

Coral farming and reef rehabilitation in Puerto Rico: Recent progress and major needs



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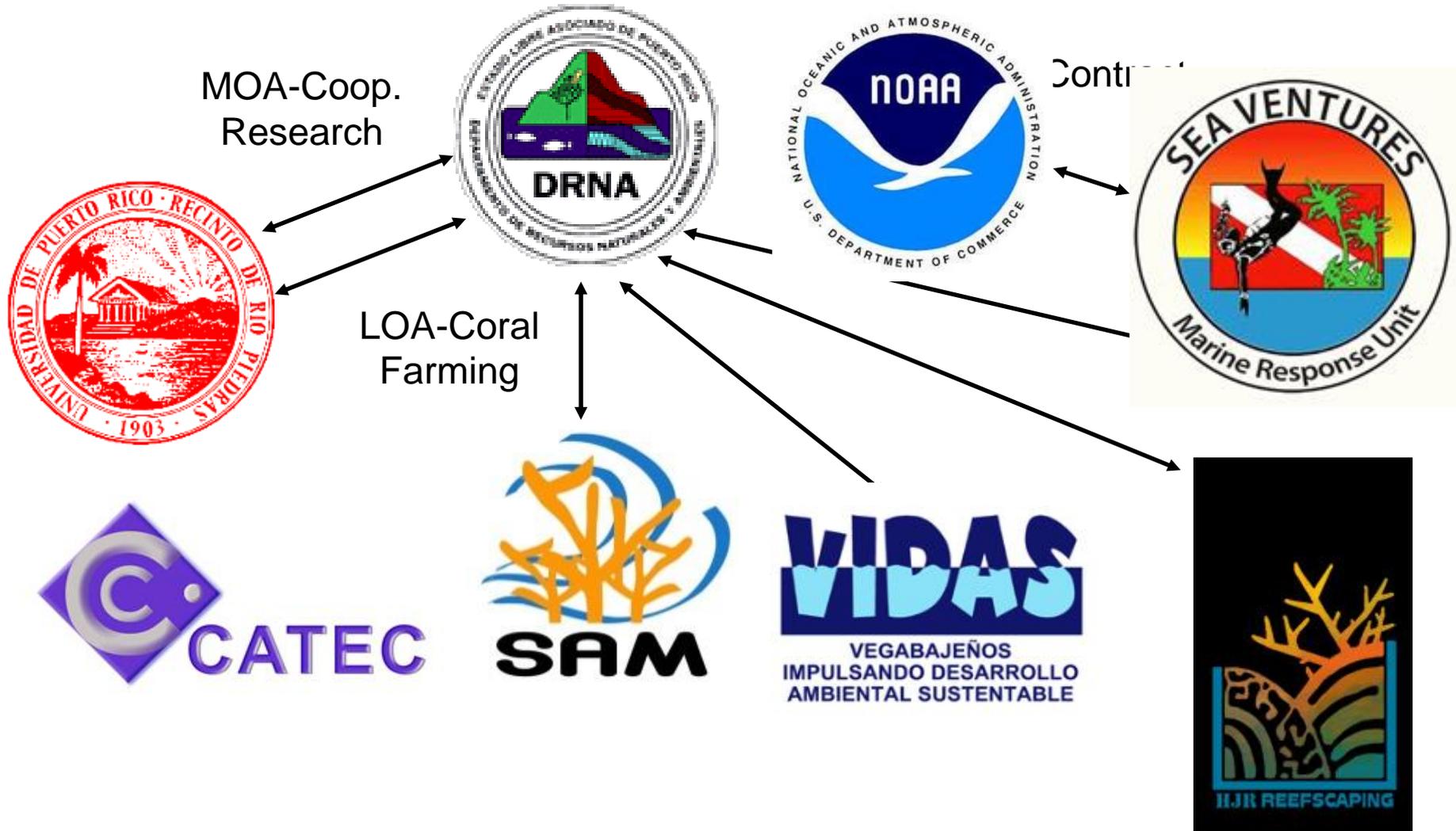
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U.S. Coral Reefs Task Force Meeting
Fajardo, Puerto Rico
October 29, 2015

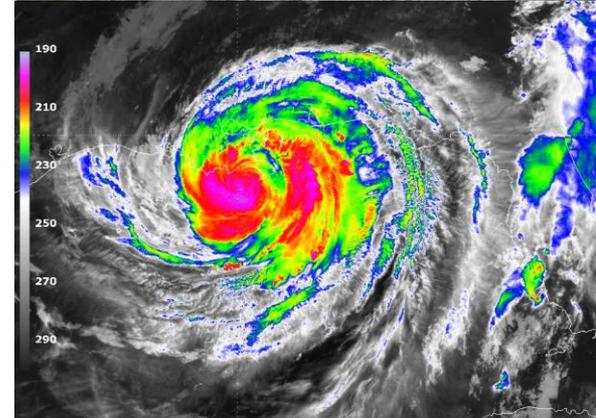


Puerto Rico National Coral Farming and Reef Rehabilitation Alliance



Objectives

- Efforts by:
 - DNER
 - NOAA-RC and Sea Ventures
 - HJR ReefScaping
 - VIDAS
 - Sociedad Ambiente Marino and CATEC/UPR
- Recommendations for improving coral farming and reef rehabilitation



35,000 corals were outplanted during 2014/15 from nurseries in Florida, Puerto Rico and the USVI to assist in the recovery of ESA listed coral populations and restore degraded reefs (n=14 farms PR; n=5 USVI)

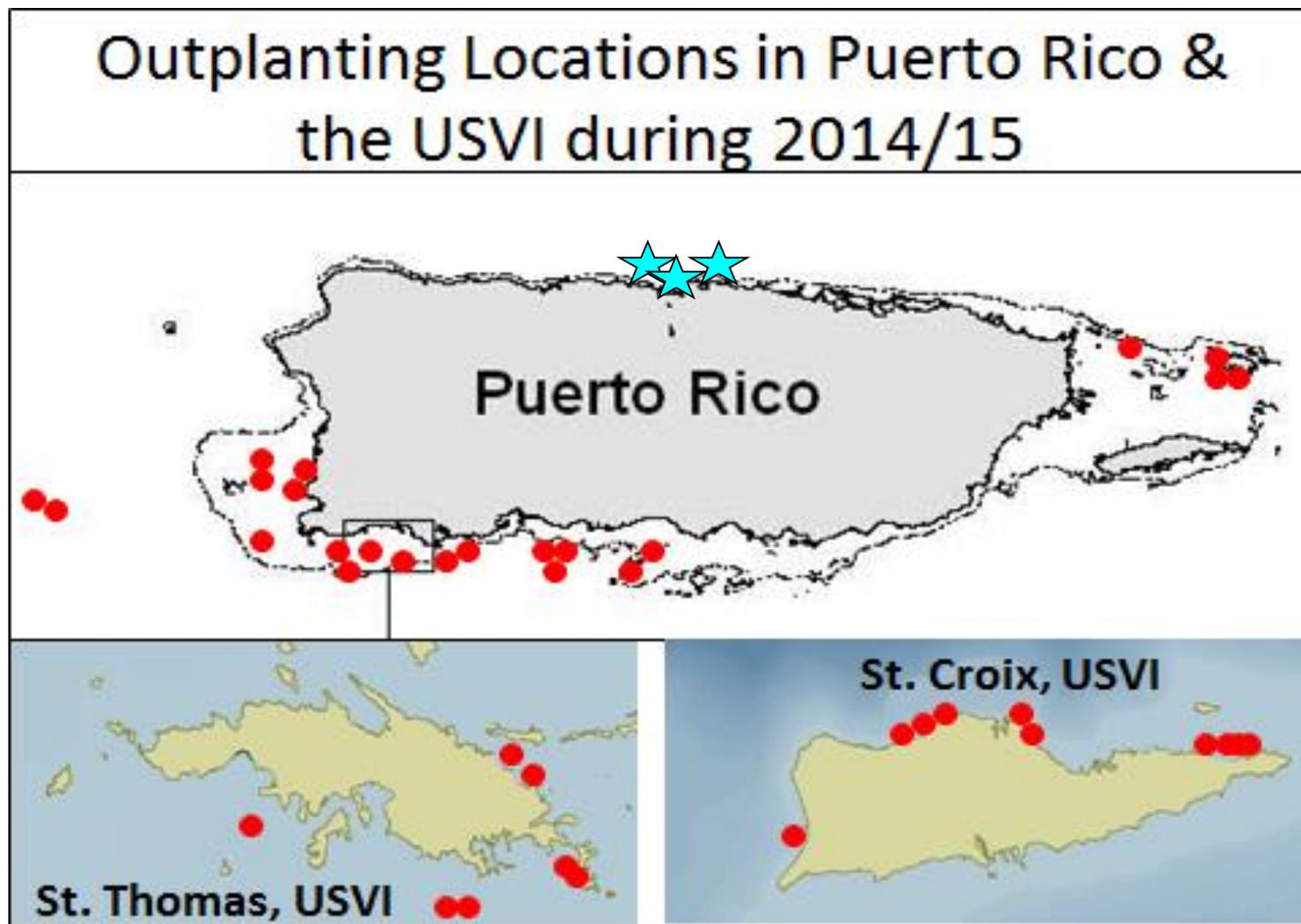
Nursery Locations in Puerto Rico & the U.S. Virgin Islands



Nursery Types

-  *A. palmata* only
-  *A. cervicornis* only
-  Both *A. cervicornis* & *A. palmata*

35,000 corals were outplanted during 2014/15 from nurseries in Florida, Puerto Rico and the USVI to assist in the recovery of ESA listed coral populations and restore degraded reefs (n=24 PR; n=16 USVI)



Cabo Rojo, Outplanting and Restoration Sites

- Coordination of all coral farming and reef rehabilitation efforts in Puerto Rico
- Signed 3-year LOA with coral farmers (October 14, 2014)
 - Operation of coral farms
 - Establish uniform methods
 - Emergency restoration (i.e., groundings, major storm swells, hurricanes)
 - Support DNER/NOAA operations
- Unsuccessful seeking NOAA programatic funds to support and coordinate coral farming efforts

Legend

- Belv INN
- Belv INN
- Belv Mid
- Belv OUT
- Guani Mid
- Guani INN



13.5 km

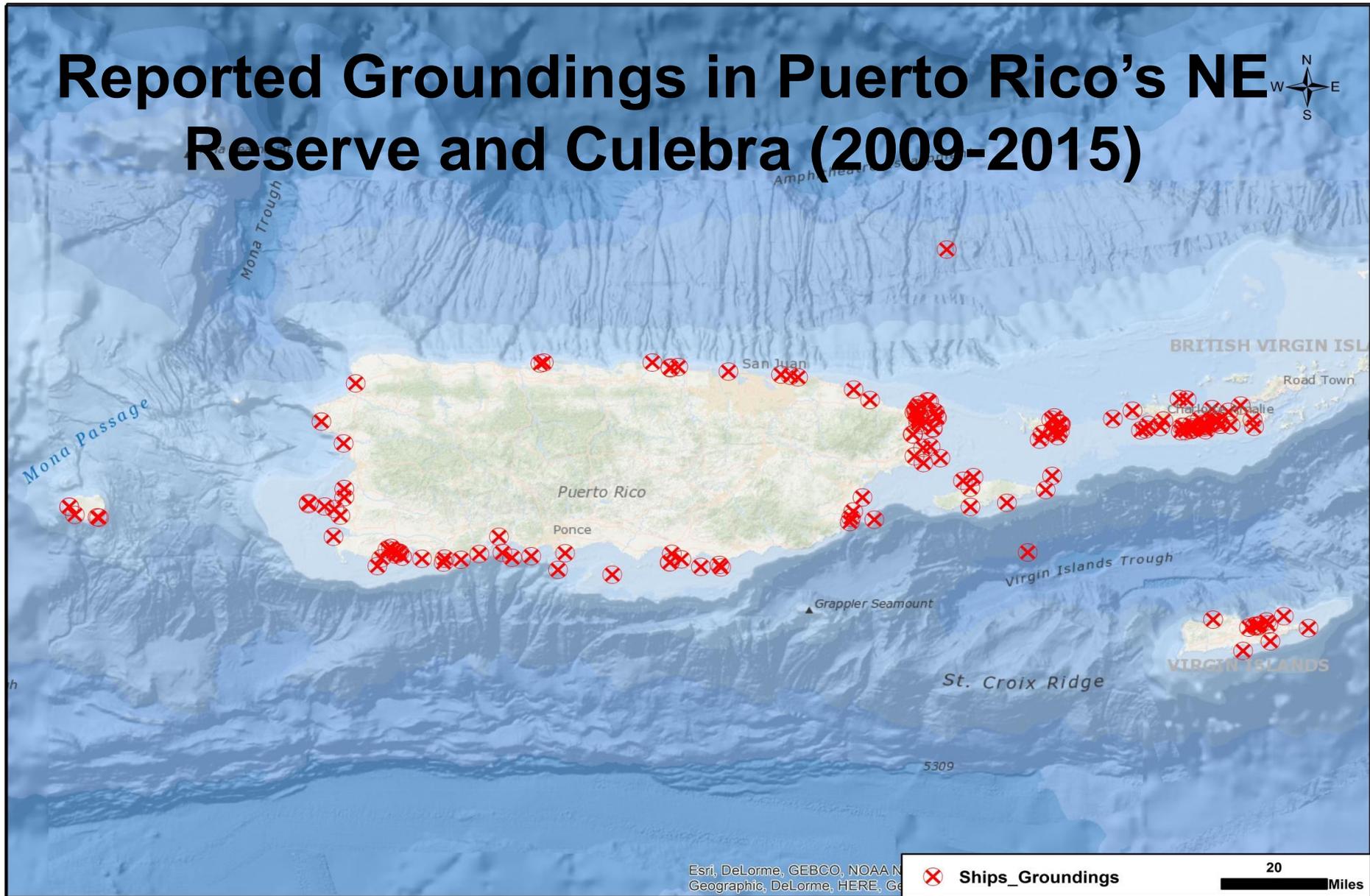
Time lapse series of stabilized *Acropora palmata* fragment in Vega Baja (10cm to over 1m in 6 years)



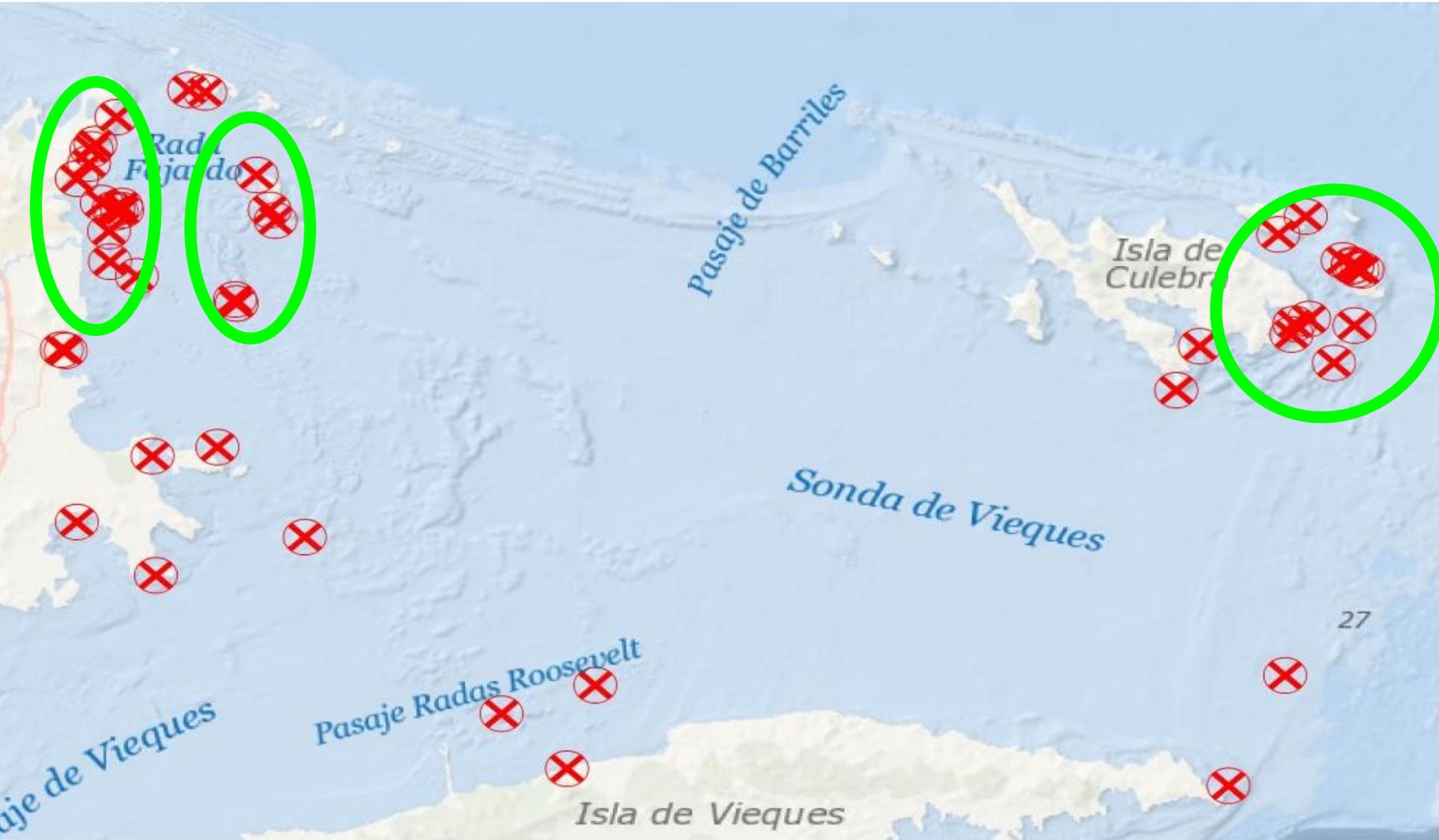
Storm generated fragments of *A. palmata* averaging 10-20cm in diameter were stabilized in 2008 in Vega Baja, PR in an area where there were no other colonies of *A. palmata*. In 2014 (shown below), many colonies were over 1 meter in diameter.



Reported Groundings in Puerto Rico's NE Reserve and Culebra (2009-2015)



NE Reserve hotspots (Fajardo, Palominos, Cayo Largo) Culebra hotspots (Las Pelas and Culebrita)



LNG-C Matthews Grounding

Guayanilla, Puerto Rico; Dec. 2009



Post Grounding: 3,200 m² of reef were damaged. Most of the reef was flattened by vessel (resembled a parking lot)

LNG-C Matthews Grounding

Guayanilla, Puerto Rico; Dec. 2009



Comprehensive restoration focused on reattaching corals, stabilizing rubble and reconstructing lost topography. 7,000 corals were reattached during restoration. Rugosity restored similar to unimpacted reef.

LNG-C Matthews Grounding

Guayanilla, Puerto Rico; Dec. 2009



Although 7,000 corals were saved during the restoration, 65,000 corals were unable to be recovered which left a lot of empty space. 1,100 *Acropora cervicornis* colonies were outplanted from the nursery at Margara to help accelerate recovery.

New publications by NOAA-RC

- Griffin et al. (2015)
- Description of *Acropora cervicornis* recovery trends at T/V Margara grounding site, PR
- 227 fragments (10-20 cm) in 2006
- 400 fragments (20-40 cm) in 2009-2011

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

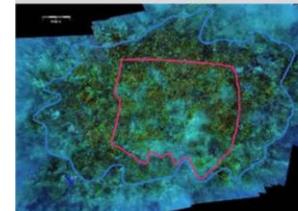


Fig. 2 Photomosaic taken in July 2014. Red polygon shows the original impact; blue polygon estimates the extent of expansion

On 27 April 2006, a 228-m oil tanker, the T/V MARGARA, grounded on coral reefs in Tallaboa, Puerto Rico, damaging approximately 7500 m² 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 m²), but *A. cervicornis* colonies can now be found in ~180 m² 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.

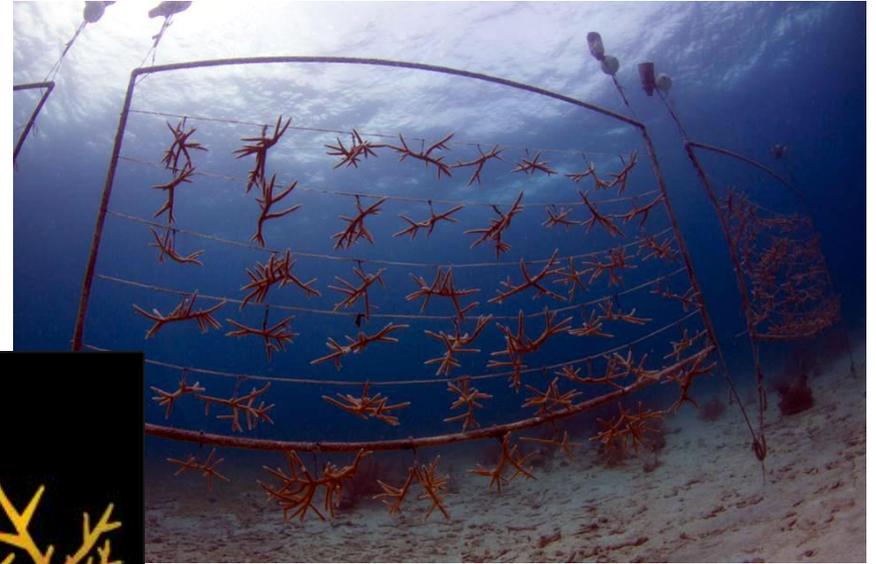
Reference

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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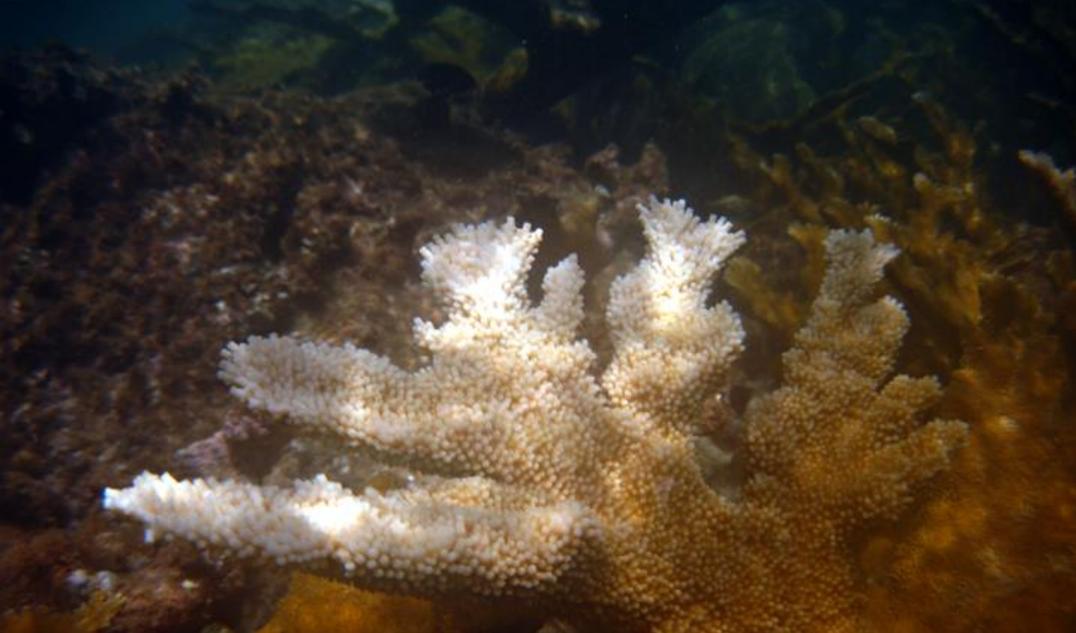
HRJ-ReefScaping



VIDAS + UPR/CATEC + SAM +DNER lead a massive Elkhorn coral (*Acropora palmata*) emergency restoration effort following a severe winter swell (March 18-21, 2008)

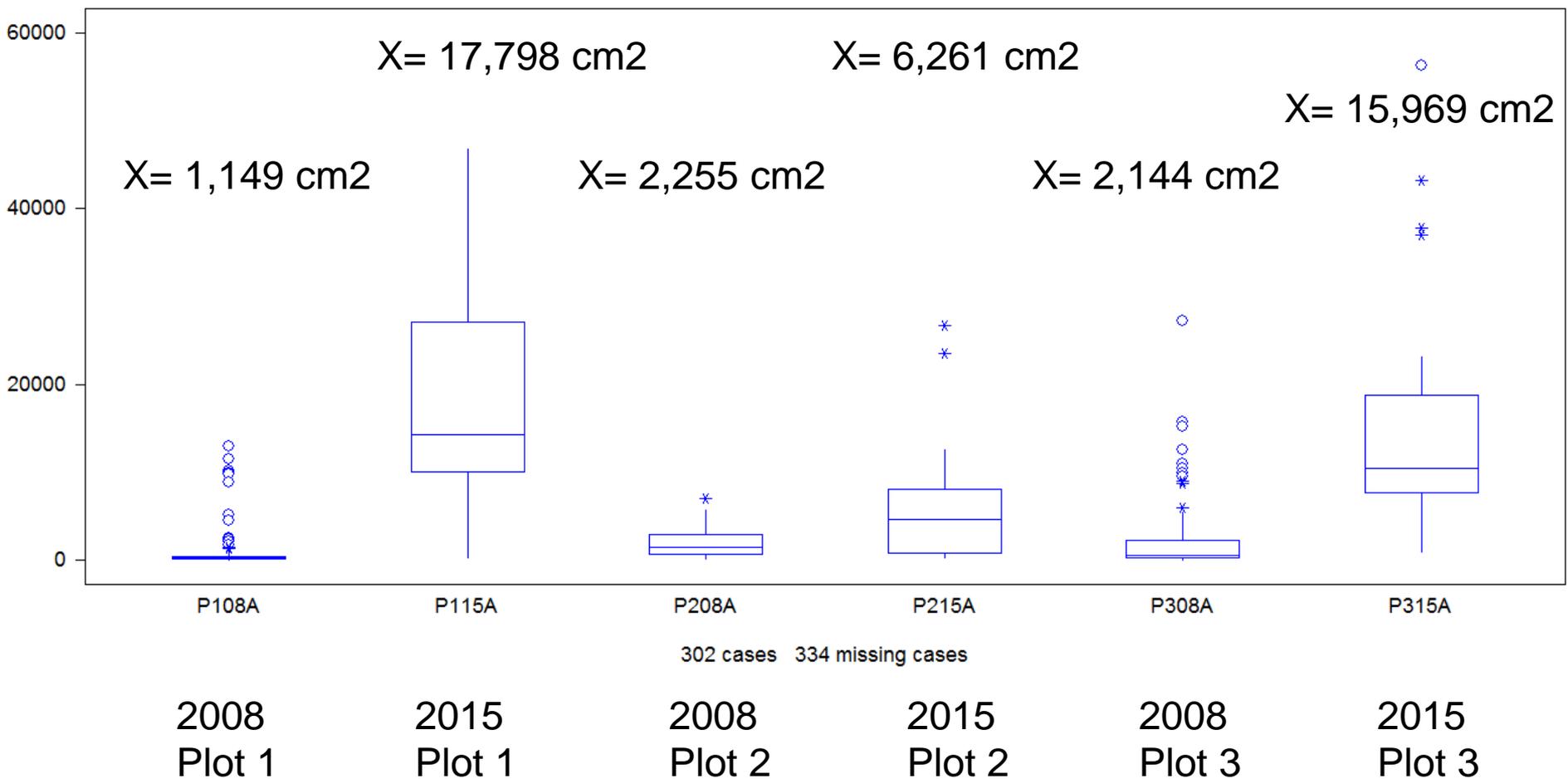


VIDAS
VIDAS
VEGABAJENOS
IMPULSANDO DESARROLLO
AMBIENTAL SUSTENTABLE



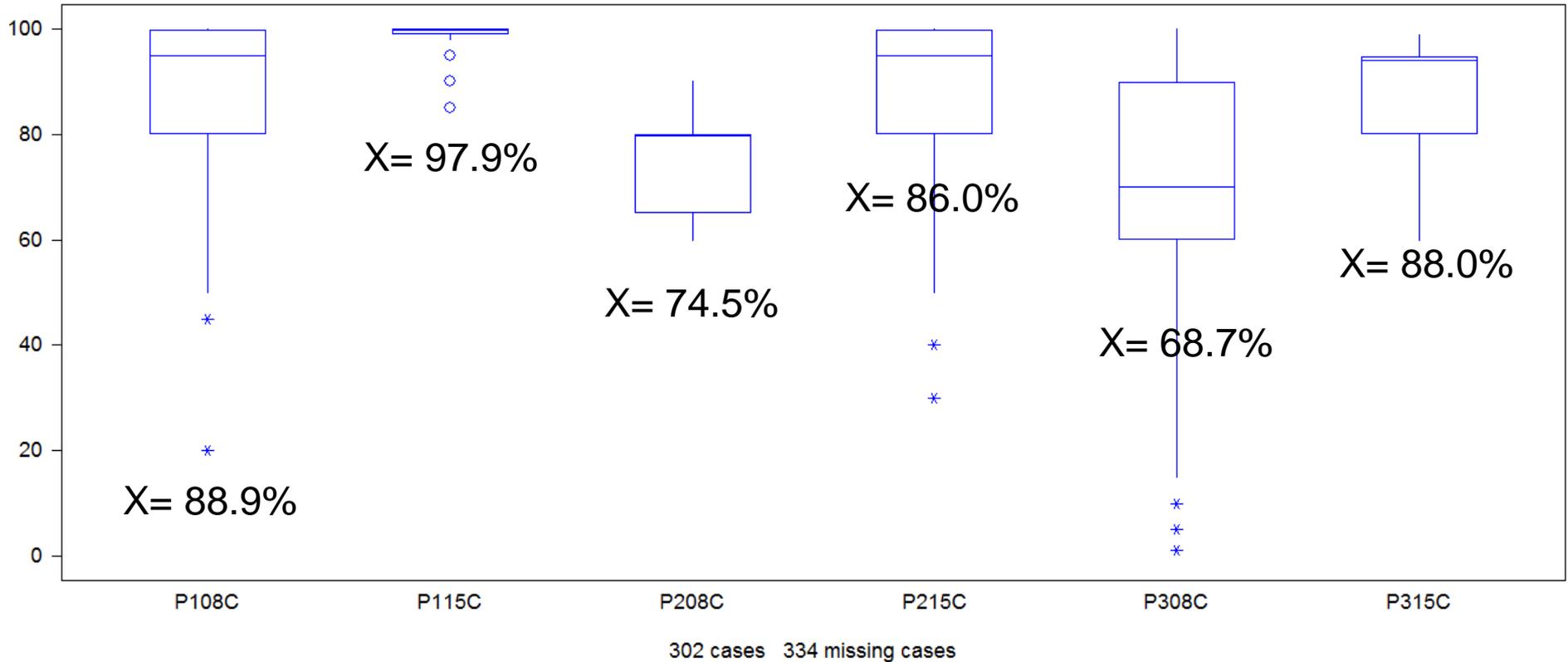
Outstanding restored *A. palmata* growth at Vega Baja (2008-2015)

Box and Whisker Plot



Outstanding restored *A. palmata* growth at Vega Baja (2008-2015)

Box and Whisker Plot



2008
Plot 1

2015
Plot 1

2008
Plot 2

2015
Plot 2

2008
Plot 3

2015
Plot 3

2 Years

7 Years



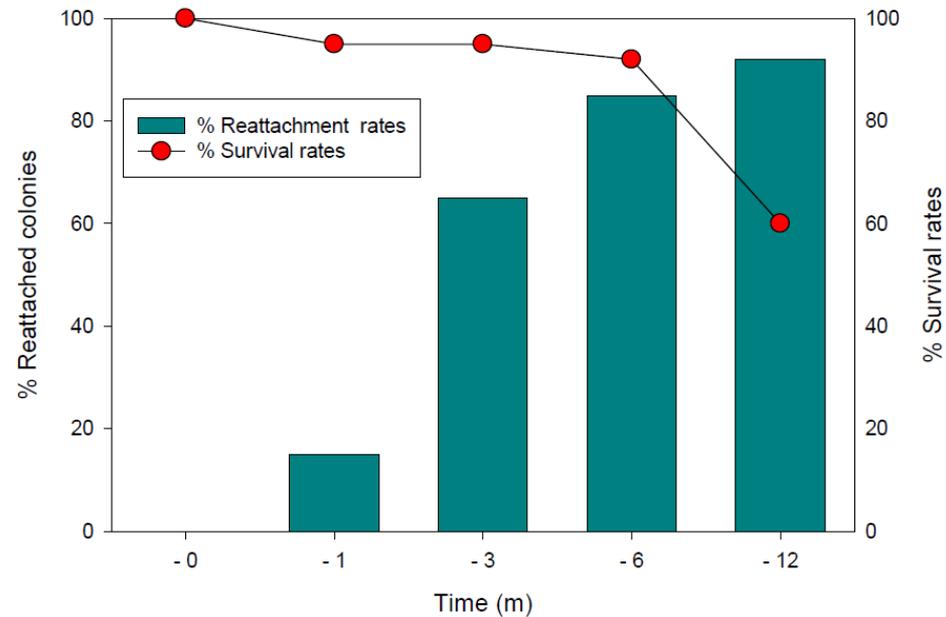
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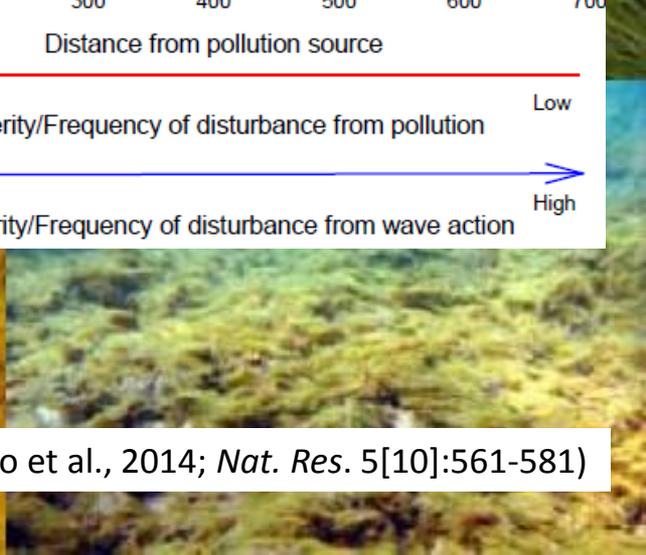
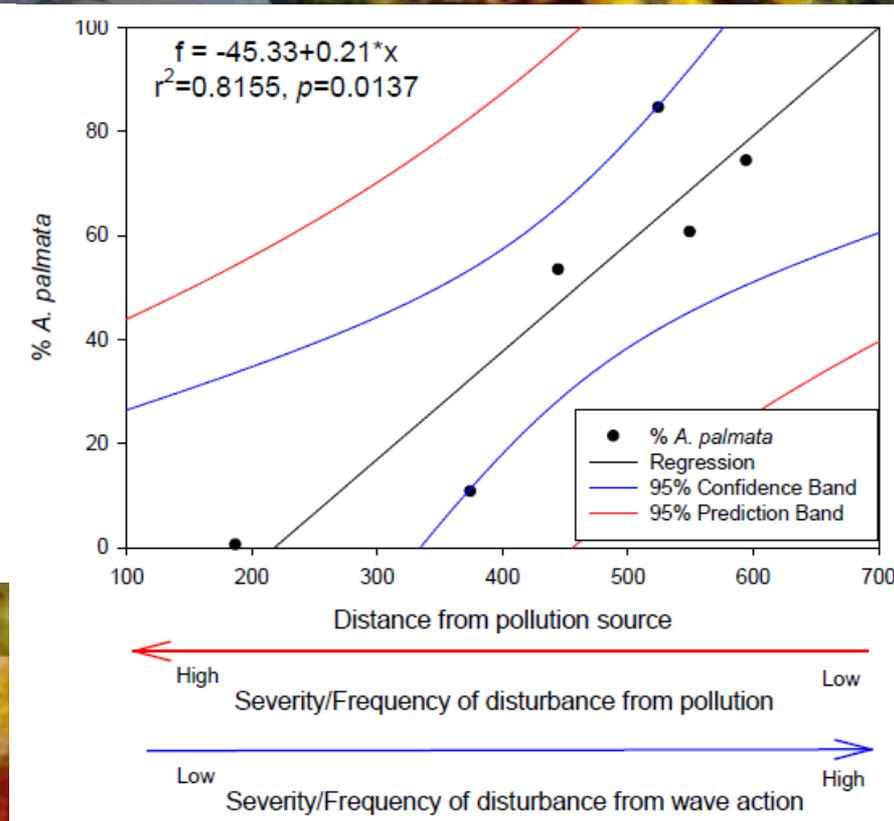
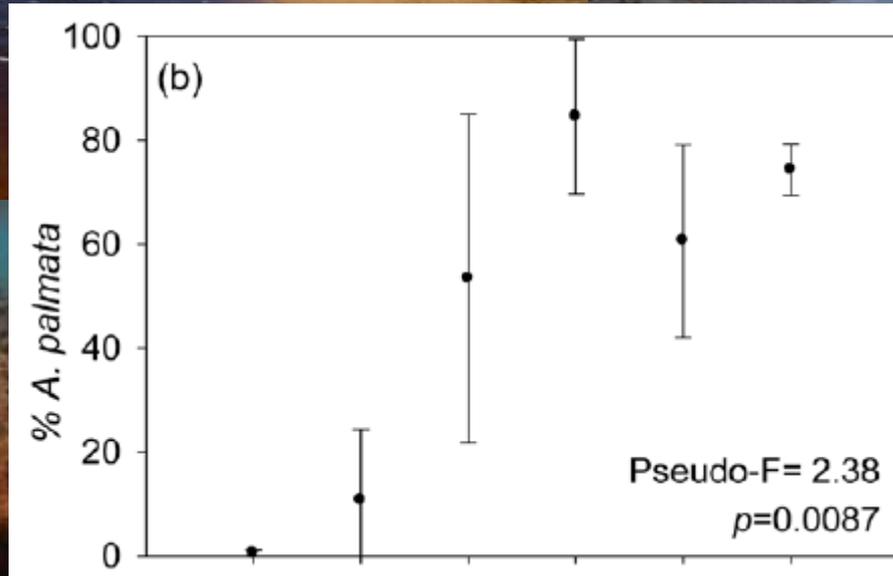
Vega Baja still supports impressive remnant populations of *Acropora palmata*



There is still illegal sewage dumping at Vega Baja

- Rapid recovery of low-tech replanted coral fragments (VIDAS, UPR, DNER) (n=645)
- High colony survival rates, skeletal growth and branching production
- But sewage and sediment bedload impacted survival across some reef segments!





(Diaz-Ortega & Hernandez-Delgado et al., 2014; *Nat. Res.* 5[10]:561-581)

Need of immediate action from Commonwealth and Federal regulatory agencies to stop raw sewage dumping along the Vega Baja coast



ESTADO LIBRE ASOCIADO DE PUERTO RICO

17^{ma}. Asamblea Legislativa

6^a. Sesión Ordinaria

SENADO DE PUERTO RICO

P. del S. _____

____ de octubre de 2015

Presentado por los señores *Tirado Rivera* y _____

LEY

Community-based (VIDAS) collaboration with academia (CATEC/UPR), DNER and the Commonwealth Legislature for the designation of the Vega Baja and Manati Submarine Gardens Natural Reserve

académicas para el manejo conjunto de la reserva, incluyendo a Vegabaja impulsando Desarrollo Ambiental Sustentable (VIDAS), la Sociedad Ambiente Marino (SAM), el Grupo de Investigación de Arrecifes de Coral (GIAC) del Centro para la Ecología Tropical Aplicada y Conservación (CATEC) de la Universidad de Puerto Rico; fijar la obligación del DRNA de rendir informes anuales a la Asamblea Legislativa; asignar fondos para la implantación de las disposiciones de esta Ley; y para otros fines relacionados.

EXPOSICIÓN DE MOTIVOS

La protección y conservación del medio ambiente y los recursos naturales es una labor que adquiere progresivamente mayor importancia, ante la presión creciente a las que la naturaleza puertorriqueña se ve sometida por el desarrollo desmedido, así como por las realidades geográficas, demográficas, económicas y sociales. Las exigencias del poder económico, el mejoramiento de la construcción de la infraestructura, la construcción de nuevas

asegurar el disfrute cual a la vez genera

La Constitución Sección 19 que: "S recursos naturales, beneficio general de Recursos Naturales la política pública r uso armonioso de lo

Desde hace ecológicamente sen municipios de Vega a protección de to estado de conserva uracanes y el a representativa de lo rianza de múltiple reserva alimentaria, arrecifes constituyen farmacológico, con para las comunida generaciones. Su va turísticas para toda

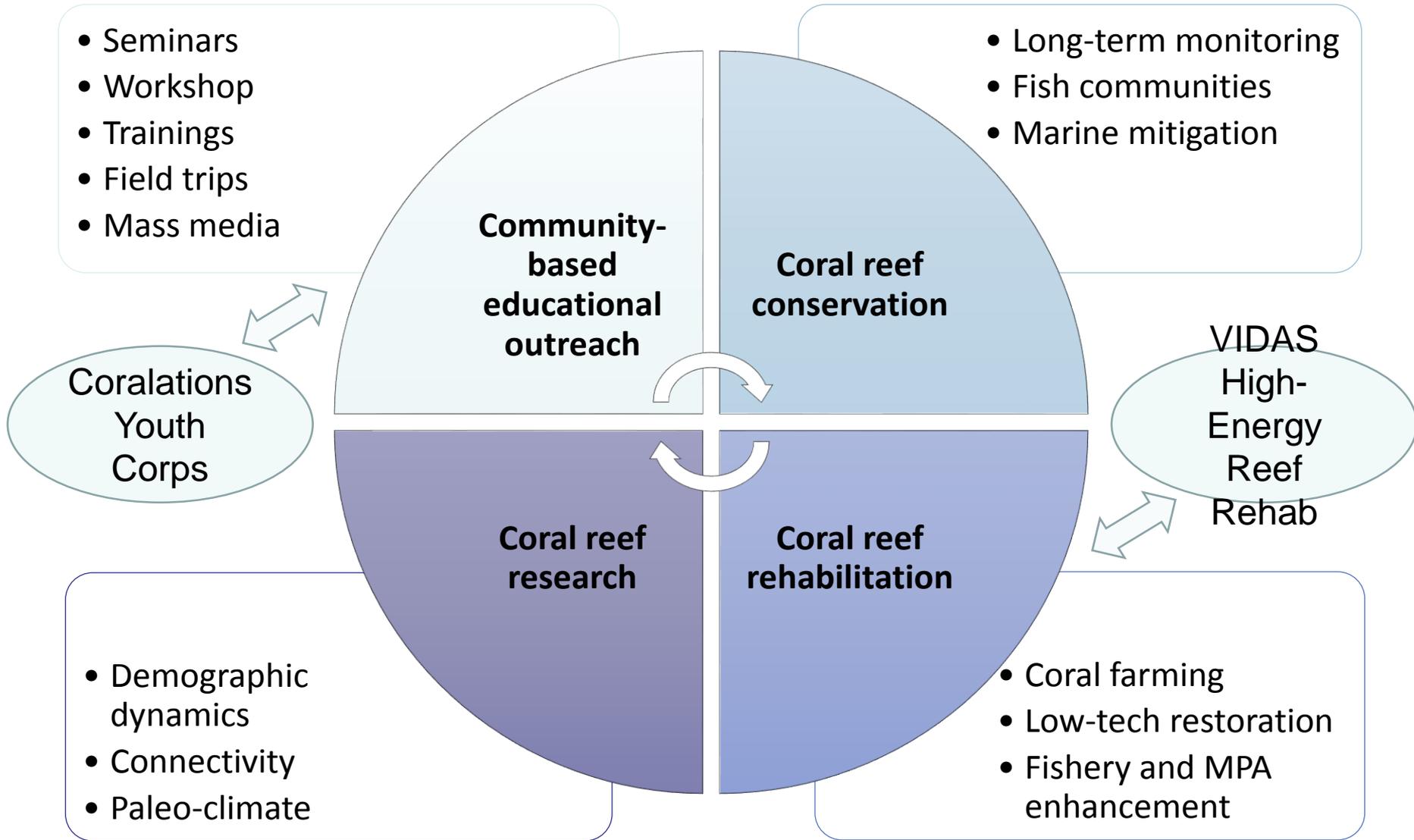
A su vez, extensos e integros sus territorios, y con se encuentra designa menos abundante e Peligro de Extinció conservación y pro poblaciones distan proponemos como E esta zona se han id incluyendo a: *Acro cibuscula*, *Posita*

Community-Based Coral Aquaculture and Reef Rehabilitation Program





CATEC-SAM collaboration



UPR/CATEC + SAM produced 16 peer-reviewed publications during 2014-2015

ARTICLE IN PRESS

Marine Pollution Bulletin xxx (2015) xxx–xxx

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journal homepage: www.elsevier.com/locate/marpolbul

ELSEVIER

Review

The emerging threats of climate change on tropical coastal ecosystem services, public health, local economies and livelihood sustainability of small islands: Cumulative impacts and synergies

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Coral Reefs
DOI: 10.1007/s00338-015-1341-8

REPORT

The Immune responses of the coral

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Accepted November 3, 2014

Abstract

Abstract text describing the immune responses of coral reefs.

04/315-318

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Sabat⁴

ntic year ty of xial nent n the

ortant reproductive strategy in the threatened reef building

collapses generated by A. coarctatus, sexual reproduction

to maintain or/else enhance local population growth. How-

ers offspring is rather limited, hampering our ability to

asses to current population growth. In this study, natural oc-

for 18 months at two sites in Puerto Rico in order to quantify

agreed survivorship did not exceed 25%. growth rates were

1.0242 ± 0.0168 (SE) and 0.0906 ± 0.0301 (SE) cm d⁻¹.

Some of these peer reviewed publications address elements critical for guiding future coral reef conservation, farming, and rehabilitation efforts (i.e., coral farming, demographic dynamics, LBSP impacts, land use change, coral immunology, climate change)

7. The enhanced vulnerability of small tropical islands: case studies from the Caribbean and the Indo-Pacific	0
8. Recommendations for adaptation and mitigation strategies on small tropical islands	0
9. Conclusions	0
Acknowledgments	0
References	0

1. Introduction

"Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last

decades. Reports of emerging coral diseases have increased since they were first described in the early 1970s (Antonius, 1973; Richardson, 2012). Currently, over 35 coral diseases have been reported (Kline and Vollmer, 2011), some of which have worldwide distribution, i.e., Black Band Disease (BBD). Others have narrower distributions, such as Yellow Band Disease (YBD), which is reported exclusively in the Caribbean (Veron, 1995). Diseases have affected over 80 coral species and their impacts have been so dramatic as to alter the seascape and the community structures of reefs (Randolf and Jackson, 2006).

Studies addressing the causations of coral diseases, as well as their prevalence, incidence, and their impacts on vital life history traits such as growth and reproduction, have dominated the scientific literature. For instance, several long-term field studies have shown that diseased corals exhibit slower growth rates and a reduced fecundity when compared to healthy ones (Baird and Marshall, 2002; Pelet et al., 2003; Toledo-Hernández et al., 2005; Weil et al., 2009). Far less

continued to thrive. Ironically, during the last century reefs of the world have undergone unprecedented declines, primarily due to human derived stresses (McClanahan et al., 2002). A combination of factors, which include water pollution (i.e., nutrient and sediment influxes), overfishing, rising water temperatures, ocean acidification and disease are causing declines in coral growth and coral cover. Such degradation is readily observed in the Indo-Pacific region where reefs are disappearing at an average rate of 2% per year (Bruno and Selig, 2007). In the Caribbean, reefs are being lost even faster, i.e., at an average rate of 5.5–9.2% per year (Buddemeier and Ware, 2003). Given increasing human impacts, these pressures are projected to exacerbate damages to coral reefs worldwide and

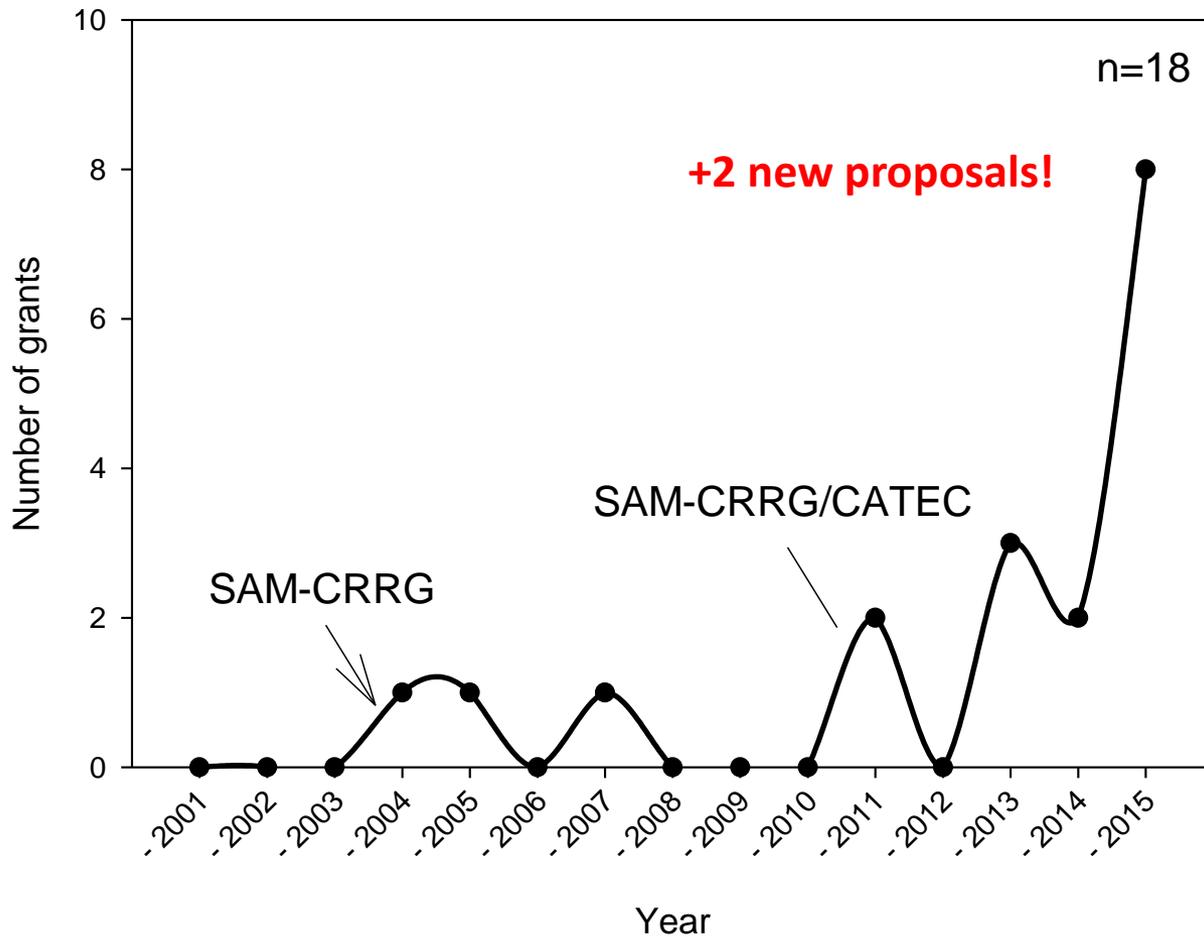
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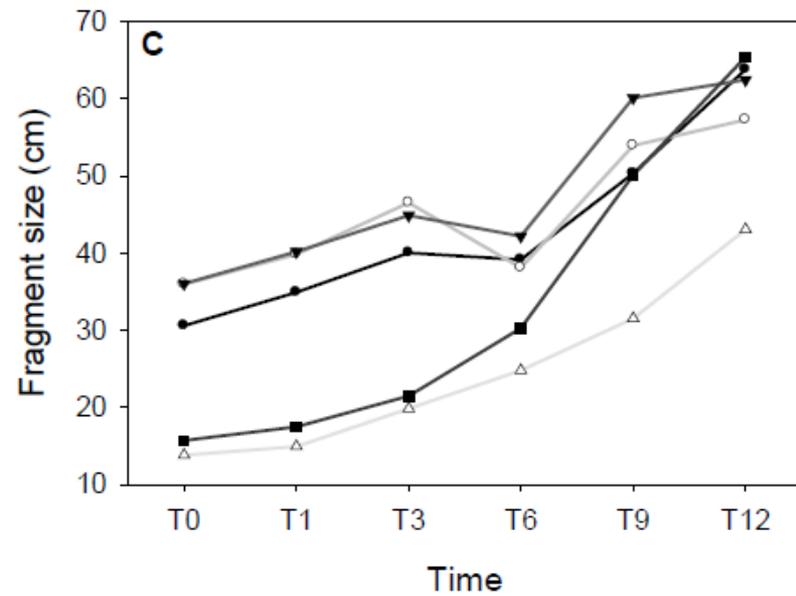
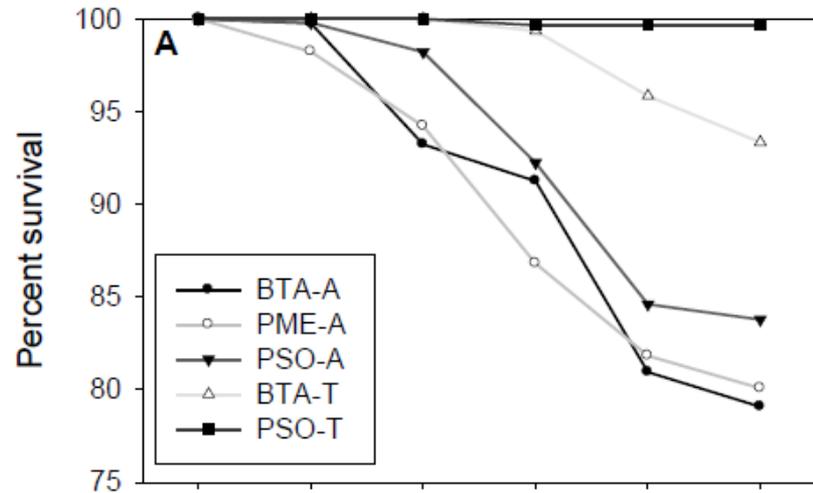
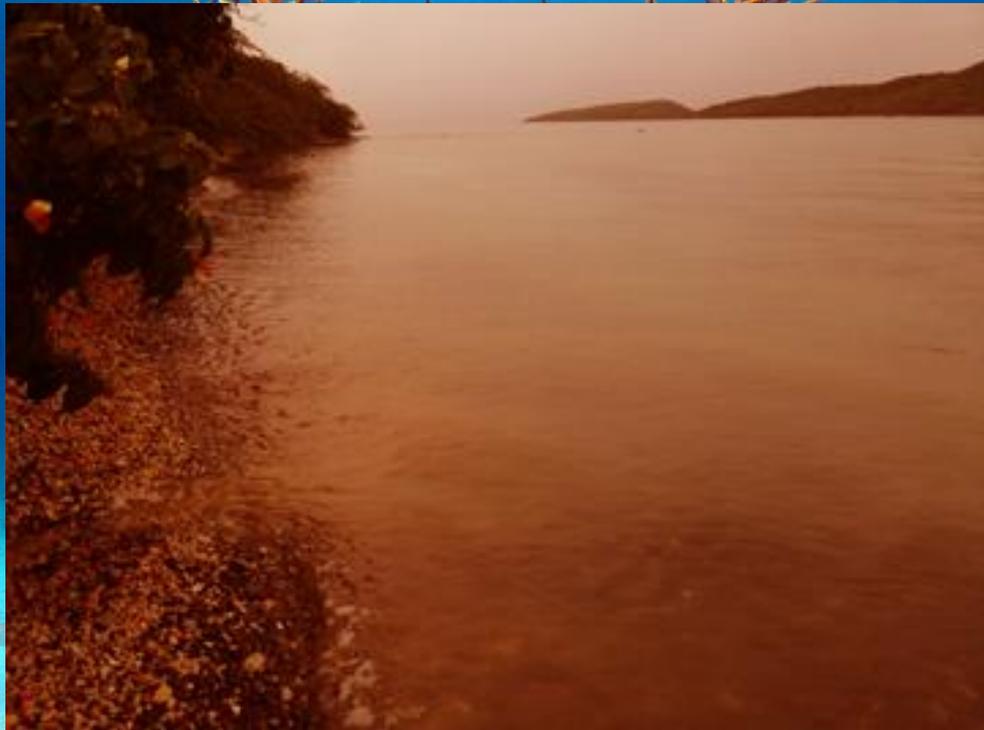
few decades. Reports of emerging coral diseases have increased since they were first described in the early 1970s (Antonius, 1973; Richardson, 2012). Currently, over 35 coral diseases have been reported (Kline and Vollmer, 2011), some of which have worldwide distribution, i.e., Black Band Disease (BBD). Others have narrower distributions, such as Yellow Band Disease (YBD), which is reported exclusively in the Caribbean (Veron, 1995). Diseases have affected over 80 coral species and their impacts have been so dramatic as to alter the seascape and the community structures of reefs (Randolf and Jackson, 2006).

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ical detrimental factors impacting coral reef ecosystems, services, benefits, and resilience across hundreds of time. Inadequate land use practices and lack of contribute to increase land-based source pollution impacts by sea surface warming trends associated Vega Baja, Puerto Rico, support extensive resistant Lemnisk 1816), which was listed in 2006 as a threat-Species Act. Chronic impacts by LBSP have significantly affected. We characterized the spatial extent of a water quality he Vega Baja coast through monthly measurements of nutrient parameters, particularly PO₄, NH₄, chlorophyll-a, and ners (OAB3) showed a statistically significant increase e to the main pollution sources, but also in waters adjacent rees also declined and turbidity increased on polluted sites. I recommended concentrations for coral reef ecosystems by

CATEC+SAM= Reversing the equation!





(Hernandez-Delgado et al., 2014a; *Open J. Ecol.* 4[14]:918-944)

Coral farming and rehabilitation of reefs in Culebra Island

SAM-UPR/CATEC and Colectivo Cayo La Yayi are launching in 2015 the Bieke Community-Based Reef Rescue Project

But there is still a need to fully remove all unexploded ordnance from Vieques and Culebra islands

The U.S. Navy must pay all cleaning and all ecological restoration of Vieques and Culebra coral reefs within impacted areas

Return all cleaned lands to the Commonwealth government

Me



All combined

Adjacent sand

Outcrop

All combined

Adjacent sand

Outcrop

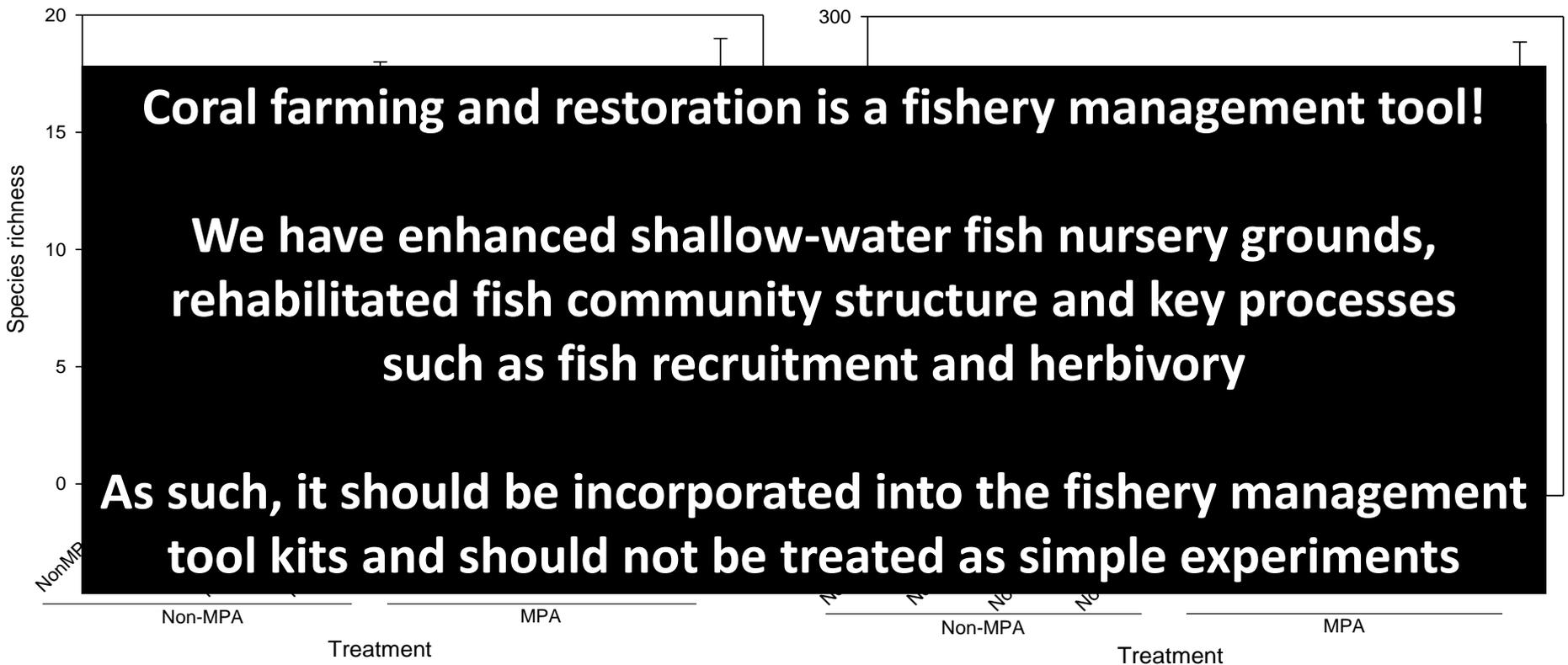
Bottom type

Bottom type

(Hernandez-Delgado et al., 2014b; *Rev. Biol. Trop.* 62[Suppl. 3]:183-200)



Juvenile reef fish habitat rehabilitation



Compromised demographic dynamics of *Acropora cervicornis* lose fragments



Projected collapse of *Acropora cervicornis* restored populations

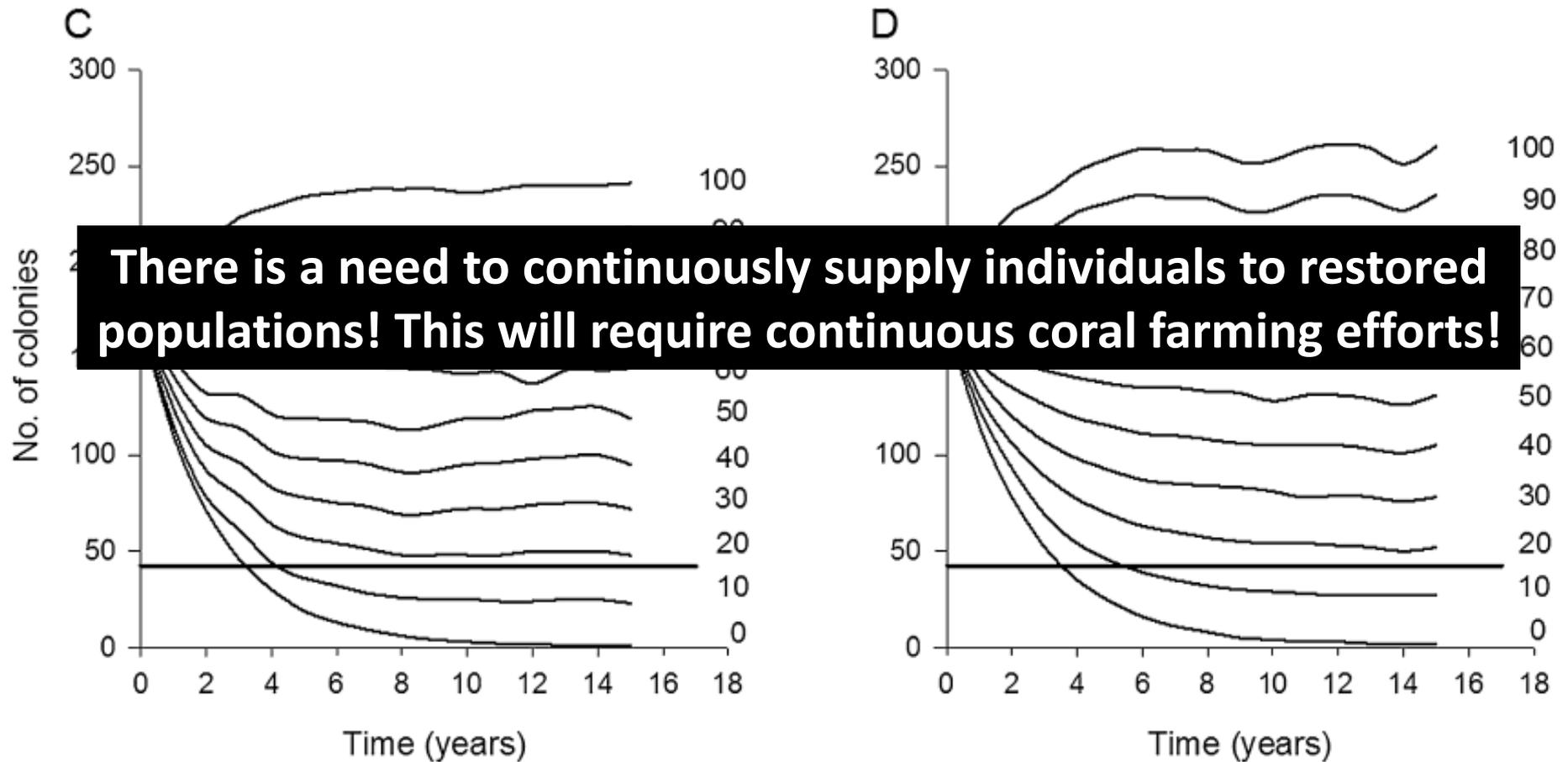
Corals need to be sustainably propagated and added to restored populations. Otherwise, restored populations (from single shot efforts) may go to extinction within less than two decades

Coral farming and restoration must be sustainably financed and should not be disregarded simply as non-priority case by case projects!

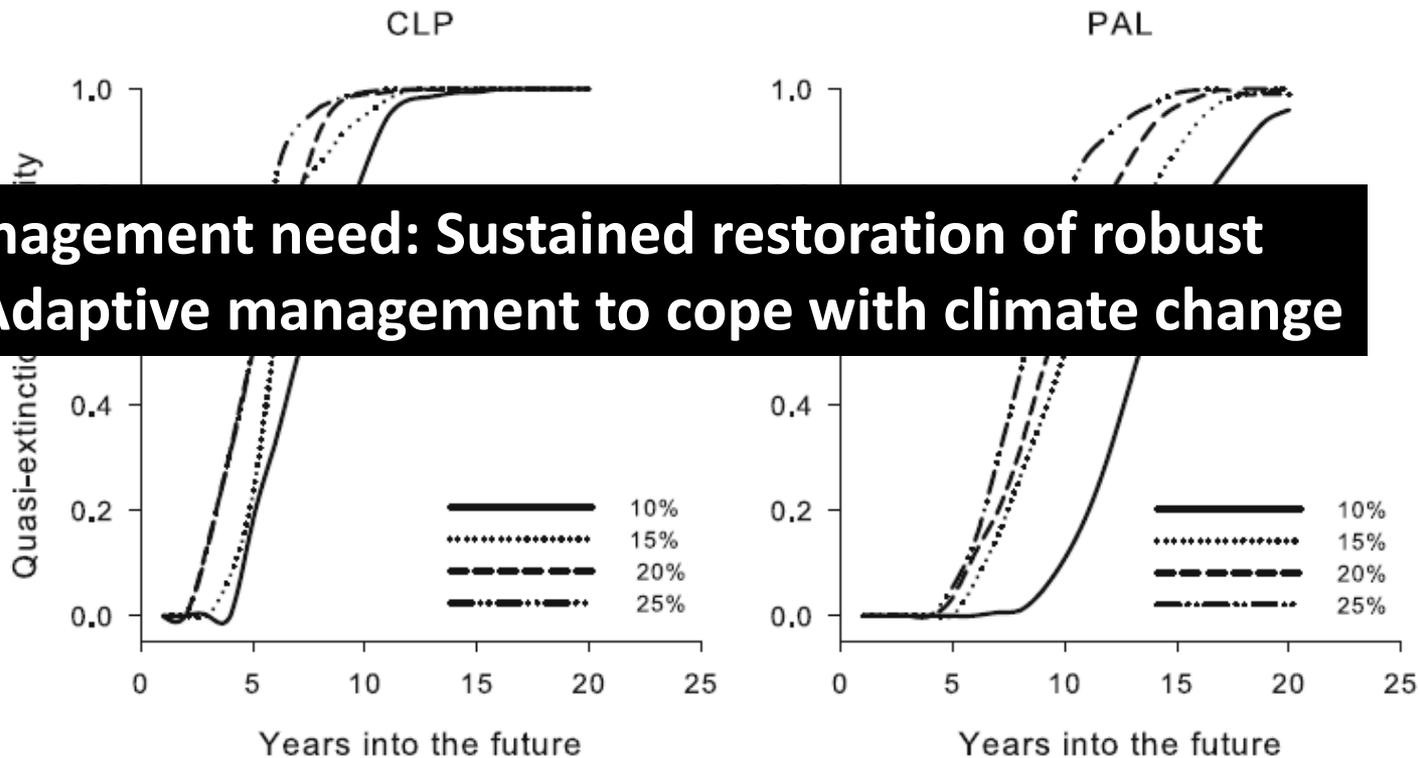
Coral farming and reef restoration must be one of the top management priorities!

Programmatic funding through DNER should be the most simple and logical way to support most operations

Sustained addition of *Acropora cervicornis* colonies to restored populations

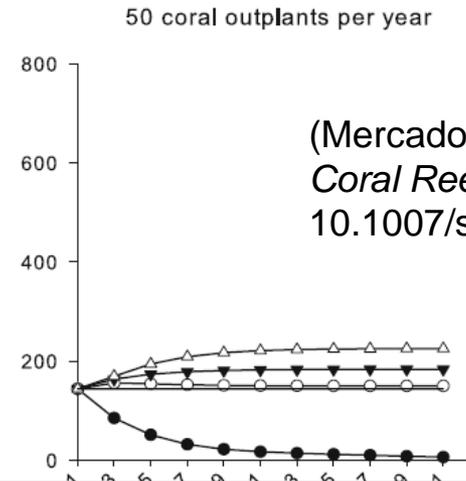
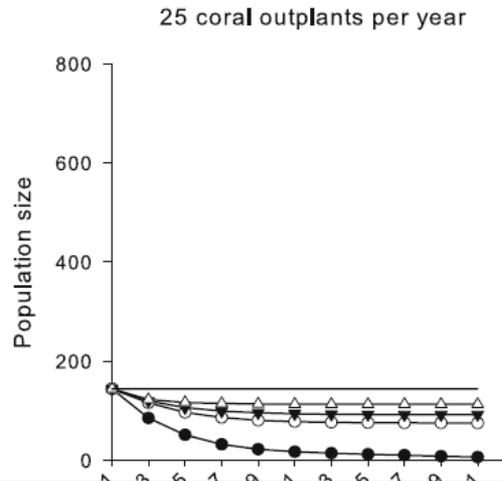


Population viability analysis of wild *Acropora cervicornis* populations suggest rapid potential of extinction



Critical management need: Sustained restoration of robust populations; Adaptive management to cope with climate change

Size does matter in *Acropora cervicornis*!!!



(Mercado-Molina et al., 2015b;
Coral Reefs DOI
10.1007/s00338-015-1341-8

There is a critical need to produce many corals >100 cm TL for outplanting and to improve population viability and growth ($\lambda > 1$)

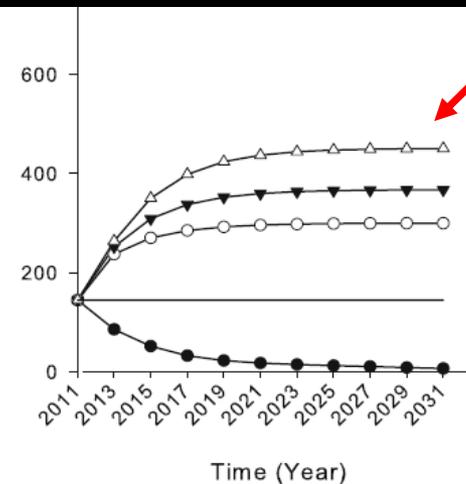
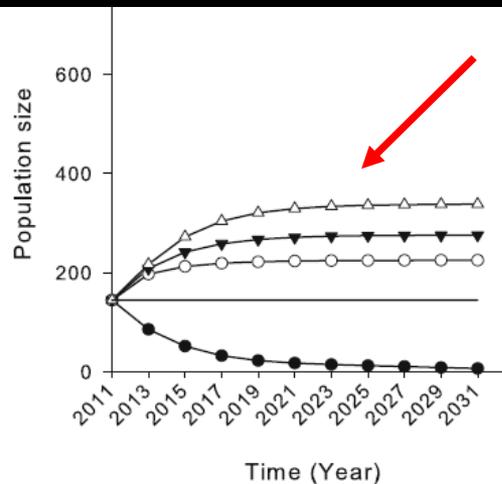
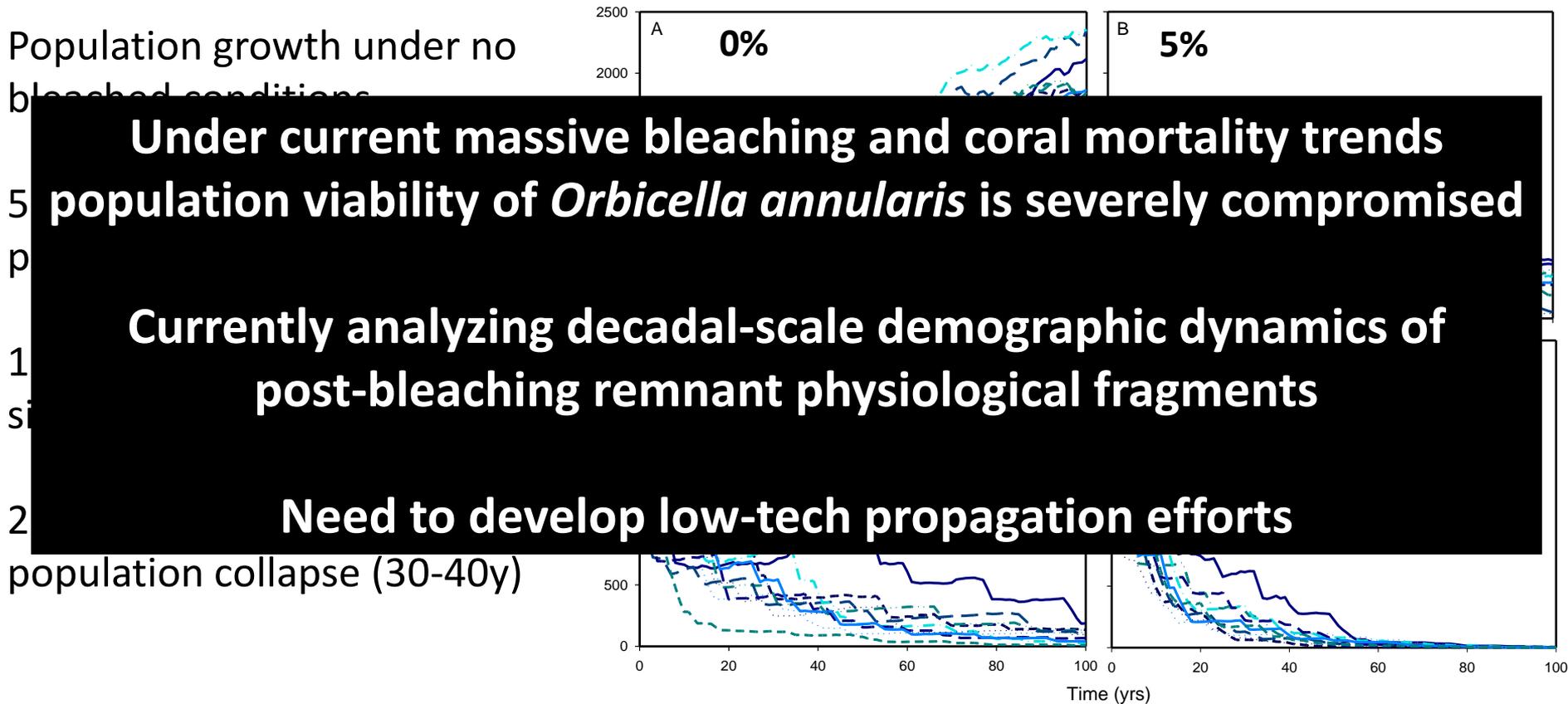


Fig. 4 Simulated trajectories of the *Acropora cervicornis* population size over time at Canal Luis Peña using different numbers and sizes of transplanted colonies based on the stochastic mean matrix. Solid line =

initial population size ($N_0 = 144$); closed circles = population trajectory with no outplants; open circles = small-sized outplants; closed triangles = medium-sized outplants; open triangles = large-sized outplant

Stochastic trajectory of an *Orbicella annularis* population through diverse massive bleaching and mass mortality probabilities



Anchoring impacts

- Destruction by accidental anchoring, even in the presence of mooring buoys
- Requires rapid emergency restoration responses
- Need to designate all coral farming and reef rehabilitation sites as Coral Reef Recovery Zones (Law 147, 1999)





Frequent Recreational Vessel Groundings at Las Pelas Reef and Los Corchos Reefs System, Culebra

Repeated grounding impacts to reef jutting out into channel at Las Pelas through Los Corchos reef system could be avoided through installation of Aids to Navigation



Final recommendations

- Need to strengthen support to coral farmers
- Support needs to become continuous and sustained
- DNER should be the leading coordinating institution in PR – Requires continuous support through Programmatic Funding from NOAA
- The U.S. Navy must support coral farming and reef restoration efforts in Vieques and Culebra

Final recommendations

- Coral farming and reef rehabilitation is a proven fishery management tool
- Program priorities need to be reviewed to incorporate coral farming and reef rehabilitation as management tools
- Need to improve the spatial scale of reef rehabilitation efforts

Final recommendations

- Incorporate coral population modeling into coral farming and reef rehabilitation management
 - Improve decision-making and management priorities
 - Improve site selection decisions (in coordination with oceanographic modeling)
 - Address multiple ecological questions, such as impacts by:
 - LBSP
 - Outcompetition by encrusting red algae *Ramicrusta textilis*
 - Diseases
 - Physiological dynamics

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<http://sampr.org>

