversity of sites to minimize risk.
4) Allow for some manipulation of site design to allow for research.

Outplanting Success Rates and Monitoring

Various sites have met with different levels of success depending on a variety of environmental parameters that can sometimes be hard to predict (water quality, predation, disease, sedimentation, bleaching events, etc.). At times, areas that are previously thought to be perfect sites for outplanting, don't have much success while other sites that don't look promising, corals thrive. Because of the difficulty in predicting outcomes, a small scale initial outplanting of 25-50 colonies is typically performed at new sites. These corals are monitored for a year, and depending on their success and survival, a decision will be made to proceed with additional outplanting or focus efforts elsewhere. During the first year, acceptable survival rates are generally >80% while the more successful sites have survival rates that are >90%. Initial monitoring normally focuses on individual growth rates, percent tissue mortality, fusion to the substrate, survival and health. Monitoring at the level of an individual colony becomes more complicated over the longer term as corals grow larger and fuse together or intertwine, tags are hard to relocate as they are grown over by the newly formed thickets or large colonies, new colonies are created through fragmentation, etc. Longer term monitoring needs to focus on the overall health of clusters and thickets, their size (expansion or reduction) and asexual recruitment. Photos and photomosaics are very useful for this type of monitoring (Griffin et al., 2015). For example, if 10 colonies (20 cm in diameter) are outplanted and only 50% survive after 5 years, this may initially sound like a poor success rate. Yet, these colonies/clusters may now be over 1 meter in diameter, they are likely to be sexually reproductive and there may also be many asexual recruits that have broken off from the original colonies and created new colonies. The amount of coral tissue/biomass is greater than what was there prior to outplanting and greater than the amount of biomass that was initially outplanted. Figure 8 shows an example of a successful outplanting site at Vega Baja in Puerto Rico after 6 years of growth. In 2008, storm generated fragments of *A. palmata* averaging 10-20cm in diameter were stabilized *in situ* by wedging fragments into crevices and holes in the reef. At the time, there were no other colonies of *A. palmata* in that section of reef. In 2014, many of the stabilized colonies were over 1 meter in diameter. Another example of a long term before and after monitoring using photomosaics can be found in Appendix III.

Figure 8: Example of a successful outplanting site at Vega Baja, Puerto Rico. In 2008, storm generated fragments of *A. palmata* averaging 10-20cm in diameter were stabilized in an area where there were no other colonies of *A. palmata.* In 2014 (shown here), many colonies were over 1 meter in diameter.

Ouplanting Effects on Fish Communities

Preliminary data analysis on fish communities collected separately at the Culebra and the Guayanilla sites suggest that fish density and diversity are significantly higher at the outplant sites, particularly for juvenile fishes. Data collected to date from grounding sites in Guayanilla has shown that impacted areas with no restoration have the lowest biomass and diversity. Areas that have been restored using traditional methods of coral reattachment and rebuilding the reef structure are showing similar densities and diversity to reference areas that were not impacted. Areas that were restored using the same methods, but incorporated *A. cervicornis* outplants into the restoration design show higher densities and diversity than the other sites in Guayanilla.

The data from Culebra suggests that outplanting sites have higher fish biomass and diversity than reference sites. Sites within the MPA have higher fish biomass and diversity compared to sites outside the MPA showing the effectiveness of management in that area. Outplanting sites within the MPA have higher fish densities and diversity than areas within the MPA with no outplants. Herbivore guilds have also shown a significant increase within restored sites in comparison to areas with no outplants. Also restored sites within the MPA have shown larger herbivore abundance and biomass than outside the reserve.

Future Focus and Needs

One way to help scale up coral propagation efforts is to ramp up response and restoration to large scale physical impacts like hurricanes and swells. As mentioned previously, these events create thousands of fragments of opportunity for both *A. palmata* and *A. cervicornis*. These fragments can either be brought into nursery or reattached directly back onto the reef (either the same reef or another reef). The latter option has the potential for significant cost savings; but since it is more opportunistic, this should not be a substitute for established nurseries which can propagate corals at a predetermined rate.

In the fall of 2016 Hurricane Matthews caused extensive damage to *Acropora palmata* thickets off Gilligan's Island in Guanica, PR. Many of the colonies were still intact and since there was a lot of *A. palmata* on this particular reef, the at-risk fragments were used to assist population recovery on other reefs where Acropora populations had died off or were suffering. 8,500 *A. palmata* fragments were rescued and transplanted to 11 other reefs in Guanica and La Parguera (Figure 9). In February, 2017, the M/V Noemi grounded on the north coast of Palomino Island off the east coast of Puerto Rico causing extensive damage to an *A. palmata thicket*. It was difficult to conduct any reattachment at this site due to exposure to wind and waves. As with the Gilligan's site, there were still a lot of intact, live *A* palmata at the site; so 2,500 at-risk loose fragments were transplanted to 10 different reefs in the NE Reserve and Culebra (Figure 9). In both cases, *A. palmata* fragments were also brought into nurseries in La Parguera, Guanica, Culebra and the NE Reserve.

Summary

During 2016/17, there were approximately 12,000 corals being maintained in the nurseries throughout the region. During this time, over 12,500 corals were outplanted from the nurseries to over 30 different coral reef sites. In addition, 11,000 at-risk fragments of *A. palmata* created by Hurricane Matthew and the M/V Noemi grounding were transplanted to over 20 different sites. Funding for this work was provided from NOAA's Restoration Center, Coral Reef Conservation Program, and Protected Resources Division in collaboration with The Nature Conservancy, Sociedad Ambiente Marino, HJR Reefscaping, Sea Ventures, VIDAs, and the University of Puerto Rico. In addition to the research referenced this report, the nursery-reared corals and outplanting sites are also being leveraged for research by other partners. Future funding availability will determine how these nurseries continue to operate. As unforeseen circumstances arise, such as ship groundings or storm events, where significant fragments of opportunity become available, there may be a need to create nurseries in other areas; either temporary or permanent. All additional nursery locations or changes will be included in annual reporting and permit renewal proposals. Funding availability will determine how many corals will be outplanted in 2016 and beyond.

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Appendix I

Description of nurseries in Puerto Rico during 2016/17

Location	# of sites	Start-up Date	Primary Operator	Species	# of corals in Nursery	# of outplants in 2016/17	Notes
Caja de Muertos	1	2015	NOAA RC, Sea Ventures	*A. cervicornis*	10 A. cerv.	0	DRNA requested a nursery. Still trying to locate an adequate site for a nursery.
Culebra, PR	3	2003	SAM & UPR	*A. cervicornis, A. palmata, D. cylidricus*	4,450 A. cerv ¿ A. palm	2,000 Ac 250 Ap	
Guánica, PR	3	2012	NOAA RC, Sea Ventures, HJR Reefscaping	*A. cervicornis & A. palmata*	500 A. cerv 500 A. palm	50	
Guayanilla, PR	1	2007	NOAA RC, Sea Ventures	*A. cervicornis; D. cylidricus other Non-Acroporids*	1,800 A. cerv	2,000	
La Parguera, PR	4	2011	NOAA RC, Sea Ventures, HJR Reefscaping	*A. cervicornis & A. palmata*	500 A. cerv 500 A. palm	1,000	
NE Reserve	5	2015	Sea Ventures, NOAA RC	*A. cervicornis, A. palmata, D. cylidricus*	2,000	350	
Shacks	1	2017	Rescate Playas	*A. palmata*	50 A. palm	0	Experimental site

Appendix II

Description of nurseries in U.S. Virgin Islands during 2016/17

Location	Start-up Date	Primary Operator	Species	# of corals in Nursery	# of outplants in 2016/17	Notes
West Cay, St. Thomas	2013	The Nature Conservancy	*A. cervicornis, A. palmata, D. cylidricus*	1,000	2,300	
Flat Cay, St. Thomas	2009	The Nature Conservancy	*A. cervicornis*	350	700	
Cane Bay, St. Croix	2009	The Nature Conservancy	*A. cervicornis*	1,750	1,368	Excellent site for outreach and education. Highly accessible to public.
Fredericksted, St. Croix	2013	The Nature Conservancy	*A. cervicornis*	1,850	1,955	
Teague Bay, St. Croix	2009	The Nature Conservancy	*A. palmata*	500	75	

Appendix III

Reef sites

Restoration using *Acropora cervicornis* at the T/V MARGARA grounding site

Fig. 1 Patch reef impacted by grounding in 2006 during initial restoration (a) and in January 2015 (b). Both photographs were taken from the north end of the same patch reef looking south

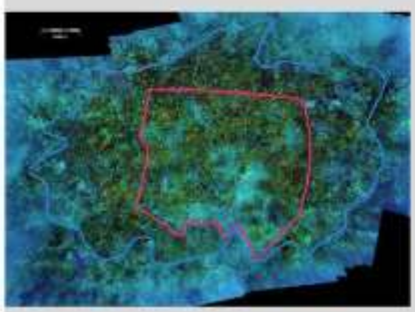

Fig. 2 Photomosaic taken in July 2014. *Red polygon* shows the original impact; *blue polygon* estimates the extent of expansion

On 27 April 2006, a 228-m oil tanker, the T/V MARGARA, grounded on coral reefs in Tallaboa, Puerto Rico, damaging approximately 7500 m^2 of reef. The photographs in Fig. 1 demonstrate the success of restoration on one patch reef at the site that used a combination of reattaching loose corals, stabilizing rubble, and outplanting *Acropora cervicornis* from a nearby coral nursery. Restoration was performed sporadically on this reef from 2006 through 2011. Initial work from 2006 to 2008 was undertaken and funded by the responsible party. Surveys by divers during the injury assessment found no *A. cervicornis* on this particular patch reef prior to restoration, although it was observed in other areas of the grounding site. In 2006, ~227 (10–20 cm) fragments of *A. cervicornis* found elsewhere in the grounding site were transferred to this patch reef and attached to wire cages and cement puddles with stakes. From 2009 through 2011, ~400 (20–40 cm) colonies were outplanted from the nursery using masonry nails, cable ties, and/or epoxy. Restoration took place within the impacted section of the patch reef (~70 m^2), but *A. cervicornis* colonies can now be found in ~180 m^2 of reef (Fig. 2).

The *A. cervicornis* outplanted at the site have developed into a self-sustaining thicket that has been expanding via asexual reproduction and has withstood impacts from several hurricanes and swells reaching 6 m. Other areas of the grounding site with similar characteristics in 2006 that have not yet been restored (loose rubble, unconsolidated substrate) have shown little to no recovery in the last 8 yr due to the high mortality of coral recruits in rubble fields (NOAA 2015).

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Reference

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