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Introduction

Staghorn coral *Acropora cervicornis* and elkhorn coral *Acropora palmata* were once dominant reef-building coral species in the Caribbean. However, since the 1970s, populations have undergone dramatic declines due to a number of stressors including disease, storm damage, and reductions in herbivory that allow algae to outcompete corals. In 2006, *A. palmata* and *A. cervicornis* were listed as threatened under the U.S. Endangered Species Act (71 FR 26852; May 9, 2006).

Successful sexual recruitment is one of the factors that affects the ability of *A. palmata* and *A. cervicornis* to recover from population declines. Both species are hermaphroditic broadcast spawners, but they do not self-fertilize. Reduced population sizes, reduced genotypic diversity, and gamete incompatibility of some genotypes affect successful fertilization. Coral nurseries are a popular method used to produce colonies that are outplanted to coral reefs to boost abundance and genotypic diversity at local sites and increase the likelihood of successful sexual reproduction.

Multiple organizations operate coral nurseries within the U.S. jurisdiction of Florida, Puerto Rico, and the Virgin Islands (Table 1). Each organization has its own goals and objectives with some more focused on outplanting to answer research questions and others more focused on growing corals predominantly for population enhancement purposes. Because of the vast numbers of corals being outplanted and the multiple organizations involved, NOAA Fisheries began to compile outplanting data in a central location to gain a broader perspective on all the work being done and to help evaluate population status as required under the Endangered Species Act.

Methods

Acropora species outplant data were gathered from permit reports and information requests to coral nursery operators. Information sought included outplant site name and geographic coordinates, species and number of colonies outplanted, outplant date, name of organization, and identification of presumed[1] genotypes outplanted. Data on outplant survival rates were also recorded. However, because survival rates available at the time data were reported were usually for a short duration (≤3 months) and were difficult to assign to a particular outplant event over a longer time frame, survival data were not well tracked in the dataset[2] and are not included in this

[1] Nursery operators give colonies collected from the wild an identification code that is used to track offspring propagated from the originally collected colony. Colonies separated by a great enough distance are presumed to be different genotypes and given different identification codes at the time of collection. However, sometimes genetic analysis indicates that colonies presumed to be different genotypes are actually clones of the same genotype.

[2] Monitoring of outplant efforts is moving away from individual colony fate tracking and toward site-level surveys, which will be included in the dataset in the future. Site level surveys will be more representative of restoration

report. Data were entered into a Microsoft Excel spreadsheet, and pivot tables were developed to summarize the information on number and species of outplants. Location data were exported and used to make maps using ArcMap. The information presented in this report covers *Acropora* species outplanted within U.S. jurisdiction for the period of 1993 to 2017.

Table 1. Organizations currently operating coral nurseries within U.S. jurisdiction. FL=Florida, USVI=U.S. Virgin Islands, PR=Puerto Rico.

Nursery Operators	Location
Nova Southeastern University	FL
University of Miami	FL
Coral Restoration Foundation	FL
Florida Wildlife Conservation Commission	FL
Mote Marine Laboratory	FL
The Nature Conservancy	FL; USVI
University of the Virgin Islands	USVI
NOAA Restoration Center	PR; USVI
Sea Ventures, Inc.	PR; USVI
HJR Reefscaping	PR
Sociedad Ambiente Marino	PR
VIDAS	PR

Results

Number of Outplants

Hundreds of thousands of coral colonies have been outplanted since coral nursery efforts first began, and nursery operators aim to outplant as many genotypes per site as they can to increase genetic diversity. Approximately 360 presumed genotypes of *Acropora* have been propagated in coral nurseries to date. Over 129,000 *Acropora* colonies were outplanted in Florida between 2003 and 2017 (Table 2). Between 2012 and 2017, over 22,000 colonies of *Acropora* were outplanted in the U.S. Virgin Islands, and over 95,000 *Acropora* colonies were outplanted in Puerto Rico between 1993 and 2017. It is difficult to estimate the exact number of corals outplanted since corals can fragment or break during transport and handling. Therefore, the number of outplanted colonies is approximate. Additionally, size of colonies outplanted may vary so that estimates of numbers of outplanted colonies do not necessarily represent similar amounts of live tissue from colony to colony. Colonies were primarily attached to the substrate

success because these species tend to break and reattach, making survival at the colony level less informative than at the site level.

using epoxy or cement, attached to nails with zip ties, or were attached using a combination of epoxy and nails. In some instances, corals were outplanted without attaching them directly to the substrate, or other methods were used. A general trend has been to develop methods to increase the efficiency in outplanting operations in order to increase the scale of restoration efforts and maximize ecological benefit.

Table 2. Number of *Acropora* colonies outplanted by year in each jurisdiction. FL=Florida, USVI=U.S. Virgin Islands, PR=Puerto Rico.

Year	FL	USVI	PR
1993			100
1994			200
1995			900
1996			500
1997			100
2003	6		4,500
2004			4,500
2005			8,500
2006			4,500
2007	18		4,500
2008	187		5,000
2009	296		5,100
2010	469		5,300
2011	575		5,893
2012	6,219	1,022	7,050
2013	13,927	1,450	7,800
2014	17,903	2,373	7,850
2015	35,402	10,514	7,810
2016	27,523	6,398	7,650
2017	26,557	423	8,177
Grand Total	**129,082**	**22,180**	**95,930**

During the period of 1993 to 2017, all coral nursery efforts focused predominantly on producing *A. cervicornis*, and only some had *A. palmata* in production. Thus, the vast majority of colonies outplanted between 1993 and 2017 were *A. cervicornis* (Table 3). However, there has recently been a shift to propagate more *A. palmata* in nurseries, and future outplant numbers should reflect a higher proportion of *A. palmata*. One coral nursery outplanted *Acropora prolifera*, a naturally occurring hybrid of *A. cervicornis* and *A. palmata*.

Table 3. Species outplanted within U.S. jurisdiction. FL=Florida, USVI=U.S. Virgin Islands, PR=Puerto Rico.

Species	FL	USVI	PR
A. cervicornis	121,198	21,003	84,410
A. palmata	7,869	1,177	11,520
A. prolifera	15	0	0
Grand Total	**129,082**	**22,180**	**95,930**

Outplant Locations

Florida

There were a total of 146 reefs, ranging from off Ft. Lauderdale down to the Dry Tortugas, that received outplants (Figure 1). *Acropora cervicornis* was outplanted across this whole range. *Acropora palmata* outplant locations occurred predominantly in the upper Florida Keys, and a few colonies of *A. prolifera* were outplanted in the Dry Tortugas. Most reefs received fewer than 500 outplanted colonies (Table 4), though some reefs received upwards of 5,000 colonies (Figure 2). The largest number of outplants per reef was over 15,700 colonies.

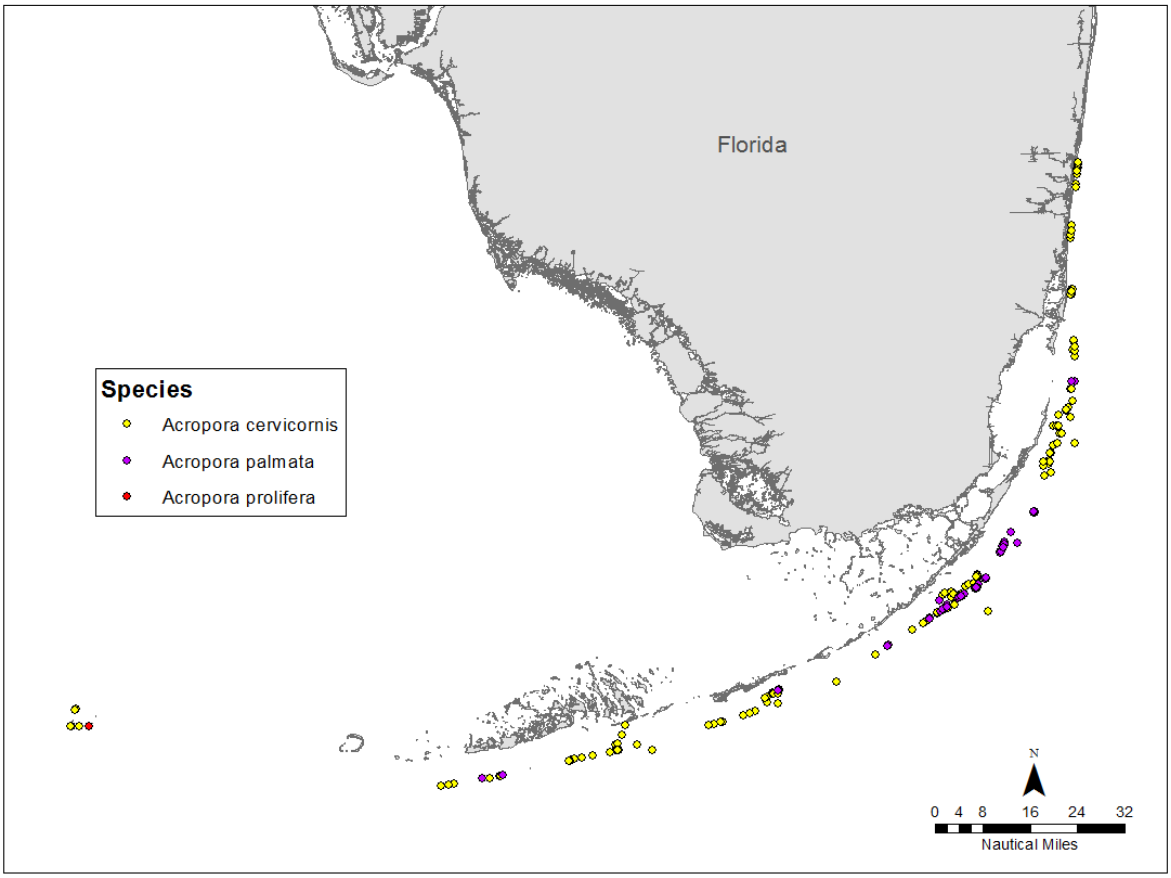

Figure 1. Florida outplant locations and species outplanted.

Table 4. Number of colonies outplanted per reef in Florida (FL), U.S. Virgin Islands (USVI), and Puerto Rico (PR).

Number of Colonies	Number of Reefs FL	Number of Reefs USVI	Number of Reefs PR
≤100	31	10	18
101-500	51	10	50
501-1000	20	6	6
1,001-2,000	21	1	2
2,001-5,000	17	3	5
5,001-10,000	4	1	0
>10,000	2	0	2
Total	**146**	**31**	**83**

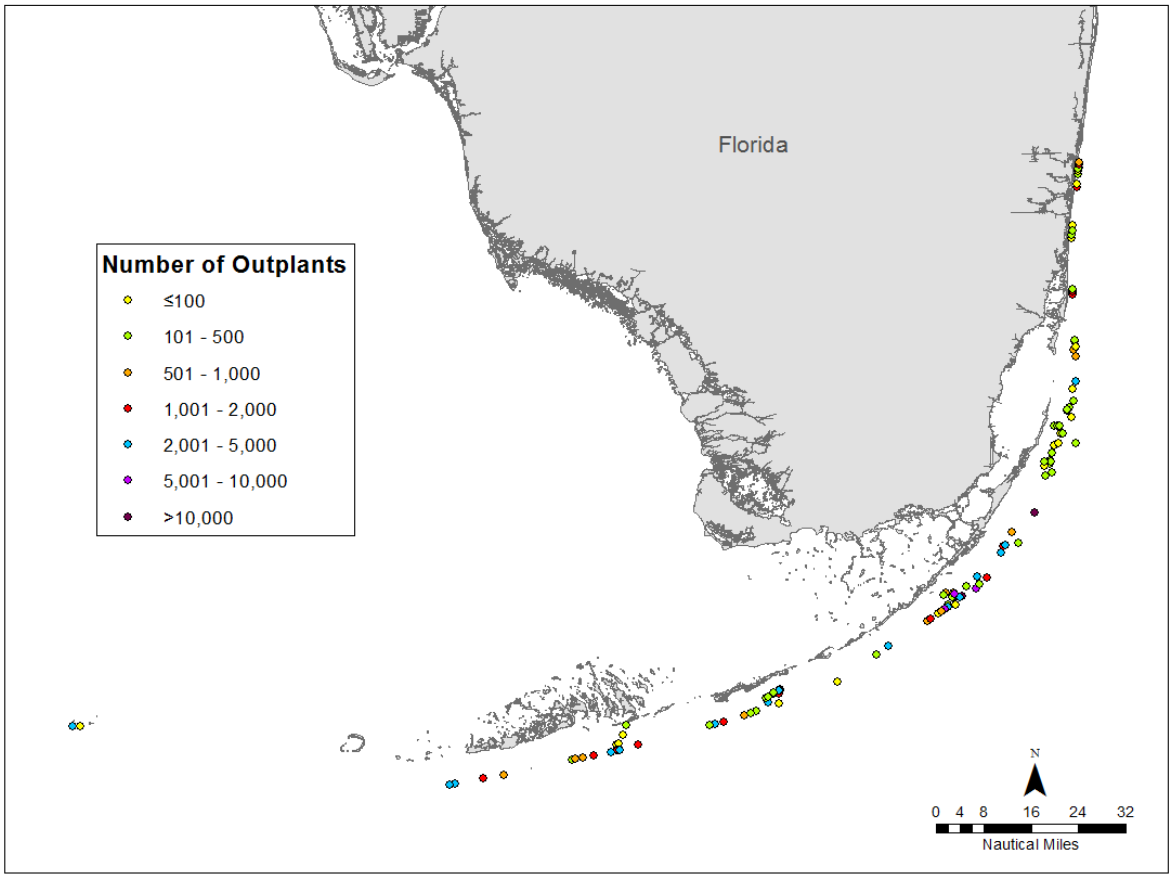

Figure 2. Number of outplanted colonies per reef in Florida.

U.S. Virgin Islands

In the U.S. Virgin Islands, corals were outplanted at 31 reefs off St. Thomas and St. Croix (Table 4). Most reefs were outplanted with *A. cervicornis*, and reefs outplanted with *Acropora palmata* were more numerous on St. Croix than on St. Thomas (Figures 3 and 4). Most reefs received fewer than 500 colonies (Figures 5 and 6). The largest number of outplants on a reef was just over 5,700 colonies.

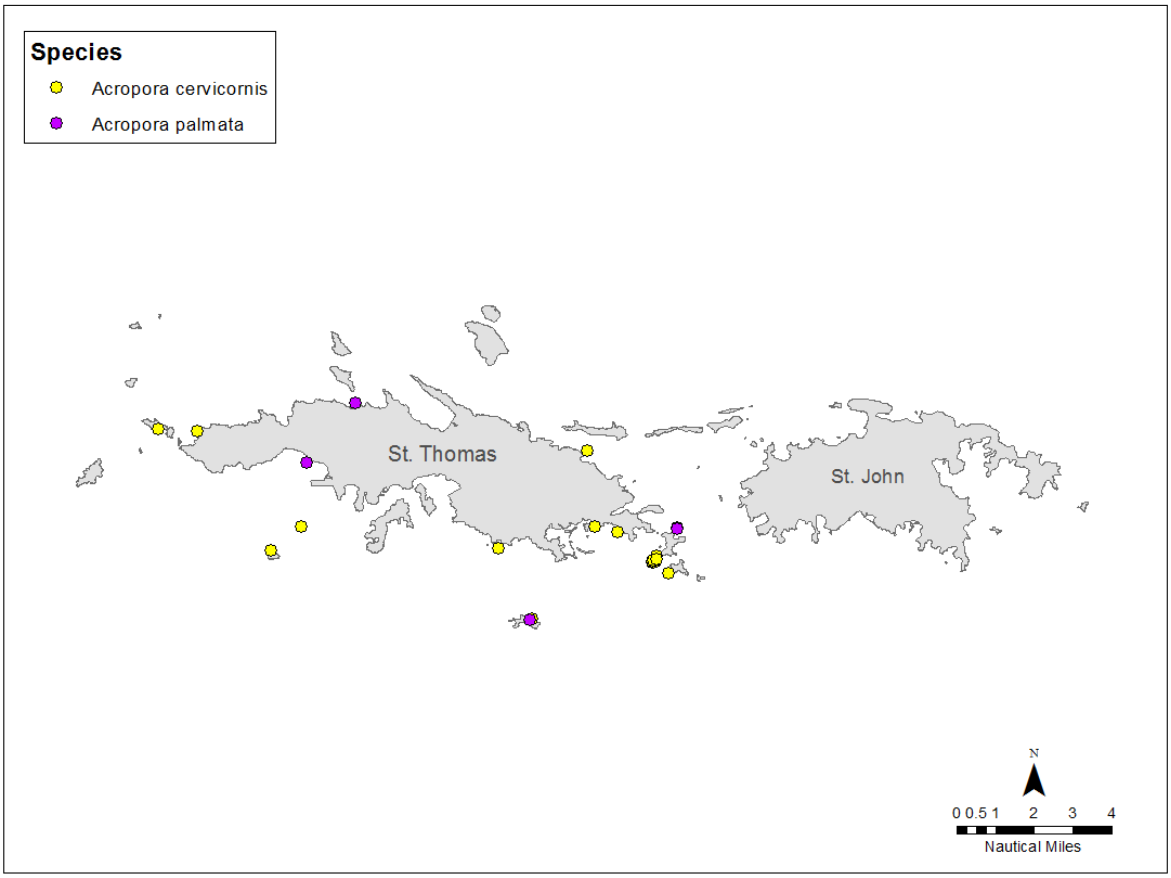

Figure 3. Outplant locations and species in St. Thomas, U.S. Virgin Islands.

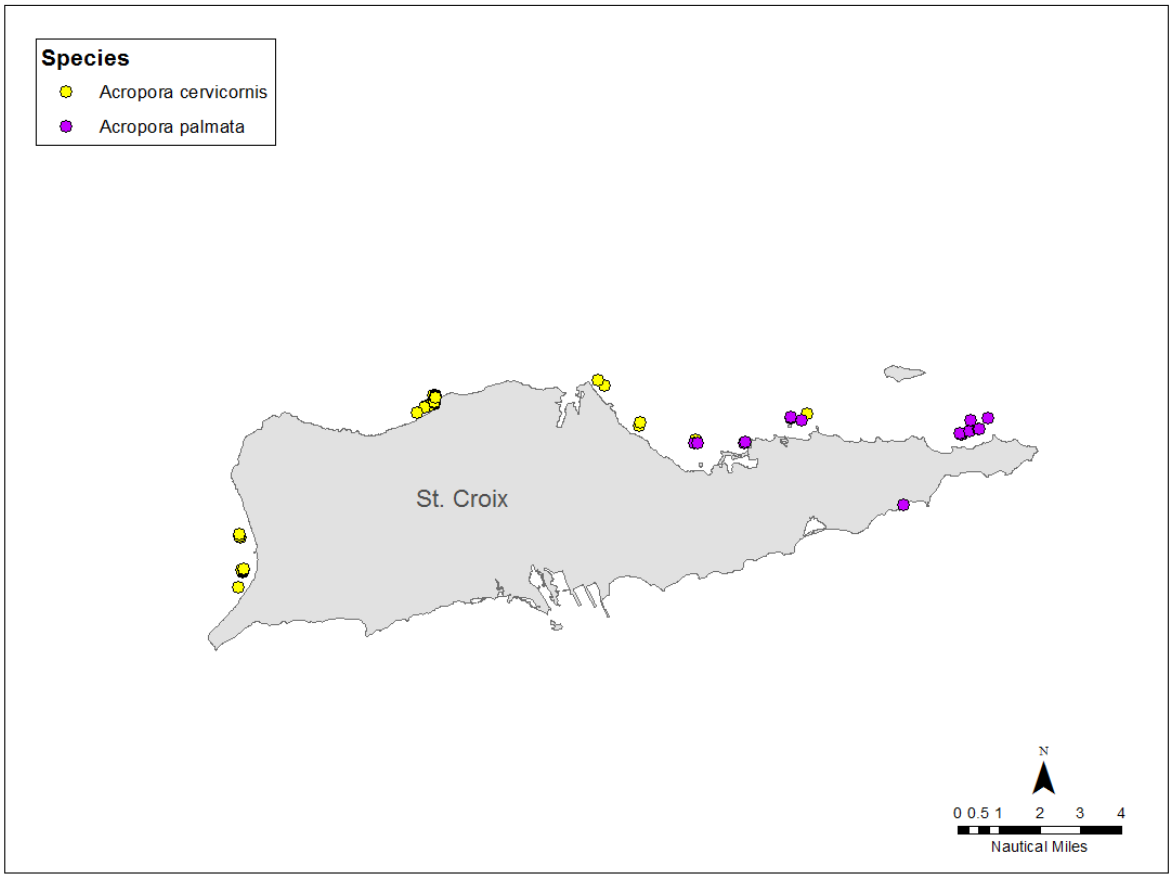

Figure 4. Outplant locations and species in St. Croix, U.S. Virgin Islands.

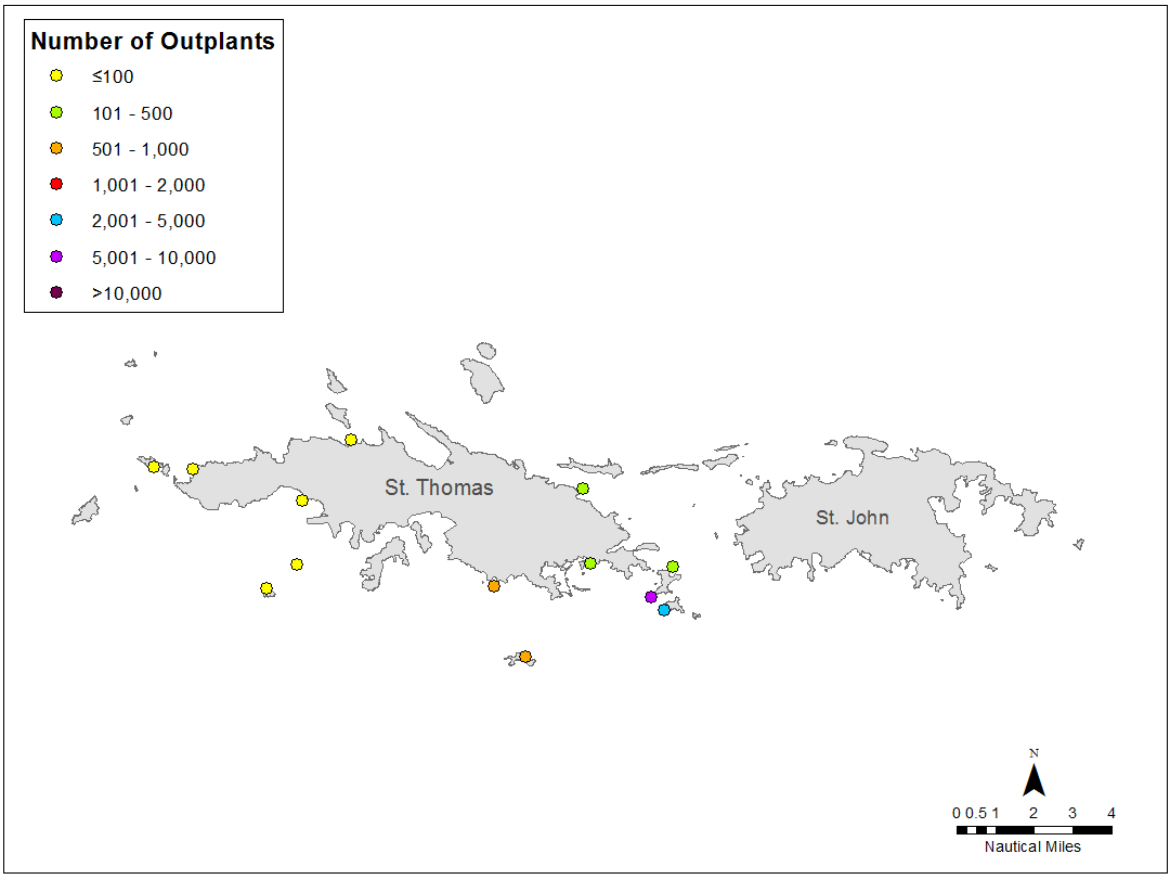

Figure 5. Number of outplanted colonies on reefs in St. Thomas, U.S. Virgin Islands.

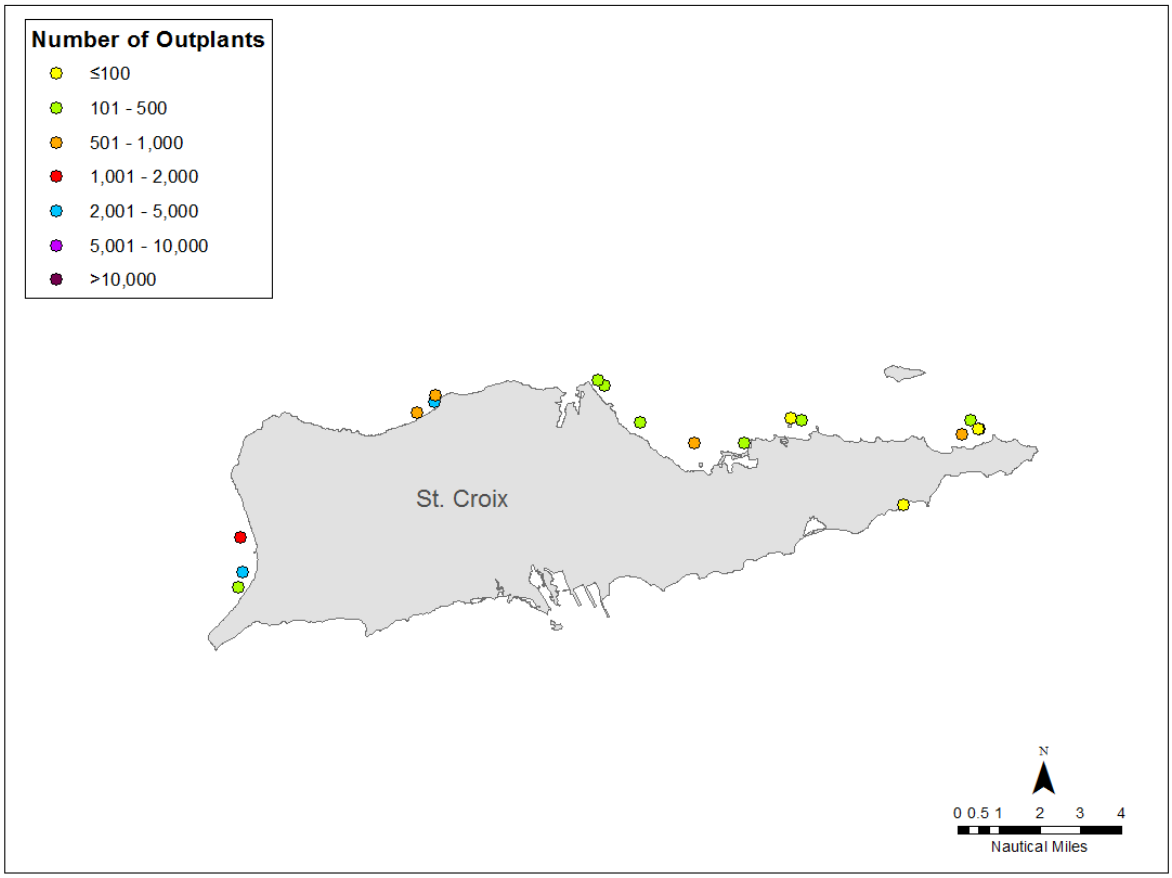

Figure 6. Number of outplanted colonies on reefs in St. Croix, U.S. Virgin Islands.

Puerto Rico

In Puerto Rico, corals were outplanted at 83 reefs off the mainland and Mona and Culebra Islands (Table 4). *Acropora cervicornis* was outplanted in higher numbers (Table 3), but *Acropora palmata* outplant locations were distributed fairly evenly across Puerto Rico (Figure 7). Most reefs received fewer than 500 outplanted colonies (Figure 8). The largest number of outplants per reef was 30,500 colonies.

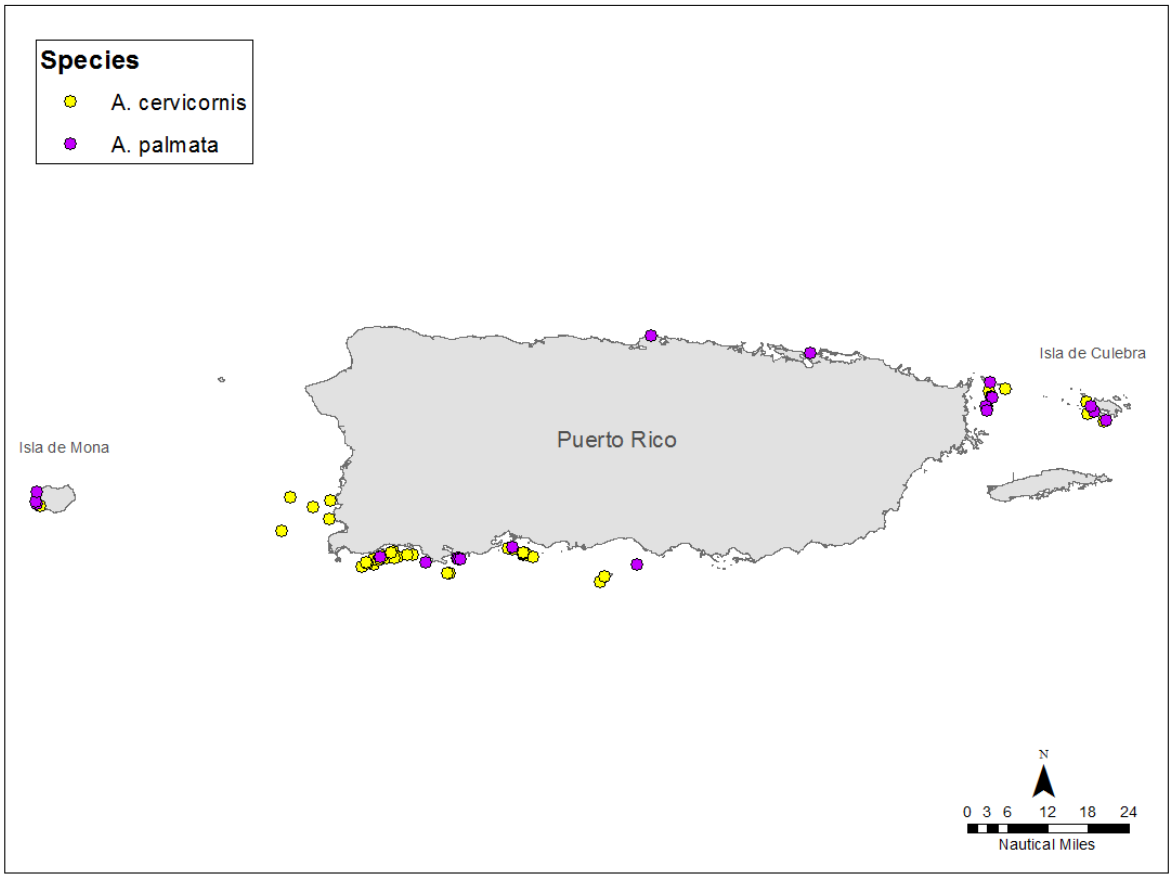

Figure 7. Outplant locations and species in Puerto Rico.

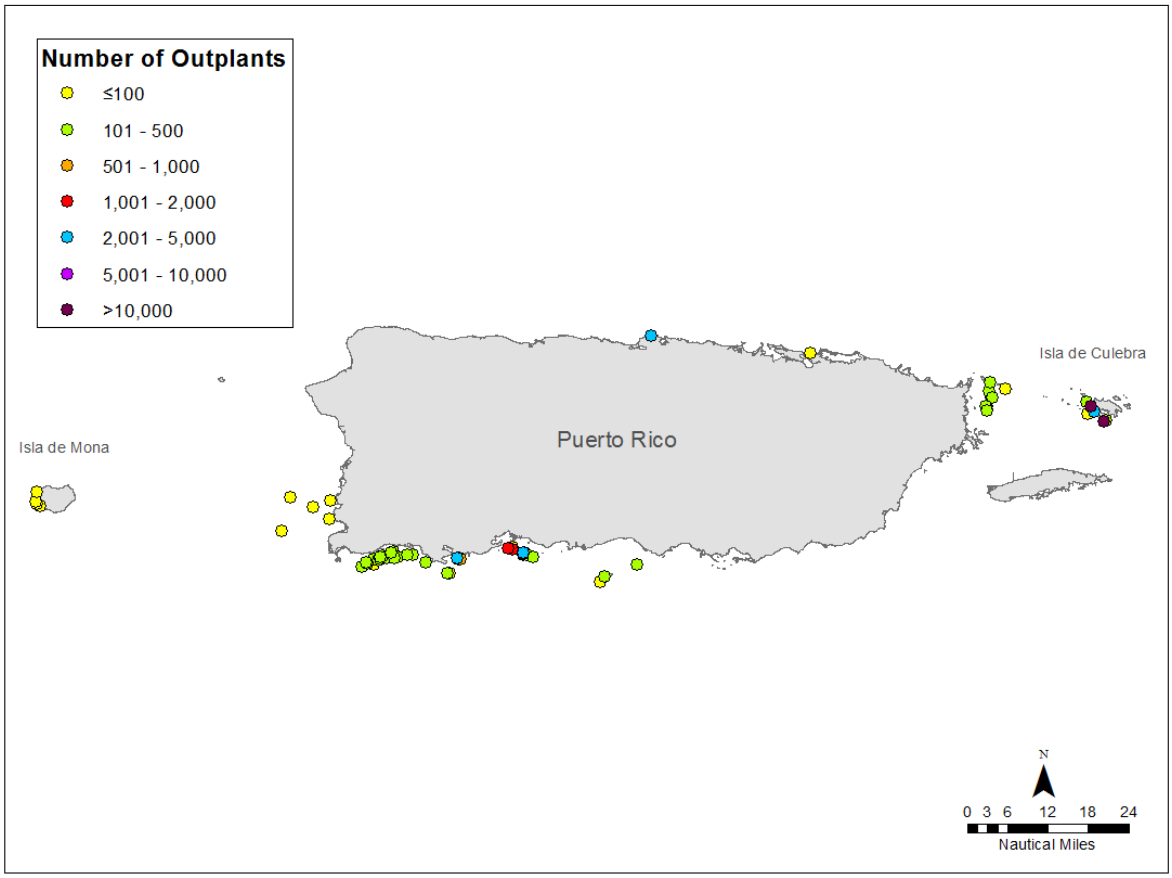

Figure 8. Number of outplanted colonies on reefs in Puerto Rico.

Ecological Value

Although nursery programs sometimes differ in their goals and measures of success, they all have a common objective to contribute to conservation of coral reefs and assisting in population recovery for the species they are outplanting. Coral outplanting can result in many benefits, including increased abundance and genetic diversity of outplanted species, increased potential for successful fertilization, creation of habitat, and reintroduction of species to sites where they have been lost. Below are some examples of the ecological value that coral outplanting has brought to sites where *Acropora* species have been replenished.

One of the major goals of outplanting is to enhance abundance and genotypic diversity at sites to increase the chances of successful sexual reproduction. Spawning of outplants has been observed as soon as two years post-transplant, indicating that outplants are reproductively active in a relatively short period of time (Figure 9). Spawning has also been observed in coral nurseries, providing an additional source of gametes that contribute to sexual reproduction of the species.

Figure 9. Spawning of *Acropora palmata* outplants in St. Croix, U.S. Virgin Islands. Photo credit: Kemit-Amon Lewis

In addition to increased potential for sexual reproduction, coral outplanting efforts have brought the species back to sites where they had been lost. Before coral nursery efforts began in 1999, *A. cervicornis* was absent from the backreef of Cayo Coral in Guanica, Puerto Rico. Colonies attached to wire frames have proliferated and formed coral thickets that are still thriving 18 years later (Figure 10). The reintroduction of *Acropora* corals to reefs where they previously existed can help speed up natural recovery using genotypes that may be resilient to current stressors. This will also help remedy the low natural recruitment success and permit expansion of outplant sites through asexual reproduction by fragmentation.

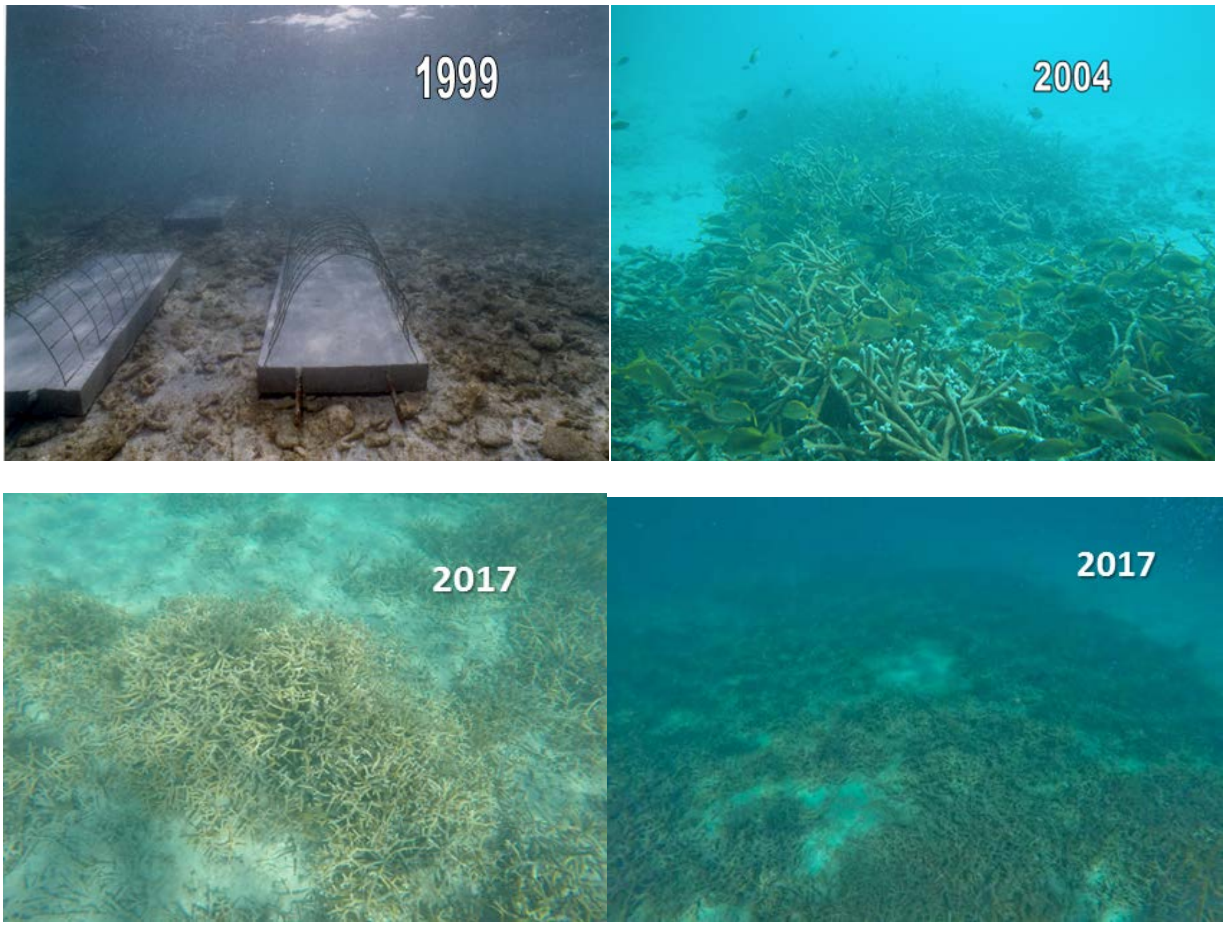

Figure 10. Installation of wire frame nurseries in Cayo Coral in Guanica, Puerto Rico (top left) and proliferation of corals to form habitat-providing thickets (top right and bottom). Photo credit: Carlos Pacheco.

Surveys of fish communities collected separately at the Culebra and the Guayanilla sites in Puerto Rico suggests 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 have 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 suggest 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. Finally, restored sites within the MPA have shown larger herbivore abundance and biomass than outside the reserve.

Conclusion

Coral outplanting from nurseries is a widespread management tool used to ensure that enough colonies and genetic diversity remain for conservation of species in the face of continued threats. Additional benefits of coral outplanting, besides increasing species abundance, include promotion of successful fertilization and reproduction through increased proximity of genetically distinct colonies and provision of habitat as evidenced by increased diversity, density, and biomass of fish species. Propagation through asexual fragmentation is the easiest and most widely used method, but sexual propagation through managed fertilization of gametes, while more difficult, is the only way to produce new genotypes. Thus, both propagation methods should be used to help increase abundance and genetic diversity of *Acropora* species.

Despite the benefits of coral outplanting, restoration alone will not be enough to ensure the conservation of *Acropora* species. Addressing stressors, particularly climate change, as well as land-based sources of pollution, physical impacts, and unsustainable fishing is essential for the long-term success of restoration efforts and recovery of these species. Without stress reduction, restored corals are subjected to the same sources of mortality that originally caused the species to decline. Therefore, the combination of reducing pressure and increasing population abundance and diversity through restoration are necessary to enable these species to naturally recover.

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