Acropora Nursery Operations in Puerto Rico and the U.S. Virgin Islands

2014 Annual Report

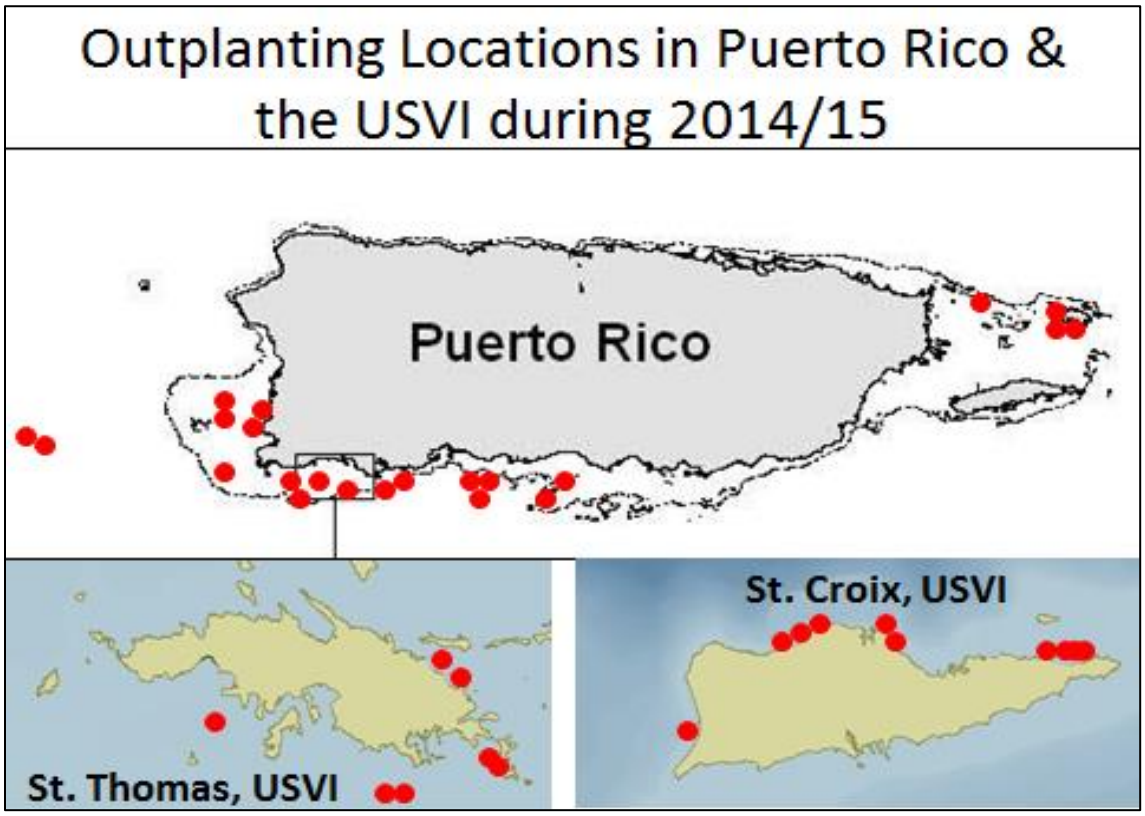

Figure 1: *Acropora* outplanting locations in Puerto Rico and the USVI during 2014/15. Red dots represent approximate locations of outplanting efforts.

Abstract

Over 16,000 corals were outplanted from coral nurseries in Puerto Rico and the US Virgin Islands during 2014/15. Corals were transplanted to over 30 sites across the region (Figure 1). Over the past 5 years, nursery operations have expanded exponentially from just two nurseries in Culebra to 11 nurseries across the region. The number of corals in nursery increased from 14,000 in 2013/14 to over 17,000 in 2014/15. The locations of the nurseries are located on the map in Figure 2 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), University of Puerto Rico, and the Gulf of Mexico Foundation.

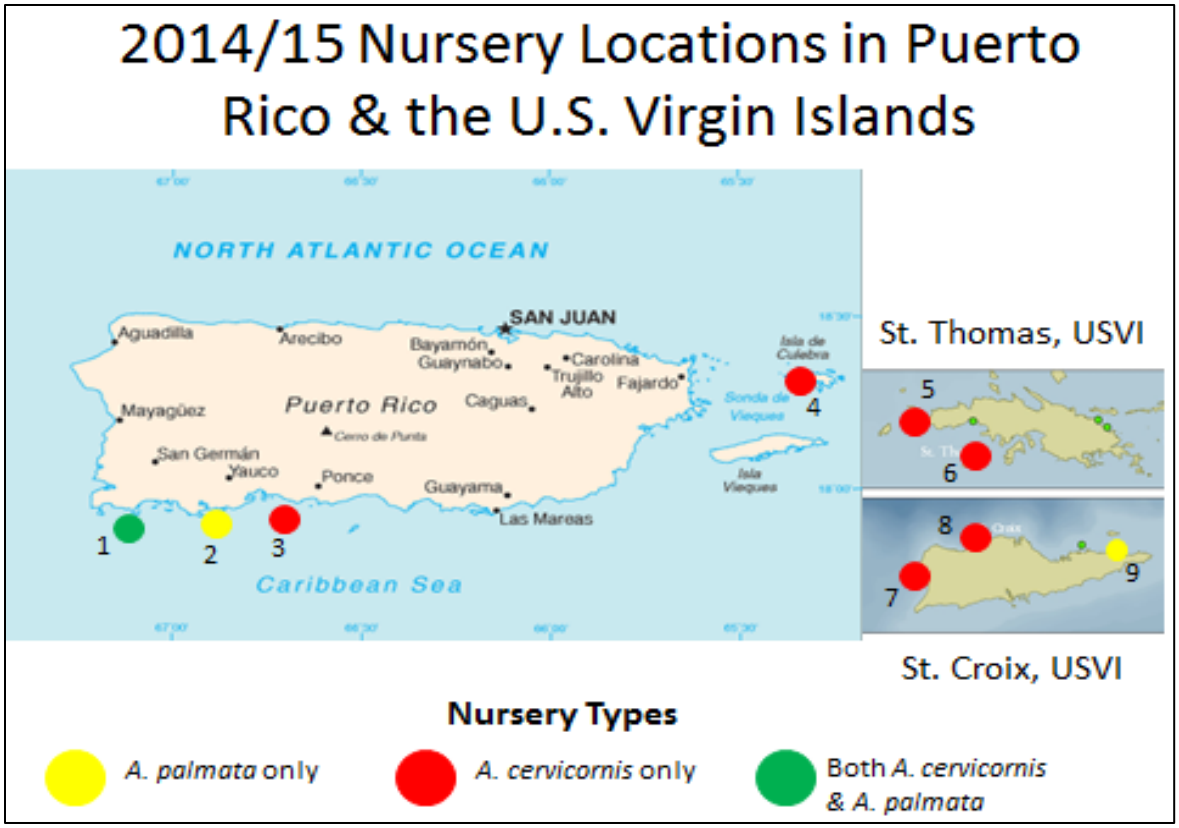

Figure 2: Location of coral nursery operations in Puerto Rico and the U.S Virgin Islands during 2014: 1) La Parguera (Margarita, San Christobal), 2) Guanica, 3) Guayanilla, 4) Culebra (Bahía Tamarindo, Punta Soldado), 5) West Cay, 6) Flat Cay, 7) Fredericksted, 8) Cane Bay, and 9) Teague Bay

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).

Over the past 5 years, nursery operations have expanded exponentially from just two nurseries in Culebra to 11 nurseries across the region (Figure 2), 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 3) 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 defined as having 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). Collected fragments are either transported underwater to nearby nurseries or placed in bins with seawater on board a vessel if they need to be transported by boat to the nursery sites. The seawater is changed regularly and the bins remain shaded during transit.

Figure 3: 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.

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 or other physical impacts to aid in the restoration of the damaged reefs or transplanted to reefs where populations were once prevalent but have declined in the past few decades because of disease outbreaks and/or bleaching events to assist in the recovery of the coral populations.

Once fragments are established in the nurseries, genetic sampling will be performed on the nursery colonies. One cm^2 tissue samples will be collected from each clone for genotyping. These samples will be stored in vials with ethanol and sent off to a lab to be analyzed. If it is determined that a particular nursery does not have high genetic diversity, then additional fragments may be collected from the wild to increase genetic diversity in the nursery. 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, 2010), and outplanting efforts in some areas have already succeeded at creating self-sustaining thickets (Griffin et al., 2015; Appendix III).

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 4-5). 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 4: Photos showing a typical 5’ x 10’ line nursery set up (left) and a tree (right).

Figure 5: Photos showing a typical 10' x 10' horizontal line nursery set up (left) and a one year old out-planted patch (right).

***Acropora palmata* Nurseries**

Fragments of *A. palmata* that are broken off during storm events or ship groundings can settle back on the reef and grow into new asexual recruits, or they are swept off the reef into sand and sea grass beds where they have low rates of survival (Lirman, 2000). Each year, there are thousands of these fragments that are lost to abrasion and burial by sediment in these less ideal habitats (Figure 3). There is a significant opportunity here to save some of these fragments and use them for creating *A. palmata* nurseries in Puerto Rico. The fragments can be brought into nurseries and used as brood stock for the nursery. There is virtually no real take from the environment since these fragments would have otherwise perished if left where they were. Several reefs around Puerto Rico and the Virgin Islands have been identified where there is frequent breakage from either storm events or the usual high wave events experienced each year. These sites could provide the coral fragments needed to start up additional new nurseries in Puerto Rico and the Virgin Islands. Rather than being brought back to a nursery, coral fragments can also be reattached *in situ* to increase to the number of colonies at each of these sites.

Because of the weight of *A. palmata,* this species is not typically grown out on line 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. These structures typically include blocks and PVC tubes. After a year in the nursery, new growth on these colonies can be used for creating additional colonies for outplanting. This typically involves cutting tissues into 2-5 cm fragments or wafers, attaching them to a cement puck, allowing them to grow in the nursery for 1-2 years and then outplanting these colonies onto the reef (Figure 6). Another option is that the fragments can be brought into the nursery, fragmented immediately, attached to pucks and then grown out for either outplanting and/or used for nursery expansion.

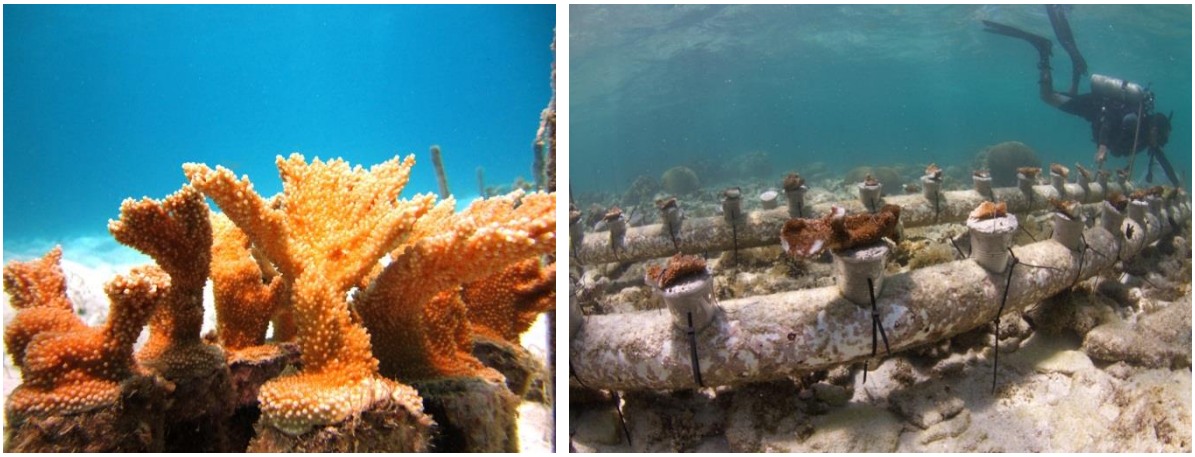

Figure 6: Example of *A. palmata* being grown out blocks in St. Croix, USVI and PVC tubes in Guanica, Puerto Rico.

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 7 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 7: Example of a successful outplanting site at Vega Baja, Puerto Rico. Storm generated fragments of *A. palmata* averaging 10-20cm in diameter were stabilized in 2008 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

The existing nurseries are having a positive significant impact on coral reefs within their respective geographical areas (i.e. Culebra, Guayanilla, La Parguera, St. Thomas, St. Croix). But in order to expand these efforts into new areas to further ESA species recovery plan goals, new nurseries will need to be

established. Logistically, it becomes more difficult to outplant a significant number of corals beyond a 5nm radius. It can, and has, been done successfully and should continue, especially in an attempt to look for potential future outplanting and nursery locations; as well as to increase genetic diversity. But if there is going to be a sustained large scale effort to outplant to locations beyond 5nm from the existing nurseries, it would be better (both logistically and economically) to establish new nurseries that are closer to those locations, if a suitable location exists. This reduces the amount of time, cost and exposure to weather for safe boat and dive ops (transporting corals is not a concern) required for these efforts. For example, given the recent emphasis on Culebra and the Northeast Reserves as a Habitat Focus Area, in order to ramp up outplanting efforts in the Northeast Reserves, new nurseries should be established within La Cordillera reserve. The same goes for Caja de Muertos and Guánica. The nursery in Guaynilla can outplant corals to these locations, but it would be easier to set up new nurseries in Guánica and Caja de Muertos to support a focused effort to restore those reefs to meet recovery plan criteria. For more focused efforts, the concept of "pop-up nurseries" can be implemented where restoration structures are located at the same reef location where the outplanting will occur and then removed a few years later after that site is restored. This allows corals to never leave the water and will significantly increase daily outplanting production. Similar focused efforts have been done after groundings when fragments are temporarily cached on nursery structures until the impact site has been stabilized and is ready for corals to be reattached. In order to accomplish these goals, more funding than was available in 2014 will need to be invested.

Summary

During 2014/15, the number of corals in nurseries in Puerto Rico and the U.S. Virgin Islands reached over 17,000 colonies in nurseries throughout the region. During this time, over 16,000 corals were outplanted from the nurseries to over 30 different coral reef sites. This is double the amount of corals that were outplanted in 2013/14. The nurseries at Lindquist Bay and Coki Point in St. Thomas were shut down because conditions were not optimal at those sites. The corals from those nurseries were either outplanted or moved to other nurseries where conditions were more favorable. After transplanting the corals, the nurseries were dismantled and all of the materials were removed from the 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, University of Puerto Rico, and the Gulf of Mexico Foundation. In addition 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 2015 and beyond.

References

Bruckner AW (2002) Proceedings of the Caribbean Acropora Workshop. Potential application of the U.S. Endangered Species Act as a conservation strategy: April 16-18, 2002, Miami, Florida. NOAA Technical Memorandum. NMFS-OPR-24 Silver Spring, MD. p 184

Edmunds AJ, Clark S (1998) Coral transplantation: a useful management tool or misguided meddling? Mar Poll Bull 37:474-488

Griffin SP, Spathias H, Moore TD, Baums I, Griffin BA (2012) Scaling up *Acropora* nurseries in the Caribbean and improving techniques. Proceedings of the 12th International Coral Reef Symposium.

Griffin SP, Nemeth MI, Moore TD, Gintert B. 2015. Restoration using *Acropora cervicornis* at the T/V MARGARA grounding site. Coral Reefs 34:855.

Hernández-Delgado, E.A., A.E. Mercado-Molina, P.J. Alejandro-Camis, F. Candelas-Sánchez, J.S. Fonseca-Miranda, C.M. González-Ramos, R. Guzmán-Rodríguez, P. Mège, A.A. Montañez-Acuña, I. Olivo-Maldonado, A. Otaño-Cruz, & S.E. Suleimán-Ramos. 2014. Community-based coral reef rehabilitation in a changing climate: Lessons learned from hurricanes, extreme rainfall, and changing land use impacts. Open J. Ecol. 4(14):918-944.

Highsmith RC (1982) Reproduction by fragmentation in corals. Mar Ecol Prog Ser 7:207-226

Lirman D (2000) Fragmentation in the branching coral Acropora palmata (Lamarck): growth, survivorship, and reproduction of colonies and fragments. J Exp Mar Bio Ecol 251:41-57.

Lirman D, Thyberg T, Herlan J, Hill C, Young-Lahiff C, Schopmeyer S, Huntington B, Santos R, Drury C (2010) Propagation of the threatened staghorn coral *Acropora cervicornis*: methods to minimize the impacts of fragment collection and maximize production. Coral Reefs. 29: 729-735.

Appendix I

Description of nurseries in Puerto Rico during 2014/15

Location	Start-up Date	Primary Operator	Species	# of corals in Nursery	# of outplants in 2014/15	Future Annual # outplants	Notes
La Parguera, PR	2011	HJR Reefscaping	*A. cervicornis & A. palmata*	2,200	1,600	1,600	
Guánica, PR	2012	NOAA RC, Sea Ventures, HJR Reefscaping	*A. palmata*	150	50	150	Nurseries were set up after Hurricanes Ernesto and Isaac caused extensive damage to *A. palmata* thickets in the area. *Approximately 800 fragments of opportunity were stabilized *in situ*.
Guayanilla, PR	2007	NOAA RC	*A. cervicornis*	2,000	1,500	1,600	Nursery set up after the M/V Margara grounding.
Culebra, PR	2003	SAM & UPR	*A. cervicornis*	2,000	3,000	3,000	Excellent sites for outreach and education. Highly accessible to public.

Appendix II

Description of nurseries in U.S. Virgin Islands during 2014/15

Location	Start-up Date	Primary Operator	Species	# of corals in Nursery	# of outplants in 2014/15	Future Annual # outplants	Notes
West Cay, St. Thomas	2013	The Nature Conservancy	*A. cervicornis & A. palmata*	3,000	2,630	2,750	
Flat Cay, St. Thomas	2009	The Nature Conservancy	*A. cervicornis*	1,250	1,000	1,000	
Coki Point, St. Thomas	2009	The Nature Conservancy	*A. cervicornis*	140	200	0	Small exhibition site at aquarium in St. Thomas. Conditions at the site were not optimal. Nursery was dismantled.
Lindquist Bay, St. Thomas	2009	The Nature Conservancy	*A. cervicornis*	1,070	1,070	0	Nursery was dismantled in April 2015. Conditions at the site were not optimal. Too much maintenance required.
Cane Bay, St. Croix	2009	The Nature Conservancy	*A. cervicornis*	2,500	2,747	2,500	Excellent site for outreach and education. Highly accessible to public.
Fredericksted, St. Croix	2013	The Nature Conservancy	*A. cervicornis*	2,500	2,744	2,700	
Teague Bay, St. Croix	2009	The Nature Conservancy	*A. palmata*	350	323	320	

Appendix III

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

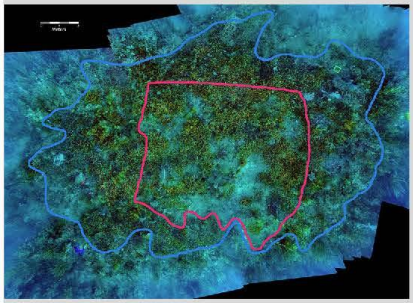

Fig. 2 Photomosaic taken in July 2014. *Red polygon* shows the original impact; *blue polygon* estimates the extent of expansion

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).

Acknowledgments We would like to thank Pedro Rodriguez and Sea Ventures, Inc for providing logistical support for work at this site over the last 10 yr. We would also like to thank Art Gleason at the University of Miami for processing the photomosaic.

Reference

NOAA (2015) Final primary restoration plan and environmental assessment for the 2006 T/V MARGARA grounding. pp 59. http://www.darrp.noaa.gov/southeast/margara/admin.html

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