Defining Success for Active Acroporid Restoration: Results from Ten Years of Work in Southern Belize

Definición del Éxito para la Restauración Acroporídica Activa: Resultados de Diez Años de Trabajo en el sur de Belice

Définition du Succès de la Restauration Acroporide Active: Résultats de Dix Années de Travail dans le Sud du Belize

LISA CARNE[1]*, LES KAUFMAN[2], and KARINA SCAVO[2]
[1]*Fragments of Hope, General Delivery, Placencia, Belize. *Lisasinbelize@Gmail.Com*
[2]*Boston University Marine Program, 5 Cummington Mall. Boston, Massachusetts 02215 USA.*
Lesk@Bu.Edu *Kscavo@Bu.Edu*

EXTENDED ABSTRACT

Introduction

Since the Caribbean acroporids were listed by the IUCN as 'Critically Endangered', coral restoration efforts have become numerous and accepted widely as an active management tool (Lirman and Schopmeyer 2016) but still lack a realistic sense of scale, agreed upon goals and success indicators. Most publications focus on nurseries themselves; culture methods, survival and growth rates, and often a single Acroporid species. Here we share survival rates on *Acropora palmata* transplants ten years old, and over 59,000 nursery grown acroporids (all three taxa) outplanted in over one hectare of degraded reef at Laughing Bird Caye National Park (LBCNP) in southern Belize 2010-2016. Our best quantitative data on scale (coverage), longevity (survival of outplanted corals) and evidence of sexual reproduction of nursery-grown, ouplanted acroporids were recently submitted for the ICRS 2016 Proceedings (Carne et al. 2016, *In review*). We highlight these again but here emphasize our current and future plans to examine other consequences of replenishing reef sites with foundation species such as the acroporids in broader terms of ecosystem restoration: looking at not only at abundance and diversity of fishes, but also crustaceans, sponges and other benthic assemblages such as crustose coralline algae. Further, we suggest that our unprecedented high long term survival rates for outplanted corals is a factor of both working in a well managed No Take Zone (LBCNP) and long-term community involvement.

Since NOAA recently released a Recovery plan for the Caribbean Acroporids (NMFS 2015), we refer to their published targets for coverage, 5% for *A. cervicornis* and 10% for *A. palmata* in their respective historical habitats (depth and reef types) and genetic diversity ratio of 0.5 for both *A. cervicornis* and *A. palmata*. Acroporids are tedious to measure effectively for thousands of colonies past a certain size, especially *A. cervicornis* and *A. prolifera* which expand and rapidly create thickets over time (Kiel et al. 2012, Walker et al. 2012, Griffin et al. 2015). For measuring coverage (which we equate with survivorship for *A. cervicornis* and *A. prolifera*) we employed the use of photo-mosaics (Lirman et al. 2007 and Lirman et al. 2010) on six pre-measured plots within outplanted subsites (n = 30, Figure 1) at LBCNP and used CPCe software to analyze benthic coverage. Since *A. palmata* colonies are discreet, we share survival rates on the first transplants (2006, n=19) and nursery grown, outplanted *A. palmata* colonies (2010 - 2016 n = 187).

Data were acquired on host genetic diversity (n = 40) to ensure multiple genets of each species are outplanted in close enough proximity to facilitate cross-fertilization during mass spawning events (acroporids are hermaphroditic broadcast spawners) and spawning was monitored visually 2014 - 2016. We suggest realizable goals and success indicators, offer guidance for expanding restoration efforts to new sites, and recognize Marine Protected Areas and stakeholder involvement as key to coral restoration.

Methods

The first 19 *A. palmata* colonies transplanted to LBCNP came from naturally broken fragments in Gladden Spit and the Silk Cayes Marine Reserve. They were transported and kept moist with sea water less than an hour, and affixed to dead reef with Portland II cement mixed with a plaster of Paris (Carne 2008). Coral nurseries (tables and A- frames) were installed in 2009 and the first massive outplanting began at LBCP in 2010 (Bowden-Kerby and Carne 2012). Outplanting 2010 - 2016 was primarily with Portland II cement and fresh water only; *A. palmata* were outplanted as single colonies while *A. cervicornis* and *A. prolifera* were outplanted in clusters of five-30. Additional table nurseries were added 2013 - 2014 (Carne et al. 2016 *ICRS Proceedings In review*).

Acroporid host genetics were samples genotyped at five previously published, polymorphic microsatellite loci with Mendelian inheritance as shown by experimental crosses (Baums et al. 2005b).

Photo-mosaics were created by the Reid-Gleason laboratory at the University of Miami (Lirman et al. 2007) and changes over time in total live coral and acroporid coverage were quantified using Coral Point Count (CPCe; http://cnso.nova.edu/cpce/) with 400 randomly positioned points per image (Lirman et al. 2007 and Lirman et al. 2010).

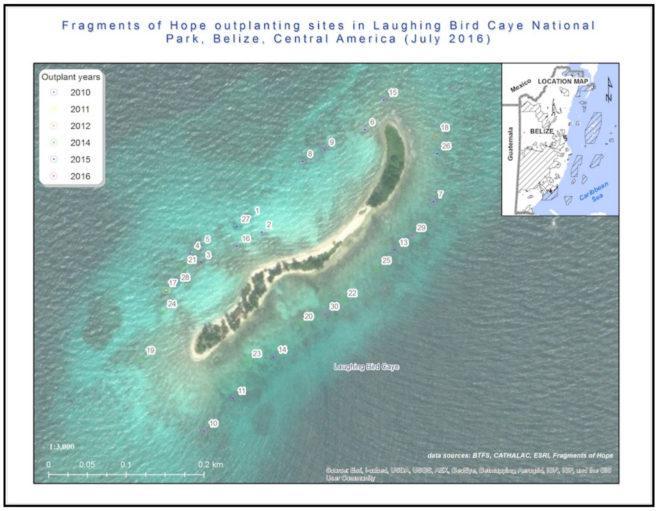

Figure 1. Accurate map of 30 subsites at Laughing Bird Caye National Park in southern Belize where over 59,000 nursery grown acroporid corals have been outplanted 2010 - 2016. Photo-mosaic plots were created within sub-sites 9, 13, 20, 21, 23, and 24.

Six plots within out-planted subsites around LBCNP were created, ranging in area from 35.5 m^2 to 180 m^2; three are on the windward side of LBCNP, and three to the lee (Figure 1). Subsites 9 and 13 were first out-planted in 2010, and there was no additional outplanting since that time. Subsites 20, 21, 23, and 24 were first outplanted in 2014. Only subsites 23 and 24 were un-planted when they were surveyed in 2014 (0% live Acroporid cover in both sites in 2014), but subsites 20 and 21 were surveyed after the initial out-planting. However, all subsites had 0% live acroporid cover before out-planting.

Monitoring for spawning events was conducted in water, at LBCNP during the August full moons 2014 - 2016. Dates and times were chosen based on recommendations from N. Fogerty (*Pers. comm*.). Weather and safety dictated which subsites were monitored each night.

Fish survey methods were created by L. Kaufman to accommodate the small size of plots measured with photos mosaics. A single 30 m transect was laid across each subsite, with fish < 20 cm recorded in 5cm size classes in a 1m belt on one side, and fish > 20 cm recorded in 5cm size classes in a 4m belt on the other side. The plots were surveyed with a 1m belt on the inner perimeter for fish > 20 cm recorded in 5 cm size classes, and 4m belt on the outside of the plot perimeter for fish > 20 cm in 5 cm size classes. All fish species were recorded.

Results

As of May 2016, 17 of the original 19 *A. palmata* colonies survive at LBCNP (89%) after being transplanted in 2006. As of June 2016, only two *A. palmata* colonies of 187 outplanted 2010 - 2016 were lost (99%). These survival rates are higher than any previously published, yet still do not reflect additional coverage created by satellite colonies (natural fragments from the original colony that survive). For better estimates we refer to the photo-mosaics results with CPCe (Table 1). To date there are 59, 285 fragments/colonies outplanted in 30 subsites at reef site LBCNP, inclusive of the first *A. palmata* transplants from 2006 (Carne et al. 2016, *In review*).

Total live coral cover increased from 2014 to 2015 in all six sub-sites at Laughing Bird Caye National Park (Table 1). All of the total coral coverage increases in 2015 are due to increased acroporid cover, which ranged from 6.5- over 23% in one year from natural asexual regeneration processes (Table 1). The percent increase of total live acroporid cover was the highest in the older (2010) outplanted plot 13 (23%) and the lowest in the newest (2014) outplanted plot, 23 (4.7%) (Table 1).

Combined outplanted acroporid cover exceeded 35% in August 2015 in the 182m^2 plot. This was achieved in six years (including nursery-time) and we suggest that the NOAA recommended targets are realistic; however it is crucial to choose optimal replenishment sites that will facilitate natural sexual reproduction because not all reefs can be restored.

Table 1. Summary of photo-mosaics plots results from CPCe analysis: total live coral, total acroporid live coral, change in coverage, area of plots and dates and species of outplanted efforts.

Sub site	Location	Area (m^2)	% total live coral cover 2014	SE	% live acroporid cover 2014	% total live coral cover 2015	SE	% live acroporid cover 2015	% change in acroporid cover	Out-plant date	Species out-planted
13	Windward	182	20.18	1.1	13.75	42.15	1.4	37.14	23.39	Dec. 2010	ACER, APAL, APRO
9	Leeward	110	22.00	0.5	18.49	30.61	0.5	27.02	8.53	April 2010	ACER
20	Windward	144	9.86	0.2	1.82	16.39	0.5	8.07	6.25	Feb. 2014	ACER, APAL
21	Leeward	109.3	6.74	0.3	3.2	14.72	0.2	11.77	8.57	Feb. 2014	ACER, APAL
23	Windward	112	0.47	0.2	0	4.98	0.6	4.43	4.73	Nov. 2014	ACER, APAL
24	Leeward	35.5	2.62	0.4	0	10.34	0.2	7.94	7.94	Nov. 2014	ACER, APAL

Three different nursery-grown *A. palmata* genets, two *A. prolifera* genets and one *A. cervicornis* genet have been visually documented spawning, with outplant ages ranging from 14 months to 5.5 years, and two additional *A. cervicornis* genets showed gamete formation at 19 months outplanted. Spawning times for all three years (2014 - 2016) were ~20:50 - 21:20 (Belize time) and spawning dates and time coincided with the wild acroporids' spawning at Carrie Bow Caye, Belize (N. Fogerty, *Pers. comm.*).

Data collection on fish is preliminary and ongoing; we have collected fish data from three natural *A. cervicornis* stands near to LBCNP to serve as controls. Anecdotally we can surmise that the fastest increase in coral coverage is on the windward side (subsite13), which also has all three acroporids-the *A. palmata* being larger structurally and affording shelter for larger fishes. Their presence may be a positive feedback for coral growth with added nutrients. Anecdotally we also note that the subsites most affected structurally by Hurricane Earl (August 2016) showed a decrease in fish abundance in 2016 (post-Earl).

In summary, we explain our relatively high survival rates over the long term in part because of the No-Take Zone status at LBCNP for over ten years. Anecdotally we also note far less predation (from snails and fireworms) on corals in the park versus in unprotected areas and suggest this may be due to a more balanced ecosystem. Since the work began in 2006, practitioners include trained tour guides, and part of their training includes removal of coral-eating snails on a regular basis. Our work continues in Belize to expand to other No-Take Zones, and includes regular training sessions for the local community stakeholders. We suggest these be included parameters in other regional replenishment efforts.

KEYWORDS: Caribbean acroporids, restoration, success, Belize

LITERATURE CITED

Baums, I.B., C.R. Hughs, and M.E. Hellberg. 2005b).Mendelian microsatellite loci for the Caribbean coral *Acropora palmata. Marine Ecology Progress Series* **288**:115-127.

Bowden-Kerby, A. and L. Carne. 2012. Thermal tolerance as a factor in Caribbean *Acropora* restoration. *Proceedings of the 12th International Coral Reef Symposium*: 1-5

Carne, L. 2008. Reef restoration at Laughing Bird Caye National Park, Belize. *Proceedings of the 11th International Coral Reef Symposium* **1**:536.

Carne, L., K. Kaufman, and K. Scavo. [2016]. Measuring Success for Caribbean Acroporid Restoration: Key Results from Ten Years' of Work in Southern Belize. *ICRS Proceedings* (*In review*).

Griffin, SP., M.I. Nemet, and T.D. Moore. 2015. Restoration using *Acropora cervicornis* at the T/V MARGARA grounding site. *Coral Reefs* **32**:885

Kiel, C., B.E. Huntington, and M.W. Miller. 2012. Tractable field metrics for restoration and recovery monitoring of staghorn coral *Acropora cervicornis*. *Endangered Species Research* **19**:171-176.

Lirman, D., N.R. Gracias, B.E. Gintert, A.C.R. Gleason, R.P. Reid, S. Negahdaripour, and P. Kramer. 2007. Development and application of a video-mosaic survey technology to document the status of coral reef communities. *Environmental Monitoring and Assessment* **125** (1):59-73.

Lirman, D., N. Gracias, B. Gintert, A.C.R. Gleason, G. Denagelo, M. Dick, E. Martinez, and R.P. Reid. 2010. Damage and recovery assessment of vessel grounding injuries on coral reef habitats by use of georeferenced landscape video mosaics. *Limnology and Oceanography Methods* **8**:88-97.

Lirman, D. and S. Schopmeyer. 2016. Ecological solutions to reef degradation: optimizing coral reef restoration in the Caribbean and Western Atlantic. *PeerJ* 4:e2597

National Marine Fisheries Service. 2015. Recovery Plan for Elkhorn (*Acropora palmata*) and Staghorn (*A. cervicornis*) Corals. Prepared by the Acropora Recovery Team for the National Marine Fisheries Service, Silver Spring, Maryland USA.

Walker, B.K., E.A. Larson, A.L. Moulding, and D.S. Gilliam. 2012. Small-scale mapping of indeterminate arborescent acroporid coral (*Acroporid cervicornis*) patches. *Coral Reefs* **31**:885-894.